Unveiling indirect greenhouse gas emissions: an environmentally extended input–output analysis of the carbon footprint in the Visegrad countries

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In a globalised world economy, direct emissions account for an increasingly smaller proportion of the total greenhouse gas emissions of countries. Thus, greenhouse gas emissions embodied in traded goods must also be calculated to identify the drivers of total greenhouse gas emissions. This study presents an environmentally extended input–output (EEIO) analysis of the embodied greenhouse gas emissions in the Visegrad countries (V4) – the Czech Republic, Hungary, Poland, and Slovakia – from 2015 to 2023. Grounded in Leontief's input–output model, the EEIO model enables the emissions to be allocated to final demand categories, such as household consumption, government spending, gross capital formation, and exports. This approach reveals the full carbon footprint of economic activities, including upstream and downstream interdependencies. The cross-country analysis includes the input–output tables of Eurostat and emissions data of 63 economic sectors. Across all V4 countries, embodied greenhouse gas emissions are, on average, more than three times higher than direct emissions. Sectoral analysis reveals that industries such as motor vehicles and electrical equipment exhibit high embodied emissions despite having relatively low direct emissions. Furthermore, the drivers of greenhouse gas emissions in the V4 countries are revealed by decomposing the final demand categories. Results indicate that household consumption primarily drives Poland's emissions, whereas exports account for nearly half of Hungary and Slovakia's embodied emissions because of their greater integration in global value chains. These differences reflect structural economic variations and differing energy profiles across the V4 countries. The study underscores the importance of EEIO analysis in identifying high-impact sectors and informing targeted mitigation strategies. It argues for the inclusion of embodied emissions into national climate policies to help the European Union (EU) achieve its decarbonisation goals. This research contributes to the discourse on carbon responsibility, trade-related emission transfers, and policy effectiveness in the EU.

Keywords:
carbon footprint,
Visegrad countries,
indirect emissions,
environmentally extended
input–output model,
climate policy

Introduction

The European Union (EU) aims to reduce greenhouse gas (GHG) emissions by 55% by 2030 in accordance with the *Fit for 55* initiative and achieve carbon neutrality by 2050 (EC 2025a). The Visegrad Group (V4), consisting of Slovakia, Poland, Hungary, and the Czech Republic, contributes 10%–13% of the total GHG emissions in the EU, with Poland being the largest emitter, contributing approximately 8%–9% (EP 2024a).

The Visegrad Group was established in 1991, with Hungary as a founding member, because of the significant political, economic, and historical similarities of the four countries (Bartha–Matarrese 2024, Harangozó–Fakó 2024, Molnár et al. 2024). However, these countries notably differ from an environmental perspective. Poland is significantly reliant on coal, accounting for over 70% of its electricity, rendering it one of the most coal-dependent nations in Europe (EP 2024b). Nevertheless, the country is making efforts to reduce its coal-dependency by investing in wind and solar energy (Our World in Data 2025). The Czech Republic and Slovakia have comparatively lower emissions and are advancing more rapidly toward cleaner energy sources (EP 2024c, OECD 2023), but they are significantly dependent on nuclear energy sources. Hungary possesses a diverse energy profile, characterised by substantial reliance on nuclear energy and modest GHG emissions (IEA 2025).

The V4 countries have often been cautious and resistant to ambitious EU-wide climate goals. This resistance typically stems from significant economic reliance on fossil fuels (particularly coal in Poland) and concerns over energy security and social impacts, such as employment losses in coal-dependent areas (Gáspár et al. 2023). Despite some resistance, the V4 countries are making efforts to access EU funds for green transition (e.g., Just Transition Fund), invest in renewable energy sources (Hungary in solar, the Czech Republic and Slovakia in nuclear and wind), and modernise grids and energy systems. The V4 countries often act as a mediating bloc between high-ambition countries (such as Germany, France, and the Nordic countries) and those advocating for a more gradual transition (Carter et al. 2019).

In assessing the achievement of climate targets, the issue of responsibility for emissions and how they are allocated has emerged. Under the Kyoto Protocol, emissions allocation is production based; thus, each nation is responsible for the emissions inside its territory. Within national sectoral emissions, upstream and downstream industries exhibit varying degrees of responsibility (Hertwich–Wood 2018). Downstream industries use inputs and intermediate goods from the production sectors. An environmentally extended input–output (EEIO) analysis is necessary to demonstrate that each sector is accountable for a specific quantity of emissions according to its final demand. Defining embodied emissions is crucial to allocating responsibility for emissions to sectors based on final demand and identifying which of these sectors produce significant emissions and where significant action is required (Skelton et al. 2011, EC 2021a).

This study aims to analyse the indirect, embodied GHG emissions of economic sectors in the V4 countries throughout their supply chains by using the EEIO model. This model provides a quantitative approach for identifying the sustainability level of national sectors based on their direct and embodied environmental impacts. This study offers an effective framework for illustrating the practical application of the EEIO model.

The extent to which the embodied GHG emissions changed from 2015 to 2023 within each country and economic sector is examined. Input–output tables are used to allocate embodied carbon emissions to specific components of final demand. This methodology identifies industries showing spillover effects and reveals the final demand categories that contribute significantly to embodied emissions within each sector.

Results of this analysis help identify the specific industries that should focus on reducing GHG emissions to meet EU targets. This analysis emphasises the effects of the structural changes after 2015 in each of the V4 countries and their economic sectors. The research addresses the following Sustainable Development Goals (SDGs): SDG 7, affordable and clean energy; SDG 12, responsible consumption and production; and SDG 13, climate action.

Recent empirical evidence on responsibility in embodied carbon accounting is summarised. The methodology of EEIO analysis and sources of data used are presented.

Literature review of EEIO modelling

The EEIO analysis was developed from Leontief's (1970) model. Input–output tables show the interconnections among economic sectors, the so-called intersectoral demand and final consumption (Miller–Blair 2009). They represent the sales and purchases of both final and intermediate products and services, grouped by either industry outputs (industry-by-industry tables) or product outputs (product-by-product tables) (OECD 2025). These models trade flows between economic sectors, diving into final demand and production.

The EEIO model belongs to the linear group of economic–macroeconomic models, which are based on three basic assumptions (Takayama 1985):

1. The relationships between economic sectors and industries are linearly dependent on each other. The production of each industry assumes that the given industry has only one homogeneous product. This means that the production function of the industry has fixed returns to scale.
2. Joint production does not exist because each industry has only one homogeneous product, i.e., exchanges within the industry are not considered.
3. Environmental relationships are considered in the same way as if they were economic sectors; thus, the environmental burden can also be considered as a linear variable in the production function of the industries.

The general input–output table can be expanded to illustrate and identify the effects of specific activities on the environment, namely, the contribution of each productive sector to the generation of pollutants. EEIO tables integrate environmental data with conventional economic input–output models, offering a tool for examining the relationship between economic activity and environmental impact (Miller–Blair 2009). They were first applied in the studies by Bicknell et al. (1998), Ferng (2001), and Wiedmann et al. (2006). Environmental extension tables or environmental accounts can include various environmental impacts, such as land use, water use, and emissions (Toth–Szigeti 2016, Ridoutt et al. 2018). They can also be used to quantify spillover effects (Alpek et al. 2022) and be regionalised (Szabó 2015).

As a 'top-down' technique, input–output analysis can be applied at the macro- or meso-level for international, national, or sectoral analysis (Andrew et al. 2009, Hertwich 2011, Sun et al. 2018). It allows the calculation of the environmental impacts throughout production. Wiedmann et al. (2009) and Tukker et al. (2009) conducted a detailed review of the application of input–output analysis.

