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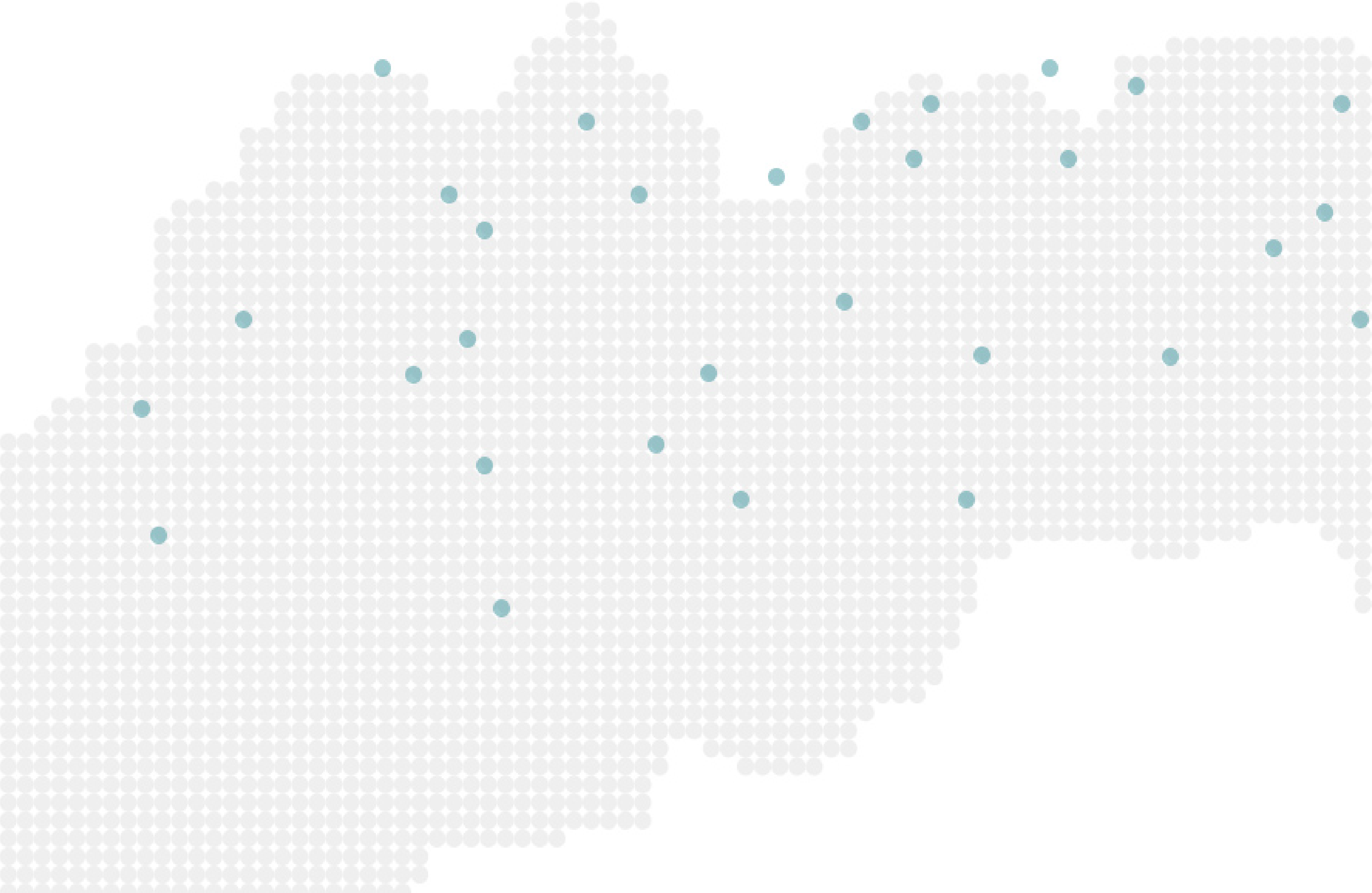

Report on Emission Projections 2025

Submission according to the Article 18 (1) (b) of the Regulation (EU) 2018/1999

Bratislava
15. March 2025

DETAILS OF PREPARATION OF THE SUBMISSION

TITLE OF REPORT	**REPORT ON EMISSION PROJECTION 2025 UNDER THE REGULATION (EU) 2018/1999**
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In 2025, the Slovak Republic is submitting report to the European Commission under the Article 18 (1) (b) of the Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action and according to the Article 38 of the related Implementing Regulation (EU) 2020/1208. The whole package of the submission 2025 of the Slovak Republic comprises:

1. National projections of anthropogenic greenhouse gas emissions [2025] – online Tables
2. Report on Emission Projection 2025

This version of the biennial GHG emission projections is the official submission 2025 released by the online tool REPORTNET 3.

The Slovakia inventory report tables for emission projections what can be downloaded from the following address: http://oeab.shmu.sk.

INTRODUCTION

As a member of the European Union, the Slovak Republic has reporting obligations under the Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on Energy Union Governance and Climate Action and Commission Implementing Regulation (EU) 2020/1208. Once every two years starting in 2021, the Member States prepare a report information on integrated reporting on the greenhouse gas policies and measures and on the projections of anthropogenic greenhouse gas emissions according to the Article 18 of the Regulation.

The Report on Emission Projections 2025 of the Slovak Republic presents GHG emission projections accompanied with the additional data and parameters were submitted through the Commission's online tool – Reportnet 3. This information was submitted on March 15, 2025.

Given the technical problems associated with the calculation of emission projections in the Energy and IPPU sectors, together with the situation connected with the COVID-19 pandemic situation, Slovakia submitted Report on GHG emission projections under the Regulation (EU) 2018/1999 and Commission Implementing Regulation (EU) 2020/1208 by March 15, 2025.

Slovakia submitted the latest GHG emissions inventory submission for the years 1990 – 2022 under the Energy Governance on March 15, 2024 and under the UNFCC the same data on December 2024.

Information on the GHG emissions inventory is provided in **Chapter 1** of this report and was prepared by the SHMÚ. Projected greenhouse gas emissions by the sectors and gases up to 2050 with the base year 2022 (submitted in 2024).

CHAPTER 1. AGGREGATED GHG EMISSION PROJECTIONS

General methodology of the emission projections calculations was based on the same structure as In the national inventory of greenhouse gases. The data structure for activities, input data, emission factors and emission calculations is based on the Common Reporting Format (CRF) of the UNFCCC. The outputs are aggregated. Emission projections are generally calculated by similar methodology as in the case for the national GHG inventory. Base year 2022 was selected for the emission projection. GWP from AR5 were used. In this report are presented results from WEM and WAM scenarios.

With Existing Measures scenario (WEM) – includes policies and measures (PAMs) adopted and implemented at the EU and national levels by the end of 2022 (base year) and the measures being in place to achieve the national renewables (RES) and energy efficiency targets.

With Additional Measures scenario (WAM) – is similar to the scenario decarbonisation scenario of CPS-PRIMES model and available draft of National Energy and Climate Plan. This is consistent with the results presented in the available draft of National Energy and Climate Plan of Slovakia, however scenario was updated based on the latest input data from operators and other parameters.

1.1. Aggregated GHG Emissions

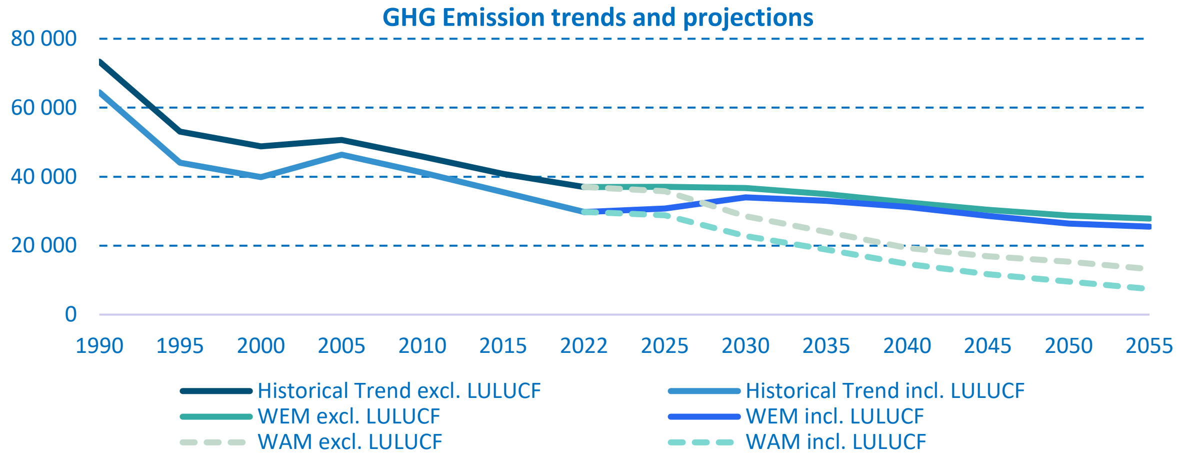
Figures and tables in this chapter describes overall trend of total aggregated emission projections. The WAM scenario achieves far greater reductions than WEM, with accelerated progress starting after 2025. Steady but moderate reduction in WEM scenario in emissions, reflecting limited measures. The steepest decline occurs between 2025 and 2035 in WAM scenario. LULUCF inclusion significantly amplifies the reduction in the WAM scenario, highlighting its critical role in achieving net-zero emissions. While WEM shows progress, it is insufficient to meet long-term climate targets, emphasizing the importance of additional measures in the WAM scenario.

Table 1.1: *Total aggregated GHG emission projections in Gg of CO_2 eq.*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
Total excluding LULUCF	37 013	37 069	36 726	34 930	32 524	30 386	28 709	27 854
Total including LULUCF	29 786.97	30 784.67	34 004.15	32 962.11	31 277.36	28 652.60	26 365.81	25 511.54
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
Total excluding LULUCF	37 013	35 801	28 550	24 012	19 351	16 922	15 355	13 207
Total including LULUCF	29 786.97	28 809.39	22 749.26	18 867.55	14 679.46	11 719.36	9 585.09	7 436.74

***** *Base year 2022; based on the GHG inventory submission 15. 3. 2024*

__Figure 1.1:__ GHG emission trends and emission projections in Gg of CO_2 eq.



1.2. AGGREGATED GHG EMISSION PROJECTIONS BY SECTORS AND BY GASES

This chapter describes in figures and tables the projections of total aggregate GHG emissions for all monitored sectors of the Slovak economy.

ENERGY (EXCLUDING TRANSPORT)

In 2022, this sector accounted for approximately 51.4% of total emissions and by 2050, its share decreases to about 45.5% in WEM scenario and to 37.7% in WAM scenario. WEM scenario reflecting a gradual reduction over time. Trend is steady decline, with emissions dropping by around 30% between 2022 and 2050. WAM scenario reflecting a faster and more substantial reduction. Trend is stronger declining, with emissions decreasing by more than 67% from 2022 to 2050.

TRANSPORT

Transport emissions make up 22.4% of the total in 2022 and in WEM they initially rise to a peak of 25.3% in 2025 but drop significantly to 19.7% by 2050 and more significantly in WAM scenario – to 13.2% of total emissions. Trend shows a short-term increase followed by a steady decline, reducing emissions by approximately 30% between 2022 and 2050 in WEM and sharp decline by 74% in WAM scenario.

IPPU (INDUSTRIAL PROCESSES AND PRODUCT USE)

This sector contributes 21.7% in 2022 and remains relatively stable at 27.0% in 2050 – WEM scenario, and 33% in WAM scenario, which shows slower decrease in trend compare to previous sectors.

AGRICULTURE

Agriculture emissions represent the share of 5.6% in 2022 and maintain a similar proportion, ending at 6.7% in 2050 in WEM scenario and 8.5% in WAM. Emissions trend in WEM remain almost flat, with minor changes across the years. In WAM scenario emissions decline by approximately 33% but maintain a relatively stable share of the total.

LULUCF (LAND USE, LAND-USE CHANGE, AND FORESTRY)

In 2022, LULUCF acts as a carbon sink, offsetting about -20.8% of total emissions. By 2050, its offset capacity decreases slightly to -8.5% in WEM, and -32.6% in WAM scenario. Reduced carbon sequestration over time in WEM scenario, indicating potential challenges in land-use management. And improved carbon sequestration capacity in WAM scenario, highlighting the effectiveness of land-use measures.

WASTE

The share of Waste emissions on national totals are 5.6% in 2022 and in WEM scenario is stable on almost same 5.6% by 2050 in WEM scenario and declining to 8.2% in WAM scenario. Trend shows gradual reduction, with emissions decreasing by about 20% in WEM, resp. 35% in WAM scenario.

Table 1.2: *Sectoral GHG emission trends and emission projections in Gg of CO_2 eq.*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
Energy (excluding transport)	17 833.28	16 432.81	15 555.23	14 744.77	13 724.26	13 117.64	12 496.17	12 200.08
Transport	7 778.85	9 118.71	9 903.88	9 282.92	7 973.86	6 447.16	5 421.12	4 957.40
IPPU	7 536.24	7 733.90	7 627.36	7 444.46	7 422.17	7 403.30	7 422.24	7 442.19
Agriculture	1 934.43	1 956.11	1 935.36	1 816.59	1 836.69	1 843.13	1 841.10	1 780.39
LULUCF	-7 225.74	-6 284.27	-2 722.09	-1 967.99	-1 246.95	-1 733.18	-2 342.86	-2 342.86
Waste	1 929.92	1 827.68	1 704.41	1 641.37	1 567.32	1 574.55	1 528.04	1 474.34
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
Energy (excluding transport)	17 833.28	16411.08	11821.41	10300.50	7686.07	6598.22	5729.63	5 232.57
Transport	7 778.85	8 309.62	7 880.07	5 583.91	3 800.69	2 625.51	2 007.38	677.06
IPPU	7 536.24	7 363.04	5 453.83	5 276.95	5 131.44	5 076.97	5 073.26	5 071.78
Agriculture	1 934.43	1 932.89	1 803.84	1 404.42	1 390.64	1 334.53	1 294.36	1 027.54
LULUCF	-7 225.74	-6 991.20	-5 800.67	-5 144.82	-4 671.43	-5 202.89	-5 770.24	-5 770.24
Waste	1 929.92	1 783.95	1 590.79	1 446.58	1 342.05	1 287.03	1 250.70	1 198.03

** Base year 2022; based on the GHG inventory submission 15. 3. 2024*

Figure 1.2: *Sectoral GHG emission trends and emission projections in Gg of CO_2 eq. in WEM scenario*

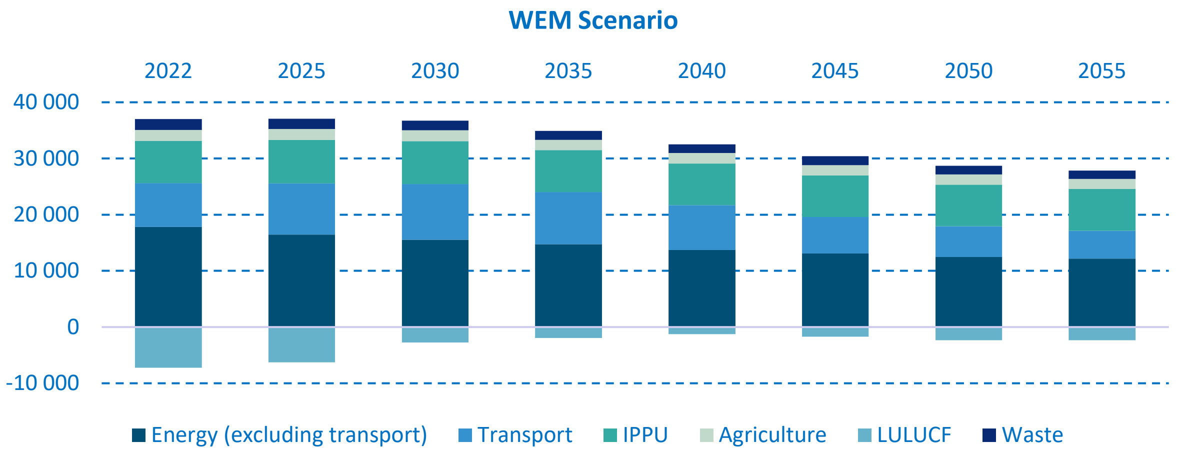
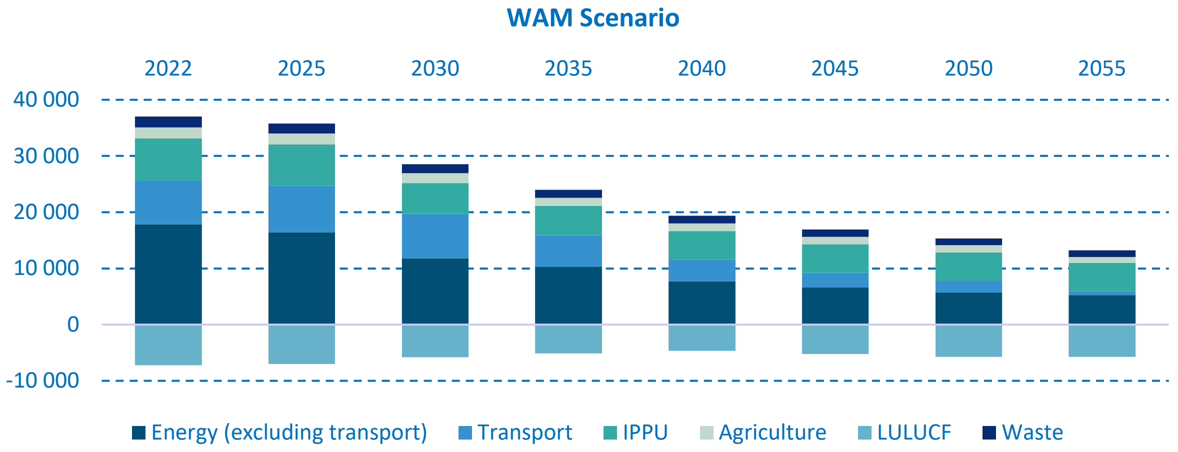


Figure 1.3: *Sectoral GHG emission trends and emission projections in Gg of CO_2 eq. in WAM scenario*



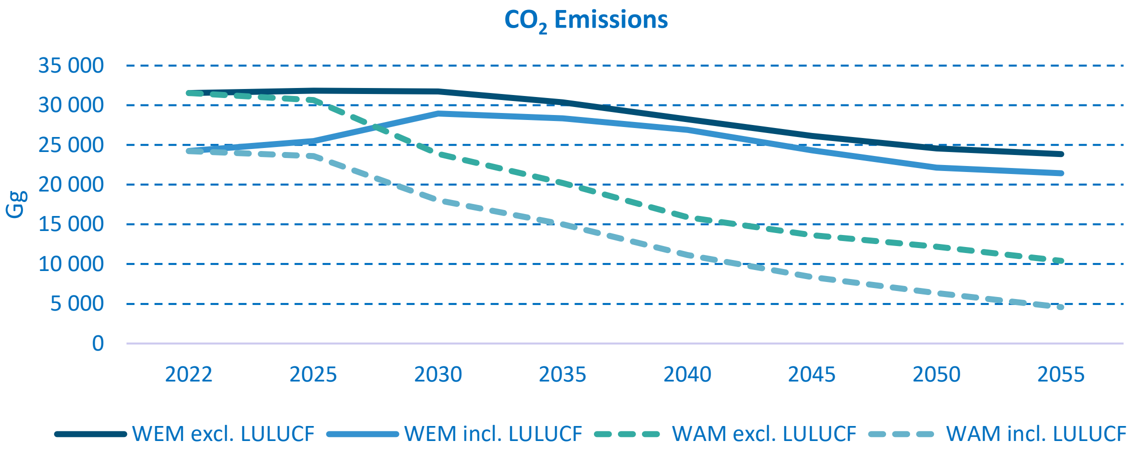
CO_2 emissions accounted for 85% of total GHG emissions in 2022 (excluding CO_2 from LULUCF). CO_2 emissions excluding LULUCF in WEM scenario are expected to decrease by 26% in 2030 compared to 2005 and by 48% compared to 1990. In 2050, a 43% decrease is expected compared to 2005 and 60% decrease compared to 1990. In WAM scenario emissions are expected to decrease by 44% in 2030 compared to 2005 and by 61% compared to 1990. In 2050, 72% decrease is expected compared to 2005 and 80% decrease compared to 1990. CO_2 emissions including LULUCF in WEM scenario are expected to decrease by 25% in 2030 compared to 2005 and by 45% compared to 1990. In 2050, a 43% decrease is expected compared to 2005 and 58% decrease compared to 1990. In WAM scenario emissions are expected to decrease by 53% in 2030 compared to 2005 and by 66% compared to 1990. In 2050, 84% decrease is expected compared to 2005 and 88% decrease compared to 1990. Projections of CO_2 emissions according to WEM and WAM scenarios are presented in ***Figure 1.4*** and ***Table 1.3***.

Table 1.3: *Emission projections of CO_2 in Gg in WEM and WAM scenarios up to 2055*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
CO_2 emissions excl. LULUCF	31 550.24	31 842.89	31 750.79	30 386.54	28 219.73	26 137.96	24 563.52	23 853.44
CO_2 emissions incl. LULUCF	24 229.26	25 491.50	28 962.88	28 354.95	26 907.08	24 337.56	22 152.97	21 442.89
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
CO_2 emissions excl. LULUCF	31 550.24	30 659.50	23 901.13	20 209.74	15 897.27	13 638.22	12 182.24	10 409.17
CO_2 emissions incl. LULUCF	24 229.26	23 606.25	18 039.94	15 007.32	11 167.12	8 375.74	6 352.23	4 579.16

** Base year 2022; based on the GHG inventory submission 15. 3. 2024*

***Figure 1.4**: Emission projections of CO_2 in Gg in WEM and WAM scenarios up to 2055*



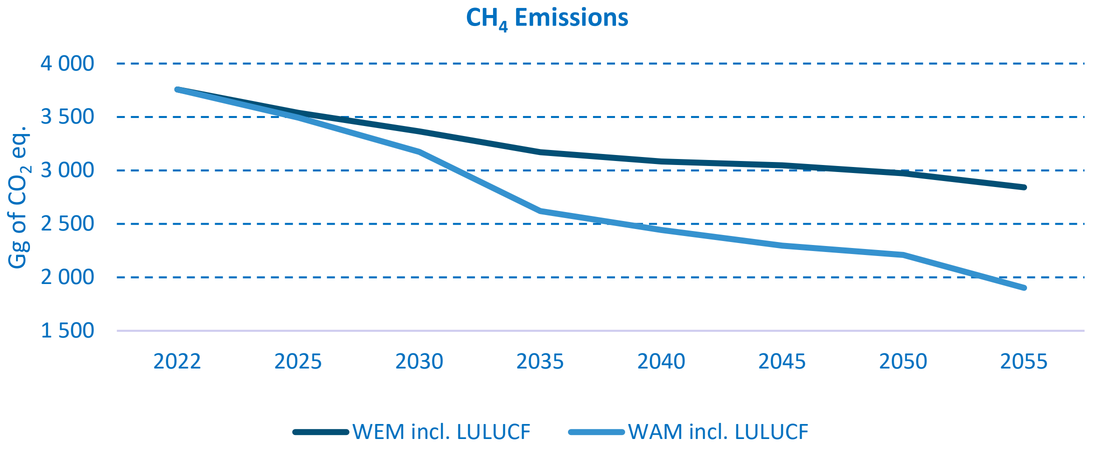
CH_4 emissions accounted for approximately 10% of total GHG emissions in 2022 (excluding CO_2 from LULUCF). CH_4 emissions including LULUCF in WEM scenario are expected to decrease by 32% in 2030 compared to 2005 and by 60% compared to 1990. In 2050, 40% decrease is expected compared to 2005 and 64% decrease compared to 1990. In WAM scenario emissions are expected to decrease by 36% in 2030 compared to 2005 and by 62% compared to 1990. In 2050, 55% decrease is expected compared to 2005 and 74% decrease compared to 1990.Projections of CH_4 emissions according to WEM and WAM scenarios are presented in ***Figure 1.5*** and ***Table 1.4***.

***Table 1.4:** Emission projections of CH_4 in Gg of CO_2 eq. in WEM and WAM scenarios up to 2055*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
CH_4 emissions excl. LULUCF	3 712.00	3 506.38	3 330.98	3 138.02	3 051.72	3 015.70	2 940.00	2 810.03
CH_4 emissions incl. LULUCF	3 757.85	3 540.51	3 364.94	3 171.67	3 085.05	3 048.40	2 972.09	2 842.12
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
CH_4 emissions excl. LULUCF	3 712.00	3 462.85	3 143.40	2 588.99	2 411.06	2 266.58	2 179.07	1 871.42
CH_4 emissions incl. LULUCF	3 757.85	3 493.86	3 174.62	2 620.24	2 442.27	2 297.42	2 209.49	1 901.83

*** Base year 2022; based on the GHG inventory submission 15. 3. 2024***

***Figure 1.5**: Emission projections of CH_4 in Gg of CO_2 eq. in WEM and WAM scenarios up to 2055*



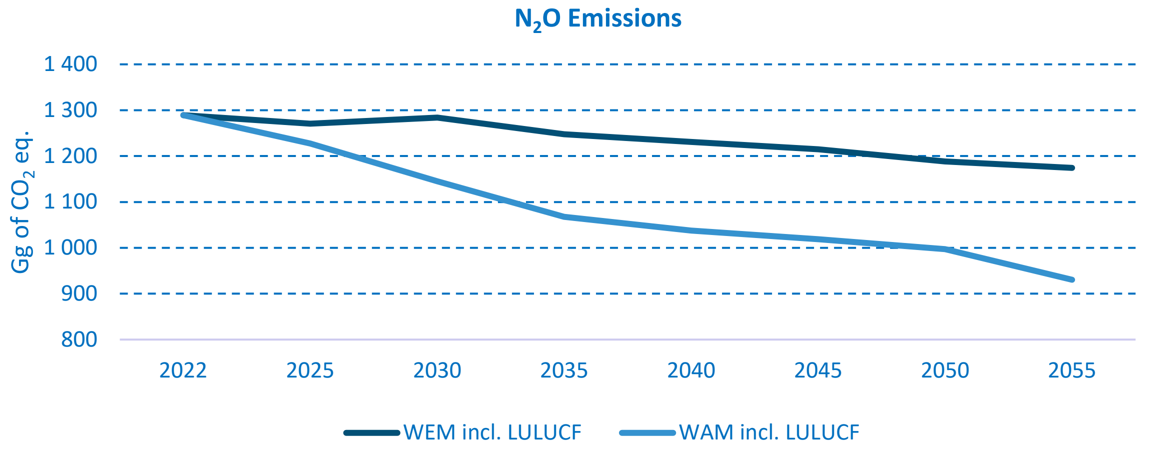
N_2O emissions accounted for less than 4% of total GHG emissions in 2022 (excluding CO_2 from LULUCF). N_2O emissions including LULUCF in WEM scenario are expected to decrease by 48% in 2030 compared to 2005 and by 63% compared to 1990. In 2050, a 52% decrease is expected compared to 2005 and 65% decrease compared to 1990. In WAM scenario emissions are expected to decrease by 54% in 2030 compared to 2005 and by 67% compared to 1990. In 2050, 60% decrease is expected compared to 2005 and 71% decrease compared to 1990. Projections of N_2O emissions according to WEM and WAM scenarios are presented in ***Figure 1.6*** and ***Table 1.5***.

Table 1.5: *Emission projections of N_2O in Gg of CO_2 eq. in WEM and WAM scenarios up to 2055*

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
N_2O emissions excl. LULUCF	1 248.32	1 237.83	1 252.34	1 217.84	1 198.63	1 180.20	1 153.04	1 138.66
N_2O emissions incl. LULUCF	1 289.14	1 270.84	1 284.20	1 247.79	1 230.99	1 214.71	1 188.65	1 174.26
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
N_2O emissions excl. LULUCF	1 248.32	1 196.63	1 115.45	1 041.40	1 010.39	989.70	967.71	901.03
N_2O emissions incl. LULUCF	1 289.14	1 227.68	1 144.74	1 067.76	1 037.91	1 018.45	997.07	930.39

** Base year 2022; based on the GHG inventory submission 15. 3. 2024*

Figure 1.6*: Emission projections of N_2O in Gg of CO_2 eq. in WEM and WAM scenarios up to 2055*



Emissions of F-gases accounted for over 1% of total GHG emissions in 2022 (excluding CO_2 from LULUCF). The most produced gases are HFCs with a share of almost 96%, followed by SF_6 with a share of 3% in 2022. Emissions of F-gases in WEM scenario are expected to increase by 22% in 2030 compared to 2005 and by 83% compared to 1990. In 2050, 84% decrease is expected compared to 2005 and 76% decrease compared to 1990. In WAM scenario emissions are expected to increase by 21% in 2030 compared to 2005 and by 82% compared to 1990. In 2050, 92% decrease is expected compared to 2005 and 88% decrease compared to 1990. Projections of F-gases emissions according to WEM and WAM scenarios are presented in ***Figure 1.7*** and ***Table 1.6***.

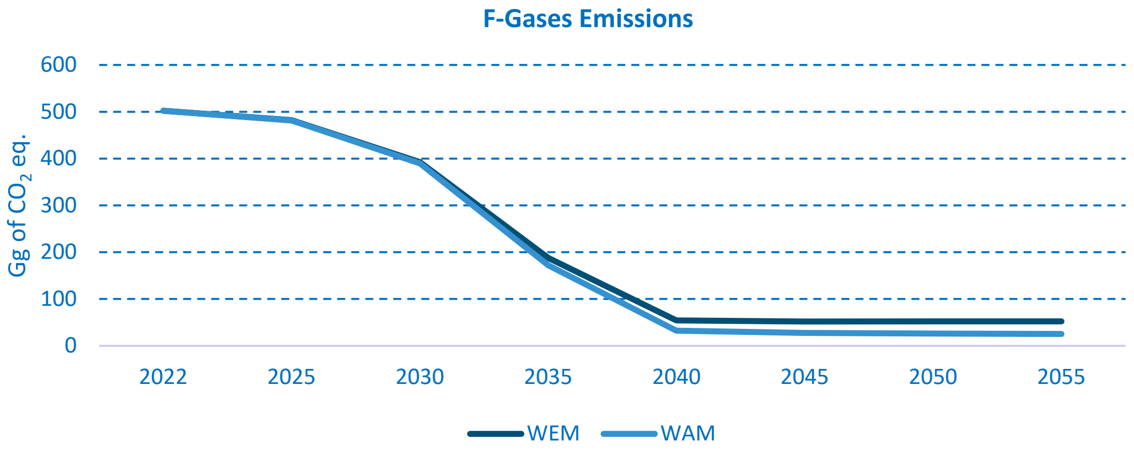
Table 1.6: *Emission projections of F-gases in Gg of CO_2 eq. in WEM and WAM scenarios up to 2055*

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
HFCs emissions	480.86	466.67	377.92	175.14	42.03	39.73	39.90	40.07
PFCs emissions	5.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SF_6 emissions	15.38	15.16	14.20	12.57	12.20	12.20	12.20	12.20
NF_3 emissions	-	-	-	-	-	-	-	-

WAM	2022*	2025	2030	2035	2040	2045	2050	2055
HFCs emissions	480.86	466.62	376.23	160.44	21.02	16.74	15.28	14.34
PFCs emissions	5.91	-	-	-	-	-	-	-
SF_6 emissions	15.38	14.98	13.73	11.79	11.14	11.02	11.02	11.02
NF_3 emissions	-	-	-	-	-	-	-	-

** Base year 2022; based on the GHG inventory submission 15. 3. 2024*

***Figure 1.7**: Emission projections of F-gases in Gg of CO_2 eq. in WEM and WAM scenarios up to 2055*



1.3. EU ETS/ESR Split

An important indicator of emission trends is their development in individual sectors. European Commission legislation categorizes greenhouse gas emissions into two main groups based on the regulatory instrument governing them: emissions included in the EU ETS (Emissions Trading System) and those included in the EU ESR (Effort Sharing Regulation). The obligation to report greenhouse gas emissions separately for the EU ETS and EU ESR is also enshrined in the Regulation on the Governance of the Energy Union. This data is prepared by the Slovak Hydrometeorological Institute - Department of Emissions and Biofuels.

Although the EU ETS directive has been in force since 2005 and is currently in its fourth phase (2021 – 2030), the EU ESR decision is divided into the period from 2013 to 2020 (originally the EU ESD decision) and the period from 2021 to 2030 with a base year of 2005 (the year from which the reduction of emissions under the EU ESR is calculated). Another difference between the two systems is the application of their obligations. While the EU ETS does not contain specific obligations for the state (only rules for individual economic operators in the scheme) but annual trajectories for reducing the emission cap, under the EU ESR, the obligation is valid at the state level. Emissions under both systems undergo annual international verifications.

Table 1.7, ***Table 1.8***, ***Figure 1.8*** and ***Figure 1.9*** show detailed split of EU ETS and ESR GHG emission projections in WEM and WAM scenarios.

Table 1.7: *GHG emission projections split in EU ETS and ESR by sectors in Gg of CO_2 eq. in WEM scenario*

WEM								
EU ETS	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
Total excluding LULUCF	17 418.25	17 208.12	16 926.45	16 587.40	16 240.51	16 007.85	15 809.14	15 724.76
1. Energy	10 534.09	10 103.69	9 837.00	9 464.39	8 999.29	8 779.86	8 560.13	8 453.69
2. Industrial processes	6 884.16	7 104.43	7 089.46	7 123.01	7 241.22	7 227.99	7 249.01	7 271.06
ESD/ESR	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
Total excluding LULUCF	19 594.46	19 859.56	19 798.44	18 341.37	16 282.46	14 376.59	12 898.14	12 128.29
1. Energy	15 078.03	15 446.57	15 620.77	14 561.96	12 697.49	10 783.59	9 355.77	8 702.44
2. Industrial processes	652.08	629.48	537.91	321.45	180.95	175.31	173.23	171.13
3. Agriculture	1 934.43	1 956.11	1 935.36	1 816.59	1 836.69	1 843.13	1 841.10	1 780.39
5. Waste	1 929.92	1 827.40	1 704.41	1 641.37	1 567.32	1 574.55	1 528.04	1 474.34

***** *Base year 2022; based on the GHG inventory submission 15. 3. 2024*

A significant trend observed in recent years is a shift in the proportion of emissions regulated under the EU ETS, which no longer account for a majority (declining from 50% in 2005 to 47% in 2022). This outflow of emissions from the EU ETS is due to several factors, including changes in the scope of the directive's application to individual installations (inclusion of aviation from 2012, expansion of the scope of activities from 2013), rising emission allowance prices, a decrease in free allowances, and, last but not least, the deliberate division of larger companies into smaller ones to avoid falling under the EU ETS.

Table 1.8*: GHG emission projections split in EU ETS and ESR by sectors in Gg of CO_2 eq. in WAM scenario*

WAM								
EU ETS	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
Total excluding LULUCF	17 418.25	16 785.42	11 519.58	11 060.23	9 536.58	9 111.14	8 887.89	8 798.27
1. Energy	10 534.09	10 066.05	6 612.01	6 093.92	4 563.32	4 179.77	3 951.70	3 855.56
2. Industrial processes	6 884.16	6 719.37	4 907.56	4 966.31	4 973.26	4 931.38	4 936.19	4 942.71
ESD/ESR	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
Total excluding LULUCF	19 594.46	19 013.91	17 029.01	12 950.80	9 812.97	7 809.77	6 466.05	4 407.31
1. Energy	15 078.03	14 653.40	13 088.12	9 789.15	6 922.09	5 042.61	3 783.92	2 052.67
2. Industrial processes	652.08	643.67	546.27	310.64	158.19	145.59	137.07	129.07
3. Agriculture	1 934.43	1 932.89	1 803.84	1 404.42	1 390.64	1 334.53	1 294.36	1 027.54
5. Waste	1 929.92	1 783.95	1 590.79	1 446.58	1 342.05	1 287.03	1 250.70	1 198.03

***** *Base year 2022; based on the GHG inventory submission 15. 3. 2024*

***Figure 1.8**: GHG emission projections split in EU ETS and ESR by sectors in Gg of CO₂ eq. in WAM scenario*

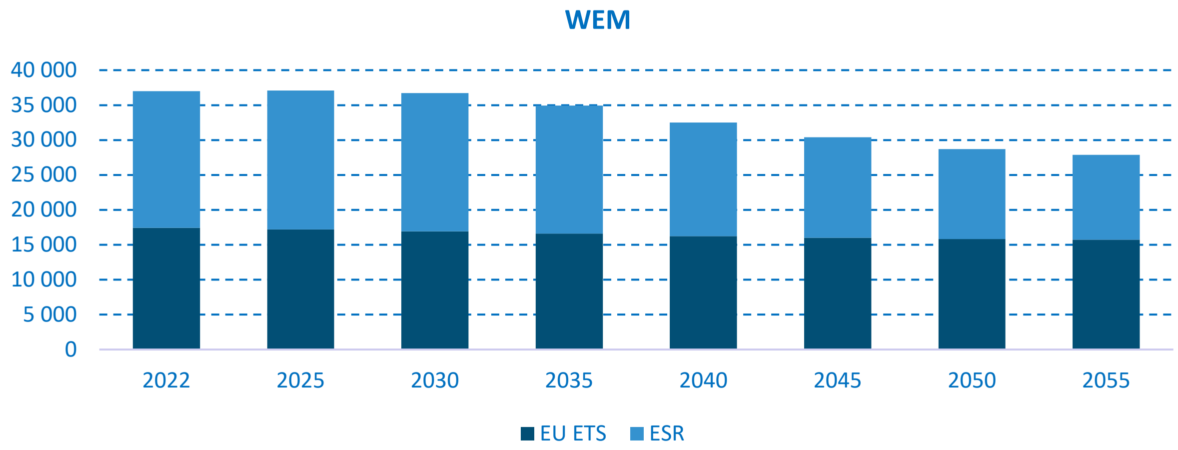
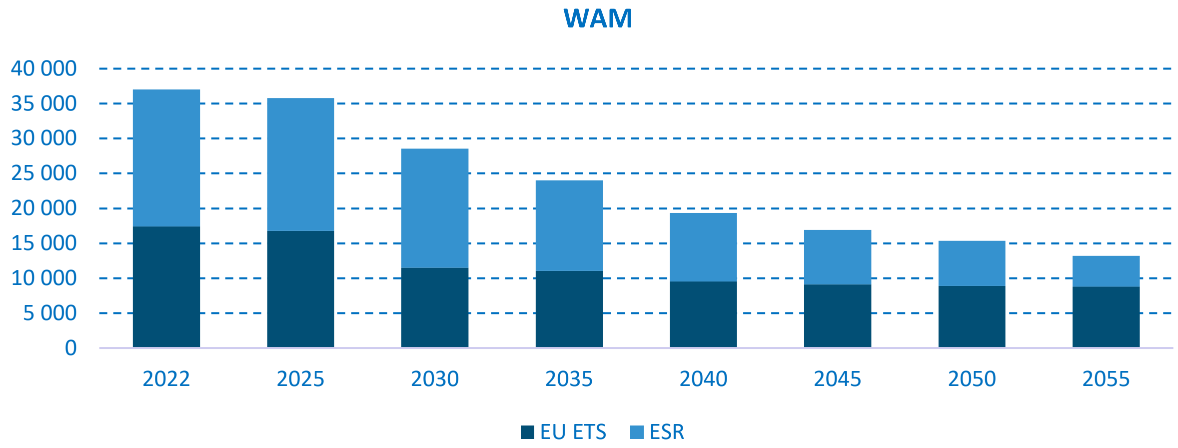


***Figure 1.9**: GHG emission projections split in EU ETS and ESR by sectors in Gg of CO₂ eq. in WAM scenario*



CHAPTER 2. GHG EMISSION PROJECTIONS IN THE ENERGY SECTOR

Dynamic changes in global politics as well as economic developments in recent years and months have also significant impact and they were complications for the preparation of GHG emission projections, especially in view of the constant changes in the estimated development of macroeconomic indicators for the near future. The long-term development of greenhouse gas emissions also depends on other parameters, such as energy market developments, technological developments and the trading of CO_2 emission allowances. The EU ETS is one of the measures that was implemented before the projected base year, but the new trading period will continue to have an impact in the future. Nevertheless, the additional impact of this measure is limited due to the technical and economic potential. Despite the existing constraints resulting from dynamic changes in critical parameters, it is possible to reach a state of actual compliance with the emission reduction targets, as well as to create the conditions for further emission reductions after 2023.

Emission projections in the Energy sector were calculated separately for large and medium-sized energy appliances, households, transport and fugitive emission categories.

2.1. GHG Emission Projections in the Energy Sector - Fuels Combustion Excluding Transport (1.A.1, 1.A.2, 1.A.4, 1.A.5)

This chapter describes the methodology for calculating emission projections from CRF categories, which includes public heat and electricity production, including industrial energy, emissions from households and other fuels combustion. This chapter excludes emissions from the fuel consumption in transport (1.A.3) and fugitive emissions (1.B). Emissions from small households not connected to a District Heating Network (DHN) were modelled separately and a description of the procedure is given in this chapter, too.

Table 2.1: *Trend of GHG emissions in Gg of CO_2 eq. by categories in particular years*

YEAR	1.A.1 ENERGY INDUSTRIES	1.A.2 MAN. INDUSTRIES AND CONST.	1.A.4 OTHER SECTORS	1.A.5 OTHER
1990	19 076.50	16 094.81	11 543.22	478.98
1995	11 917.42	11 809.02	7 208.06	279.39
2000	12 342.73	9 434.03	6 713.60	147.82
2005	12 125.38	8 576.38	6 717.37	95.72
2010	9 491.57	7 664.18	6 710.90	69.85
2015	8 076.34	6 768.99	4 933.84	63.93
2020	7 308.61	7 032.32	5 317.86	64.06
2021	6 407.46	5 922.85	4 828.48	62.38
2022	19 076.50	16 094.81	11 543.22	478.98

Years 1990 – 2022 based on the GHG inventory submission 15.3.2024

Table 2.1 shows trend in GHG emissions by categories in particular years indicated the significant decrease in emissions followed by decrease in fuels consumption and fuel switch (increase of gas, other fuels, peat and biomass and decrease of liquid and solid fuels).

2.1.1. Input Parameters for Emission Projections

Input data for the calculation of GHG projections in model TIMES-Slovakia for energy are provided by CPS and Macro Economical Model (IEP), which was developed for the needs of the Low Carbon Strategy (NUS SK). Additional input data was available from the EU ETS Reports, National Energy Statistical yearbook, National Emission Information System (NEIS), NIMs (National Implementation Measures).

Fuels data provided by (ÚRSO) - prices of tradable fuels, if possible also separately for sectors such as industry, households and others: natural gas in EUR/GJ, heating oils, brown coal, black coal, coke, fuel wood, waste wood, wood chips in EUR/ton or EUR/GJ. Input data for the calculation of GHG projections in model TIMES from industry and energy are provided by model Compact PRIMES for Slovakia (CPS) and Macro Economical Model Envisage, which was developed for the needs of the Low Carbon Development Study of the Slovak Republic (LCDS). Additional input data was available from the EU ETS Reports, National Energy Statistical yearbook, NEIS, NIMs templates for benchmarking emissions of participating installations.

RES technologies provided by Ministry of Economy of the Slovak Republic - or with the association of operators of renewable sources accompanied with structure and time development. For individual types of resources, the following data are taken from: The JRC European TIMES Energy System Model.[1]

- Photovoltaics - estimated potential of electricity production in MWh/year in topographic distribution, i.e. by districts or regions
- Annual distribution of production - when it can be divided into hours, days, weeks and months, as the case may be, in a different arrangement than this production is balanced
- Investment costs EUR/kW
- Wind power plants - similar to photovoltaics
- Investment costs EUR/kW
- Annual power distribution as in the case of photovoltaics, (CPS-Slovakia)
- Biomass - biomass potential in TJ/year according to its type - wood, wood chips, etc., (CPS-Slovakia)
- Geothermal - Potential TJ/year in geographical distribution, investment costs EUR/GW, (CPS-Slovakia)

As a first step for the input parameters for projections in the TIMES-Slovakia model, energy and industrial sources included in the EU-ETS were analysed. The reasons for this approach are as follows:

- Sources included in this group are the most significant stationary sources of GHG emissions, primarily CO_2. These inputs parameters are crucial for correct aggregation of total CO_2, CH_4 and N_2O emissions.
- The new sets of NIMs (submitted in 2024) tentatively show decreasing trend of EU-ETS enterprises,

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[1] https://data.jrc.ec.europa.eu/collection/id-00287

- The analysis is based on the data of 2022, for which there are data from files processed for the preparation of NIMs after 2022. These files contain data not only on fuel consumption and CO_2 emissions, but also on the production of electricity, heat, and benchmark commodities necessary for setting free emission allowances.
- Recommended parameters for reporting on GHG projections in ***Table 2.2*** shows the trajectory of the carbon price for sectors under the existing ETS in its current scope (power, industry, centralized heat, aviation sectors, and maritime industry) up to 2030, corresponding to the legally binding -55% climate target context. For long-term values beyond 2030, Table 3 shows two trajectories: a trajectory based on the EU Reference Scenario 2020 for the carbon value in "WEM" scenarios, and an indicative carbon value trajectory across the economy to reaching the EU climate neutrality for national ("WAM") scenario.

Table 2.2: *Harmonized trajectory for the carbon price based on EC recommendations*

Scenario	Carbon price	2025	2030	2035	2040	2045	2050	2055
WEM	ETS ETS 2	95* -	95* -	100 -	100 -	160 -	190 -	220 -
WAM	ETS ETS 2	95* -	95* 45	140 70	290 100	430 130	490 160	520 -

* The corresponding carbon prices expressed in nominal values are about 100 and 102 EUR / t CO_2 for 2025 and 2030, assuming an index of 126.38 in 2023, 132 in 2025 and 145.74 in 2030, compared to 100 in 2015.[2]

- In addition to carbon prices, the model also offers other options for how measures can be achieved - it is possible to prohibit the purchase of new equipment with a certain fuel, to discard equipment that does not meet the technical parameters (such as older coal-fired boilers) or, depending on the scenario, to enable the use of new technologies such as artificial carbon capture, hydrogen fuel based on regional availability in JRC-EU TIMES.[3]
- ***Table 2.3*** shows the proposed central harmonized trajectories for oil, gas, and coal fuel international prices recommended by European Commission.
- Final energy consumption figures are integrated, and primary energy consumption and the energy used in other energy conversion sectors are determined, using data provided by CPS-Slovakia.[4]

Table 2.3: *Proposed harmonized central trajectories for international fuel prices*

EUR2023	Oil			Gas (NCV)		Coal	
	€/GJ	**€/toe**	**€/boe**		**€/GJ**	**€/toe**	**€/boe**
2022*	16.7	701	102	2022*	16.7	701	102
2023*	12.5	523	76	2023*	12.5	523	76
2024	13.1	547	80	2024	13.1	547	80
2025	12.4	520	76	2025	12.4	520	76
2030	13.9	582	85	2030	13.9	582	85
2035	15.4	645	94	2035	15.4	645	94
2040	15.8	663	97	2040	15.8	663	97

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[2] Combining ESTAT HICP index for data until 2023 (data extracted in February 2024) and ECB HICP Survey of Professional Forecasters (Q1 2024) for data in 2024-2028:
https://www.ecb.europa.eu/stats/ecb_surveys/survey_of_professional_forecasters/html/ecb.spf2022q1~082bc1deaa.en.html

[3] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/models/model-jrc-eu-times/

[4] https://www.minzp.sk/files/iep/2019_01_low-carbon-study.pdf

EUR2023	Oil			Gas (NCV)		Coal	
	€/GJ	€/toe	€/boe		€/GJ	€/toe	€/boe
2045	17.2	718	105	2045	17.2	718	105
2050	19.7	825	121	9.6	403	4.0	166
2055	23.8	996	146	9.6	403	4.1	170

Note: * 2018-2023 data are yearly average of daily value expressed in current EUR of dated Brent for oil, TTF day ahead for gas, steam coal CIF ARA 6000k for coal. The conversion from current EUR to EUR2023 uses the ESTAT HICP index (data extracted in March 2024).

2.1.2. Methodologies and Key Assumptions/Trends

The 2024 Projection Report, which forms the basis for this report, shows how greenhouse gas emissions might develop up to 2050, assuming the framework data in place and the parametrization of the instruments.

The projection report is based on models calculations by the Emissions and Biofuels Department (OEaB) with cooperation of Institute of Environmental Policy (IEP), Ministry of Environment of the Slovak Republic (MŽP SR) and with individual companies and their technological management-experts.

The results are presented with the sectors as defined in the Integrated National Energy and Climate Plan (NECP): energy, industry, buildings, (transport, agriculture, LULUCF and waste/other – sectors covered by other models). The results of the sectoral models are integrated with the assistance of an overarching model. Framework data, instruments to be included, and major assumptions for their parametrization were coordinated with the relevant ministries in the year 2023 – 2024.

The methodological model represents individual agents' energy demand and supply decisions and balances their supply and demand decisions using cost minimization. This approach, according to economic theory, leads in conditions of perfect competition to a solution with minimal energy costs (Objective function) for end users. The output of the model are projections of key energy indicators in individual sectors:

- Energy demand (from the point of view of energy efficiency)
- Use of individual fuels
- Consumption and use of electricity
- Share of renewable energy sources
- CO_2, CH_4, N_2O emissions
- Amount of investments, fuel and other costs
- Fuel and electricity prices for the end user

Key assumption:

Hydropower

Looking ahead to the year 2030, it can be concluded that the construction of additional hydropower plants will be significantly limited, both for the sake of maximum use of the effective potential of water flows, as well as from the point of view of the effects of these waterworks on the environment. Further increase of installed capacity and production from hydro will take place mainly in the form of their reconstruction or modernization.

Geothermal

Support for the search and exploration of geothermal energy sources in order to make them available for energy purposes is also included in the Slovakia Program. The aim of this measure is mainly to support exploratory wells, which are the riskiest part of the investment in the use of geothermal resources. The most important project is the national project "Use of geothermal energy in the Košice basin".

Photovoltaic

Currently, support mechanisms for the installation of photovoltaic panels are operating in Slovakia, such as Green Homes and partially the Renovate the House program, which can be used by residents and households. In addition, the planned Green program is an enterprise that small and medium-sized enterprises will be able to use for the installation of photovoltaic panels. The basic prerequisite for the maximum use of photovoltaics in Slovakia is the ability to effectively integrate them into the electricity system, which is combined with the need to adapt and strengthen the electricity system so that it can provide capacity for these energy sources. In addition, the speed of development of commercial sources that supply power directly to the grid will depend mainly on the ability to increase the flexibility of the electricity system using battery storage, consumption management and intelligent grid management.

Wind

In December 2023, Slovakia joined the European Wind Charter, which includes, among other things, the acceleration of permitting processes or the commitment of member states to build new capacities. Based on this situation, it can be assumed that by 2030 it will be possible to build and put into operation wind power plants with a total installed capacity of 750 MW.

Biogas

Several projects are currently being prepared, including new biogas stations in Leopoldov and Žiar nad Hronom, and an increase in the installed capacity of the already existing biomethane production facility in Jelšava. Conversion of currently active biogas stations to biomethane stations is also planned. The produced biomethane will be used mainly as a fuel in heating plants in the highly efficient combined production of electricity and heat, and to a lesser extent in transport.

Preparation of data into model for projections

Structure of the model, TIMES-Slovakia, needs to process the conversion chain from primary sources to final energy consumption. This chain is compatible with the structure of the energy balance, which includes the levels of final consumption according to economic sectors, the area of energy transformation, i.e. production of electricity, heat, use of fuels in technologies, etc. and primary energy sources. The system applied in modelling is expressed by the following simplified diagram, where a virtual fuel mix level is created - where the fuel input to individual conversion technologies is simulated and the emission factors of the emissions are assigned at plant – specific level.

In the previous projections, for the increase in consumption - demand, we were based on the assumptions of economic growth expressed by the growth of sectoral value added (VA) for individual economic sectors. The final consumption of energy in the form of electricity, heat or direct consumption of fuels was aggregated for individual sectors, and its further increase was then controlled by the growth of VA. Due to the uncertainty of the economic development, we have decided where it is possible to tie the final consumption to a selected commodity for sources within the ETS, such as e.g. cement, glass, steel products, plastics, etc. However, where no representative commodity can be used, the output flows were aggregated according to the NACE category.

For non-EU ETS sources, we used a modelling approach that recalculates sectoral value added from the CPS Primes Slovakia model. These values are tied to sectoral fuel consumption and a pre-determined 'Demand projection' input." EU ETS-2 extension to transport and residential & commercial sectors is not included. Currently, there is not enough information about the implementation of this extension to reliably model its effects.

Emission projections in households

Emission from households combustion was modelled separately in MS Excel sheet model, where was taken into account improving of efficiency, equipment status and structure and good practise.

The projection calculation is based on inputs from CPS model calculations by Institute of environmental policy (IEP) and in line with the prepared National Energy and Climate Plan.

Information were obtained from the questionnaire surveys in households, new implemented and planned measures were taken into account. Based on this information datasets were improved together with estimations of natural improvement in the structure of households and heating equipment was implemented.

Main characteristic:

- Based on emission inventory methodology – excel model,
- Estimation of total energy demand per m^2 of living space in the household sector,
- Number of flats - living area of flats, flats under DH, age and renewal of flats,
- Structure of heating equipment, method of heating,
- Climatic conditions.

2.1.3. Model Description

TIMES (an acronym for *The Integrated MARKAL-EFOM System*) is an economic model generator for local, national, multi-regional, or global energy systems, which provides a technology-rich basis for representing energy dynamics over a multi-period time horizon. It is usually applied to the analysis of the entire energy sector, but may also be applied to study single sectors such as the electricity and district heat sector. Estimates of end-use energy service demands (e.g., car road travel; residential lighting; steam heat requirements in the paper industry; etc.) are provided by the user for each region to drive the reference scenario. In addition, the user provides estimates of the existing stocks of energy related equipment in all sectors, and the characteristics of available future technologies, as well as present and future sources of primary energy supply and their potentials.