Direct emission accounting is commonly employed in national and international statistical energy databases, allocating input use to primary production sectors (IEA 2024). Conversely, embodied emission accounting by EEIO tables allocates carbon emissions to downstream sectors. Quantifying embodied emissions sheds light on their substantial significance within specific downstream industries (Meng et al. 2018, Ma et al. 2019).

One major advantage of the EEIO analysis is that it identifies direct and embodied environmental impacts throughout whole supply chains. Indirect, embodied emissions include those from transportation activities, purchased material manufacture, outsourced operations, waste disposal, and other intersectoral consumption not directly linked to production (Xu et al. 2022, Major et al. 2023). The EEIO analysis facilitates the evaluation of environmental impacts, including GHG emissions, resource use, and waste production associated with consumption and production trends (Steen-Olsen et al. 2016, Beylot et al. 2019). Thus, it may identify critical sectors and activities that substantially contribute to environmental impact, enabling focused mitigation strategies (Wang et al. 2018, Pan et al. 2022). Indirect GHG emissions should be incorporated into the emission allocation framework utilized for climate policy (Huang et al. 2009). Emissions from imported items used for final domestic demand are included in the embodied carbon accounting.

An important benefit of the EEIO framework is its ability to disaggregate GHG emissions of individual sectors to those associated with the production of final goods and services or the generation of intermediate inputs supplied to different economic sectors (Vetőné Mózner 2015, de Boer et al. 2019, Donati et al. 2020). The model facilitates the examination of structural interdependencies by redistributing emissions among sectors, as the output of upstream sectors serves as intermediate inputs for downstream sectors, ultimately supplying final products for household consumption, export production, and gross capital formation (Wilting–In't Veld 2025).

The importance of integrating embodied effects in accounting practices has been underscored by various scholars (Lenzen 2002). The integration of environmental data into economic modelling supports a comprehensive understanding of the ways in which economic processes exert environmental pressures, hence enhancing informed decision-making in research and a practical application in policy contexts (Csutora–De Palma 2008, Somé et al. 2018).

EEIO provides quantitative guidance, with responsibility and climate justice being the keywords and main narratives. Embodied carbon accounting can even be termed as the 'carbon footprint' of a nation or economic sector, which quantifies its embodied CO_2 emissions. However, the term 'carbon footprint' possesses various interpretations within climate accounting (Stechemesser–Guenther 2012).

The objective of this study is to address the following research questions:

RQ1: To which extent have the embodied GHG emissions changed from 2015 to 2023 in each of the V4 countries and their economic sectors? RQ2: What is the structure of embedded carbon emissions according to the components of final demand, and how has it changed from 2015 to 2023 in the V4 countries?

To answer these questions, input–output analysis is conducted with EEIO tables using the most recent data sources for the V4 countries within the examined period.

Methodology

Monetary input–output tables give the basis of the EEIO model. They show the financial transactions between various economic sectors.

$$x = Ax + y \tag{1}$$

where x is the total economic output vector for every sector, y is the final demand vector for every economic sector, A is the matrix of direct requirements. It indicates the amount of inputs required to generate a single unit of output.

Reorganising *equation* (1) results in

$$x = (I - A)^{-1} y \tag{2}$$

where I is the identity matrix, $(I - A)^{-1}$ is the Leontief inverse matrix. It shows how much input is needed to generate an additional unit of output.

The Leontief inverse matrix is useful for examining the interconnectedness of economic sectors because it captures the direct and indirect input requirements. Monetary input–output tables are expanded to include carbon emissions in physical measures.

Calculation of direct emission coefficients

The direct emission intensities are calculated for each type of GHG emissions $m = 1, ..., q$

$$e_m = d_m \langle x \rangle^{-1} \tag{3}$$

where e_m is the direct emission intensities vector, m is the GHG type, d_m is the direct emissions vector, x is the total output vector in every sector, and $\langle x \rangle$ is the matrix with x in the diagonal.

The value of each component of e_m can be derived by dividing the corresponding element in d_m by the respective element in x. This direct emission intensity indicates the quantity of direct emissions generated by each economic sector for every unit of output.

The rows of the $q \times n$ matrix E are the row vectors e_m. Matrix D consists of the row vectors d_m and

$$E = D \langle x \rangle^{-1} \tag{4}$$

where E is the direct carbon intensity matrix ($q \times n$), D is the carbon emission matrix ($q \times n$), and x is the total output vector in each sector.

Calculation of embodied GHG emissions

The embodied GHG emissions are computed below:

$$C_{em} = 1E(I - A)^{-1} \langle y \rangle \tag{5}$$

where C_{em} is the embodied carbon emissions vector, 1 is the summation vector with elements one, and $\langle y \rangle$ is the matrix with y in the diagonal.

Decomposing embodied GHG emissions

The final demand vector y can be decomposed into four components according to *equation* (6):

$$y = y_h + y_{gov} + y_{gcf} + y_{exp} \tag{6}$$

where y_h is the final demand of households, y_{gov} is the final demand of government, y_{gcf} is the final demand of gross capital formation, and y_{exp} is the final demand of exports,
or in diagonalised form $\langle y \rangle = \langle y_h \rangle + \langle y_{gov} \rangle + \langle y_{gcf} \rangle + \langle y_{exp} \rangle$.

Equation (5) was utilized to allocate direct emissions into the components of final demand for economic sectors. The embodied GHG emissions for the final demand categories, namely, household consumption, governmental consumption, gross capital formation, and exports, can be separately calculated:

Equations (7)–(10) show the embodied GHG emissions decomposed into the final demand categories:

Household consumption:

$$C_{em,h} = 1E(I-A)^{-1}\langle y_h \rangle \tag{7}$$

Governmental consumption:

$$C_{em,gov} = 1E(I-A)^{-1}\langle y_{gov} \rangle \tag{8}$$

Gross capital formation:

$$C_{em,gcf} = 1E(I-A)^{-1}\langle y_{gcf} \rangle \tag{9}$$

Exports:

$$C_{em,exp} = 1E(I-A)^{-1}\langle y_{exp} \rangle \tag{10}$$

Data sources

The data required for the calculation were available from the statistical databases of Eurostat. The symmetric product-by-product input–output tables for the V4 countries were obtained from the Eurostat database of 'Symmetric input–output table at basic prices (product-by-product)' (Eurostat 2025a). In our research, 63 economic sectors were appraised according to the sectoral aggregation of Eurostat's database (sectors were classified according to the NACE Rev.2. classification). Emissions data for 2015 and 2023 were obtained from the 'Air emissions accounts by NACE Rev. 2 activity' (Eurostat 2025b). Air emissions accounts included data for GHG emissions, measured in CO_2 equivalents, including CO_2, N_2O, CH_4, HFC, PFC, SF_6, and NF_3.

Based on *equation* (5), embodied emissions in 2015 and 2023 were calculated for all economic sectors in the V4 countries. Embodied GHG emissions were decomposed according to the final demand categories in *equation* (6).

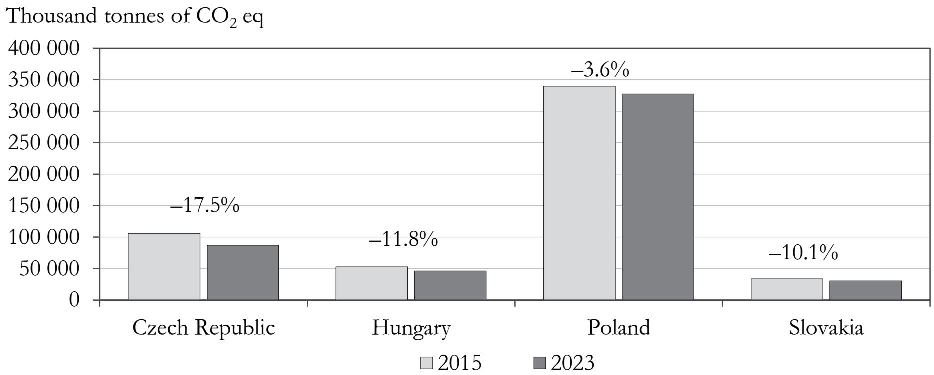
Results and discussion

Comparison of direct and embodied GHG emissions, sectoral analysis

The total direct emissions decreased from 2015 to 2023 in all V4 countries. The largest GHG emission reduction was achieved by the Czech Republic (17.5%), followed by Hungary (11.8%), and Slovakia (10.1%). Poland, as the largest emitter among the V4 countries, could not reduce its GHG emissions by only 3.6% (see Figure 1). The Czech Republic receives heavy government support for renewables, and it is transitioning from hard coal. In Hungary and Slovakia, the share of coal is significantly low, and their capacities for renewable energy have considerably increased in recent years. As heavily energy-dependent countries, Hungary and Slovakia strongly focus on energy-saving measures. Notably, Hungary, the Czech Republic, and Slovakia do not rely on coal but on nuclear energy, which Poland currently lacks (EP 2024b). However, Poland has not set a coal phase-out date and continues to support its coal mining sector due to political and socioeconomic reasons (Gawlik 2018, Černoch et al. 2024). Given its large coal-sector workforce and lower GDP per capita than Western Europe, Poland resists structural shifts away from coal, fearing social unrest.

Figure 1

Greenhouse gas emissions in the Visegrad countries



Indirect input requirements for intermediate products are necessary to generate end products. Although several industries emit lower amounts of GHG emissions, they may depend on inputs from other industries that contribute more significantly to GHG emissions. The carbon footprint is further increased by the final demand for products from those sectors. Embodied GHG emissions were calculated using *equation* (5).

Results indicated that embodied emissions can be on average 3–4 times more than direct emissions in all V4 countries. Table 1 shows the 10 key sectors with the highest share of embodied GHG emissions to direct emissions in the Czech Republic. These sectors exhibited significantly higher GHG emissions when direct and indirect emissions were integrated.

The last column of the table shows the proportion in percentages of embodied emissions to the direct GHG emissions for each sector. In the Czech Republic, the 'Food, beverages and tobacco products' and 'Constructions' sectors had the highest embodied emissions. In this country, the embodied emissions were more than three times larger than the direct emissions. Some industries with somewhat lower embodied emissions had a much larger share of embodied emissions to direct emissions. These industries include 'Motor vehicles, trailers and semi-trailers', 'Real estate services excluding imputed rents', and 'Electrical equipment'.

Table 1

Top 10 sectors in the Czech Republic with the highest embodied GHG emissions, 2023

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Food, beverages and tobacco products	1,151	5,884	511
Constructions and construction works	1,617	5,822	360
Motor vehicles, trailers and semi-trailers	206	4,072	1,974
Real estate services excluding imputed rents	118	2,768	2,339
Wholesale trade services, except of motor vehicles and motorcycles + Retail trade	1,079	2,360	219
Machinery and equipment n.e.c.	234	2,346	1,003
Public administration and defence services; compulsory social security services	221	1,820	822
Fabricated metal products, except machinery and equipment	285	1,804	634
Human health activities	254	1,414	558
Electrical equipment	94	1,245	1,318

The 10 most important industries with the highest embodied emissions in Hungary are presented in Table 2.

Table 2

Top 10 sectors in Hungary with the highest embodied GHG emissions, 2023

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Food, beverages and tobacco products	910	4,515	496
Constructions and construction works	1,110	3,172	286
Public administration and defence services; compulsory social security services	741	2,104	284
Motor vehicles, trailers and semi-trailers	243	1,670	686
Wholesale trade services, except of motor vehicles and motorcycles	938	1,593	170
Retail trade services, except of motor vehicles and motorcycles	474	1,544	326
Accommodation and food services	178	1,027	578
Electrical equipment	159	900	564
Human health services	298	800	269
Machinery and equipment n.e.c.	165	635	385

However, in Hungary, the ‘Public administration’ sector had higher embodied GHG emissions than direct GHG emissions. In Poland, ‘Real estate services excluding imputed rents’ had the third highest level of embodied GHG emissions.

As shown in Table 3, the ‘Constructions’ sector in Slovakia had the highest embodied GHG emissions with the ‘Machinery and equipment n.e.c.’ sector. Slovakia has been investing heavily in infrastructure projects, many of which are co-financed by the EU. These projects include highways, railways, and public buildings, which require large quantities of concrete, steel, and machinery, materials and equipment with a high carbon footprint (EC 2021b). However, in Hungary, the construction growth rate (after a boom in the mid-2010s) declined, especially during Covid-19 and post-pandemic inflation, which reduced material demand and emissions (GKI 2025). Furthermore, the country adopted stricter building energy regulations aligned with EU directives, which reduced the lifecycle emissions of new buildings. Hungary has also implemented several EU-supported programmes that promote low-emission construction, including energy retrofits and upgrades to public buildings (EC 2025b).

Table 3

Top 10 sectors in Slovakia with the highest embodied GHG emissions, 2023

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Food, beverages and tobacco products	5,516	45,355	822
Constructions and construction works	798	19,234	2,410
Real estate services excluding imputed rents	469	14,716	3,140
Wholesale trade services, except of motor vehicles and motorcycles	6,886	11,365	165
Retail trade services, except of motor vehicles and motorcycles	2,702	10,902	404
Public administration and defence services; compulsory social security services	1,978	9,078	459
Water transport services; Air transport; Warehousing and postal services	6,741	7,877	117
Motor vehicles, trailers and semi-trailers	304	7,140	2,348
Basic metals	6,352	6,693	105
Human health services	1,397	5,530	396

Table 4 illustrates the sectors in Poland with the highest embodied GHG emissions.

Table 4

Top 10 sectors in Poland with the highest embodied GHG emissions, 2023

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions/direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Constructions and construction works	2,081	2,759	133
Motor vehicles, trailers and semi-trailers	233	2,124	912
Food, beverages and tobacco products	627	1,553	248
Machinery and equipment n.e.c.	272	1,353	497
Retail	168	889	530
Real estate services excluding imputed rents	243	884	364
Public administration and defence services; compulsory social security services	259	715	276
Rubber and plastic products	558	607	109
Human health activities	152	462	303
Wholesale trade services, except of motor vehicles and motorcycles	213	429	202

Table 5 shows the economic sectors with the highest embodied GHG emissions in all V4 countries compared with the total emissions. Detailed results for direct and embodied emissions can be found in the Appendix. See Appendix Tables A1 (Czech Republic), A2 (Hungary), A3 (Poland) and A4 (Slovakia).