All VEDA-TIMES model input data is organized in Excel workbooks (or files). VEDA2.0 then integrates information from all of these workbooks into internal databases to facilitate management of the model data and to prepare and submit a TIMES model, generated and solved with the GAMS sub-system.

The main goal of the model TIMES (***Table 2.4***) is to find energy system, that meets all demands over the entire time period at least costs. The scenarios are used specifically for region needed based on the possibilities of energy supplies, energy trade and technology availability. The configuration of production and consumption of commodities and their prices is performed.

The optimization is done across all sectors as well as across time periods. The result is optimal mix of technologies and fuels for the specific time period including emissions produced.

Once all the inputs, constraints and scenarios have been put in place, the model will attempt to solve and determine the energy system that meets the energy service demands over the entire time horizon at least cost. It does this by simultaneously making equipment investment decisions and operating, primary energy supply, and energy trade decisions, by region. TIMES assumes perfect foresight, which is to say that all investment decisions are made in each period with full knowledge of future events. It optimizes horizontally (across all sectors) and vertically (across all time periods for which the limit is imposed). The results will be the optimal mix of technologies and fuels at each period, together with the associated emissions to meet the demand. The model configures the production and consumption of commodities (i.e. fuels, materials, and energy services) and their prices; when the model matches supply with demand, i.e. energy producers with energy consumers, it is said to be in equilibrium. The model itself operates with several sectors:

- Energy Industry Combustion – (Public electricity and heat)
- Manufacturing Industries Combustion – (Food processing, Pulp and paper, Other)
- Iron and Steel - IPPU
- Chemicals - IPPU
- Non - Metallic Mineral - IPPU
- Non - Ferrous Metal - IPPU
- Refinery and Petrochemicals - IPPU

Initial work and prerequisites for the implementation of the TIMES model.

As a first step for the preparation of projections in the TIMES model were analysed energy and industrial resources included in the EU-ETS. The reasons for this procedure are as follows:

Sources included in this group are the most significant stationary sources of greenhouse gas emissions, primarily CO_2.

There is a need for price economic pressure to reduce CO_2 emissions caused by those CO_2 quotas and thus also the assumption of an increased price of CO_2 on the market with emission quotas. The new NIMs tentatively indicate this trend, especially for sources that will be reclassified from "carbon leakage" (CL) to nonCL.

The analysis is based on the data of the year 2022, for which there are data from the files processed for the preparation of NIM after 2023. These files only contain data on fuel consumption and CO_2 emissions, but also on the production of electricity, heat, and commodities necessary for setting the benchmark (this serves for set quotas for the period after 2023). However, some files also contain data on the production of other commodities, even if these are not used to set quotas.

In the case of changed projects, the growth of consumption - demand is based on the assumptions of the growth of the economy expressed by the growth of the added value "VA" for individual economic sectors. The final consumption of energy in the form of electricity, heat or direct consumption of fuels was aggregated for individual sectors and the further increase was then controlled by the growth of VA. With the uncertainty of the economic development (pandemic), we decided that where it is possible to link the final consumption to the selected commodity such as the production of cement, glass, steel products, plastics, etc. within the EU ETS. Where no representative commodity could be used, output streams were aggregated according to NACE rev.2 category - first two digits.

TIMES model is used in the EU and outside it. It is very flexible, allows data processing individually for important sources or groups of sources, and the scope is not limited.

Before preparing input data for the model, it is necessary to prepare a balance sheet, i.e. so. Called the spider, which represents the network of progress and processing of incoming commodities - fuels and materials in the process of processing, energy production, distribution and final consumption of products and energy. In the entire scheme (***Figure 2.1***) there are several levels that more or less coincide with the energy statistics data processing system for the Statistical Office of the Slovak Republic:

- Primary fuels – simulation**s** of their import or extraction.
- Material inputs. This represents for individual sources a summary of material inputs that participate in the formation of CO_2, for example by the decomposition of carbonates contained in them - inputs to lime plants, cement plants, ceramic production, glass plants, etc.
- Secondary fuels. In the specific conditions of the Slovak Republic, these are petroleum products, i.e. their production in the Slovnaft refinery together with the refinery gas that is burned

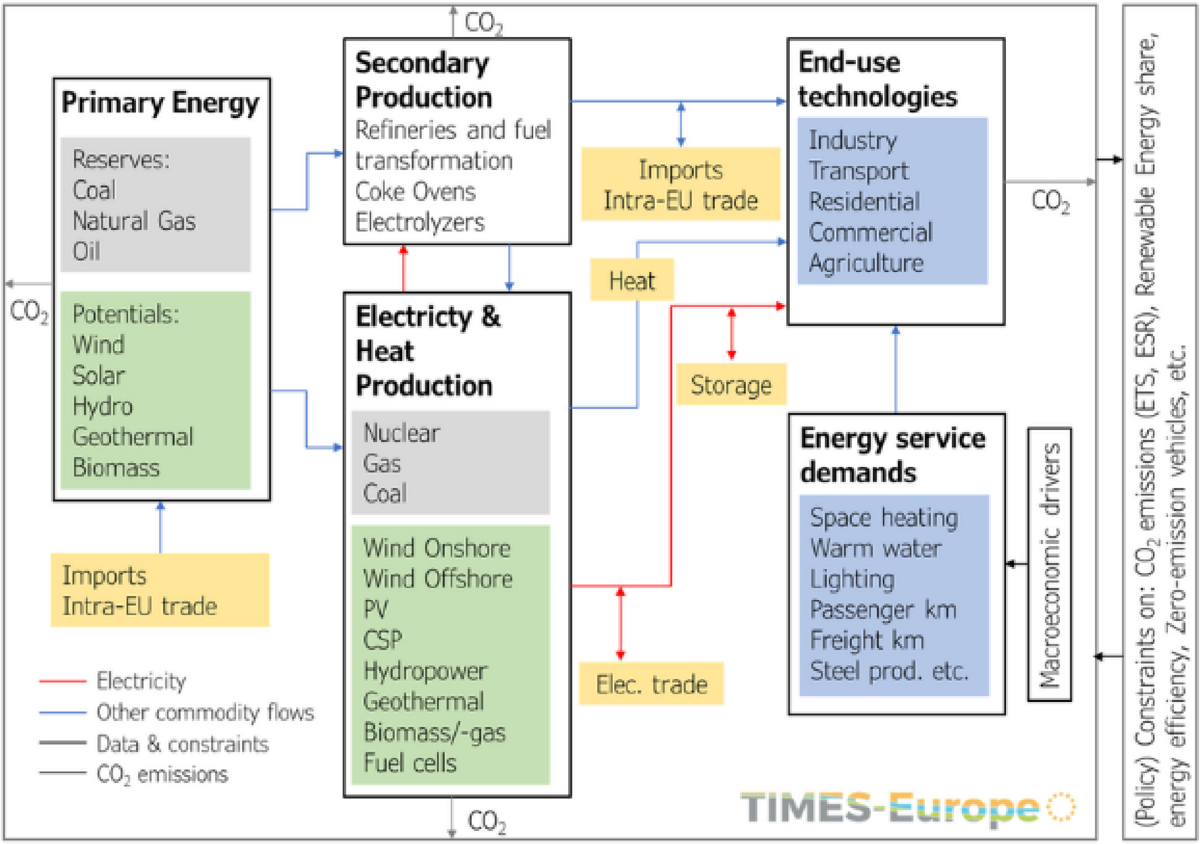
in this complex. Furthermore, there are technical gases such as blast furnace gas, coke oven gas and converter gas, all produced and consumed within metallurgy.

- Fuelmix represents the simulation of the entry of fuels into energy or production processes. At this level, based on the composition of the fuel mixture, the aggregated GHG emission factor is defined for individual appliances and, if necessary, also the other AP.
- Production of energy carriers - electricity and heat. A mixture of fuels enters each such set, and electricity and heat leave in heating and power plants, and only heat in heating plants. Within the framework of the scheme, the distribution of the produced heat is used directly by the source or enters the remote supply system - DH.
- Integration of energy and material flows for the enterprise. This applies to enterprises with their own consumption of electricity and heat, which produce it themselves. Here, the flow of heat and electricity from own consumption is integrated with the material flow as well as the external supply of electricity and heat. In the latter case, the balance of import and export of electricity or heat is calculated.
- Simulation of the public electricity and heat distribution network.
- Simulation of final consumption - Demand according to macroeconomic and/or production indicators = assumption of product volumes, value added (VA) sectors, etc.
- Data processing from ETS reports and National implementation measures (NIMs) for modelling CO_2 and other GHG emissions.

Table 2.4: *SWOT analysis of the TIMES – Veda model*

Strengths	Opportunities
- Compatibility with emission model for emission inventories - Detailed data break down - Database used is compatible with EU data and national data - Detailed sectoral break down - Available Emission trading system - Finding Objective function (optimal solution) - Stochastic modelling - Seasonal availability - User constraint options (environmental, energy, monetary, supply, production, subsidies…)	- Incorporate to the model new technologies (CHP,HP, ELE) - Attach transport (all transport categories) - Versatile use on different geographical level (Regional break down of energy demand) - Versatile use of time series (Day, Night and Peak availability) - Modelling of particulate matter (PM) - Stochastic modelling of RES - Trading between regions
Treats	**Weakness**
- Maintenance fee - Infeasibility due to lack of macro economical and technology data - GAMS solvers need to be paid separately	- Disconnected from macroeconomic models - Too much pre-calculations needed - Lack of economic data - Lack of technology data (Investment cost for new technology) - Whole structure needed to be built up from scratch

Figure 2.1: *Different elements and structure of the TIMES model*



The projections should provide the decision-making authorities with answers to the following questions:

- Will it really be economically and technically possible to achieve carbon neutrality in 2050?
- What political, economic and technical measures will have to be applied?
- Will the technical measures considered so far be sufficient, such as changes in the fuel base, the use of biomass and other renewable energy sources, and measures on the side of consumption and reduction of energy intensity?
- Is it realistic to apply the CCS system in conditions of Slovakia?
- What preliminary costs would the considered measures represent?

Attributes for TIMES – Times contains so called „sets „which describes structural information of the energy system or qualitative characteristics of its entities (e.g. processes or commodities), parameters contain numerical information. Examples of parameters are the import price of an energy carrier or the investment cost of a technology. Most parameters are time-series where a value is provided (or interpolated) for each year (data year). The TIMES model generator distinguishes between user input parameters and internal parameters. The former is provided by the modeler (usually by way of a data handling system or “shell” such a VEDA-FE or ANSWER-TIMES), while the latter are internally derived from the user input parameters, in combination with information given by sets, in order to calculate for example, the cost coefficients in the objective function.

Basic modelling assumptions - TIMES model is particularly suited to the exploration of possible energy futures based on contrasted scenarios. Given the long horizons that are usually simulated with TIMES, the scenario approach is really the only choice (whereas for the shorter term, econometric methods may provide useful projections). Scenarios, unlike forecasts, do not pre-suppose knowledge of the main drivers of the energy system. Instead, a scenario consists of a set of coherent assumptions about the future trajectories of these drivers, leading to a coherent organization of the system under study. A scenario builder must therefore carefully test the scenario assumptions for internal coherence, via a credible storyline.

Policy 1: Carbon tax

A tax is levied on emissions of CO_2 at point of source. This policy is easily represented in TIMES making sure that all technologies that emit CO_2 have an emission coefficient, and then defining a tax on these emissions. The policy may indicate that the tax be levied upstream for some end-use sectors (e.g. automobiles), in which case the emission coefficient is defined at the oil refinery level rather than at the level of individual car types.

Policy 2: Cap-and-trade on CO_2

An upper limit on CO_2 emissions is imposed at the national level (alternatively, separate upper limits are imposed at the sector level). If the model is multi-country, trade of emission permits is allowed between countries (and/or between sectors). The trade may also be upper bounded by a maximum percentage of the actual emissions, thus representing a form of the subsidiarity principle.

Policy 3: Portfolio standard A sector is submitted to a lower limit on its efficiency

A sector is submitted to a lower limit on its efficiency. For instance, the electricity subsector using fossil fuels must have an overall efficiency of 50%. A similar example is an overall lower limit on the efficiency of light road vehicles.

This type of policy requires the definition of a new constraint that expresses that the ratio of electricity produced (via fossil fuelled plants) over the amount of fuel used be more than 0.5. TIMES allows the modeler to define such new constraints via the user constraints.

Policy 4: Subsidies for some classes of technologies

A more elaborate form of the subsidy might be to first levy an emission tax, and then use the proceeds of the tax to subsidize low-emitting and non-emitting technologies. Such a compound policy requires several sequential runs of TIMES, the first run establishing the proceeds of the carbon tax, followed by subsequent runs that distribute the proceeds among the targeted technologies. Several passes of these two runs may well be required in order to balance exactly the proceeds of the tax and the use of them as subsidies.

GHG Emission Projections in Households – Excel Sheet Model

Emission projections from households combustion was modelled separately (outside of model TIMES) in the MS Excel sheet model, where was taken into account improving of efficiency, equipment status and structure and good practise. Based on information which were obtained from the statistical questionnaire surveys in households, new implemented and planned measures were taken into account. Based on this information datasets were improved together with estimations of natural improvement in the structure of households and heating equipment was implemented.

Main characteristic of the emission projections modelling of household heating:

- Based on emission inventory methodology – excel model,
- Estimation of total energy demand per m^2 of living space in the household sector,
- Number of flats - living area of flats, flats under DH, age and renewal of flats,
- Structure of heating equipment, method of heating,
- Climatic conditions.

2.1.4. Scenarios, Parameters and PAMs

The base (reference) year for modelling the GHG emissions projection was the latest revised inventory year 2022 in all scenarios.

The policies and measures used were taken from the Low Carbon Strategy of the Slovak Republic[5], the National Program for the Reduction of Pollutant Emissions[6] and the Recovery Plan of the Slovak Republic.[7]

WEM scenario includes the following policies and measures at EU level and related national measures.

- Eco-design Framework Directive (Directive 2005/32/EC)
- Energy Labelling Directive (Directive 2010/30/EÚ)
- Energy Performance of Buildings Directive (2010/31/EU), Energy Efficiency Directive (Directive 2012/27/EU)
- Completion of the internal energy market, including the provisions of the 3rd package (Directive 2009/73/EC, Directive 2009/72/EC), Regulation (EC) 715/2009, Regulation (EC) 714/2009
- Directive on the Promotion of the Use of Energy from Renewable Sources - Renewable Energy Directive - including the amendment on ILUC (Directive 2009/28 EC as amended by Directive (EU) 2015/1513)
- Implementation of the Commission's proposed EU objective for a 25% share of renewable energy sources (RES) in total consumption by 2030, which was based on the proposal for a "Clean Energy for All Europeans" package presented by the European Commission in November 2016. The modelling did not take into account the fact that a considerably more ambitious EU objective (32%) was eventually adopted in December 2018
- National Renewable Energy Action Plan, in force since 2011
- EU ETS Directive 2003/87/EC with the latest amendment in 2015 (Decision (EU) 2015/1814 - Market Stabilization Reserve). The EU ETS is an economic and regulatory measure with a high positive impact on the reduction of greenhouse gas emissions and stimulates the use of biomass in the fuel mix and forces technological innovation
- Act No. 137/2010 Coll. on Air Protection as amended. This Act is supplemented by Act No. 401/1998 Coll. on air pollution charges, which serves to control and regulate emission limits for basic air pollutants
- Increasing energy efficiency with a number of measures in force since 2014 on the energy consumption side, according to which energy savings are reflected as a reduction in final energy consumption. These measures are broken down by sector (buildings, industry, public sector, transport and appliances). In the buildings sector, it is mainly about improving the thermal-technical performance of buildings by carrying out cost-effective deep renovation. Legislation and changes to national technical standards since 2012 have introduced conditions for progressively stricter energy performance requirements for new and substantially renovated

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[5] Ministry of Environment of the Slovak Republic, "Low Carbon Strategy of the Slovak Republic," Ministry of Environment, 2020. [Online]: https://www.minzp.sk/klima/nizkouhlikova-strategia/

[6] Ministry of the Environment of the Slovak Republic, "National Emission Reduction Program" Ministry of the Environment, 2020. [Online]: https://www.minzp.sk/ovzdusie/ochrana-ovzdusia/narodne-zavazky-znizovania-emisii/narodny-program-znizovania-emisii/

[7] European Commission, "Recovery Plan", Office of the Government of the Slovak Republic, 2021. [Online]: https://www.planobnovy.sk/kompletny-plan-obnovy/zelena-ekonomika/

buildings, which are regularly reviewed. Measures in the buildings sector represent the most important source of potential energy savings by 2030.

- Optimization of district heating systems - switching from fossil fuels to biomass and natural gas and installation of combined heat and power (CHP) units in district heating systems. Industrial cogeneration plants produce industrial steam, which can also be used for district heating or is a secondary use of industrial steam. Other measures are also taken into account (e.g. improving the efficiency of central heat supply (CHS) systems, installing innovative district heating technologies, improving the supply of heat from combined heat and power plants).
- Earlier decommissioning of solid fuel power plants. The decommissioning of the Vojany and Nováky plants is foreseen in 2024 and 2023, in that order.

The specification of the WAM scenario according to the Low Carbon Development Strategy of the Slovak Republic depends on the logic of the draft EU scenarios and in particular on the EUCO3030 scenario[8], which sets the EU target for energy efficiency for 2030 at 30%.

The WAM scenario includes all measures from the WEM scenario named in the Low Carbon Development Strategy of the Slovak Republic, while additionally includes measures and more ambitious targets for RES and EE, ambitious plans of the new EC under the Green Deal.[9]

- The national target for the ESR is -22.7%
- Increasing the EU ETS carbon price after 2022 - The EU ETS carbon price affects the energy sector as well as energy-intensive industries and is a major driver of emissions reductions. Electricity generators will need to respond to the pressure of rising allowance prices to facilitate their own transition from coal to other low- to zero-emission sources.
- Decarbonizing electricity generation after 2022 through RES and nuclear development.
- RES support scheme in electricity generation with envisaged RES technologies such as solar PV, onshore wind turbines, biogas/biomethane and biomass. The scenarios assume support of 50 MW in the period 2030-2050, followed by support of a further 500 MW on the basis of auctions.
- Increasing the share of nuclear energy in the energy mix of the Slovak Republic. This increase in the medium term (2022-2027) will be mainly due to the commissioning of two new nuclear reactors at the Mochovce Nuclear Power Plant.
- Continuing to reduce final energy consumption in all sectors after 2022. The measure puts emphasis on policies supporting the acceleration of the renewal of the building stock (residential and non-residential, public and private), with a focus on carrying out cost-effective in-depth renovations and applying minimum energy performance requirements for near-zero energy buildings after 2025 for new buildings.

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[8] European Commission, „EUCO scenarios,“ 2016. [Online]: http://www.e3mlab.eu/e3mlab/index.php?option=com_content&view=article&id=532%3Aeuco-scenarios&catid=1%3Alatest-news&Itemid=82&lang=en

[9] European Commission, „EU Green Deal,“ 2019. [Online]: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal#documents

Most of the above measures were applied at the level of the Compact Primes for Slovakia (CPS-PRIMES[1])[10] model, from which trends in energy consumption or other parameters were taken for modelling emissions in the TIMES model.[11]

In addition to the measures mentioned above, the WAM scenario also took into account:

- Assessment of the future structure of appliances used for domestic heating based on survey data.
- Support for the replacement of old solid fuel boilers in households with low-emission systems.
- Support for insulation of family houses - Program Slovakia, Green renovation.
- Awareness campaign and education on good coal and biomass combustion practices.

Emission levels in the coming years are determined only by the final energy growth rate.

The long-term development of greenhouse gas emissions also depends on other parameters, such as energy market developments, technological developments and the trading of CO_2 emission allowances. The EU ETS is one of the measures that was implemented before the projected base year, but the new trading period will continue to have an impact in the future. Nevertheless, the additional impact of this measure is limited due to the technical and economic potential. Despite the existing constraints resulting from dynamic changes in critical parameters, it is possible to reach a state of actual compliance with the emission reduction targets, as well as to create the conditions for further emission reductions after 2025.

This chapter exclude emissions from the fuel consumption in transport and fugitive emissions. Emissions from small households not connected to district heating system (DHS) were modelled separately and a description of the procedure is given at the chapter “Methodologies and key assumption”.

2.1.5. Emission Projections in Energy Sector Fuels Combustion Excluding Transport (1.A.1, 1.A.2, 1.A.4, 1.A.5)

Emission projections in the Energy sector were modelled separately for large and medium-sized energy appliances, households’ categories. The calculations of the scenarios in the projection report are based on the national Greenhouse Gas Inventory. The current Greenhouse Gas Inventory available at the time this scenario was calculated is the provisional Greenhouse Gas Inventory from the 2024 reporting year. It was prepared in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The greenhouse gas potentials used for the 2024 projections correspond to those of the 5th Assessment Report of the IPCC (AR5).

Figure 2.2 shows trend of the GHG emission projections in the energy sector in stationary fuels combustion categories. The decrease in emissions is visible especially in the category of electricity and heat production and in households (1.A.4). The largest share of the decrease in emissions in the WAM scenario is visible in category 1.A.1 (***Figure 2.3***). A shorter decrease in emissions is expected in industrial energy.

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[10] European Commission, „Integrated National Energy and Climate plan for 2021 to 2030 for Slovakia,“ 2019. [Online]: https://ec.europa.eu/energy/sites/ener/files/sk_final_necp_main_en.pdf

[11] ETSAP, „The TIMES model,“ The Energy Technology Systems Analysis Program, 2005. [Online]: https://iea-etsap.org/index.php/etsap-tools/model-generators/times

Figure 2.2: *Total GHG emission projections in Gg of CO_2 eq. in the Energy sector in WEM scenario*

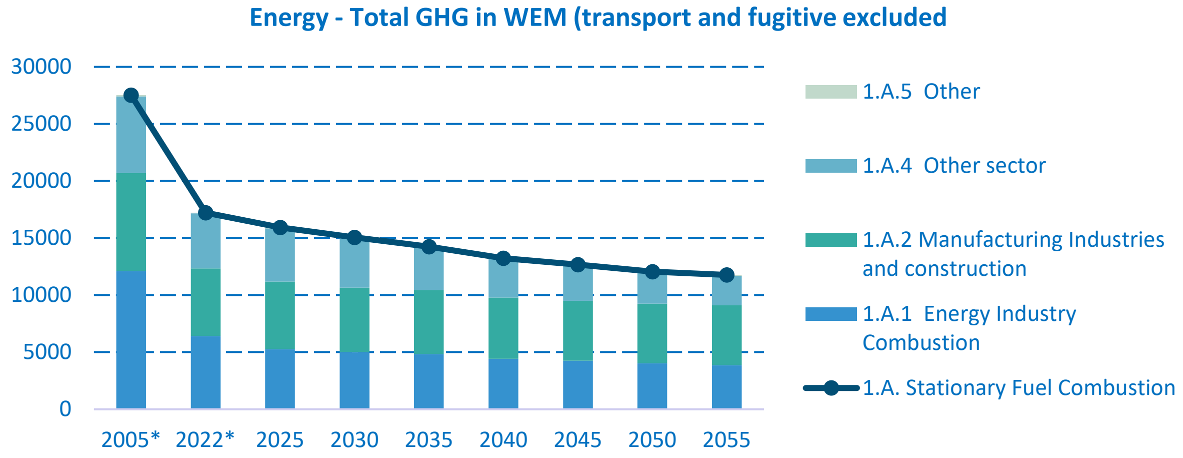


Figure 2.3: *Total GHG emission projections in Gg of CO_2 eq. in the Energy sector in WAM scenario*

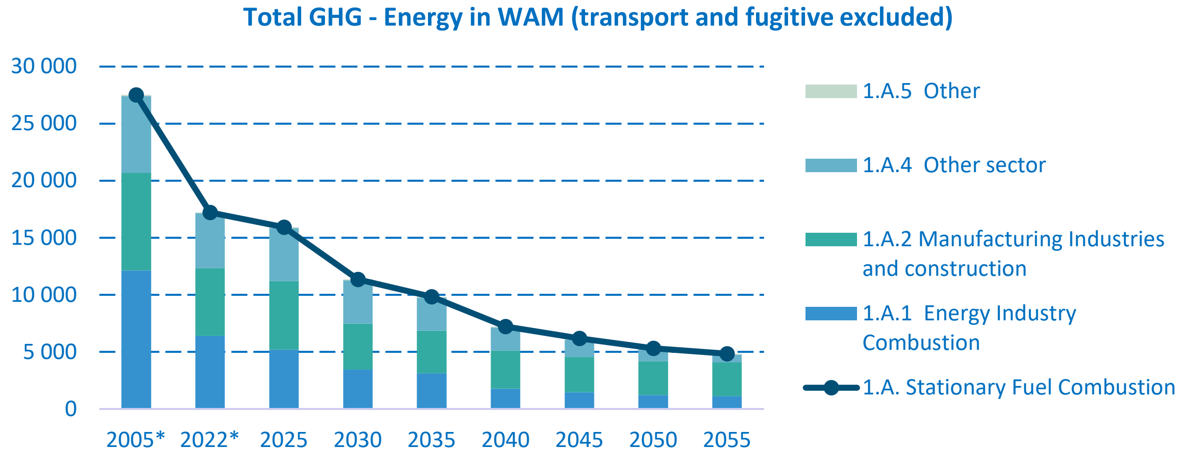


Table 2.5: *GHG emission projections in Gg of CO_2 eq. in Energy sector in WEM and WAM scenarios*

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
1.A. Stationary Fuel Combustion	17 221.17	15 927.51	15 070.00	14 250.79	13 244.38	12 661.96	12 060.63	11 776.09
1.A.1 Energy Industry Combustion	6 407.46	5 251.81	5 023.25	4 836.86	4 424.12	4 242.35	4 024.53	3 868.88
1.A.2 Manufacturing Industries and construction	5 922.85	5 941.10	5 641.26	5 633.23	5 353.29	5 264.02	5 220.06	5 236.17
1.A.4 Other sector	4 828.48	4 645.80	4 314.78	3 689.66	3 376.91	3 067.34	2 729.60	2 585.42
1.A.5 Other	62.38	88.80	90.71	91.03	90.06	88.24	86.43	85.62
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1.A. Stationary Fuel Combustion	17 221.17	15 927.49	11 357.81	9 835.15	7 237.44	6 173.51	5 326.45	4 844.30
1.A.1 Energy Industry Combustion	6 407.46	5 200.48	3 468.38	3 124.04	1 782.18	1 463.09	1 213.50	1 122.02
1.A.2 Manufacturing Industries and construction	5 922.85	6 005.65	3 997.01	3 735.62	3 336.52	3 091.44	2 971.82	2 952.81
1.A.4 Other sector	4 828.48	4 632.56	3 801.72	2 884.45	2 028.68	1 530.73	1 054.70	630.10
1.A.5 Other	62.38	88.80	90.71	91.03	90.06	88.24	86.43	85.07

** Base year 2022; based on the GHG inventory submission 15. 3. 2024*

Projections of CO_2 emissions in the Energy sector

CO_2 emissions in the Energy sector decreased between 2005 and 2022 from 27 Gg CO_2 to 16,8 Gg CO_2. The mentioned decrease represents a value of 37%. Emissions in the energy sector - fuel combustion come mainly from the energy industry (production of electricity and heat), processing industry and construction, fuel pipeline transport and other energy industries. The most important sources of emissions are emissions from electricity and heat production, oil refineries and iron and steel production. Emissions from road, rail, air and ship transport are listed separately in the subsection below. The breakdown of emissions within the EU ETS into individual parts is shown in ***Figures 2.4*** and ***2.5*** In the ***Table 2.6*** are projection in energy sector for both WEM and WAM scenarios. As it is visible, both scenarios contain decarbonisation measure, known as phase-out of solid fossil fuel in Slovakia's biggest thermal power plant in Vojany and Nováky.