Table 5

Top 10 industries with the highest embodied GHG emissions in all V4 countries, 2023

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions/direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Czech Republic			
Food, beverages and tobacco products	1,151	5,884	511
Constructions and construction works	1,617	5,822	360
Motor vehicles, trailers and semi-trailers	206	4,072	1,974
Wholesale trade services, except of motor vehicles and motorcycles	1,079	2,360	219
Machinery and equipment n.e.c.	234	2,346	1,003
Public administration and defence services; compulsory social security services	221	1,820	822
Human health activities	254	1,414	558
Electrical equipment	94	1,245	1,318
Accommodation and food services	67	1,177	1,764
Rubber and plastic products	205	1,042	508

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Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions/direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Hungary			
Food, beverages and tobacco products	910	4,515	496
Constructions and construction works	1,110	3,172	286
Motor vehicles, trailers and semi-trailers	741	2,104	284
Wholesale trade services, except of motor vehicles and motorcycles	243	1,670	686
Machinery and equipment n.e.c.	938	1,593	170
Public administration and defence services; compulsory social security services	474	1,544	326
Human health activities	178	1,027	578
Electrical equipment	159	900	564
Accommodation and food services	298	800	269
Rubber and plastic products	165	635	385
Poland			
Food, beverages and tobacco products	5,516	45,355	822
Constructions and construction works	798	19,234	2,410
Motor vehicles, trailers and semi-trailers	469	14,716	3,140
Wholesale trade services, except of motor vehicles and motorcycles	6,886	11,365	165
Machinery and equipment n.e.c.	2,702	10,902	404
Public administration and defence services; compulsory social security services	1,978	9,078	459
Human health activities	6,741	7,877	117
Electrical equipment	304	7,140	2,348
Accommodation and food services	6,352	6,693	105
Rubber and plastic products	1,397	5,530	396
Slovakia			
Food, beverages and tobacco products	2,081	2,759	133
Constructions and construction works	233	2,124	912
Motor vehicles, trailers and semi-trailers	627	1,553	248
Wholesale trade services, except of motor vehicles and motorcycles	272	1,353	497
Machinery and equipment n.e.c.	168	889	530
Public administration and defence services; compulsory social security services	243	884	364
Human health activities	259	715	276
Electrical equipment	558	607	109
Accommodation and food services	152	462	303
Rubber and plastic products	213	429	202

Upstream industries in all V4 countries

By contrast, several sectors had lower embodied emissions than direct emissions because they pass on their emissions to sectors that use their products as intermediate materials. The most important upstream sectors with higher direct GHG emissions than embodied emissions in the V4 countries are listed in Table 6.

These sectors typically produce raw materials or intermediate products for the secondary or tertiary sectors. In Slovakia, embodied GHG emissions from the 'Products of agriculture, hunting, and related services' sector accounted for 78% of direct emissions; this share was significantly lower than those in the three other economies. The 'Mining and quarrying' sector passed on its GHG emissions to downstream industries. It had the lowest share (8%) compared to direct emissions in Poland and the highest, although still low, share of 16% in Hungary. Direct emissions from 'Land transport services and transport services via pipelines' were lowest in Poland and highest in the Czech Republic.

Table 6

Upstream sectors with high direct GHG emissions in the V4 countries, 2023

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Czech Republic			
Products of agriculture, hunting and related services	9,124	4,555	50
Other non-metallic mineral products	3,363	2,275	68
Land transport services and transport services via pipelines	8,622	6,667	77
Electricity, gas, steam and air conditioning	34,135	19,231	56
Basic metals	5,927	3,178	54
Mining and quarrying	4,388	495	11
Hungary			
Products of agriculture, hunting and related services	7,945	4,134	52
Other non-metallic mineral products	1,572	829	53
Land transport services and transport services via pipelines	2,841	2,149	76
Electricity, gas, steam and air conditioning	8,976	3,846	43
Basic metals	483	323	67
Mining and quarrying	571	92	16

(Table continues the next page.)

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Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Poland			
Products of agriculture, hunting and related services	50,999	27,374	54
Other non-metallic mineral products	17,170	11,061	64
Land transport services and transport services via pipelines	42,264	24,949	59
Electricity, gas, steam and air conditioning	120,793	44,892	37
Basic metals	6,352	6,693	105
Mining and quarrying	21,723	1,748	8
Slovakia			
Products of agriculture, hunting and related services	1,772	1,376	87
Other non-metallic mineral products	1,450	673	46
Land transport services and transport services via pipelines	2,180	1,653	76
Electricity, gas, steam and air conditioning	5,395	3,047	56
Basic metals	5,822	3,503	60
Mining and quarrying	282	26	9

Structure of embodied emissions according to final demand

Embodied GHG emissions were further decomposed according to *equation* (6) to final demand categories. Results are shown in Table 7 for 2015 and 2023, expressed as a percentage of total GHG emissions for all final demand categories.

The share of household emissions remained stable during the period analysed in all V4 countries; only a slight decrease can be observed in Poland. The share of household emissions was highest in Poland (2023: 48%), followed by the Czech Republic (2023: 42%); meanwhile, it was lowest in Slovakia (2023: 33%) and Hungary (2023: 31%). Poland has the highest share of household emissions (48% in 2023) among the V4 countries, with only slight improvements since 2015. This is primarily due to the country's high reliance on solid fuels and outdated heating systems. Many Polish households, especially in smaller towns and villages, still use inefficient coal boilers and produce significant GHGs and particulate emissions (Jaworek et al. 2021, Piwowar 2024). Other important reasons include poor insulation, ageing housing stock, and insufficient energy efficiency programmes (Sokołowski 2023). Different from those in Slovakia and Hungary, where gas-based district heating is widespread, the rural and suburban areas in Poland often rely on individual boilers with no centralised system. This scenario leads to increase per-household emissions (Piwowar 2024). Among the V4 countries, the Czech Republic has the strongest heating efficiency (Mišík et al. 2024) owing to its subsidy programmes supporting energy efficiency (EC 2022). Meanwhile, Slovakia and Hungary show the best household efficiency owing to their predominantly gas heating and better renovation programmes (Roguljet al. 2023). In Slovakia, GHG emissions from households increased from 31% to 33% from 2015 to 2023; however, in absolute terms, no growth occurred, as household GHG emissions decreased from 10,519 thousand tonnes of CO_2 equivalents to 9,854 thousand tonnes of CO_2 equivalents. By 2023, GHG emissions in the three other countries decreased in both absolute and relative terms.

Table 7

Decomposition of embodied GHG emissions according to final demand categories in the V4 countries

(percentage of total GHG emissions, %)

Final demand categories	Czech Republic		Hungary		Poland		Slovakia	
	2015	2023	2015	2023	2015	2023	2015	2023
Households	43	42	35	31	53	48	31	33
Government	6	7	9	11	9	9	7	7
Gross capital formation	8	10	11	11	7	8	12	12
Export	43	41	46	47	32	36	50	48

In Hungary and Slovakia, the primary source of embodied emissions is not the final demand of households but rather exports that drive these emissions. Among the V4 countries, Slovakia and Hungary had the largest shares of exports (47% of total embodied emissions in Hungary, 48% of total embodied emissions in Slovakia in 2023), whereas Poland had the lowest. This difference can be ascribed to the fact that although both countries have relatively small domestic markets, they are highly integrated into global value chains. Consequently, a much larger proportion of their emissions are linked to goods produced for export rather than for domestic consumption. They specialise in energy-intensive manufacturing, such as the automotive sector in Slovakia and the chemical and machinery industries in Hungary, which include substantial embodied GHG emissions in each exported unit. By contrast, the economic circumstances in Poland allow a much larger internal demand. In specific, the population size and national consumption in this country create a larger domestic share of embodied emissions.

Selected sectors with the highest share of exported GHG emissions and contributing to a high share of total GHG emissions in the Czech Republic are shown in Table 8. The final column indicates the sector's ranking based on the amount of embodied emissions in 2015 and 2023, allowing for an assessment of changes in emission levels between these periods.

A few sectors experienced a shift in responsibility for final embodied emissions. In the Czech Republic, 'Products of forestry, logging, and related services' ranked 31st in 2015 regarding the share of embodied GHG emissions due to exports.

However, this sector is now one of the most important in 2023. Recent government agreements, including building regulations that promote the use of timber in public buildings, reflect a strategic shift toward treating wood as a national resource. Although this supports domestic consumption, it also reinforces an export orientation in forestry activities.

Table 8

Most significant economic sectors with the highest share of exports in the Czech Republic, embodied emissions according to final demand, 2023

Economic sectors according to NACE Rev.2.	Embodied GHG 2023 (thousand tonnes of CO_2 eq)				
	households	government	gross capital formation	export	total embodied GHG emissions
Fabricated metal products, except machinery and equipment	63	0	81	1,661	1,804
Electrical equipment	91	0	75	1,079	1,245
Motor vehicles, trailers and semi-trailers	268	0	321	3,483	4,072
Chemicals and chemical products	445	0	35	2,557	3,037
Textiles, wearing apparel, leather and related products	116	9	8	446	579
Air transport services	181	0	0	524	706
Computer, electronic and optical products	44	2	149	557	752
Machinery and equipment n.e.c.	14	0	716	1,616	2,346

Economic sectors according to NACE Rev.2.	Embodied GHG (%) 2023				Rank of sector in	
	household share	government	gross capital formation	export	2015	2023
Fabricated metal products, except machinery and equipment	3	0	4	92	9	6
Electrical equipment	7	0	6	87	12	10
Motor vehicles, trailers and semi-trailers	7	0	8	86	11	11
Chemicals and chemical products	15	0	1	84	10	12
Textiles, wearing apparel, leather and related products	20	2	1	77	19	14
Air transport services	26	0	0	74	18	16
Computer, electronic and optical products	6	0	20	74	22	17
Machinery and equipment n.e.c.	1	0	31	69	23	21

Table 9 shows the most significant sectors in Hungary with the highest share of exports and contributing to a high share of total GHG emissions in 2023 and their embodied emissions according to final demand.

Table 9

Most significant sectors with the highest share of exports in Hungary, embodied emissions according to final demand, 2023

Economic sectors according to NACE Rev.2.	Embodied GHG 2023 (thousand tonnes of CO_2 eq)				
	households	government	gross capital formation	export	total embodied GHG emissions
Fabricated metal products, except machinery and equipment	63	0	81	1,661	1,804
Electrical equipment	91	0	75	1,079	1,245
Motor vehicles, trailers and semi-trailers	268	0	321	3,483	4,072
Chemicals and chemical products	445	0	35	2,557	3,037
Textiles, wearing apparel, leather and related products	116	9	8	446	579
Air transport services	181	0	0	524	706
Computer, electronic and optical products	44	2	149	557	752
Machinery and equipment n.e.c.	14	0	716	1,616	2,346

Economic sectors according to NACE Rev.2.	Embodied GHG (%) 2023				Rank of sector in	
	household share	government	gross capital formation	export	2015	2023
Fabricated metal products, except machinery and equipment	3	0	4	92	9	6
Electrical equipment	7	0	6	87	12	10
Motor vehicles, trailers and semi-trailers	7	0	8	86	11	11
Chemicals and chemical products	15	0	1	84	10	12
Textiles, wearing apparel, leather and related products	20	2	1	77	19	14
Air transport services	26	0	0	74	18	16
Computer, electronic and optical products	6	0	20	74	22	17
Machinery and equipment n.e.c.	1	0	31	69	23	21

In Hungary, a significant shift in embodied emissions occurred in the 'Basic pharmaceutical products and pharmaceutical preparations' sector, which was among the most significant in 2023 but ranked 21st in 2015 based on embodied emissions.

The results for embodied emissions according to final demand categories in Poland are presented in Table 10. In this country, the 'Rubber and plastic products' and 'Paper and paper products' sectors had high GHG emissions due to exports. Both industries are highly energy intensive and rely heavily on fossil fuels during production. These sectors produce goods such as packaging materials, automotive parts, and industrial products, which are in high demand across Europe.

Table 10

Most significant sectors with the highest share of exports in Poland, embodied emissions according to final demand, 2023

Economic sectors according to NACE Rev.2.	Embodied GHG 2023 (thousand tonnes of CO_2 eq)				
	households	government	gross capital formation	export	total embodied GHG emissions
Rubber and plastic products	503	0	31	4,096	4,630
Paper and paper products	407	1	20	2,173	2,600
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	406	0	19	1,924	2,350
Electrical equipment	701	0	529	3,727	4,958
Computer programming, consultancy and related services; Information services	8	6	259	643	916
Fabricated metal products, except machinery and equipment	172	0	1,379	2,799	4,350
Other transport equipment	110	0	562	1,178	1,850
Land transport services and transport services via pipelines	5,003	3,640	452	15,854	24,949
Furniture and other manufactured goods	1,663	0	398	3,330	5,391
Wholesale trade services, except of motor vehicles and motorcycles	2,987	224	1,263	6,891	11,365

Economic sectors according to NACE Rev.2.	Embodied GHG (%) 2023				Rank of sector in	
	house-hold share	govern-ment	gross capital formation	export	2015	2023
Rubber and plastic products	11	0	1	88	3	3
Paper and paper products	16	0	1	84	4	4
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	17	0	1	82	5	5
Electrical equipment	14	0	11	75	7	7
Computer programming, consultancy and related services; Information services	1	1	28	70	12	8
Fabricated metal products, except machinery and equipment	4	0	32	64	13	11
Other transport equipment	6	0	30	64	18	12
Land transport services and transport services via pipelines	20	15	2	64	20	13
Furniture and other manufactured goods	31	0	7	62	14	14
Wholesale trade services, except of motor vehicles and motorcycles	26	2	11	61	16	16

In 2015, the ‘Other transport equipment’ and ‘Land transport services’ sectors were ranked 18th and 20th, respectively, based on embodied GHG emissions; however, in 2023, their ranking changed to 12th and 13th, respectively. This is primarily due to increased industrial activity and growing demand for transport services, driven by export-oriented economic growth and supply chain expansion. The geographic location of Poland as a central logistics corridor in Europe has amplified the trend of increased export activities, increasing fuel consumption and emissions from trucks and freight carriers.

Table 11 shows the embodied emissions according to final demand categories for Slovakia.

Table 11

Most significant sectors with the highest share of exports in Slovakia, embodied emissions according to final demand, 2023

Economic sectors according to NACE Rev.2.	Embodied GHG 2023 (thousand tonnes of CO_2 eq)				
	households	government	gross capital formation	export	total embodied GHG emissions
Basic metals	1	0	163	3,338	3,503
Motor vehicles, trailers and semi-trailers	49	0	85	1,990	2,124
Legal and accounting services; services of head offices; management consultancy services	5	0	9	217	232
Electrical equipment	21	0	12	233	266
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	13	0	0	87	100
Computer, electronic and optical products	17	0	24	216	256
Fabricated metal products, except machinery and equipment	49	0	218	1,086	1,353
Other transport equipment	15	0	45	153	212
Chemicals and chemical products	211	0	16	486	712
Machinery and equipment n.e.c.	5	0	446	902	1,353

Economic sectors according to NACE Rev.2.	Embodied GHG (%) 2023				Rank of sector in	
	house-hold share	govern-ment	gross capital formation	export	2015	2023
Basic metals	0	0	5	95	1	2
Motor vehicles, trailers and semi-trailers	2	0	4	94	6	4
Legal and accounting services; services of head offices; management consultancy services	2	0	4	94	3	5
Electrical equipment	8	0	4	87	11	8
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	13	0	0	87	7	9
Computer, electronic and optical products	6	0	9	84	8	10
Fabricated metal products, except machinery and equipment	4	0	16	80	5	12
Other transport equipment	7	0	21	72	19	14
Chemicals and chemical products	30	0	2	68	15	16
Machinery and equipment n.e.c.	0	0	33	67	20	17

In Slovakia, the 'Basic metals', 'Motor vehicles, trailers, and semi-trailers', and 'Fabricated metal products' sectors showed high levels of embodied GHG emissions due to exports. The decomposition of embodied emissions by final demand revealed stark contrasts among the V4 countries. These differences reflect structural economic disparities: Poland's large domestic market and energy-intensive households versus Hungary and Slovakia's integration into global manufacturing value chains. In the Czech Republic, the high export volume and energy- and feedstock-intensive industrial processes, as well as the carbon-heavy energy supply, explain why the 'Electrical equipment', 'Motor vehicles', and 'Chemicals and chemical products' sectors became major contributors to the embodied GHG emissions in exports by 2023.