Figure 2.4: *Emission projections of CO_2 in Gg in the Energy sector in WEM scenario up to 2055*

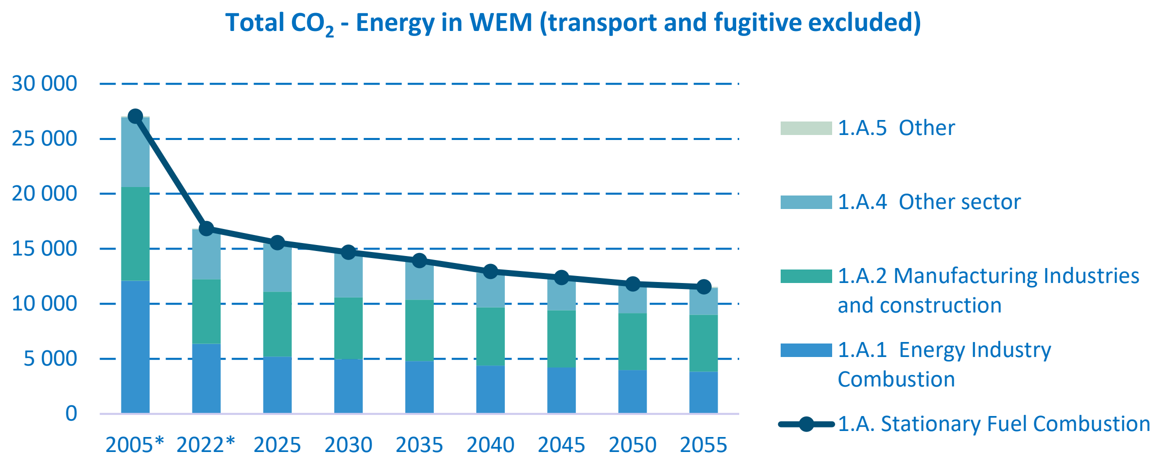


Figure 2.5: *Emission projections of CO_2 in Gg in the Energy sector in WAM scenario up to 2055*

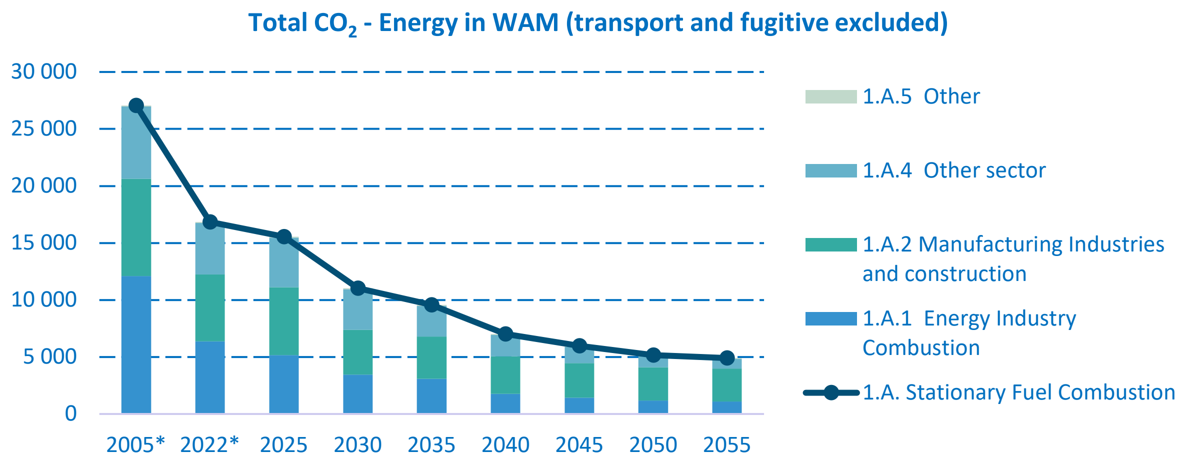


Table 2.6: *Emission projections of CO_2 in Gg in Energy sector in WEM and WAM scenarios*

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
1.A. Stationary Fuel Combustion	16 832.08	15 555.71	14 699.12	13 919.59	12 930.71	12 380.38	11 806.34	1 1527.12
1.A.1 Energy Industry Combustion	6 366.07	5 217.18	4 986.82	4 800.10	4 387.02	4 205.66	3 987.24	3 832.00
1.A.2 Manufacturing Industries and construction	5 873.92	5 897.97	5 588.66	5 583.05	5 294.44	5 204.98	5 162.09	5 178.20
1.A.4 Other sector	4 530.23	4 352.30	4 033.47	3 445.95	3 159.74	2 882.04	2 571.12	2 431.85
1.A.5 Other	61.85	88.26	90.17	90.49	89.52	87.71	85.89	85.07

WAM	2022*	2025	2030	2035	2040	2045	2050	2055
1.A. Stationary Fuel Combustion	16 832.08	15 553.27	11 032.83	9 567.92	7 022.44	5 990.95	5 163.48	4 905.07
1.A.1 Energy Industry Combustion	6 366.07	5 165.94	3 443.71	3 098.89	1 757.42	1 438.32	1 186.80	1 093.80
1.A.2 Manufacturing Industries and construction	5 873.92	5 959.45	3 949.49	3 685.41	3 280.57	3 035.99	2 915.73	2 895.40
1.A.4 Other sector	4 530.23	4 339.62	3 549.46	2 693.13	1 894.93	1 428.93	975.06	630.10
1.A.5 Other	61.85	88.26	90.17	90.49	89.52	87.71	85.89	85.07

** Base year 2022; based on the GHG inventory submission 15. 3. 2024*

Projections of CH_4 Emissions in the Energy Sector

CH_4 emission projections in the Energy sector ***Figures 2.6*** and ***2.7*** and ***Table 2.7***.

Figure 2.6: *Emission projections of CH_4 in Gg in the Energy sector in WEM scenario up to 2055*

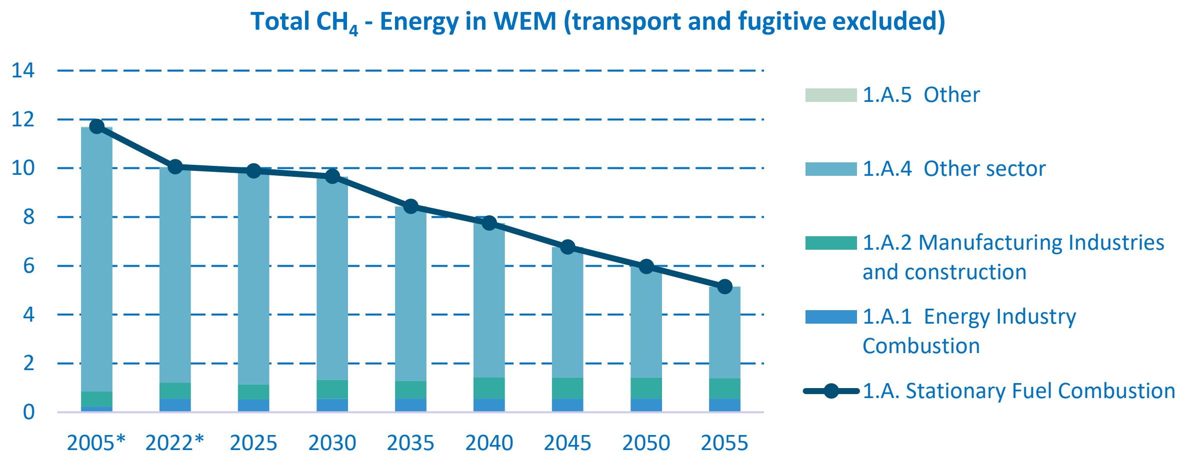
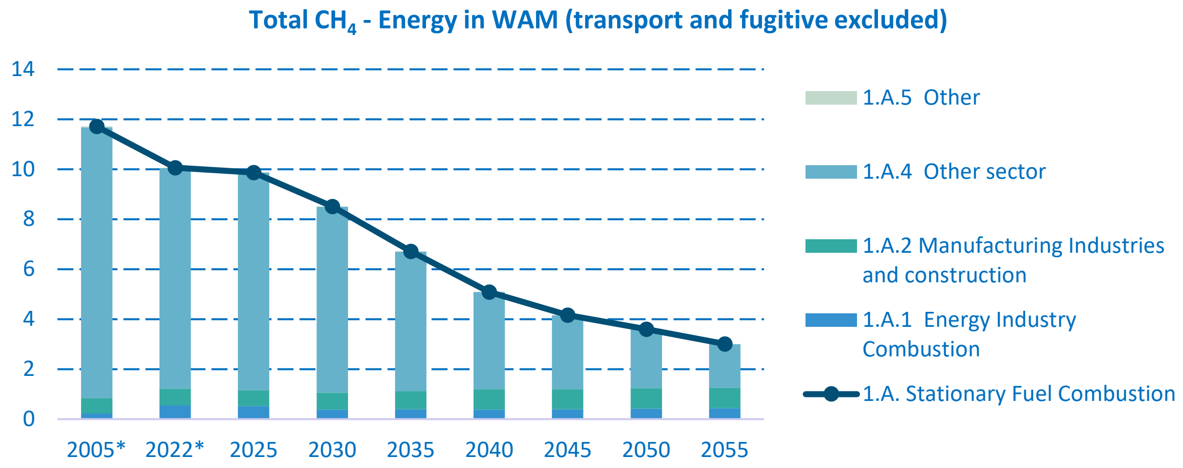


Figure 2.7: *Emission projections of CH_4 in Gg in the Energy sector in WAM scenario up to 2055*



The following ***Table 3.23*** shows result of projections for both scenario WEM and WAM for CH_4.

Table 2.7: *Emission projections of CH_4 in Gg in Energy sector in WEM and WAM scenarios*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1.A. Stationary Fuel Combustion	10.06	9.89	9.66	8.43	7.75	6.77	5.97	5.77
1.A.1 Energy Industry Combustion	0.56	0.53	0.55	0.56	0.56	0.56	0.56	0.56
1.A.2 Manufacturing Industries and construction	0.66	0.63	0.78	0.74	0.87	0.87	0.85	0.84
1.A.4 Other sector	8.83	8.73	8.33	7.13	6.31	5.34	4.54	3.36
1.A.5 Other	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1.A. Stationary Fuel Combustion	10.06	9.88	8.51	6.71	5.09	4.16	3.60	2.80
1.A.1 Energy Industry Combustion	0.56	0.53	0.39	0.40	0.39	0.39	0.42	0.44
1.A.2 Manufacturing Industries and construction	0.66	0.63	0.68	0.73	0.81	0.81	0.82	0.82
1.A.4 Other sector	8.83	8.71	7.44	5.58	3.88	2.96	2.35	1.53
1.A.5 Other	0.011	0.01	0.01	0.01	0.01	0.01	0.01	0.01

***** *Base year 2022; based on the GHG inventory submission 15. 3. 2024*

Less than 1.6% of emissions average comes from methane (CH_4), which is associated with processing and combusting fossil fuels. Emissions from the electricity sector are almost entirely covered by the European Emission Trading System. In WEM scenario, category (Public electricity and heat production) and Manufacturing Industries and construction we are expecting to slight increase of methane emission due to biomass consumption increase and shortage of natural gas.

Energy-related CH_4 emissions arise from the combustion and conversion of fossil fuels. Fugitive methane emissions arise from the extraction, transport and processing of fuels. Projections of CH_4 emissions from the combustion and conversion of fossil fuels were modelled using the fuel consumption in each scenario according to the IPCC method and the IPCC recommended aggregated emission factors.

The modelling used the same scenarios as for CO_2 emissions from combustion and fuel switching. This approach makes it possible to determine the impact of CO_2 reduction measures on the level of CH_4 emissions. Annual fugitive CH_4 emissions were calculated separately in chapter “Fugitive emission”.

Projections of N_2O Emissions in the Energy Sector

N_2O emissions in the Energy sector are described in the following ***Figures 2.8*** and ***2.9*** for WEM and in the ***Table 2.8*** for WAM scenario. Energy-related N_2O emissions arise from the combustion and conversion of fossil fuels. N_2O emissions from transport have been calculated within this sector. Projections of methane N_2O emissions were similarly calculated using the IPCC method, which uses recommended emission factors. The scenarios for calculating emissions from combustion and fuel conversion are the same as those for CO_2 and CH_4 emissions, making it possible to analyse the impact of measures to reduce CO_2 emissions and N_2O production.

Figure 2.8: *Emission projections of N_2O in Gg in the Energy sector in WEM scenario up to 2055*

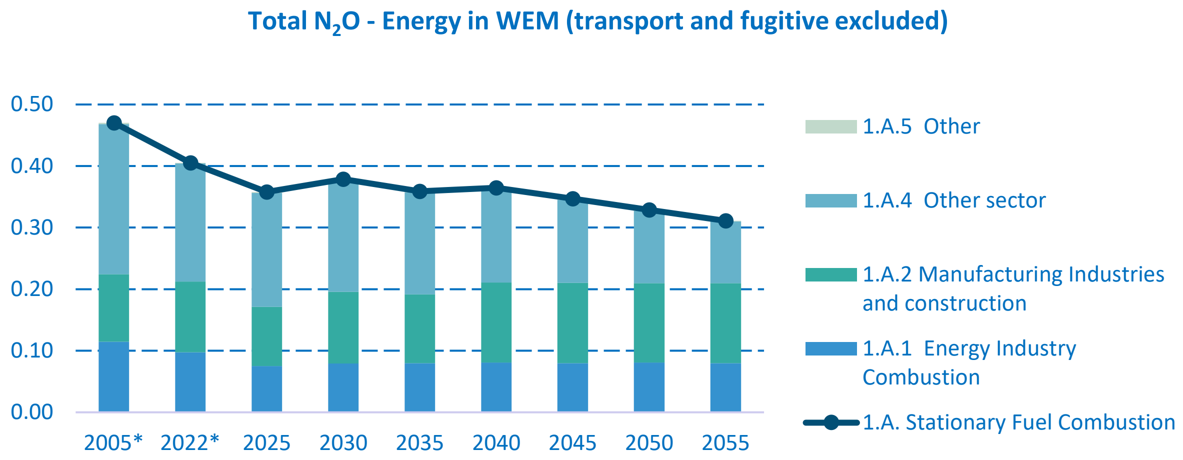


Figure 2.9: *Emission projections of N_2O in Gg in the Energy sector in WAM scenario up to 2055*

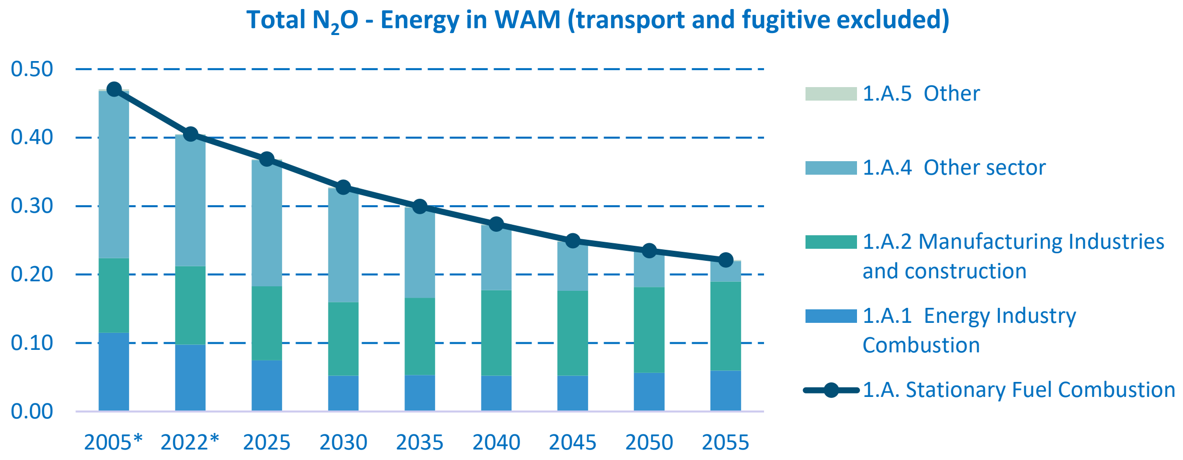


Table 2.8: *Emission projections of N_2O in Gg in Energy sector in WEM and WAM scenarios*

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
1.A. Stationary Fuel Combustion	0.405	0.358	0.379	0.359	0.365	0.347	0.329	0.330
1.A.1 Energy Industry Combustion	0.098	0.075	0.079	0.080	0.081	0.080	0.081	0.080
1.A.2 Manufacturing Industries and construction	0.115	0.096	0.116	0.111	0.130	0.131	0.129	0.130
1.A.4 Other sector	0.192	0.185	0.182	0.166	0.152	0.135	0.118	0.119
1.A.5 Other	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1.A. Stationary Fuel Combustion	0.405	0.369	0.327	0.299	0.274	0.249	0.235	0.232
1.A.1 Energy Industry Combustion	0.098	0.075	0.052	0.053	0.052	0.052	0.056	0.060
1.A.2 Manufacturing Industries and construction	0.115	0.108	0.108	0.113	0.125	0.124	0.125	0.130
1.A.4 Other sector	0.192	0.185	0.166	0.132	0.095	0.072	0.052	0.041
1.A.5 Other	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

** Base year 2022; based on the GHG inventory submission 15. 3. 2024*

General Summary

Emissions in WAM scenario will continue to decline across all sectors between 2025 and 2035, with the largest declines, both absolute and relative, expected in the electricity and heat sector. Electricity and heat emissions will decrease because the capacity of solar and wind energy will increase further towards 2035, while electricity demand will increase in WAM scenario mainly due to higher consumption in households and services. In WEM scenario we used a less ambitious electrification scenario provided by Slovak electricity transmission system (SEPS). Additionally, we are assuming the start-up of the fourth nuclear reactor (Mochovce IV) in both scenarios.

Overall, this would result in emissions by 2030 that would be 52% below 1990 levels respectively 60% in WAM scenario. In both variants, the national target to reduce greenhouse gas emissions with 55% by 2030 compared to 1990 levels is achieved only in WAM. Looking towards 2040, greenhouse gas emissions are expected to decline further in almost all sectors after 2035. However, as described in the Climate and Energy Outlook, there are currently limited policies which detail further major emission reductions by 2040. In February 2024, the European Commission proposed a European climate target for 2040 of a net 90 percent greenhouse gas emission reduction compared to 1990 European decision-making on the 2040 target still has to take place, however.

Achieving the short-term binding target of a 55% emission reduction by 2030 would be possible primarily through the electrification of the Kosice steelworks. Other important measures include the adoption of electric vehicles (described in Transport category), building insulation, and electrification across various sectors. The closure of coal-fired power plants in Nováky and Vojany, along with the launch of an additional unit at the Mochovce nuclear power plant (Block IV), has already contributed to a cleaner energy mix. A crucial step is the introduction of an Emissions Trading System (ETS) for the building and transport sectors (ETS 2) starting in 2027, with an anticipated price of around €59 per ton in 2030.[12]

Electricity production

The Slovak government approved a plan in 2018 to phase out coal-based electricity generation at the Nováky power plant by the end of 2023. This decision has raised concerns about the future of heat supply in the region of Horná Nitra, which heavily relies on the plant for heating. The Nováky power plant provides heat to several cities and towns, including Prievidza, Nováky, and Zemianske Kostoľany, as well as various industrial facilities. The current system of heat supply is centred around a centralized heat source that combust brown coal.

With the imminent closure of the coal-fired plant, there is an urgent need to find a sustainable alternative to ensure uninterrupted heat supply for the region. The Slovak government has identified the development of a sustainable heating system as a priority, focusing on solutions that are both environmentally friendly and economically viable.

Key points:

- Phase-out of coal: The Nováky power plant, a major source of heat for the Horná Nitra region, is set to close in 2023.
- Need for a sustainable alternative: A new heating system must be developed to replace the coal-fired plant and ensure continued heat supply.
- Government involvement: The Slovak government is actively involved in finding a solution and has organized discussions with stakeholders.

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[12] The implementation of ETS 2 measures was hindered by the incomplete sectoral representation within the TIMES-Slovakia model.

- Challenges: The transition to a new heating system presents challenges, including the need to balance environmental concerns with economic viability.

In essence, need to find a sustainable solution for heating the Horná Nitra region following the closure of the coal-fired power plant. The government is actively seeking a solution that will meet the region's energy needs while also protecting the environment. One of the options in (WEM and WAM) is the installation of a new solid biomass heat source, a heat pump and a natural gas backup source.

The Vojany power plant in Slovakia has experienced a significant decline in its operations due to the phasing out of coal-fired power generation.

Key points:

- Gradual shutdown: Several units at Vojany were taken out of service starting in 2014 due to factors such as technical obsolescence, environmental regulations, and market conditions.
- Reduced capacity: The total capacity of the units that were decommissioned amounted to 1210 MW.
- Operational units: Before its complete closure, Vojany consisted of two operational units with a combined capacity of 220 MW.
- Flexible operation: These units were typically operated based on the demand for electricity and prevailing market prices.
- Final closure: The coal-fired operations at Vojany were fully terminated in March 2024, marking a significant milestone in Slovakia's transition away from coal-based power generation.

Fuel production

Slovakia has one large refinery, situated in capital city of Bratislava. This refinery has a total capacity of about 5.5 million tonnes of crude oil. The degree of utilisation is high, in some years reaching 100%. It is the biggest seller in the domestic market. In the petrochemical segment, main activities include the production and sale of polyethylene and polypropylene. The refinery in Slovakia produce many relatively light oil products (LPG, naphtha, petroleum, diesel) from heavier crude oil with a sulphur content of 1.5%. During 2023, refinery processed the most alternative oil in history, namely 815 thousand tons, which is almost 4 times the volume compared to the year 2022. In the coming period, refinery will focus on the implementation of transformation projects in connection with the expansion of the processing of non-Russian oil. Given the constraints of the available technological measures, we do not foresee a substantial decrease in emissions within this scenario. The reduction is predominantly attributed to a decline in the proportion of fossil fuels in the transport sector, as projected by the COPERT model (see section Transport). Both scenarios within this category are contingent upon projected developments in transportation. Notably, the WAM scenario exhibits a more pronounced reduction in GHG emissions from fuel production (Slovnaft) owing to synergistic effects stemming from the proliferation of electric mobility and the advent of hydrogen technologies.

Steel production (industrial combustion)

"U.S. Steel Košice experienced a slight recovery after the COVID-19 pandemic, with increased production. However, the steel industry is facing a financially and technologically challenging period, especially considering the potential disruption to decarbonisation plans due to a potential change in ownership. The company had planned to install electric arc furnaces to significantly reduce greenhouse gas emissions, a crucial step for both the company and Slovakia in meeting its -55% emissions reduction target by 2030. Other planned measures in Energy sector included the decommissioning of the coking battery (category 1.A.2) and replacing the combustion of energy-grade coal used for generating process steam and electricity with natural gas. Further decarbonisation efforts involved additional shutdowns and efficiency improvements in various divisional plants. However, the future of these plans hinges on the new owner's commitment to decarbonisation. There is a possibility that the company may pursue a different path, such as hydrogen-based iron ore reduction. The full picture regarding these uncertainties is expected to become clearer after 2025." As a result, we have chosen to keep these scenarios unchanged and to proceed with the planned technological shift from two conventional blast furnaces to two electric arc furnaces, as envisaged in the WAM scenario.

Fertilizer production

The biggest ammonia producer in Slovakia consumes, natural gas as basic raw material for ammonia production, where, in addition to energy use, it serves as a raw material for the production of hydrogen by steam reforming. Today, nitrogen is almost exclusively produced by low-temperature rectification of liquefied air, and rather forms surpluses during the production of more desirable oxygen. The energy source here is electrical energy for liquefaction. It is the production of hydrogen that is responsible for the consumption of natural gas, and by replacing it with electrolysis we obtain the so-called green hydrogen in the event that electricity from renewable energy sources is used as a source - photovoltaics, wind power plants and/or electricity from nuclear power plants. The proposed measure aims to transition the existing ammonia production process from using grey hydrogen produced by steam methane reforming to a hybrid system that incorporates green hydrogen produced via electrolysis powered by renewable energy. Under current EU rules for non-ETS installations, the resulting ammonia will be a blend of grey and green ammonia, with the composition directly related to the proportion of each hydrogen feedstock. This measure was excluded from all scenarios due to the unavailability of the required technical data within the timeframe of our projections. Additionally, an external study commissioned by the manufacturer revealed a negligible reduction in GHG emissions within the Energy section.

Heat production

The Slovak government is aiming to decarbonize the heating sector by promoting the use of renewable energy sources, improving energy efficiency, and supporting flexible operation of heat plants. This transition is aligned with the EU's broader climate goals

The key points include:

- Promotion of renewable energy sources: The government will prioritize the use of renewable energy sources (RES) such as biomass, biogas, and waste for heat production. This includes supporting district heating systems (DHS) that utilize RES and waste heat from industrial processes.
- Encouraging heat pumps: Heat pumps, which are considered a form of RES, will also be promoted due to their significant cost savings in heat production.
- Phased transition from coal to natural gas: While the transition from coal to natural gas will be supported, investments in natural gas-fired heat generation facilities must align with the EU's climate goals for 2030 and 2050.
- Promoting flexible operation of heat plants: The government plans to stimulate flexible operation of heat plants for regulatory purposes, such as providing capacity payments.
- Prioritizing combined heat and power (CHP): CHP plants will be preferred over traditional fossil fuel-based power generation, as they offer greater efficiency and can contribute to grid stability.
- Integrating renewable energy into existing infrastructure: The existing infrastructure of heat plants will be utilized to integrate RES, such as biogas and biomethane, into the CHP process.
- Promoting circular economy: The text also emphasizes the importance of promoting the circular economy by utilizing waste for energy generation.

Households

The WEM scenario projects a significant reduction in solid fossil fuel consumption and balanced trend in gas consumption these two trends will stabilise greenhouse gas emissions by 2030, keeping them at slightly lower level as in the 2022. In the WAM scenario, a significant reduction in emissions by 2030 (-23.6%). This reduction will be mainly due to significant savings in heating. Due to investments in insulation and more efficient equipment. There will be a decrease in the consumption of natural gas (-19.7%) and solid fuels (-76.1%).

After 2030, the share of heat pumps in heating will increase the use of heat pumps will lead to partial savings in final energy consumption. These will be significantly supported, especially in the WAM scenario, by investments in improving the thermal insulation properties of buildings. The final energy consumption of fuels for heating and hot water (excluding electricity consumption) in households sector between 2030 and 2050 will decrease by 45% in WEM scenario and by 70% in WAM scenario.

Due to decarbonisation in the WAM scenario will also see a significant shift away from natural gas, which will be gradually replaced by biogas and hydrogen and with mix of synthetic gases. In the WEM scenario, the share of natural gas will also be significantly reduced, mainly in favour of electricity. Due to the significant electrification of heating (especially through the use of heat pumps), the use of biomass will decrease between 2030 and 2050 in both scenarios.

Energy efficiency

Slovakia has made significant strides in reducing its energy intensity over the past few decades, particularly between 2000 and 2015 when it achieved a 50.8% reduction. This progress is attributed to industrial restructuring, adoption of low-energy production processes, improvements in building insulation, and a shift towards more energy-efficient appliances. Despite these achievements, Slovakia still ranks seventh among EU countries in terms of energy intensity. This is largely due to the structure of its industry, with a significant portion consisting of energy-intensive sectors. To address this, Slovakia plans to focus more on industrial energy efficiency and related services, including energy production. The country aims to further reduce its energy intensity and align with the European average. Slovakia has fully integrated the EU's energy efficiency framework into its national policies and regulations.

Renewable energy sources

Slovakia has a substantial hydropower capacity, but further expansion is limited due to geographical constraints and environmental considerations. The focus is now on optimizing the performance of existing plants and exploring smaller-scale hydropower projects. While there is potential for modest growth in the coming years, the overall hydropower capacity is expected to stabilize.

Key points:

- Slovakia has a long history of hydropower generation.
- Most of the hydropower potential has already been exploited.
- Future growth will focus on modernizing existing plants and smaller-scale projects.
- Environmental concerns will limit the construction of new large hydropower plants.
- Hydropower plays a crucial role in meeting peak demand and providing ancillary services.

Slovakia's geothermal energy potential is substantial, with estimated reserves of 48 500 GWh. However, uneven distribution, high exploration costs, and complex permitting processes have hindered widespread development. Geothermal waters, found at depths of 200-5 000 meters, are the primary resource. While there are numerous geothermal wells, current utilization remains relatively low. The Košice project, aiming to use geothermal heat for district heating, demonstrates the potential for large-scale applications. The TIMES model, a tool for energy system analysis, could provide more detailed insights but lacks necessary data for the Košice project. Government support and technological advancements are expected to drive future growth in geothermal energy utilization in Slovakia.

2.2. GHG Emission Projections in the Energy Sector – Transportation (1.A.3)

The transport sector consists of five subcategories:

- 1.A.3.a Air transport (0.02%)
- 1.A.3.b Road transport (98.53%)
- 1.A.3.c Rail transport (1.17%)
- 1.A.3.d Water transport (0.07%)
- 1.A.3.e Other mode of transport (e.g. pipeline transport) (0.21%)

The largest contributor to transport emissions is road transport, in particular the use of diesel heavy-duty vehicles (HDV), but also passenger cars. The transport sector includes emissions from road transport (passenger cars, light-commercial vehicles, heavy-duty vehicles and buses, mopeds and motorcycles) as well as emissions from petrol evaporation, tyre and brake wear abrasion and road abrasion. In addition to road transport, this includes air, rail, maritime and pipeline transport (e.g. of natural gas). However, almost 99% of all emissions in 2022 came from road transport, including pipeline transport. If pipeline transport, which is included in the EU ETS emissions trading system. For this reason, Slovakia focuses on and analyses in detail only the potential reduction of emissions from road transport and for other transport categories the ARIMA model is used.

The starting point for gaining control over emissions is a thorough understanding of the current situation and an understanding of how emission trends have changed both quantitatively and compositionally. Based on official sources a detailed, complete and consistent set of data on vehicles and their activity can be prepared. This dataset is the basis for calculating the most accurate emissions at the national level using highly advanced emissions modelling tools.

Both the WEM and WAM scenarios for transport show an increase in emissions (***Figure 2.10*, *Table 2.9***), with the WAM scenario peaking as early as 2025, followed by a slow and gradual decline in GHG emissions, which are only 2% higher in 2030 compared to 2005 and 74% lower in 2050 compared to 2005. In the WEM scenario, emissions will continue to rise until 2030 before declining thereafter and are still expected to be 20% lower in 2050 compared to 1990 levels. The high emissions from road transport are mainly due to the fact that the development of transport as the main carrier system took place only at the beginning of the 21st century, in particular with the development of the light-commercial vehicle (LCV) segment, which will continue to play an important role in the future. In terms of climate change, road transport will be a key sector for reducing GHG emissions. The year 2055 was extrapolated based on emissions in the WEM and WAM scenarios.

Figure 2.10: *Historical, WEM and WAM scenario GHG emissions from transport in CO_2 eq. (Gg)*

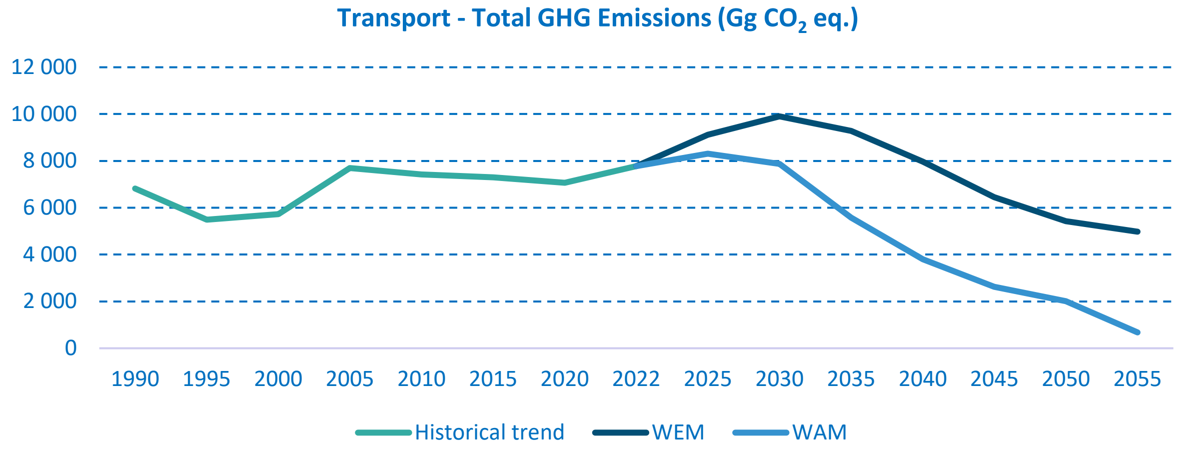

Table 2.9: *GHG emission projections from transport*

YEAR	WEM	WAM
	Gg CO_2 equivalents	
1990	6 816.32	6 816.32
1995	5 490.92	5 490.92
2000	5 721.59	5 721.59
2005	7 693.08	7 693.08
2010	7 421.48	7 421.48
2015	7 293.40	7 293.40
2020	7 061.50	7 061.50
2022	7 778.85	7 778.85
2025	9 118.71	8 309.62
2030	9 903.88	7 880.07
Comparison with 1990	45.30%	15.48%
Comparison with 2005	28.74%	2.37%
2035	9 282.92	5 583.91
2040	7 973.86	3 800.69
2045	6 447.16	2 625.51
2050	5 421.12	2 007.38
Comparison with 1990	-20.47%	-70.58%
Comparison with 2005	-29.53%	-73.92%
2055	4 957.40	677.06

2.2.1. Methodologies and Key Assumptions/Trends

Input (historical) data for the calculation of GHG emission projections from road transport are the IS EVO (Vehicle Registration Information System) database provided by the Ministry of Interior of the Slovak Republic – Police department (DI PPZ), the database of the Slovak Technical Control (STK) of the Ministry of Transport and Construction of the Slovak Republic (MDV SR) and the transport indicators from the CPS+ model (Compact PRIMES model) provided by the Institute of Environmental Policy (IEP). The Sybil database is also an important input source of information in the preparation of emission projections and input parameters. This database is being prepared by EMISIA[13] on the basis of:

- EUROSTAT statistical data (national statistics)
- Project outputs (FLEETS, TRAACS, NMP project) for all EU countries
- EC Statistical Pocketbooks
- ACEA (The European Automobile Manufacturers' Association)
- ACEM (The Motorcycle Industry in Europe)
- CO_2 monitoring database (operated by the EEA)
- EAFO
- NGVA EUROPE/NGV GLOBAL
- UNFCCC reports
- Weibull´s distribution for preparing the age structure until 2050

The data in this database are based on the same input parameters as the EU Reference Scenario for Slovakia, which was discussed and presented in 2018 – 2019. The EU Reference Scenario for Slovakia was modelled using the PRIMES model and its transport module TREMOVE. The fleet development trends are therefore based on the same parameters and complex calculations, taking into account changes in the market as well as dynamic developments in the sector. This model is not directly applicable to Slovak conditions, as it requires a lot of detailed data, which Slovakia does not have.

Using trends from the Sybil database, an estimate of fleet development was prepared based on real data for the years 2013 – 2022. The data for this time period were obtained from IS EVO as a by product of a project[14]. Data and emissions prior to 2013, i.e. the period 1990 – 2012, were compiled according to official DI PPZ statistics and historical emission inventories.

Another important factor for calculating emissions and energy demand is the average value of annual mileage in each vehicle category and the average value of total vehicle kilometres travelled in each category. These data for the historical years 1990 – 2012 were taken from emission inventories. Subsequently, for the years 2013 – 2019, these figures were calculated using the information contained in the Slovak Technical Control database. Specifically, it is the information from the odometer about the kilometres driven. Using the VIN number, the data is matched with the data from IS EVO. A detailed description of the methodology was published in the first phase of the project "Improving the allocation of road transport emissions in the AEA module".

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[13] Spin-off of the Applied Thermodynamics Laboratory of the Aristotle University of Thessaloniki: https://www.emisia.com/

[14] Project: Improving the allocation of road transport emissions in AEA module and coherence between AEA and PEFA modules, Grant agreement no. 101022801 — 2020-SK-ENVACC: https://oeab.shmu.sk/app/cmsSiteBoxAttachment.php?ID=124&cmsDataID=0

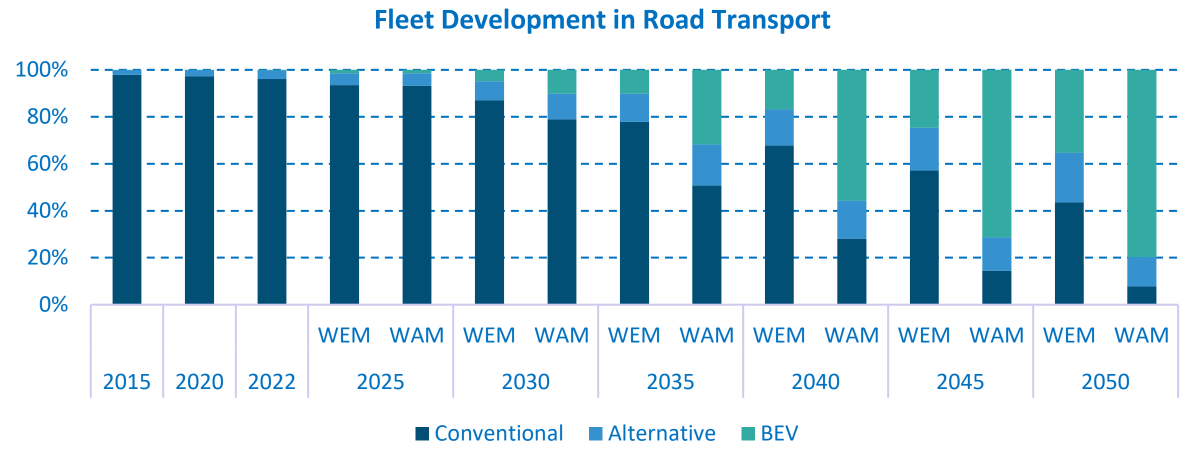
The COPERT model itself operates with 5 vehicle categories:

- Passenger cars (M1)
- Light-commercial vehicles (N1)
- Heavy-duty vehicles- trucks (N2 and N3)
- Buses (M2 and M3)
- L-category (L1 to L7)

Estimates for the period 2020 – 2050 were taken directly from the Sybil database and then broken down into individual fuel bases, segments (by engine capacity or vehicle weight) and emission standards. The model works with up to 620 separate data streams in total. The numbers of vehicles in each data stream each year are determined by an age composition matrix and a "survival rate" calculated from the data of the above-mentioned projects and the Weibull distribution and EUROSTAT data.

Vehicle engines (fuel types) are subdivided and described in detail in the model, but for the purpose of this report, the different types of engines are divided into three groups: conventional, alternative, and zero emission (BEV). Conventional engines are diesel and gasoline with their bio-component. CNG, LPG, LNG, hybrid (both diesel and petrol) and plug-in hybrid (both diesel and petrol) are being considered as alternative engines. BEV is currently represented by electric and hydrogen engine. The overall evolution of the fleet can be seen in ***Figure 2.11***.

Figure 2.11: *Fleet development by fuel types in WEM and WAM scenarios*

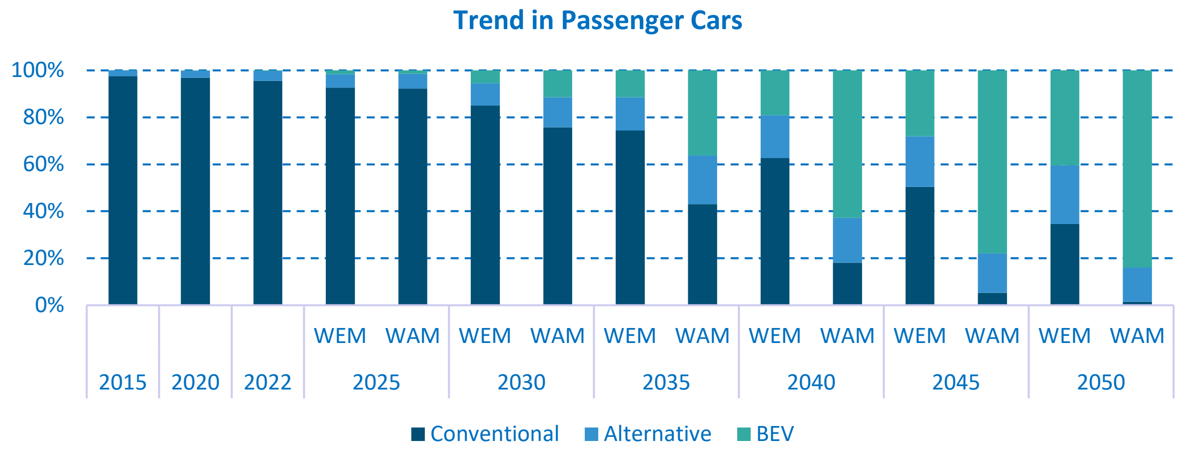


Passenger cars (M1)

Passenger cars account for the largest share of the fleet. In recent years, there has been a significant increase in their number. The main assumption for the projections is that the number of passenger cars in the fleet has still not at its peak. It is expected to peak around 2040, followed by a gradual and slow decline in the number of passenger cars, also driven by a declining demographic curve.

WEM scenario expects conventional passenger car sales will peak in 2030 (***Figure 2.12***). In the case of the WAM scenario, this peak could happen earlier, sometime around the year 2026. For alternative engines, there is a slightly lower increase in the WAM and this is due to the greater weight given to BEV in the fleet development for this scenario, which have exponential growth up to 2050.

Figure 2.12: Development of passenger cars in WEM and WAM scenarios



Light-commercial vehicles (LCV or N1)

The light-commercial vehicle category (category N1 - up to 3.5 tonnes) has undergone a significant change, moving from a category of no major importance in the 1990s to one of the key categories for future decarbonisation. The reason for its significant growth and the assumption of further growth is mainly due to the development of courier services and the "last mile" transport of goods. If the Slovak Republic does not try to decarbonise this part of road transport, the number of these conventionally fuelled vehicles (petrol and diesel) could reach up to 350 000 vehicles in 2050 (***Figure 2.13***). For LCVs, there is little expectation of a turnover to alternative fuels as there would be a reduction in transport space and hence the WAM scenario will not affect this category. For the overall decarbonisation of road transport, it will be necessary to decarbonise in particular the 'last mile' in the form of zero-emission vehicles.

Heavy-duty vehicles – trucks (HDV or N2 and N3)

The heavy-duty vehicles category (traditional freight transport) is also extremely specific within road transport, mainly because of the possibilities of replacing conventional fuels with alternative fuels. This often leads to greenwashing campaigns about emission-free transport in the form of LNG/CNG. Decarbonisation is challenging due to the need for extremely high range and engine power.

In the WEM scenario, there is a steady increase in the number of HDVs (***Figure 2.14***) as the production of goods that will needed to be transported over medium and long distances are projected to increase by the CPS+ model. Alternative fuels can contribute to reducing GHG emissions but cannot be the ultimate solution in this category. The WAM scenario assumes a significant change and an exponential increase and shift away from conventional fuels towards BEV. This is limited, as for the other categories, only by the production capacities of the car manufacturers.

Figure 2.13: *Development of light-commercial vehicles in WEM and WAM scenarios*

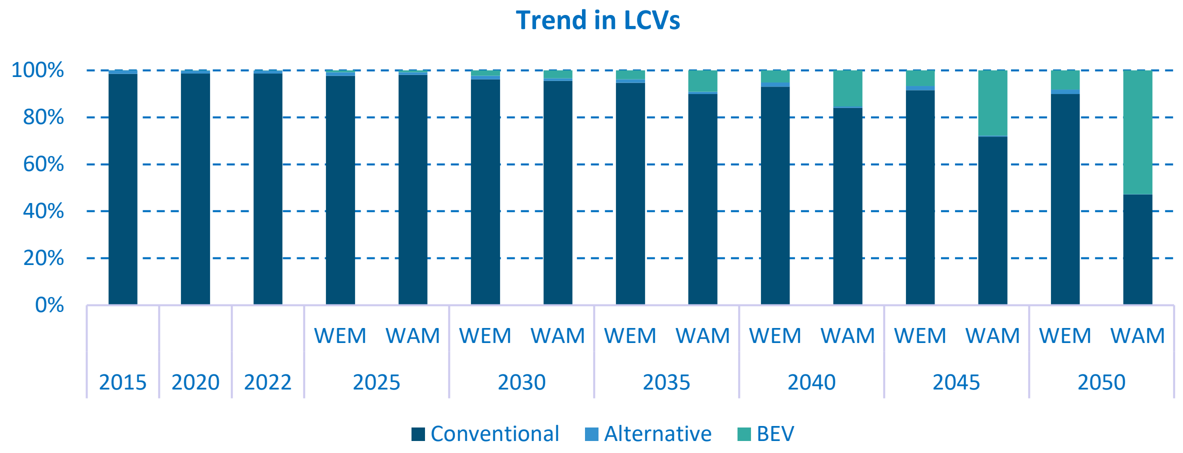
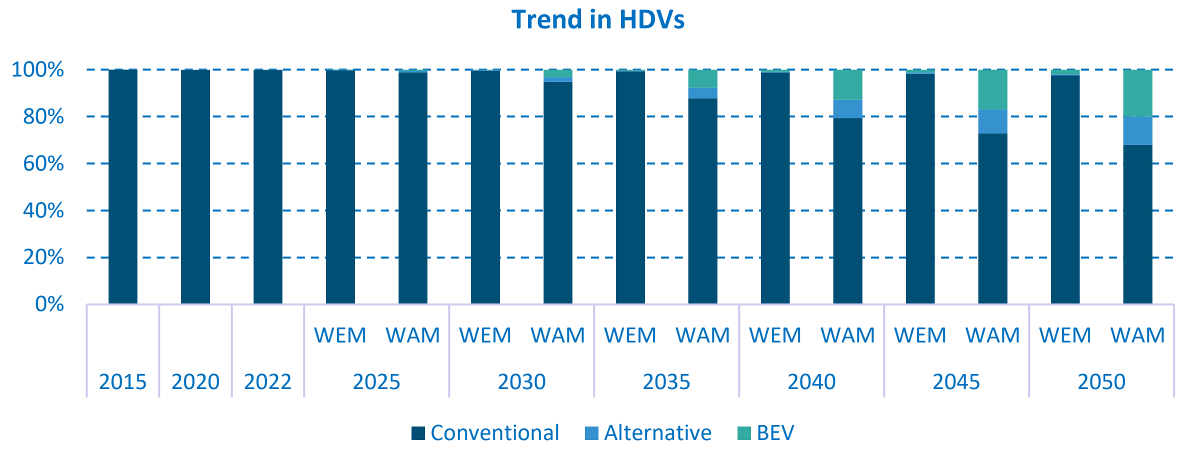


Figure 2.14: *Development of HDV fleet in WEM and WAM scenarios*

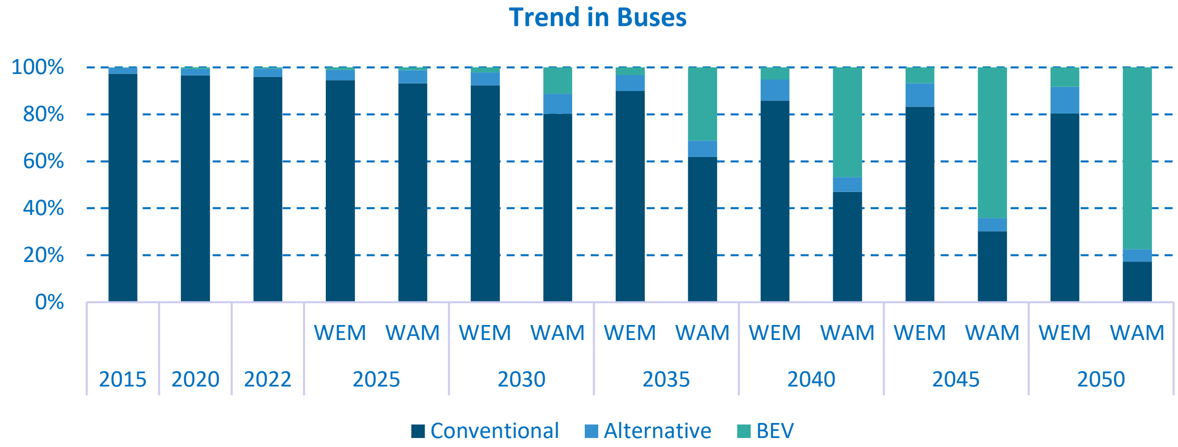


Buses (M2 and M3)

In the case of public passenger transport (PPT), there is no difference between the development in the WEM and WAM fleet scenario in total number of vehicles, but there is a turnover of the fleet (***Figure 2.15***). The WAM scenario assumes a shift of passengers to rail and a densification of PPT intervals, which is reflected in higher annual bus mileage. This assumption was subsequently reflected in the model. Given the small share in road transport, no major interventions in the form of measures to support the fleet turnover have been necessary.

The decline in alternative fuel buses between 2015 and 2020 is mainly due to the phasing out of CNG buses. This trend is changing with the gradual introduction of hybrid buses and their gradual growth, replacing not only conventional buses but also older CNG-powered buses.

Figure 2.15: *Development of buses fleet in WEM and WAM scenarios*



L-category (L1 to L7)

This category includes all two- and three-wheel vehicles. In addition to these, quadricycles (ATVs) and micro-cars are included. The term micro-car is used in the model to unite all vehicles of category L (1-7) that use diesel as a source of energy. Overall, this category consists of:

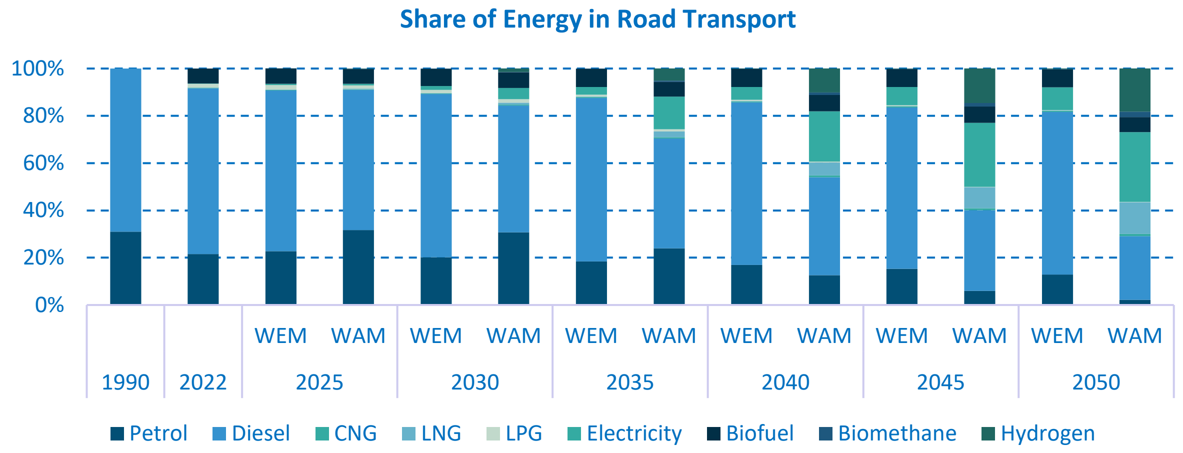
- Mopeds
- Motorbikes
- ATVs
- Buggies
- Micro-cars

This is the smallest and least important vehicle category in terms of emissions. These vehicles account for around 0.3% of greenhouse gas emissions and projections show that this trend should not change, with the massive decarbonisation of the passenger car category seeing the share rise to around 1% in 2050.

Energy consumption

In terms of energy, according to the WEM scenario, in Slovakia will dominate consumption of diesel oil until 2050. Its consumption will slowly decrease in this scenario but will still account for up to 69% of the total energy consumption of road transport in 2050. From other alternative fuels will be the most dominant electricity consumption, rising gradually from a share of 2% (2 178 TJ or 605 GWh) in 2030 to around 10% (7 710 TJ or 2 140 GWh) in 2050 (***Figure 2.16***).

Figure 2.16: *Historical evolution of the energy demand for road transport for the years 1990 – 2022 and WEM and WAM scenarios development assumptions*



In the WAM scenario, significant diversification and an overall decline in fuel and energy consumption is expected in 2050. In this case, electricity will be the most used source of fuel, accounting for 1% (856 TJ or 240 GWh) in 2030 and up to 30% (15 400 TJ or 4 300 GWh) of the total energy demand in 2050. Diesel oil will still have a similarly important but significantly smaller share, with a share of 54% in 2030, falling to half (27%) in 2050. This significant share, despite strong decarbonisation, is mainly due to the heavy-duty vehicles' category, which is extremely difficult to decarbonise while maintaining the parameters required of them.

2.2.2. Model Description

Input data for the calculation of GHG projections from road transport are databases provided by the Traffic Inspectorate of the Presidium of the Police Force of the Slovak Republic (IS EVO - Information System of Vehicle Registration) and the Ministry of Transport and Construction of the Slovak Republic (STK=PTI – Periodical Technical Inspection), transport indicators from the CPS+ model (IEP MŽP SR), which was developed for the needs of the Low Carbon Strategy.