Discussion

All V4 countries showed reductions in total direct emissions between 2015 and 2023. The Czech Republic experienced the most significant decrease in GHG emissions (17.5%), whereas Poland exhibited the least reduction (3.6%). The Czech government is promoting renewable energy as it shifts away from hard coal. By contrast, Poland lacks a nuclear energy source and is significantly dependent on coal. Economic and social factors impede its transition to alternative energy sources, confirming the finding from Szép et al. (2023). As demonstrated by Rogulj et al. (2023), the Visegrad countries have been working to reduce the emission intensity of their production processes and are making significant progress in transitioning to renewable energy sources (Rahaman et al. 2023).

The most significant economic sectors with the highest level of embodied GHG emissions were revealed in the four Visegrad countries by using an EEIO model. These sectors included 'Food, beverages, and tobacco products', 'Constructions and construction works', 'Motor vehicles, trailers, and semi-trailers', and 'Machinery and equipment'.

The food and beverage manufacturing sector is highly carbon emission intensive. The downstream conversion and processing stages increase embodied emissions per monetary unit in the sector (Camanzi et al. 2017), whereas food waste across the supply chain increases embodied emissions per unit of consumed food (FAO 2024). These results are consistent with those of previous research on the V4 countries, which confirmed high GHG levels in the food sector (Mrówczyńska-Kamińska et al. 2025).

Both motor vehicle and machinery production rely heavily on steel, aluminium, and other metals, the manufacturing of which is carbon intensive. The V4 countries have large automotive and engineering sectors, which are significant exporters. These sectors are deeply embedded in complex international supply chains, including the sourcing of parts, semiconductors, and raw materials. Previous multi-regional input–

output analyses showed that sectors linked to global value chains accumulate high embodied emissions (Zhu et al. 2022). In addition, the slow adoption of low-carbon manufacturing technologies retains a high emissions intensity per unit of production.

The construction sector has high embodied emissions because it requires extensive transportation, which is carbon intensive. Cement production is also highly carbon intensive (Andrew 2018). Rapid infrastructure modernisation and housing construction increased demand for construction materials during the post-2004 EU accession period (HCSO 2022). Furthermore, higher production volumes, technological lag, and waste management inefficiencies resulted in higher embodied emission intensities relative to EU averages (Gálvez-Martos et al. 2018, Eurostat 2020).

We identified the upstream industries that supply raw materials and intermediate goods to other sectors in the V4 countries. These industries resulted in higher direct GHG emissions than embodied emissions. The most significant upstream sectors in the four countries were other non-metallic minerals, the mining and quarrying industry, land transport services, transport services via pipelines, and agricultural goods.

Decomposing embodied GHG emissions into final demand categories revealed that the proportion of household emissions remained unchanged throughout the analysed period across the V4 countries. These results are in line with previous findings on the Czech Republic (Mach et al. 2018). Poland exhibited the highest share of household emissions. The country could hardly reduce its GHG emissions because of its strategic choice to prioritise energy security and economic stability over decarbonisation (Kovács et al. 2024). Thus, the use of solid fuels for residential purposes remains the largest source of local air pollution in Poland (Gruszecka-Kosowska et al. 2021). This phenomenon shifts the policy focus to reducing smog rather than mitigating carbon emissions.

The sectors with the greatest proportion of exported embodied GHG emissions were identified. In the Czech Republic, the forestry, logging, and associated services sector is becoming increasingly prominent owing to its increased export activity (Sujová et al. 2016). Meanwhile, in Hungary, the 'Basic pharmaceutical items and pharmaceutical preparations' sector has gained prominence (Antalóczy et al. 2021); in Poland, the ‘Other transport equipment’ and ‘Land transport services’ sectors have shifted due to the country's strategic location as a major European logistics hub. Analysis of embodied emissions by final demand revealed significant disparities among the V4 nations. For example, Poland's large domestic market and energy-intensive households’ contrast with Hungary and Slovakia's integration into global industrial value chains (Szabó–Fabók 2020).

Policy implications

The study used EEIO analysis to reveal direct and embodied emissions. It provides a perspective on carbon leakage that is especially relevant for the V4 countries.

To mitigate carbon leakage (the relocation of energy-intensive sectors to countries with lower environmental standards), the EU has introduced measures such as the Carbon Border Adjustment Mechanism (CBAM). This mechanism aims to level the playing field by imposing a carbon price on imports that is equivalent to the EU's internal carbon price (Wróblewska–Zmitrowicz 2024). This policy is crucial for protecting the competitiveness of sectors in the V4 countries and encouraging the adoption of green technologies (Portrusching et al. 2024). However, stricter GHG reduction policies may impact the competitiveness of trade-sensitive sectors (Cosbey et al. 2019).

Results highlighted another important policy implication: the need to change the methodology used for carbon accounting in climate policy. Conventional production-based GHG accounting methods may not accurately reflect the true environmental impacts and costs (Vetőné Mózner et al. 2025). International climate agreements, including the Paris Agreement, do not fully address the emissions embodied in traded goods. Although countries are held responsible for emissions from exports, emissions from imports are often overlooked (Bastianoni et al. 2014, Torpman 2022). Shifting to shared responsibility accounting could reflect emissions responsibility more accurately as it accounts for emissions embodied in imported goods (Vetőné Mózner 2013). Implementing shared responsibility-based accounting could lead to stricter environmental regulations and encourage countries to rethink their trading activities to reduce the environmental load of production (Pan et al. 2022).

These policy implications highlight the need for comprehensive strategies to address the high embodied GHG emissions in the V4 countries.

Limitations and future research directions

The study has several limitations. One is the use of 63 aggregated economic sectors based on Eurostat's classification. Future studies could use more detailed sectoral classifications or hybrid models that combine EEIO with firm-level or regional data to better capture emission hotspots.

Another limitation is the assumption of the EEIO model that pricing within and among sectors is uniform. The model uses monetary input coefficients instead of physical ones, assuming, that the environmental intensity per euro of production remains consistent across all enterprises and product variations. Consequently, the model does not accurately reflect actual disparities in pricing strategies, profit margins, and cost structures. This constraint requires a careful analysis of empirical results, particularly when making international comparisons involving highly aggregated data.

However, in the present analysis, real-world secondary data were used from the Eurostat database.

An additional limitation is the lack of adjustments for purchasing power parity (PPP) in cross-country comparisons, which can result in a systematic over- or underestimation of embodied emissions for low-price economies. Adjusting for PPP is significant when differences in the economic and income development between the analysed countries are large. Comparisons between developed and developing countries are especially sensitive (Sato 2014, Rodrigues et al. 2018). The present analysis deals with a relatively homogeneous group of Central and Eastern European countries; therefore, no significant differences are expected. However, this simplifies the interpretation of the results. As Rodrigues et al. (2018) pointed out, PPP adjustments present methodological challenges and are important sources of uncertainty.

Conclusions

As members of the European Union, the V4 countries are subject to EU regulations and policies aimed at reducing GHG emissions. Compliance with these regulations can help mitigate the impact of high embodied emissions. EEIO tables improve our comprehension of the interconnections between economic activity and environmental impacts. Their use in statistical analyses and policy formulation substantially enhances the achievement of climate policy goals. Increased responsibility for sectoral emissions within the V4 countries can facilitate the development of further mitigation strategies and promote cleaner industrial practices.

The high export share of embodied emissions in Hungary and Slovakia reflects their export-driven industrial economies, which are heavily centred on manufacturing globally traded intermediate goods with significant carbon footprints. Both countries are essential players in EU manufacturing supply chains. Key export sectors such as basic metals, fabricated metal products, vehicles, and electronic equipment are part of globally segmented production networks. These industries have high carbon intensities and contribute significantly to embodied emissions in exports. In contrast to Poland, which relies more on domestic consumption, Hungary and Slovakia have export-oriented industrial structures, resulting in emissions being embodied in exported goods. The findings indicate that the varying energy structures of countries are manifested in their embodied GHG emissions and export orientation.

Linking emissions data with price indices and cost structures could help assess the economic feasibility of decarbonisation strategies and identify cost-effective mitigation pathways. Optimization modelling can be a further step in the scenario analysis for future production trends and changes in macroeconomic variables, such as wages or gross value added, and the consequence on emissions impacts.

Final consumers may experience excessive burdens because of their responsibility for embodied emissions. Both producers and producer nations benefit from traded goods, as do end users. Compared with the production-based approach, a consumption-based approach would lead to substantially higher emissions in industrialised countries. Conversely, for developing countries with an increase in exports, the opposite holds true. Consequently, the significance of shared responsibility is increasingly examined in international literature, employing diverse methodological approaches to identify how responsibility might be allocated between producer and consumer countries (Wang et al. 2024, Csutora–Vetőné Mózner 2014). Aside from the examination of data from intra-national sectors, examining responsibility for global emissions may be a fruitful research field for which EEIO provides an excellent methodological framework.

In conclusion, the V4 countries struggle to balance economic growth and environmental sustainability. They have significant GHG emissions embodied in exports and reducing emission intensity and adopting cleaner technologies are essential to reducing their environmental impact. Consumption-based emissions accounting could improve GHG reporting and policy effectiveness. By highlighting the sectors and demand categories most responsible for embodied emissions, this research provides actionable insights for policymakers. It supports the V4 in developing strategies that can help the EU achieve its decarbonisation goals.

Data availability

Data will be made available on request.

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Appendix

Table A1

Direct and embodied emissions in the Czech Republic, 2023

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Products of agriculture, hunting and related services	9,124	4,555	50
Products of forestry, logging and related services	49	172	347
Fish and other fishing products; aquaculture products; support services to fishing	73	89	122
Mining and quarrying	4,388	495	11
Food, beverages and tobacco products	1,151	5,884	511
Textiles, wearing apparel, leather and related products	77	579	749
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	166	352	212
Paper and paper products	442	659	149
Printing and recording services	23	18	80
Coke and refined petroleum products	200	812	405
Chemicals and chemical products	4,439	3,037	68
Basic pharmaceutical products and pharmaceutical preparations	32	222	688
Rubber and plastic products	205	1,042	508
Other non-metallic mineral products	3,363	2,275	68
Basic metals	5,927	3,178	54
Fabricated metal products, except machinery and equipment	285	1,804	634
Computer, electronic and optical products	91	752	831
Electrical equipment	94	1,245	1,318
Machinery and equipment n.e.c.	234	2346	1,003
Motor vehicles, trailers and semi-trailers	206	4,072	1,974
Other transport equipment	32	392	1,207
Furniture and other manufactured goods	66	665	1,008
Repair and installation services of machinery and equipment	100	297	297
Electricity, gas, steam and air conditioning	34,135	19,231	56
Natural water; water treatment and supply services	80	177	222
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	7,597	4,427	58
Constructions and construction works	1,617	5,822	360
Wholesale and retail trade and repair services of motor vehicles and motorcycles	134	273	204
Wholesale trade services, except of motor vehicles and motorcycles + Retail trade	1,079	2,360	219
Land transport services and transport services via pipelines	8,622	6,667	77
Water transport services	40	15	37
Air transport services	912	706	77
Warehousing and support services for transportation	430	1,169	272

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Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Postal and courier services	96	68	70
Accommodation and food services	67	1,177	1,764
Publishing services	10	120	1,182
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	6	102	1,760
Telecommunications services	26	216	837
Computer programming, consultancy and related services; Information services	52	294	563
Financial services, except insurance and pension funding	21	59	286
Insurance, reinsurance and pension funding services, except compulsory social security	5	165	3,543
Services auxiliary to financial services and insurance services	13	16	127
Real estate services excluding imputed rents	118	2,768	2,339
Legal and accounting services; services of head offices; management consultancy services	41	127	310
Architectural and engineering services; technical testing and analysis services	61	80	132
Scientific research and development services	17	427	2,476
Advertising and market research services	7	40	549
Other professional, scientific and technical services and veterinary services	15	34	231
Rental and leasing services	188	75	40
Employment services	28	8	29
Travel agency, tour operator and other reservation services and related services	4	234	5,948
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	162	181	112
Public administration and defence services; compulsory social security services	221	1,820	822
Education services	97	771	797
Human health activities	254	1,414	558
Residential care services; social work services without accommodation	40	216	544
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	23	307	1,339
Sporting services and amusement and recreation services	40	205	507
Services furnished by membership organisations	7	125	1,748
Repair services of computers and personal and household goods	2	35	1,612
Other personal services	23	184	801

Table A2

Direct and embodied emissions in Hungary, 2023

Economic sectors according to NACE Rev.2.	Direct GHG (thousand tonnes of CO_2 eq)	Embodied GHG (thousand tonnes of CO_2 eq)	Embodied GHG emissions /direct GHG emissions (%)
Products of agriculture, hunting and related services	7,945	4,134	52
Products of forestry, logging and related services	113	82	72
Fish and other fishing products; aquaculture products; support services to fishing	8	9	113
Mining and quarrying	571	92	16
Food, beverages and tobacco products	910	4,515	496
Textiles, wearing apparel, leather and related products	45	117	263
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	70	86	123
Paper and paper products	254	351	138
Printing and recording services	206	16	8
Coke and refined petroleum products	1,411	1,002	71
Chemicals and chemical products	2,531	1,712	68
Basic pharmaceutical products and pharmaceutical preparations	332	511	154
Rubber and plastic products	206	509	247
Other non-metallic mineral products	1,572	829	53
Basic metals	483	323	67
Fabricated metal products, except machinery and equipment	197	284	144
Computer, electronic and optical products	189	596	314
Electrical equipment	159	900	564
Machinery and equipment n.e.c.	165	635	385
Motor vehicles, trailers and semi-trailers	243	1,670	686
Other transport equipment	10	91	876
Furniture and other manufactured goods	115	301	262
Repair and installation services of machinery and equipment	45	109	244
Electricity, gas, steam and air conditioning	8,976	3,846	43
Natural water; water treatment and supply services	25	79	315
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	4,437	2,198	50
Constructions and construction works	1,110	3,172	286
Wholesale and retail trade and repair services of motor vehicles and motorcycles	659	595	90
Wholesale trade services, except of motor vehicles and motorcycles	938	1,593	170
Retail trade services, except of motor vehicles and motorcycles	474	1,544	326
Land transport services and transport services via pipelines	2,841	2,149	76
Water transport services	13	12	98
Air transport services	4,883	3,723	76