An important aspect in the preparation is the Sybil database. This database is being prepared by EMISIA on the basis of:

- EUROSTAT statistics (national statistics),
- Project outputs (FLEETS, TRAACS, NMP project) for all EU countries,
- EC Statistical Pocketbooks
- ACEA (The European Automobile Manufacturers' Association)
- ACEM (The Motorcycle Industry in Europe)
- CO_2 monitoring database (operated by the EEA)
- EAFO (European Alternative Fuels Observatory)
- NGVA EUROPE/NGV GLOBAL (The Natural & bio Gas Vehicle Association)
- UNFCCC reports
- Proprietary algorithms for the preparation of the age structure up to 2050

The data in this database are based on the same input parameters as the EU reference scenario for Slovakia. The EU reference scenario for Slovakia was modelled using PRIMES and its transport module

TREMOVE. However, for the conditions of Slovakia, as a small country, this model is directly inapplicable, as it requires many detailed data, which Slovakia does not have.

Using trends from the Sybil database, an estimate of fleet development was prepared based on real data for the years 2013 – 2022. The data for this time were obtained from IS EVO. Data and emissions prior to 2013, i.e. the period 1990 – 2012, were compiled from official Traffic Inspectorate of Police statistics and historical emission inventories.

Another important factor for calculating emissions and energy demand is the average value of annual mileage in each vehicle category and the average value of total vehicle kilometres travelled in each category. These data for the historical years 1990 – 2012 were taken from emission inventories. Subsequently, for the years 2013 – 2023, these data were calculated using the information contained in the Vehicle Technical Inspection (VTI) database.

The model itself operates with 5 vehicle categories:

- Passenger vehicles (M1)
- Light-commercial vehicles (N1)
- Heavy-duty vehicles - trucks (N2 and N3)
- Buses (M2 and M3)
- L-category (L1 to L7)

Table 2.10: *SWOT analysis of the COPERT CLI model*

Strengths	**Opportunities**
Compatibility with emission model for emission inventories Detailed data break down Database used is compatible with EU data and national data	Incorporate to the model new technologies Versatile use on different geographical level Versatile use of time series
Treats	**Weakness**
Easy data entry Basic software is free	Disconnected from macroeconomic models Disconnected from national energy models (needs to feed outcomes to energy models) Too much pre-calculations needed

Estimates for the period 2023 – 2050 were taken directly from the Sybil database. These estimates are based on European statistics and qualified estimates by transport experts. Subsequently divided into individual fuel bases, segments (by engine capacity or vehicle weight) and emission standards, the model works with up to 866 separate data streams in total. The numbers of vehicles in each data stream each year are determined by an age composition matrix and a "survival rate" calculated based on data from the above-mentioned projects and EUROSTAT data.

The COPERT model is used for the actual calculation using the CLI module, which allows new technologies that are not directly defined by the model to be brought into the model. This includes emissions-intensive technologies such as LNG, flexi-fuel, e-fuel or hydrogen engines.

The COPERT model always reflects and incorporates the latest developments and scientific knowledge into emissions calculations. The emission calculation methodology is described in the EMEP/CORINAIR Atmospheric Emissions Inventory Guidebook (EMEP GB) on tailpipe emissions from road transport. The model has roughly 50 predefined (and modifiable) parameters, ranging from environmental conditions (air temperature and humidity) to parameters detailing the generation of emissions in individual vehicle types. When using the CLI module, many of these parameters are unavailable and set to the default value.

Basic emission factors are integrated in the model, which are adjusted based on user-supplied input parameters. Emission factors are defined for each greenhouse gas separately. Carbon dioxide emissions are specific as they are calculated based on the ratio of hydrogen to carbon in fuels and thus the amount of CO_2 depends on the total amount of fuel burned. Actual values for 2022 were used for the model, except for new technologies where it was necessary to supply emission factors directly.

In terms of technology and the use of different technologies within a single vehicle (plug-in hybrids, CNG, LPG), basic settings were used. In the case of CNG and LPG, it is assumed that 100% of these fuels are used at the expense of petrol, and in the case of plug-in hybrids, the split is 75% in favour of petrol and diesel and 25% in favour of electricity (electric motor). The low share of electric motor use is based on several studies summarised by the ICCT (International council on clean transportation).

Minimum and maximum temperatures have also been introduced into the model, which affect emissions to some extent. The regional climate model KNMI-RACMO22E and its optimistic scenario RCP2.6 were used.

2.2.3. Scenarios, Parameters and PAMs

Slovakia prepared two scenarios for road transport: WEM and WAM scenario. The WEM scenario describes the development of vehicle fleet and GHG emissions using only existing measures in force until end of 2022. In contrast, the WAM scenario foresees a number of additional measures and policies that will need to be put in place both nationally and locally. The policies and measures used are based directly on legislation or on national and EU strategies and action plans. The reference year to compare to the WAM scenario was 2005. The reason for choosing this year as a reference year for comparison is that in 1990 road transport in Slovakia was not yet developed in all areas and did not reflect the current situation. In 1990, the light-commercial vehicle segment, which plays an important role today and especially in the future, was almost non-existent. At the same time, the last validated year with real values was determined to be 2022.

The policies affecting emissions from road transport can be split to three types: energy policies, transport policies and environmental policies. Energy policies and measures focus mainly on energy efficiency and renewable energy sources in transport. Transport policies and measures focus on transport infrastructure and intensity, and environmental policies and measures focus directly on reducing emissions of greenhouse gases and pollutants. The policies and measures taken into account in each scenario are based on a number of national documents:

- Low-Carbon Development Strategy of the Slovak Republic until 2030 with a view to 2050 (NUS SR)
- Action plan for the development of electromobility in Slovakia
- National Air Pollution Control Program (NAPCP)
- Strategic plan for the development of transport in Slovakia up to 2030
- Integrated National Energy and Climate Plan of Slovakia (NECP)
- Review and update of the National Policy Framework for the Development of the Alternative Fuels Market
- EU hydrogen strategy

In addition to these documents, separate acts and European directives also intervene in the preparation of individual scenarios:

- Act No. 277/2020 amending Act No. 309/2009 Coll. on the Promotion of Renewable Energy Sources and High Efficiency Combined Heat and Power Generation
- Regulation (EU) 2018/1999 of the European Parliament and of the Council on the Governance of the Energy Union and Climate Action
- Regulation (EU) 2021/1119 of the European Parliament and of the Council establishing the framework for achieving climate neutrality

WEM Scenario

The baseline scenario is the WEM (With Existing Measures) scenario, which includes only policies and measures in place by the end of 2022. The WEM scenario contains only five known measures that affect the energy mix and the vehicle fleet. They are:

- Act No. 277/2020, which is a partial national transposition of consolidated Directive (EU) 2018/2001 of the European Parliament and of the Council (RED III) on the promotion of the use of energy from renewable sources
- Sale of low-emission vehicles (electric hybrids or plug-in hybrids) or directly zero-emission vehicles (battery electric cars and fuel-cell electric cars)
- Energy efficiency
- Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO_2 emission performance standards for new passenger cars and light-commercial vehicles
- Regulation (EU) 2019/1242 of the European Parliament and of the Council of 20 June 2019 setting CO_2 emission performance standards for new heavy-duty vehicles

The RED III Directive on the promotion and use of energy from renewable sources is currently still not fully transposed into national legislation. Its validity and inclusion in the WEM scenario was necessary and mandatory based on the scenario preparation framework. The RED III Directive sets new targets for the blending of renewable fuels (biofuels) into fossil fuels.

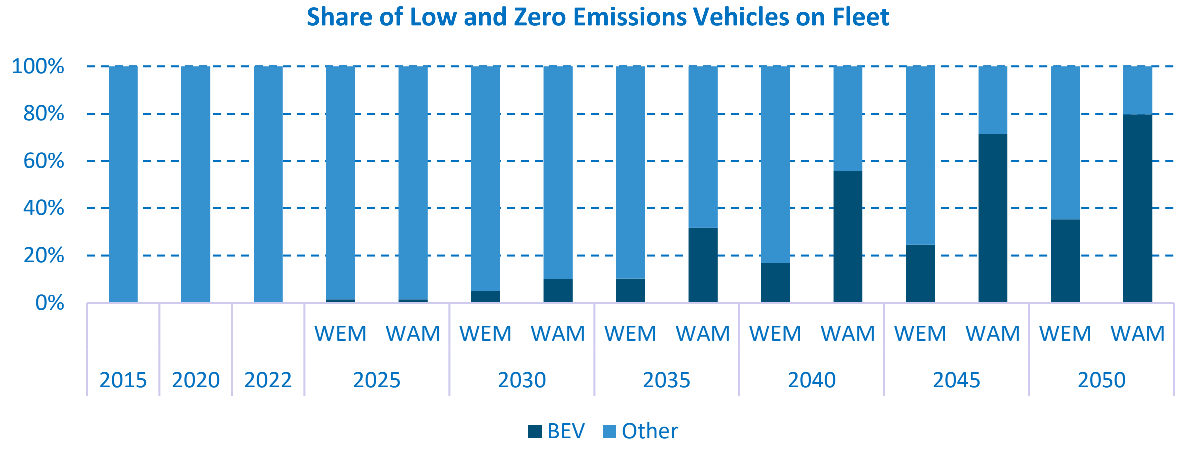
The new, increased targets are:

2023	2024	2025	2026	2027	2028	2029	2030
8.6%	8.8%	9.2%	9.5%	10.0%	10.4%	10.8%	11.4%

At the same time as this increased target, the possibility of double counting of the energy share of advanced biofuels has also been introduced. However, the double counting of advanced biofuels has no impact on the production of greenhouse gas emissions.

The historical and projected promotion of zero-emission vehicles (BEV) can be seen in ***Figure 2.17***. Total BEV accounts for 4.9% of the vehicle fleet in 2030, 35% in 2050 according to the WEM scenario and 9.2% in 2030 and 44% in 2050 according to the WAM scenario. Passenger cars account for the largest share of eBEV, accounting for 75% in 2022, 86% in 2025 and up to 93% of all BEV on the road in 2030 and up to 96% in 2050 in the WAM scenario.

Figure 2.17: *Share of low- and zero-emission vehicles in the total vehicle fleet of the Slovak Republic - historical development and projections to 2050*



Energy efficiency is converted into the model identically to the real options. The potential for improving combustion and engine efficiency to the level of "ultra-efficiency" was estimated at 15% in the ERTRAC report for passenger cars with spark-ignition engines. For diesel engines for passenger cars, this estimate was a 12% improvement by 2050, but for light and heavy duty vehicles there is only a 10% level by making the engine more efficient. In the model it is represented by coefficient directly reducing the outputs of energy demand and CO_2 emissions. Both EU regulations (2019/631 and 2019/1242) are also incorporated into the model this way.

WAM Scenario

WAM (With Additional Measures) scenario is built on policies and measures, strategies and action plans that have not been put into force before 2022. The list of policies and measures used is summarised in ***Table 2.11***.

Table 2.11: *List of policies and measures used in WAM scenario*

Name of the measure	Scenario	Short description for WAM
Regulation for CO_2 emission standards for new passenger cars & light commercial vehicles	WEM, WAM	WEM: 2021 Targets WAM: 2025, 2030, 2035 targets (Fit for 55) achieved
Regulation for CO_2 emission standards for new heavy-duty vehicles	WAM	2030, 2035, 2040 targets partially achieved
Freight Modal Shift	WEM, WAM	WEM: Low Modal Shift - e.g. Trucks to Rail WAM: High Modal Shift - e.g. Trucks to Rail
Passenger Modal Shift	WAM	High Modal Shift - e.g. cars to cycling or public transport
Euro 7: Council adopts new rules on emission limits for cars, vans and trucks	WAM	In compliance
Support for the use of low-emission vehicles	WEM, WAM	WEM: Moderate transition to low-emission forms of transport WAM: High transition to low-emission forms of transport
Promotion of biofuels	WEM, WAM	WEM: In compliance WAM: High increase of biofuels share
Low-emission zones in cities	WAM	UVAR for conventional vehicles
Setting stricter requirements for regular technical inspections	WEM, WAM	Stricter technical control to prevent tampering

The measure to support the continuation of direct support for the use of low-emission vehicles is mentioned in the Action Plan for the Development of Electromobility in the Slovak Republic and is also referred to in the National Air Pollution Control Program. In this measure, the penetration of electric vehicles in the passenger car segment is assumed to be more efficient, up to twice as strong, than in the WEM scenario.

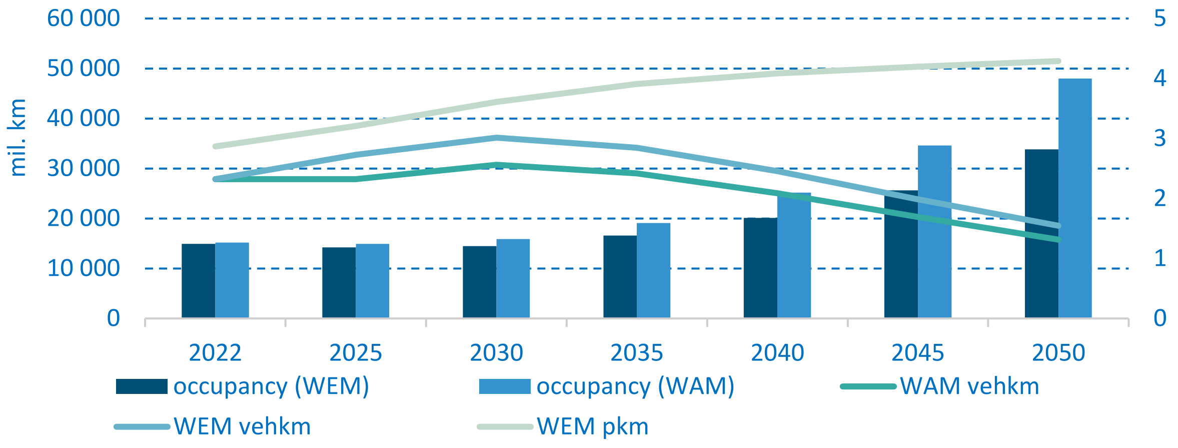
Stricter technical and emission inspections should result in the capture and removal of the oldest and non-compliant vehicles from transport. Strict rules are now in place for technical and emission inspection stations, but despite these measures, there is still circumvention of the rules. According to some research there can be up to 60% of tampered heavy-duty vehicles. This measure is expected to have a gradually diminishing effect under the influence of positive changes in the behaviour of vehicle owners. In the model, this measure manifests itself as a change in the age structure of the passenger car fleet.

Modal shift in passenger transport implies a shift of passengers from passenger vehicle transport to public passenger transport (PPT) or cycling in cities. As a result, the occupancy rate of passenger vehicles is expected to increase by 50% compared to 2022, reducing in particular the number of kilometres travelled by passenger vehicles up to 33% by 2050. The transfer of passengers to the PPT will go in two directions at the same time: road PPT and rail PPT. In the case of the rail PPT, it is expected that there will be an improvement in the quality of transport as well as the restoration of a number of railway connections. The prerequisite for this is the approved new Transport Service Plan for railways passenger transport. In the case of bus services, it is expected that there will be a slight increase in kilometres travelled. This effect on public bus services was reflected in a 10% increase in average annual mileage.

For shorter distances and in the city, it is also possible to use bicycle transport in addition to PPT. This possibility should also results from the National Strategy for the Development of Cycling Transport and Cycling Tourism in the Slovak Republic. It is estimated that it could reduce the share of road passenger transport in cities up to 10% by 2030. For the purposes of the projections, more conservative estimates of 6% have been used (3% for traffic peak and 3% for off-peak traffic).

The input data are pkm (person-km), which is a macroeconomic indicator from the CPS+ model for the Low Carbon Development Strategy of the Slovak Republic. From this data, the vehicle occupancy was then calculated, to which the increased occupancy was applied. It was then possible to calculate the new mileage with increased vehicle occupancy while maintaining passenger kilometres (***Figure 2.18***).

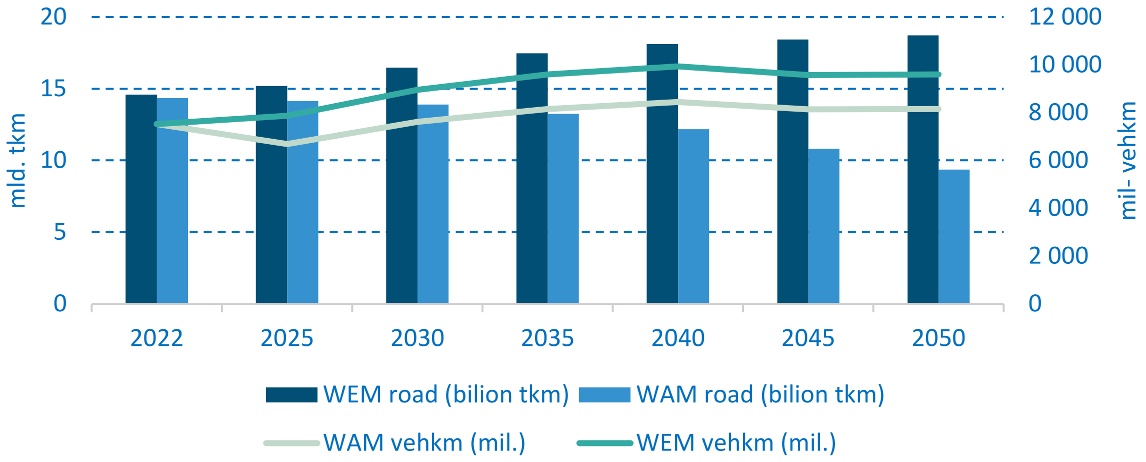
Figure 2.18: *Changes in passenger vehicle occupancy, annual passenger vehicle miles travelled, and passenger vehicle miles travelled by CPS+ model*



Modal shift in freight transport or the movement of goods in Slovakia is currently mainly carried out by freight road transport. From this point of view, modal shift in freight transport is more than necessary. According to the freight modal shift policy, the volume of goods transported by trucks is expected to decrease by 50% by 2050. This goal is foreseen in the Low Carbon Development Strategy of the Slovak Republic. As a consequence of shifting some of the goods to the railways, the annual vehicle mileage will be reduced and ultimately the number of trucks will also be reduced. A possible reduction in the number of trucks has not been estimated, as the WAM scenario currently only assumes a reduction in annual mileage.

The calculation procedure is analogous to the modal shift in passenger transport. In this case, tonne-kilometres (tkm) play a role, which were also obtained from the CPS+ model for the Low Carbon Development Strategy of the Slovak Republic as a macroeconomic indicator (***Figure 2.19***).

Figure 2.19: *Changes in freight transport, annual boarding and goods transported by road and rail (billion tkm)*



The most effective measure in this scenario appears to be the phasing out of fossil fuelled cars and light-commercial vehicles and their replacement by electric and hydrogen vehicles, especially for last mile goods movements. A complete ban on the sale of these pure fossil fuel vehicles (diesel and petrol) is due to take place in 2035. This measure will result in an exponential growth of BEVs in the light-commercial vehicle category. This measure will be also facilitated by the introduction of low emission zones in cities.

The introduction of hydrogen passenger vehicles, similar to trucks, was estimated in the European Hydrogen Strategy report to reach a maximum possible implementation rate of 20% of the vehicle fleet by 2050. In Slovakia, this level is reduced to 10% in the WAM scenario following a consensus of experts in the field.

The addition of bio-based methane (bio-methane) to vehicle fuels is now common practice in other EU countries. In Slovakia, this obligation will be introduced by the amendment of Act No. 309/2009 on the Promotion of Renewable Energy Sources and High Efficiency Combined Production. This amendment introduces an obligation to add a bio-component to compressed natural gas (CNG) and liquefied natural gas (LNG) from 2023. The minimum energy content of this bio-ingredient is determined as follows:

2023	2024	2025	2026	2027	2028	2029	2030
2.0%	3.0%	4.0%	6.0%	8.0%	10.0%	12.0%	14.0%

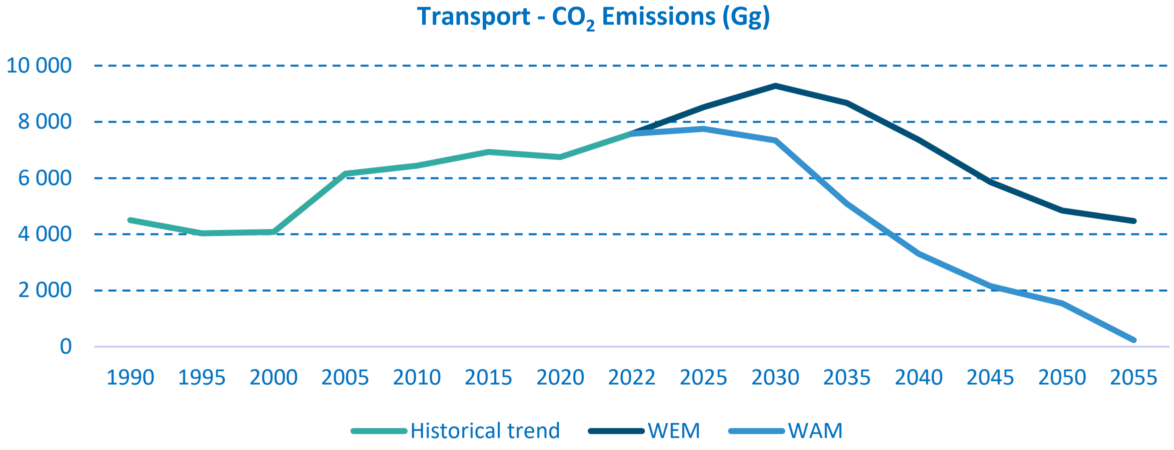
Even at the highest achievable share in 2030 (14% of the bio-based component), this does not have a significant reduction impact on emissions and traffic intensity in the scenario.

2.2.4. Emission Projections in the Energy Sector – Road Transportation (1.A.3.b)

CO_2 emission projections

CO_2 emissions are the most significant GHG emissions for road transport. All measures are primarily aimed directly at reducing these emissions. Therefore, the CO_2 emission scenarios (***Figure 2.20***) also follow the trend of GHG emissions expressed in CO_2 equivalents.

Figure 2.20: *Historical trends of CO_2 emissions in Gg from road transport for the years 1990 – 2022 and emission projections in the WEM and WAM scenarios*



CH_4 and N_2O emission projections

CH_4 and N_2O emissions (***Figure 2.21*** and ***2.22***) are insignificant in terms of the amount produced by road transport and the impact on total GHG emissions in Slovakia, as they account for only 1% of total GHG emissions from road transport. Methane emissions decline in the WAM scenario, but at a significantly slower rate than the other two GHGs. This is mainly due to the introduction of compressed or liquefied natural gas vehicles as an alternative to petrol and diesel vehicles. On the one hand, these fuels reduce overall CO_2 emissions, but on the other hand they reduce the effect of other measures that also reduce methane emissions.

Figure 2.21: *Historical trends of CH_4 emissions in Gg of CO_2 eq. from road transport for the years 1990 – 2022 and emission projections in WEM and WAM scenarios*

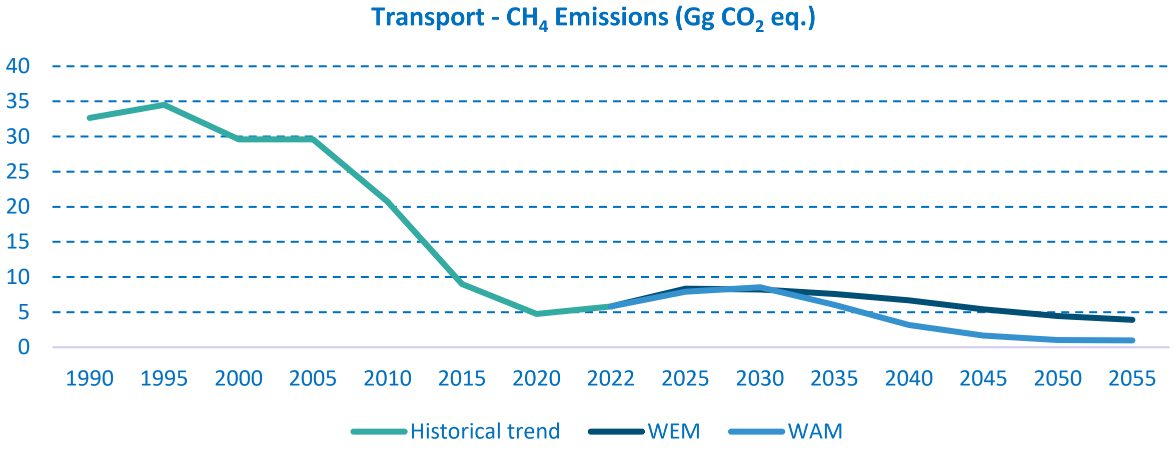
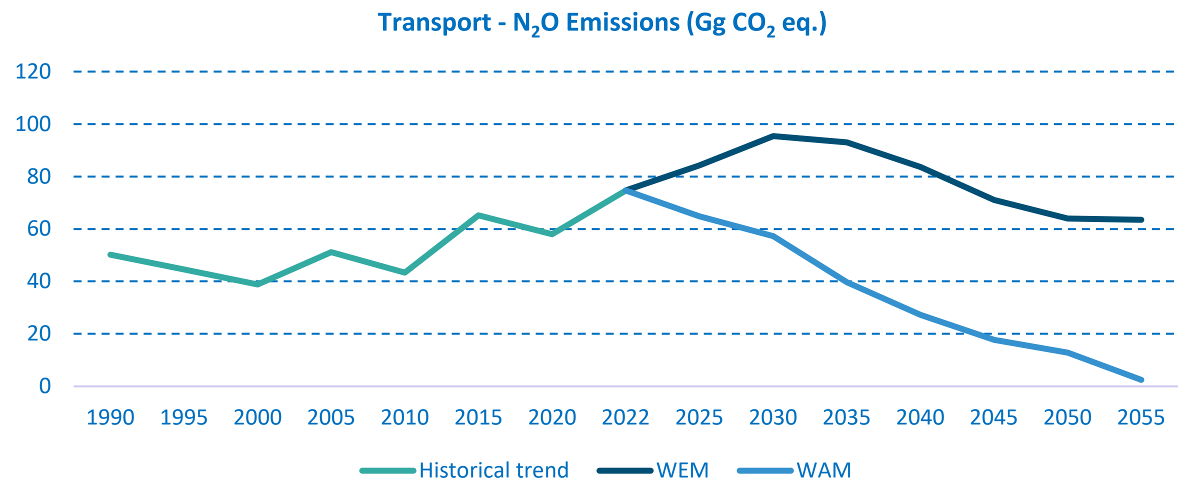


Figure 2.22: *Historical trends of N_2O emissions in Gg of CO_2 eq. from road transport for the years 1990 – 2022 and emission projections in WEM and WAM scenarios*



2.2.5. Emission Projections in the Energy Sector – Non-Road Transportation (1.A.3.a, c, d, e)

In addition, projections of GHG emissions from non-road transport in the Slovak Republic have been prepared, but their relevance to overall GHG emissions projections is negligible, so only the WEM scenario has been prepared. Projections of non-road emissions were calculated using ARIMA (AutoRegressive Integrated Moving Average) modelling. Emissions from pipeline transport have been prepared based on information about projections of long-distance transmission of natural gas through the pipelines system (***Table 2.12***).

Table 2.12: *GHG emission projections by gases in non-road transport for the WEM scenario*

Gas	Transport Sector	Unit	2022	2025	2030	2035	2040	2045	2050	2055
CO_2	Air transport	kt	1.48	1.25	1.34	1.34	1.34	1.34	1.38	1.35
	Rail transport		82.29	108.02	111.46	115.28	119.31	131.71	139.60	121.98
	Navigation transport		5.29	2.66	2.27	2.08	1.89	1.04	0.53	0.29
	Pipeline transport		16.12	290.91	287.28	283.28	294.08	280.53	274.13	275.70
CH_4	Air transport	t	0.03	0.031	0.031	0.031	0.031	0.031	0.032	0.032
	Rail transport		4.95	5.50	5.70	5.90	6.10	6.34	6.57	6.77
	Navigation transport		0.50	0.30	0.30	0.30	0.30	0.25	0.23	0.23
	Pipeline transport		0.29	0.005	0.005	0.005	0.005	0.005	0.005	0.005
N_2O	Air transport		0.04	0.019	0.019	0.019	0.019	0.019	0.02	0.02
	Rail transport		34.14	37.80	39.00	40.40	41.80	61.61	71.38	72.38
	Navigation transport		0.14	0.06	0.06	0.06	0.06	0.04	0.03	0.03
	Pipeline transport		0.0288	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

2.3. GHG Emission Projections of Fugitive Emissions (1.B)

Fugitive emissions from the mining and post-mining activities of brown coal, solid fuels transformation and production, transmission and distribution of crude oil and natural gas (NG) were projected. Total share of emissions represented in CO_2 eq., in the Slovak Republic has decreasing trend and is almost negligible in comparison with the emissions from combustion of fuels (around 1%).

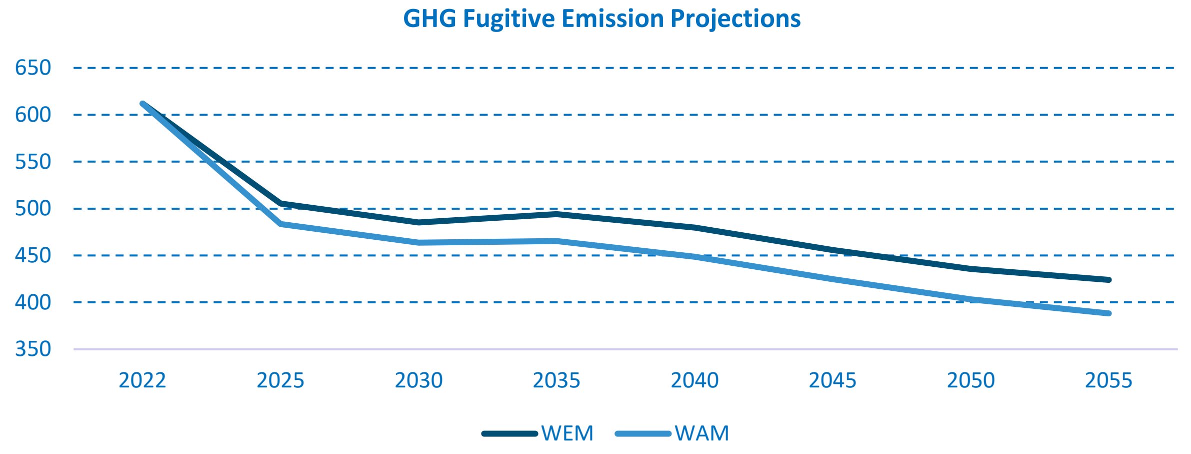
Based on the information on trends in the solid fuels mining and handling activity, as well as fuel transformation, and the information on trends in the oil and NG activity in Slovakia, the following emissions projections based on the WEM and WAM scenario were calculated and are presented in ***Table 2.13*** and ***Figure 2.23***.

Table 2.13: *Projections of GHG emissions in Gg of CO_2 eq. in WEM and WAM scenarios up to 2055*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1.B Fugitive emissions from fuels	612.11	505.30	485.23	493.99	479.89	455.68	435.54	423.99
1.B.1 Solid fuels	200.66	85.67	75.31	70.48	66.41	63.12	60.28	53.83
1.B.2 Oil and natural gas	411.45	419.63	409.92	423.50	413.48	392.56	375.26	370.16
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1.B Fugitive emissions from fuels	612.11	483.59	463.59	465.35	448.62	424.70	403.17	388.22
1.B.1 Solid fuels	200.66	85.77	73.44	68.61	64.54	61.24	58.40	51.30
1.B.2 Oil and natural gas	411.45	397.82	390.15	396.74	384.08	363.46	344.77	336.93

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Figure 2.23: *Projections of GHG emissions in Gg of CO_2 eq. in WEM and WAM scenarios up to 2055*



2.3.1. Methodologies and Key Assumptions/Trends and Model Description

Projections of emissions were prepared in accordance with the methodology of IPCC 2006 Guidelines and its 2019 IPCC Refinements. The methodology is consistent with the methodology of estimating emissions under Article 26 par. 3 of Regulation (EU) 2018/1999. The calculation analysis tool is based on the MS Excel platform and the calculation includes various policies and measures (in numerical formulation) defined according to the WEM and WAM scenarios. The year 2055 was extrapolated based on emissions in the WEM and WAM scenarios. Data for the calculation of fugitive emissions for 2025 – 2050 were obtained from sources:

- EU Reference Scenario for Slovakia for 2020 – 2050 (EU REF 2020);
- Integrated National Energy and Climate Plan 2022 – 2050 (NECP);
- Data provided by EUSTREAM, a. s. on the projected outlook for fugitive methane emissions from natural gas transit pipelines (Long-distance transport of natural gas; 20°C, 101 325 kPa).

For the calculation of fugitive methane emissions, emission factors from the following sources were used:

- 2006 IPCC Guidelines for National GHG Inventories - Chapter 4: Fugitive emissions;
- 2019 Refinement to the 2006 IPCC Guidelines for National GHG Inventories – Vol. 2, Chapter 4: Fugitive emissions
- IPCC Guidelines on best practices and management of unpredictability in national GHG inventories - Fugitive emissions from oil and gas operations;
- Results on crude oil processing, NG consumption and coke production from model TIMES;
- Results on residential appliances based on national model for sector 1.A.4.b.

2.3.2. Scenarios, Parameters and PAMs

Reference year for the preparation of emission projections was the year 2022, projections were prepared until 2050. In the sector 1.B.1 Solid fuels were prepared two scenarios based on the two scenarios for Energy sector:

- WEM scenario – with measures already in place (adopted) by the end of 2023;
- WAM scenario – with additional measures (optimistic).

For the period from 2023 onwards, all mines are categorised as "closed mines" (WEM and WAM scenarios). The emission factor for fugitive methane emissions from abandoned mines was estimated based on emission factors from 2019 Refinements to the 2006 IPCC Guidelines.

In the sector 1.B.2 Oil and Natural gas were prepared two scenarios:

- WEM scenario based on the starting average level of the years 2015 – 2022. The intensity and mitigation of fugitive emissions are at the same level as it is average of the years 2015 – 2022. Replacement or investments into technological equipment only in limited range. Installed capacity at compressor stations and the capacity of the transmission network would remain at the same level until 2050. The scenario also calculates with the SK-PL (Slovak-Poland) gas pipeline with a new metering station put into operation in 2022.
- CH_4 Action scenario (WAM) – this scenario is based on the assumption of further optimization and reduction of the installed capacity at some compressor stations after 2022. This scenario calculates with lower transmission and distribution of NG and crude oil procession. These data are based on projections for the Energy sector from the TIMES model.

Oil and NG

EUSTREAM, a. s. – the transmission company for NG. The capacity of the transmission network of the EUSTREAM, a. s. company is about 80-90 billion m^3 of the natural gas (NG) per year. The construction of the Poland-Slovakia gas pipeline (Veľké Kapušany) with a capacity of approx. 6 billion m^3/year, together with the current reverse flow of the NG from Veľké Kapušany to Ukraine, as well as the considered strengthening of capacity from Hungary to the Slovak Republic will change the transport characteristics. A massive redirection of the NG flows will take place, but the total transported volume of the NG will maintain unchanged. The increasing transport capacity of the NG through the Slovak Republic from the Czech Republic will also contribute to these circumstances.

SPP Distribution, a. s. – company provides distribution of the natural gas in the Slovak Republic. Leakages of GHGs from distribution pipelines (approximately 30 million m^3 annually) significantly contribute to fugitive CH_4 emissions.

Nafta, a. s. – carries out oil and gas extraction in the Slovak Republic. It operates underground storage tanks with a capacity of more than 3 billion storage tanks. Oil production after 2023 will be stopped, while the extraction of gas will continue until 2045 without significant changes.

Ministry of Economy – Integrated National Energy and Climate Plan 2022 – 2030 (NECP SK), Energy Policy and Energy Security Strategy. Fugitive CH_4 emissions from transport and distribution of natural gas and oil in the Slovak Republic were calculated from the data listed below. Data on natural gas and oil were obtained from sources:

- Statistical Office of the Slovak Republic
- EUSTREAM, a. s.
- SPP Distribúcia, a. s.
- Nafta, a. s.
- TIMES model

2.3.3. Fugitive Emissions Projections by Gases

The most important gas in fugitive emissions is methane accounting for over 90% of total GHG emissions in 2022. Projections of emissions by gas according to WEM and WAM scenarios are presented in ***Tables 2.14*** and ***2.15, Figures 2.24*** and ***2.25***.

Table 2.14: *Projections of fugitive GHG emissions by gas in Gg in WEM scenario up to 2055*

Year	CO_2 emissions	CH_4 emissions	N_2O emissions
2022*	57.1824	19.8111	0.0005
2025	49.1555	16.2864	0.0005
2030	49.2672	15.5653	0.0005
2035	48.0088	15.9231	0.0005
2040	45.5817	15.5066	0.0004
2045	42.0411	14.7690	0.0004
2050	38.7478	14.1675	0.0004
2055	37.8186	13.7881	0.0004

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Table 2.15: *Projections of fugitive GHG emissions by gas in Gg in WAM scenario up to 2055*

Year	CO_2 emissions	CH_4 emissions	N_2O emissions
2022*	57.1824	19.8111	0.0005
2025	28.0805	16.2638	0.0005
2030	26.7116	15.5985	0.0005
2035	26.3446	15.6752	0.0004
2040	25.6781	15.1026	0.0003
2045	24.1033	14.3053	0.0002
2050	21.1706	13.6415	0.0002
2055	21.4244	13.0999	0.0002

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Figure 2.24: *Projections of Fugitive emissions by gas in WEM scenario up to 2055*

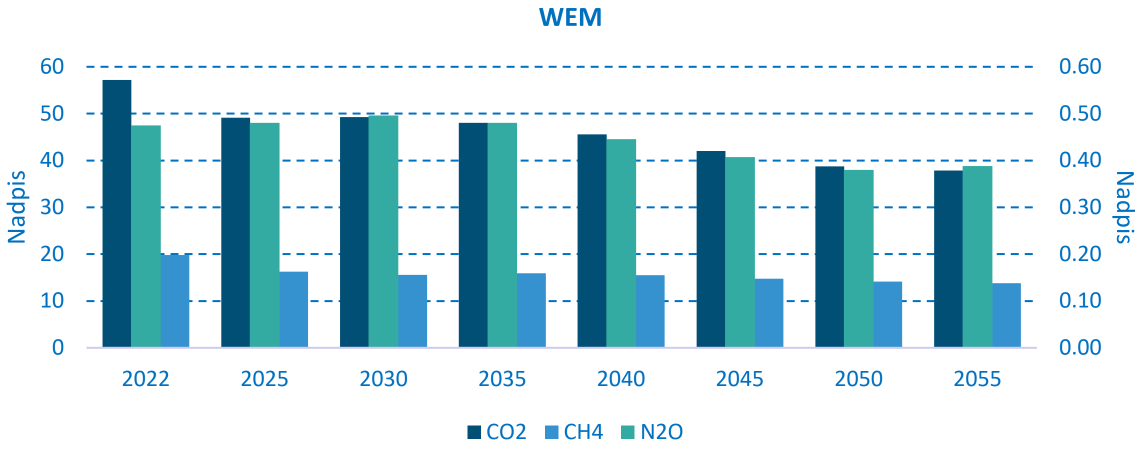
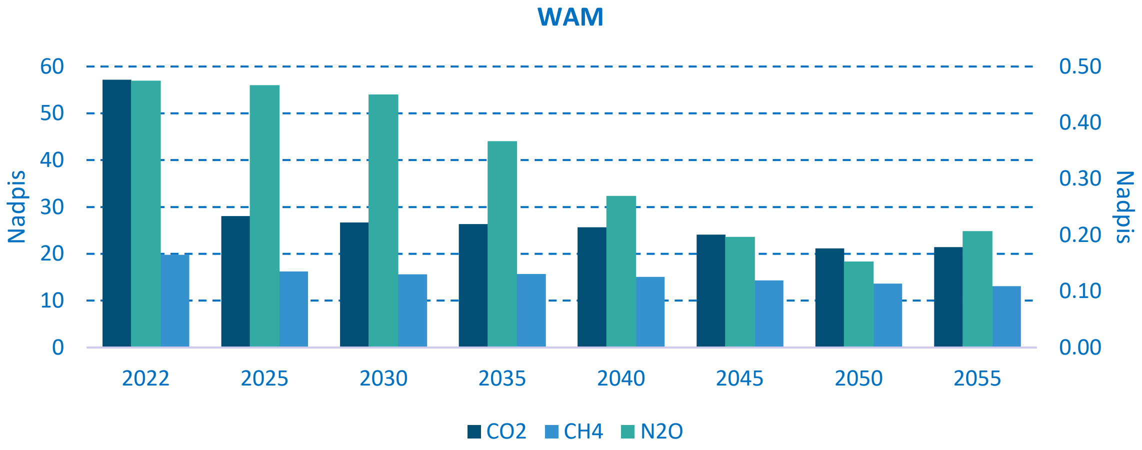


Figure 2.25: *Projections of Fugitive emissions by gas in WAM scenario up to 2055*



2.4. GHG Emission Projections in the Energy sector

This chapter presents the overall results of emission projections from the Energy sector, which include stationary sources, mobile sources and fugitive emissions.

Table 2.16 shows the aggregated projections of GHG emissions in the energy sector. ***Figure 2.26*** shows a comparison of projected emissions in the energy sector in eq. CO_2 by 2050 for all scenarios. The results show a decrease of emissions in Energy sector in the WEM scenario by 32% and in the WAM scenario by 72%. The most significant decrease of emissions in the WAM scenario can be seen in the transport sector, where, taking into account all measures, there would be a decrease of 80%. A significant decrease is also recorded in the category of energy industries by 81%. Emissions in industrial energy, on the other hand, remain at a similar level, this is caused by the expected production trend, measures already applied in the past and the need to ensure the level of the technological process.

Table 2.16: *GHG emission projections in Gg of CO_2 eq. in the Energy sector by categories*

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
1. Energy	25 612	25 552	25 459	24 028	21 698	19 565	17 917	17 157
1.A. Fuel combustion	25 000	25 046	24 974	23 534	21 218	19 109	17 482	16 733
1.A.1. Energy industries	6 407	5 252	5 023	4 837	4 424	4 242	4 025	3 869
1.A.2. Manufacturing industries & cons.	5 923	5 941	5 641	5 633	5 353	5 264	5 220	5 236
1.A.3. Transport	7 779	9 119	9 904	9 283	7 974	6 447	5 421	4 957
1.A.4. Other sectors	4 828	4 646	4 315	3 690	3 377	3 067	2 730	2 585
1.A.5. Other	62	89	91	91	90	88	86	86
1.B. Fugitive emissions from fuels	612	505	485	494	480	456	436	424
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1. Energy	25 612	24 721	19 701	15 884	11 487	9 224	7 737	5 318
1.A. Fuel combustion	25 000	24 237	19 238	15 419	11 038	8 799	7 334	4 930
1.A.1. Energy industries	6 407	5 200	3 468	3 124	1 782	1 463	1 214	1 122
1.A.2. Manufacturing industries & cons.	5 923	6 006	3 997	3 736	3 337	3 091	2 972	2 953
1.A.3. Transport	7 779	8 310	7 880	5 584	3 801	2 626	2 007	684
1.A.4. Other sectors	4 828	4 633	3 802	2 884	2 029	1 531	1 055	86
1.A.5. Other	62	89	91	91	90	88	86	86
1.B. Fugitive emissions from fuels	612	484	464	465	449	425	403	388

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Figure 2.26: *GHG emission projections in Gg of CO_2 eq. in the Energy sector by categories in WEM and WAM scenarios*

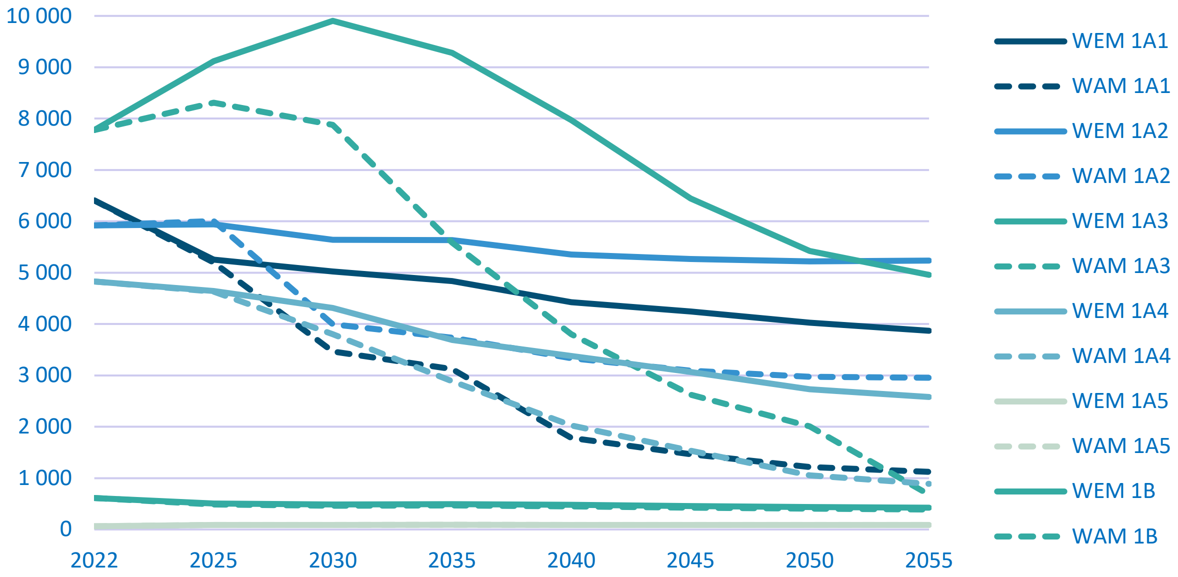


Figure 2.27 and ***Table 2.17*** shows the results of modelling projections of CO_2 emissions under the relevant scenarios. The projected economic growth dynamics will lead to an increase in CO_2 emissions. The impact of the included measures resulted in emission reductions in the WEM and WAM scenarios.

Figure 2.27: *CO_2 emission projections in Gg of CO_2 eq. in the Energy sector according to WEM and WAM scenarios up to 2050*

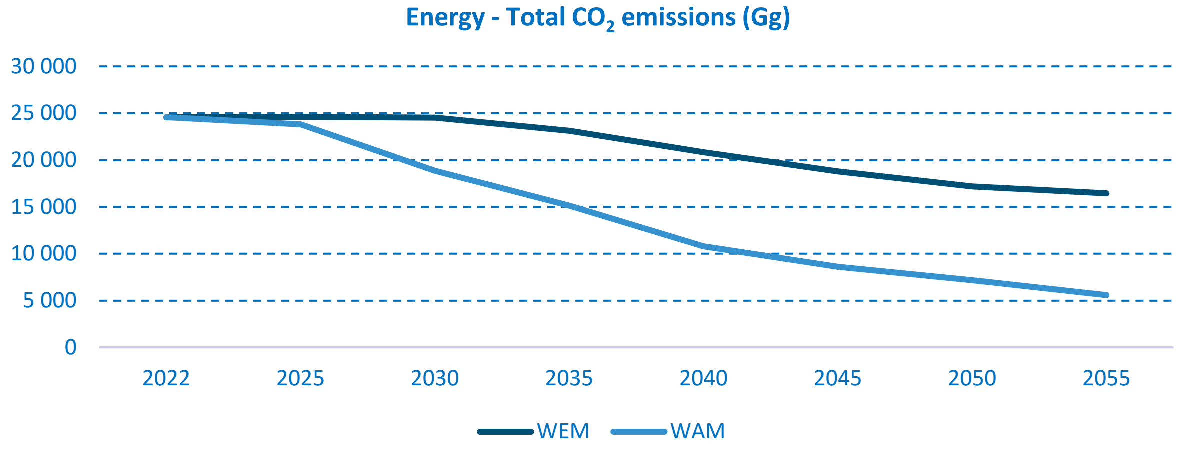


Table 2.17*: CO_2 emission projections in Gg of CO_2 in the Energy sector by categories*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1. Energy	24 578	24 621	24 538	23 139	20 849	18 777	17 179	16 436
1.A. Fuel combustion	24 521	24 572	24 489	23 091	20 803	18 735	17 140	16 398
1.A.1. Energy industries	6 366	5 217	4 987	4 800	4 387	4 206	3 987	3 832
1.A.2. Manufacturing industries & cons.	5 874	5 898	5 589	5 583	5 294	5 205	5 162	5 178
1.A.3. Transport	7 689	9 016	9 790	9 171	7 872	6 354	5 334	4 871
1.A.4. Other sectors	4 530	4 352	4 033	3 446	3 160	2 882	2 571	2 432
1.A.5. Other	62	88	90	90	90	88	86	85
1.B. Fugitive emissions from fuels	57	49	49	48	46	42	39	38
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1. Energy	24 578	23 808	18 863	15 122	10 807	8 605	7 159	5 380
1.A. Fuel combustion	24 521	23 780	18 837	15 095	10 781	8 581	7 138	5 359
1.A.1. Energy industries	6 366	5 166	3 444	3 099	1 757	1 438	1 187	1 094
1.A.2. Manufacturing industries & cons.	5 874	5 959	3 949	3 685	3 281	3 036	2 916	2 895
1.A.3. Transport	7 689	8 227	7 804	5 527	3 759	2 590	1 974	654
1.A.4. Other sectors	4 530	4 340	3 549	2 693	1 895	1 429	975	630
1.A.5. Other	62	88	90	90	90	88	86	85
1.B. Fugitive emissions from fuels	57	28	27	26	26	24	21	21

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Energy-related CH_4 emissions arise from the combustion and conversion of fossil fuels. Fugitive methane emissions arise from the extraction, transport and processing of fuels. Projections of CH_4 emissions from the combustion and conversion of fossil fuels were modelled using the fuel consumption in each scenario according to the IPCC method and the IPCC recommended aggregated emission factors. For transport CH_4 emissions, the COPERT model emission factors were used for each vehicle type. The modelling used the same scenarios as for CO_2 emissions from combustion and fuel switching. This approach determined the impact of CO_2 reduction measures on the level of CH_4 emissions.

***Table 2.18**: CH_4 emission projections in Gg of CH_4 in the Energy sector by categories*

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
1. Energy	30.09	26.48	25.52	24.63	23.50	21.74	20.30	19.71
1.A. Fuel combustion	10.27	10.20	9.96	8.71	8.00	6.97	6.13	5.92
1.A.1. Energy industries	0.56	0.53	0.55	0.56	0.56	0.56	0.56	0.56
1.A.2. Manufacturing industries & cons.	0.66	0.63	0.78	0.74	0.87	0.87	0.85	0.84
1.A.3. Transport	0.21	0.30	0.30	0.28	0.25	0.20	0.17	0.15
1.A.4. Other sectors	8.83	8.73	8.33	7.13	6.31	5.34	4.54	4.36
1.A.5. Other	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1.B. Fugitive emissions from fuels	19.81	16.29	15.57	15.92	15.51	14.77	14.17	13.79
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1. Energy	30.09	26.43	24.42	22.61	20.31	18.53	17.28	15.95
1.A. Fuel combustion	10.27	10.16	8.82	6.93	5.21	4.23	3.64	2.85
1.A.1. Energy industries	0.56	0.53	0.39	0.40	0.39	0.39	0.42	0.44
1.A.2. Manufacturing industries & cons.	0.66	0.63	0.68	0.73	0.81	0.81	0.82	0.82
1.A.3. Transport	0.21	0.29	0.31	0.22	0.12	0.07	0.04	0.04
1.A.4. Other sectors	8.83	8.71	7.44	5.58	3.88	2.96	2.35	1.53
1.A.5. Other	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1.B. Fugitive emissions from fuels	19.81	16.26	15.60	15.68	15.10	14.31	13.64	13.10

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Energy-related N_2O emissions arise from the combustion and conversion of fossil fuels. N_2O emissions from transport have been calculated within this sector. Projections of N_2O emissions were similarly calculated using the IPCC method, which uses recommended emission factors. In the transport sector, the emission factors for each vehicle type are taken from the COPERT model. The scenarios for calculating emissions from combustion and fuel conversion are the same as those for CO_2 and CH_4 emissions, making it possible to analyse the impact of measures to reduce CO_2 emissions and N_2O production.

***Table 2.19**: N_2O emission projections in Gg of N_2O in the Energy sector by categories*

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
1. Energy	0.7221	0.7140	0.7785	0.7508	0.7226	0.6768	0.6422	0.6420
1.A. Fuel combustion	0.7213	0.7135	0.7780	0.7503	0.7221	0.6764	0.6418	0.6416
1.A.1. Energy industries	0.0975	0.0750	0.0793	0.0800	0.0807	0.0798	0.0811	0.0800
1.A.2. Manufacturing industries & cons.	0.1147	0.0964	0.1164	0.1113	0.1301	0.1306	0.1285	0.1300
1.A.3. Transport	0.3161	0.3557	0.3991	0.3915	0.3575	0.3296	0.3128	0.3120
1.A.4. Other sectors	0.1921	0.1849	0.1817	0.1660	0.1523	0.1349	0.1179	0.1186
1.A.5. Other	0.0009	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0010
1.B. Fugitive emissions from fuels	0.0008	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
1. Energy	0.7221	0.6516	0.5832	0.4899	0.4188	0.3780	0.3551	0.3138
1.A. Fuel combustion	0.7213	0.6512	0.5827	0.4896	0.4185	0.3778	0.3549	0.3136
1.A.1. Energy industries	0.0975	0.0748	0.0522	0.0530	0.0523	0.0523	0.0563	0.0600
1.A.2. Manufacturing industries & cons.	0.1147	0.1079	0.1077	0.1129	0.1251	0.1239	0.1254	0.1300
1.A.3. Transport	0.3161	0.2824	0.2553	0.1902	0.1449	0.1286	0.1199	0.0818
1.A.4. Other sectors	0.1921	0.1846	0.1661	0.1319	0.0948	0.0716	0.0518	0.0408
1.A.5. Other	0.0009	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0010
1.B. Fugitive emissions from fuels	0.0008	0.0005	0.0005	0.0004	0.0003	0.0002	0.0002	0.0002

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

2.5. GHG Emission Projections from Bunkers (1.D)

GHG emissions from international transport are not included in the national balance sheet. However, projections of GHG emissions from international aviation and international maritime transport were developed for the scenario with measures. The data in ***Table 2.20*** shows that the projected GHG emissions from these categories are negligible compared to other sources.