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Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Warehousing and support services for transportation	353	413	117
Postal and courier services	38	23	61
Accommodation and food services	178	1027	578
Publishing services	17	68	391
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	16	51	312
Telecommunications services	54	121	223
Computer programming, consultancy and related services; Information services	134	278	208
Financial services, except insurance and pension funding	122	153	126
Insurance, reinsurance and pension funding services, except compulsory social security	5	35	723
Services auxiliary to financial services and insurance services	24	3	11
Imputed rents of owner-occupied dwellings	0	192	1,923,357
Real estate services excluding imputed rents	442	288	65
Legal and accounting services; services of head offices; management consultancy services	118	167	142
Architectural and engineering services; technical testing and analysis services	65	155	237
Scientific research and development services	51	238	469
Advertising and market research services	20	31	154
Other professional, scientific and technical services and veterinary services	47	112	236
Rental and leasing services	702	343	49
Employment services	36	0	1
Travel agency, tour operator and other reservation services and related services	9	75	867
Security and investigation services; services to buildings and landscape; office administrative, office support, and other business support services	116	36	31
Public administration and defence services; compulsory social security services	741	2104	284
Education services	163	533	327
Human health services	298	800	269
Residential care services; social work services without accommodation	48	280	578
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	37	170	455
Sporting services and amusement and recreation services	27	246	895
Services furnished by membership organisations	34	112	324
Repair services of computers and personal and household goods	9	18	203
Other personal services	66	253	384

Table A3

Direct and embodied emissions in Poland, 2023

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Products of agriculture, hunting and related services	50,999	27,374	54
Products of forestry, logging and related services	744	507	68
Fish and other fishing products; aquaculture products; support services to fishing	310	49	16
Mining and quarrying	21,723	1,748	8
Food, beverages and tobacco products	5,516	45,355	822
Textiles, wearing apparel, leather and related products	178	1,989	1,119
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	452	2,350	519
Paper and paper products	1,876	2,600	139
Printing and recording services	33	311	935
Coke and refined petroleum products	11,406	9,529	84
Chemicals and chemical products	10,764	9,427	88
Basic pharmaceutical products and pharmaceutical preparations	118	678	574
Rubber and plastic products	776	4,630	597
Other non-metallic mineral products	17,170	11,061	64
Basic metals	6,352	6,693	105
Fabricated metal products, except machinery and equipment	530	4,350	821
Computer, electronic and optical products	35	1,666	4,783
Electrical equipment	226	4,958	2,191
Machinery and equipment n.e.c.	214	3,233	1,512
Motor vehicles, trailers and semi-trailers	304	7,140	2,348
Other transport equipment	112	1,850	1,658
Furniture and other manufactured goods	167	5,391	3,233
Repair and installation services of machinery and equipment	55	965	1,744
Electricity, gas, steam and air conditioning	120,793	44,892	37
Natural water; water treatment and supply services	2,685	636	24
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	2,521	3,090	123
Constructions and construction works	798	19,234	2,410
Wholesale and retail trade and repair services of motor vehicles and motorcycles	955	2,013	211
Wholesale trade services, except of motor vehicles and motorcycles	6,886	11,365	165
Retail trade services, except of motor vehicles and motorcycles	2,702	10,902	404
Land transport services and transport services via pipelines	42,264	24,949	59
Water transport services; Air transport; Warehousing and postal services	6,741	7,877	117
Accommodation and food services	326	4,520	1,387
Publishing services	64	646	1,003

(Table continues the next page.)

(Continued.)

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	133	337	254
Telecommunications services	329	1,919	584
Computer programming, consultancy and related services; Information services	518	916	177
Financial services, except insurance and pension funding	625	1,094	175
Insurance, reinsurance and pension funding services, except compulsory social security	21	783	3,783
Services auxiliary to financial services and insurance services	200	545	273
Real estate services excluding imputed rents	469	14,716	3,140
Legal and accounting services; services of head offices; management consultancy services	426	740	174
Architectural and engineering services; technical testing and analysis services	313	840	268
Scientific research and development services	170	1,795	1,059
Advertising and market research services	264	368	139
Other professional, scientific and technical services and veterinary services	88	393	445
Rental and leasing services	627	1,204	192
Employment services	212	1	1
Travel agency, tour operator and other reservation services and related services	33	620	1,870
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	949	3,000	316
Public administration and defence services; compulsory social security services	1,978	9,078	459
Education services	918	3,950	430
Human health services	1,397	5,530	396
Residential care services; social work services without accommodation	163	1,934	1,184
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	175	890	509
Sporting services and amusement and recreation services	113	1,251	1,106
Services furnished by membership organisations	108	643	596
Repair services of computers and personal and household goods	90	319	356
Other personal services	253	1,092	431

Table A4

Direct and embodied emissions in Slovakia, 2023

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Products of agriculture, hunting and related services	1,772	1,376	78
Products of forestry, logging and related services	121	51	42
Fish and other fishing products; aquaculture products; support services to fishing	1	2	179
Mining and quarrying	282	26	9
Food, beverages and tobacco products	627	1,553	248
Textiles, wearing apparel, leather and related products	61	155	254
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	89	100	113
Paper and paper products	111	207	186
Printing and recording services	14	34	241
Coke and refined petroleum products	1,130	835	74
Chemicals and chemical products	906	712	79
Basic pharmaceutical products and pharmaceutical preparations	40	60	150
Rubber and plastic products	558	607	109
Other non-metallic mineral products	1,450	673	46
Basic metals	5,822	3,503	60
Fabricated metal products, except machinery and equipment	1,534	1,353	88
Computer, electronic and optical products	24	256	1,090
Electrical equipment	74	266	358
Machinery and equipment n.e.c.	272	1,353	497
Motor vehicles, trailers and semi-trailers	233	2,124	912
Other transport equipment	64	212	334
Furniture and other manufactured goods	83	180	217
Repair and installation services of machinery and equipment	36	0	0
Electricity, gas, steam and air conditioning	5,395	3,047	56
Natural water; water treatment and supply services	94	81	86
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	2,098	1,276	61
Constructions and construction works	2,081	2,759	133
Wholesale and retail trade and repair services of motor vehicles and motorcycles	107	62	58
Wholesale trade services, except of motor vehicles and motorcycles + Retail trade	213	429	202
Retail	168	889	530
Land transport services and transport services via pipelines	2,180	1,653	76
Water transport services	10	10	95
Air transport services	41	25	61
Warehousing and support services for transportation	226	272	120

(Table continues the next page.)

(Continued.)

Economic sectors according to NACE Rev.2.	Direct GHG	Embodied GHG	Embodied GHG emissions /direct GHG emissions (%)
	(thousand tonnes of CO_2 eq)		
Postal and courier services	304	132	44
Accommodation and food services	153	224	146
Publishing services	4	67	1,765
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	6	33	520
Telecommunications services	3	58	1,778
Computer programming, consultancy and related services; Information services	32	99	310
Financial services, except insurance and pension funding	28	73	263
Insurance, reinsurance and pension funding services, except compulsory social security	1	54	4,405
Services auxiliary to financial services and insurance services	5	9	176
Real estate services excluding imputed rents	243	884	364
Legal and accounting services; services of head offices; management consultancy services	409	232	57
Architectural and engineering services; technical testing and analysis services	32	22	69
Scientific research and development services	2	70	3,145
Advertising and market research services	25	21	86
Other professional, scientific and technical services and veterinary services	25	41	161
Rental and leasing services	258	23	9
Employment services	5	0	0
Travel agency, tour operator and other reservation services and related services	7	15	233
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	81	20	25
Public administration and defence services; compulsory social security services	259	715	276
Education services	93	305	327
Human health activities	152	462	303
Residential care services; social work services without accommodation	10	73	748
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	105	321	305
Sporting services and amusement and recreation services	18	63	349
Services furnished by membership organisations	105	75	71
Repair services of computers and personal and household goods	5	12	254
Other personal services	9	50	541

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