Table 2.20: *GHG emission projections in Gg of CO_2 eq. from international transport in the WEM=WAM scenario*

Item	2022*	2025	2030	2035	2040	2045	2050	2055
International air transport	131.57	186.99	186.99	186.99	186.99	186.99	186.99	186.99
International maritime transport	17.59	15.95	15.95	15.95	15.95	15.95	15.95	15.95
International transport	149.16	202.94	202.94	202.94	202.94	202.94	202.94	202.94

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

CHAPTER 3. GHG EMISSION PROJECTIONS IN THE IPPU SECTOR

For the Industrial Processes, Product Use (IPPU) sector, we have prepared two distinct scenarios: with existing measures (WEM) and, with additional measures (WAM). These scenarios were designed to determine the 2030 and 2050 emissions targets for various industrial activities not currently covered by the EU Emissions Trading System (EU ETS). We have categorized IPPU activities into three primary groups based on their primary greenhouse gas emissions:

CO_2, CH_4, and N_2O emissions from categories 2.A to 2.D

- HFC emissions from category 2.F
- N_2O and SF_6 emissions from category 2.G

Figure 3.1 and ***Table 3.1*** illustrate the emission trends projected by the WEM and WAM scenarios for each of these categories. The overall trend is largely influenced by the steel industry. The WEM scenario suggests a modest decline in emissions, primarily driven by anticipated technological advancements and efficiency improvements. However, due to the inherent challenges in reducing emissions from certain industrial processes, particularly in the mineral production and chemical industries, the overall reduction is limited. The WAM scenario presents a more strict approach, aiming for a 35% reduction in emissions. This significant decrease is primarily attributable to substantial measures implemented in the steel industry, such as increased use of low-carbon technologies and improved process efficiency. While the mineral production and chemical industries may experience some stabilization in emissions, the overall trend is expected to be downward due to anticipated policy measures and technological innovations.

Figure 3.1: *Total GHG emission projections in Gg of CO_2 eq. in the IPPU sector in WEM and WAM*

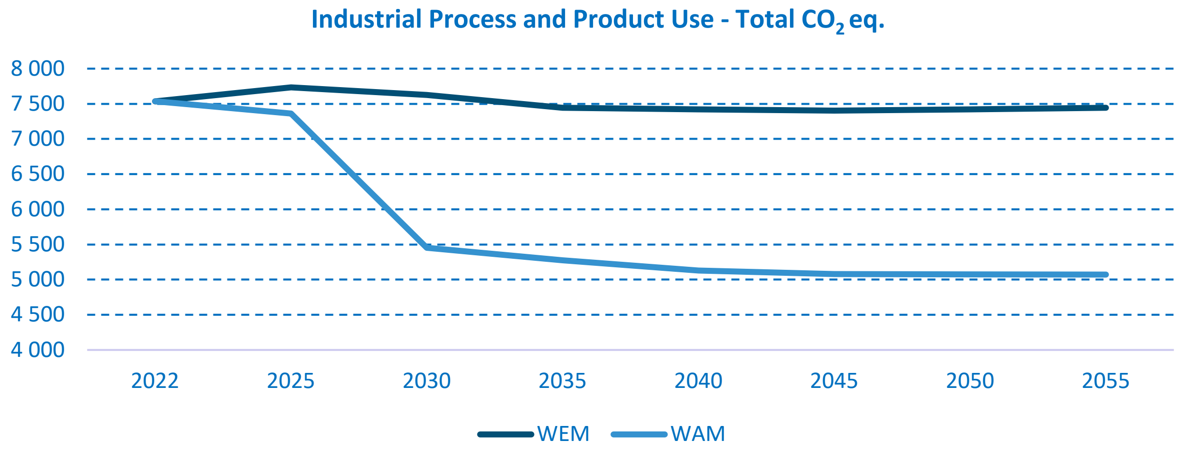


Table 3.1: *GHG emission projections in Gg of CO_2 eq. in the IPPU sector in WEM and WAM scenarios*

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
2. Industrial processes	7 536.24	7 733.90	7 627.36	7 444.46	7 422.17	7 403.30	7 422.24	7 442.19
2.A. Mineral Industry	2 332.71	2 321.36	2 305.07	2 342.25	2 456.47	2 438.12	2 461.90	2 485.64
2.B. Chemical industry	1 076.42	1 133.47	1 145.17	1 132.94	1 129.69	1 131.06	1 127.13	1 125.01
2.C. Metal industry	3 533.08	3 692.81	3 696.64	3 701.66	3 705.16	3 706.53	0.00	3 707.17
2.D. Non-energy products	40.77	38.82	38.83	33.88	31.40	30.66	30.59	30.48
2.E. Electronics industry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
2.F. Product uses as subs. for ODS	480.89	466.67	377.92	175.14	42.03	39.73	39.90	40.07
2.G. Other product man. and use	72.38	70.80	67.56	63.62	60.92	58.56	56.19	53.82
2.H. Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
2. Industrial processes	7 536.24	7 363.04	5 453.83	5 276.95	5 131.44	5 076.97	5 073.26	5 071.78
2.A. Mineral Industry	2 332.71	1 932.19	1 919.06	1 949.59	2 044.15	2 029.18	2 049.08	2 062.41
2.B. Chemical industry	1 076.42	1 148.78	1 140.92	1 100.52	1 042.75	1 006.69	953.37	927.57
2.C. Metal industry	3 533.08	3 706.01	1 916.17	1 978.67	1 945.77	1 954.37	1 992.53	2 011.57
2.D. Non-energy products	40.77	38.82	38.83	33.88	31.40	30.66	30.59	30.48
2.E. Electronics industry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.F. Product uses as subs. for ODS	480.89	466.62	376.23	160.44	21.02	16.74	15.28	14.34
2.G. Other product man. and use	72.38	70.62	62.60	53.86	46.36	39.34	32.40	25.41
2.H. Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

3.1. Input Parameters for Emission Projections

A general assumption for the IPPU sector is the assumption of durability of equipment and availability of input materials (*Parametric-technical data*). The main driving force is the GDP trend respectively sectoral value added (SVA) represented in ***Table 3.2***. For industrial processes, the largest decline can usually only be expected as a result of a reduction in the production of a particular product.

The NIMs report, ETS Report and NEIS data described in chapter “Projection in Energy sector” encompassing granular production data for benchmark commodities, provides a robust foundation for modelling specific products ***Table 3.3*****.** Individual raw material inputs, installed capacity, annual availability and equipment-level emission factors are meticulously calculated for each EU-ETS installation. This granular level of detail ensures that the models accurately reflect the unique operational characteristics of each facility.

Moreover, to enhance the precision and reliability of these models, data was further refined through direct consultations with various operational unit-expert. These collaborative efforts enabled the development of tailored modelling approaches, ensuring that each EU-ETS installation is represented with a level of complexity commensurate with its specific production processes. By considering the intricacies of individual operations, the models provide more accurate projections of emissions and the potential impacts of mitigation measures.

The models process these parameters until mitigation measures, such as material substitution, are introduced. The effects of these measures are exogenously modelled as parametric scenarios, adjusting unit inputs or process emission factors accordingly. This allows for a comprehensive assessment of the potential environmental benefits of various mitigation strategies.

Further work in exogenous data and assumptions

Regarding the improvements in currently used data and assumptions, the most relevant improvements can be grouped as follows: demand for energy services and materials, energy transformation, electricity and heat generation technologies, end-use sectors and policy assumptions.

Table 3.2: *Subsectors and main input sources modelled in IPPU sector*

Industry subsector	Sources of Input parameters	Main processes considered in the model	Materials (modelled as Mt)
Iron and steel	National implementation measure files (NIMs), ETS Report, National Emissions Reporting System (NEIS), Inputs from plant operations	Iron Blast Furnace (charcoal or equivalent, direct coal injection), COREX, with and without CCS, Cyclone Convertor Furnace CCF, Argon Oxygen Furnace AOD. Regular, Blast Oxygen Furnace BOF, with and without CCS; Blast Oxygen Furnace with top gas recirculation, with and without CCS. Regular, Blast Oxygen Furnace BOF Scrap, EAF for DRI, with and without CCS, EAF for DRI	Steel plus the following intermediate materials: Ore, Pellet, Sinter, Raw Iron, DRI Iron, Scrap Iron, Oxygen, Quick Lime, Ferrochrome, Crude Steel
Aluminium		Heroult Inert Anodes	Aluminium plus the following intermediate materials: Bauxite, Scrap, Crude Aluminium
Copper		Standard process and process with recycling	Copper plus the following intermediate materials: Ore, Scrap
Ammonia		In general, ammonia production includes the currently adopted thermochemical (Haber–Bosch), electrochemical, and photochemical cycle processes - Steam reforming process	Ammonia
Chlorine		Standard Mercury, Standard Diaphragm, Standard Membrane, and Advanced Membrane	Chlorine
Cement		Dry clinker kiln, wet clinker kiln, advanced dry kiln regular and advanced kiln with CO2 capture.	Clinker and Blast Furnace Slag

Table 3.3: *Added value of industrial sectors in the years 2019 to 2050 (in millions of euros)*

Sectoral Value Added (in MEUR '19)	2025	2030	2035	2040	2045	2050
Iron & Steel	998	985	994	1 006	1 014	1 018
Non-Ferrous	307	316	336	346	347	346
Chemicals	777	812	855	897	932	956
Building Materials	840	914	988	1 051	1 100	1 139
Paper & Pulp	486	532	585	640	688	726
Food, Drink, Tobacco	1 216	1 336	1 484	1 613	1 700	1 749
Engineering	11 032	12 813	13 994	15 020	16 033	16 999
Textiles	661	640	608	555	478	415
Other Industries	2 997	3 262	3 540	3 755	3 970	4 174

Source: IEP / GEM-E3 SK

3.2. Methodologies and Key Assumptions/Trends

The industrial sector is analysed in detail following an initial description that distinguishes between energy intensive industries and other industries. The energy intensive industries are: iron and steel, non-ferrous metals (aluminium, copper), chemical (ammonia, chlorine), non-metallic minerals (cement, lime, glass) and pulp, paper and printing. For each one of these industrial branches a detailed description of the production processes is being used in the model.

For each industry, a series of base-year technologies produce different industrial materials themselves used in the process chain. They are modelled using expert assumptions (NIMs) on input and output value. Emission projections from industrial processes come from processes other than fuel combustion. CO_2 emissions account for the largest share of total greenhouse gas emissions in this sector. A general assumption for the IPPU sector is the assumption of durability of equipment and availability of input materials. The main driving force is the GDP trend respectively sectoral value added (SVA). For industrial processes, the largest decline can usually only be expected as a result of a reduction in the production of a particular product. However, such a decline is not expected, but we can reduce or capture a significant amount of emissions through various modernisation processes. In Slovakia, iron and steel production accounts for the largest share of IPPU emissions.

For process-specific emissions, coefficients are declared at the process level and vary with the process' activity (e.g. Mt on produced cement clinker). This is the case of process emissions for cement, glass, ammonia and steel production and for the refining, petroleum products. Transport, fugitive emissions and Land-use emissions are not considered in the TIMES-Slovakia model. The emission coefficients considered in the model are the ones used in several national emission inventories. In the case of the industrial process emissions, the CO_2 emission coefficients will be technology dependent and will vary according to technologies' performance. For industry two types of exogenous demands are considered in TIMES-Slovakia: materials demand in Mt for the case of the energy intensive industries (cement, steel, glass, ammonia, aluminium, paper and chlorine) and useful energy demand for specific energy services in other industry: other Non-ferrous metals, other chemical and petrochemical, other non-metallic minerals, food, beverages and tobacco, textile and leather, transport equipment, machinery, and mining and quarrying and other non-energy-intensive industries. For these the following exogenous demands for energy services are considered: steam, process heat, machine drive, electrochemical processes and other processes. Each of the industry sub-sectors has a specific demand for each of these energy services (e.g. machine drive for other industry or process heat for other chemicals).

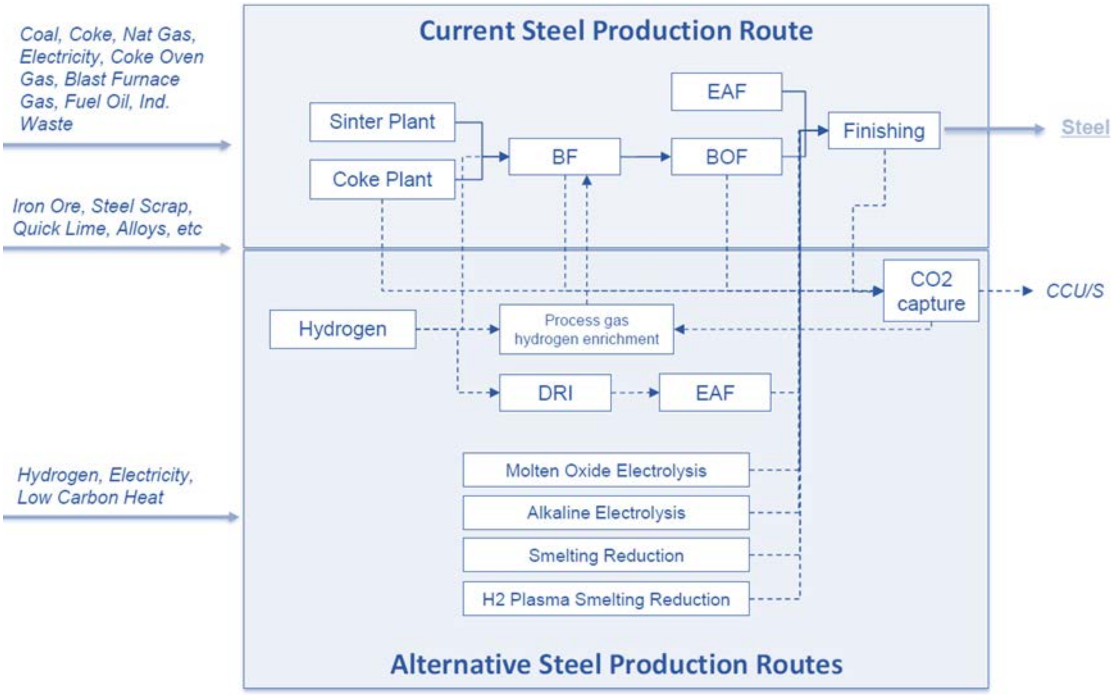
3.3. Predominant and Key Sectors in IPPU Modelled by TIMES-Slovakia

Steel production methodology

The existing steel production ***Table 3.4*** technologies in Slovakia (U. S. Steel Košice) are the Blast Furnace – Basic Oxygen Furnace (BF-BOF), which is assumed to be used for high-quality steel, and the electric arc furnace (EAF), used mostly for low-quality steel. The steel sector is generally divided into iron ore pre-treatment, iron reduction, steel production, rolling & casting, auxiliary processes and finishing and forming (this last process represents small and distributed companies at the end of the supply chain).

Process emissions are estimated to be around 50% of the total emissions in IPPU category. Moreover, the use of blast furnace gas for the production of electricity is accounted for in the power sector, which reduces the emissions allocated to the steel sector. There are two main paths for the steel sector: hydrogen for the direct reduction of iron (DRI) and CCUS.

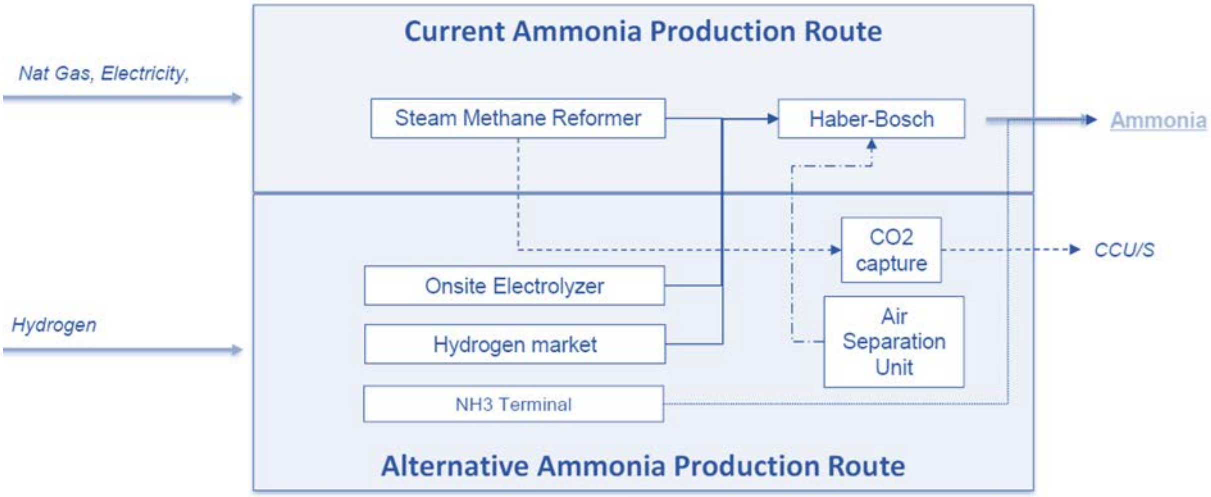
Table 3.4: *Steel current and alternative production routes in TIMES-Slovakia*



Ammonia production methodology

Ammonia production in Slovakia ***Table 3.5*** is done in single plant. It is represented in TIMES-Slovakia as one unique Haber-Bosch process coupled with a Steam Methane Reformer (NG/SMR). The options to decarbonize the production of ammonia include the integration of CCUS into the exiting processes – which already includes a CC unit to capture process-related emissions to prevent damaging the catalyst for the ammonia synthesis. This highly pure CO_2 stream is already captured and used in downstream utilizations such as urea production or the food industry. The remaining combustion emissions, which represent 1/3 of the total emissions, can be captured by installing an additional CC unit. This configuration (Natural Gas/Steam methane Reforming + carbon capture) produces the so-called blue hydrogen needed in the Haber-Bosch. A different alternative to grey hydrogen or blue hydrogen is the production of yellow hydrogen –hydrogen produced with grid electricity– both onsite or centralized, or the use of imported green hydrogen. In such cases, there is a need to provide nitrogen for ammonia synthesis using an Air Separation Unit (ASU). Nitrogen is currently obtained from steam methane reforming.

***Table 3.5:** Ammonia current and alternative production routes in TIMES-Slovakia*



Chlorine production methodology

Chlorine production in Slovakia is done by (FORTISCHEM). The production is mostly done through membrane cell electrolysis (93%). Being the former the most recent and commonly used route worldwide. This process has already been fully electrified and produces hydrogen as a by-product. Consequently, chlorine production doesn't have direct CO_2 emissions. For this reason, in TIMES-Slovakia chlorine is always produced through the membrane cell electrolysis, and refurbishment of existing assets is considered. The hydrogen that is obtained as a by-product (0.9Kt/H_2) is assumed to currently be consumed within the industry and, thus, it is not available for new processes such as DRI steelmaking.

High-Value Chemicals

High-Value Chemical (HVC) production in (Slovnaft) heavily relies on energy-intensive processes like naphtha cracking and propane dehydrogenation. To reduce greenhouse gas emissions and transition to more sustainable practices, the industry is exploring options such as electrification, carbon capture, and utilization of renewable energy sources. While innovative technologies like methanol-to-olefins and methanol-to-aromatics are under development, the near-term focus remains on optimizing existing processes, including furnace electrification and carbon capture, to achieve significant emissions reductions.

Cement production methodology

The cement sector in Slovakia is spread across different regions, while clinker production is concentrated in different regions in mainly in eastern and western Slovakia. There are several types of cement based on their production characteristics as well as on their final use. Portland cement: The most common type of cement used in a wide variety of concrete mixes. White Portland cement: Used for the production of decorative concrete and plaster mixes. To simplify the cement production, TIMES-Slovakia considers only one type of cement demand, which is produced using blast furnace slag and clinker, with a clinker-to-cement ratio of 0.72. The production of cement in TIMES-Slovakia is modelled in such a way that represents the main steps, namely raw mill, kiln and precalcinator, and cement mill. The thermal consumption in the sector –almost entirely dedicated to the kiln & precalcinator– is provided by fossil fuels, while the remaining part comes from biofuels and waste. These values are aligned with the European estimated average consumption. However, the increasing share of biomass and waste in the kiln has a limitation to reducing the emission of the cement sector, as roughly 2/3 of the emissions are attributed to the calcination of limestone, and these are the so-called process emissions. TIMES-Slovakia was designed to model process and combustion emissions separately, which allows the model to find alternatives to produce the heat needed in the kiln, while for the process emission CCUS options could be explored.

Table 3.6: *High-Value Chemicals current and alternative production routes in TIMES-Slovakia*

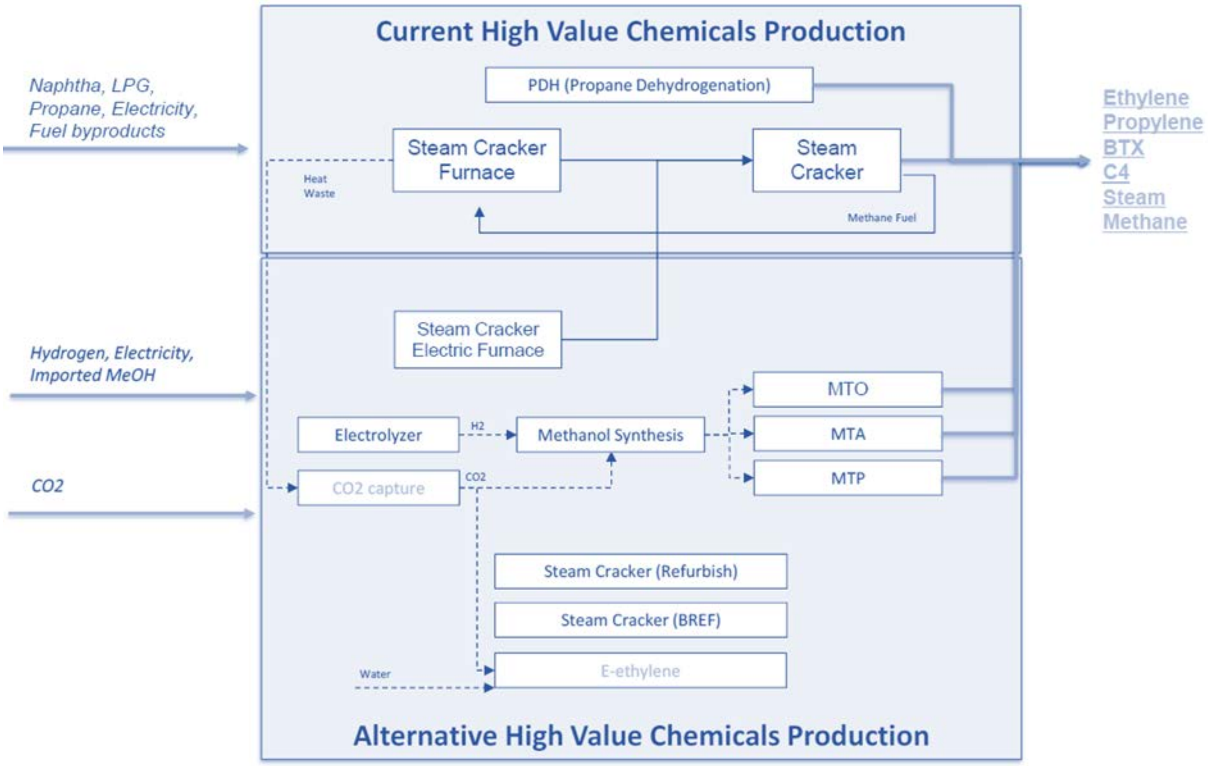
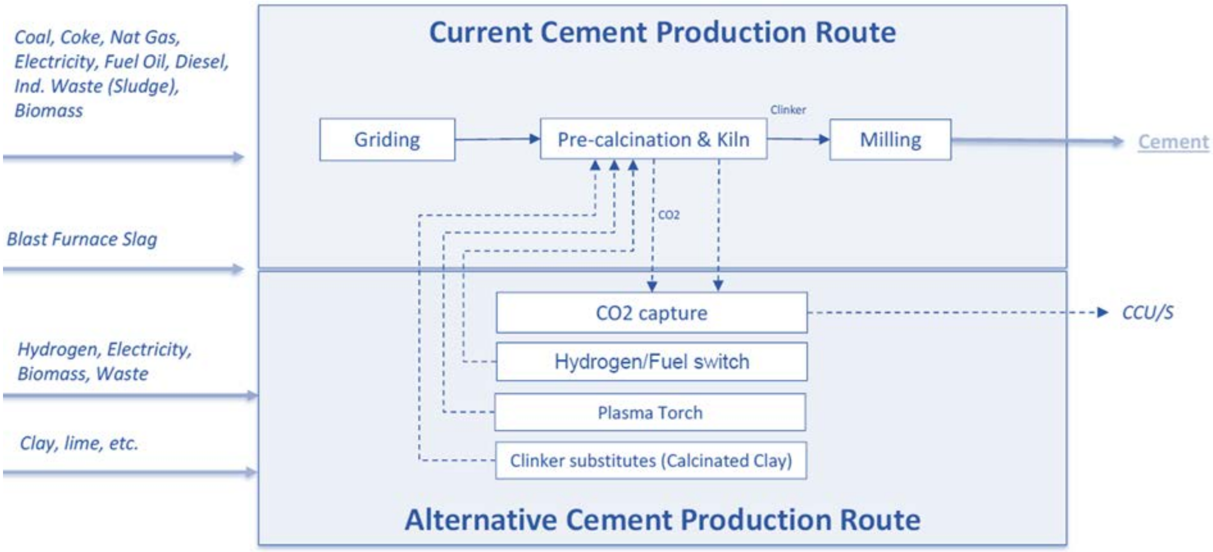


Table 3.7: *Cement current and alternative production routes in TIMES-Slovakia*



Possible areas for model expansion and possible future model applications:

- Expand the technology detail for dwelling, agriculture, transport and/or more industry sub-sectors,
- Include endogenous modelling of land competition between sectors (e.g. agriculture and energy) and among energy technologies (biomass, wind, solar)
- Include modelling of water uses for energy technologies;

- Endogenously model the use of materials (including critical materials) for energy technologies, including the linkages to the whole production chain (e.g. use of steel for wind turbines);
- Include non-CO_2 emissions (also process related), both for other GHG and for air pollutants.

3.4. Model Description

As the IPPU sector is interconnected within the industrial energy system, the TIMES-Slovakia model is also utilized for modelling industrial processes. A more detailed description of this model can be found in the **Chapter 2.1.3**.

The model is built with a time horizon 2022 – 2050 (calibrated to 2022), with optimisation accounting for annual and sub-annual operations. TIMES-Slovakia provides annual outputs from 2025 until 2050 for every 5 years' time step (e.g. 20025, 2030, 2035, etc.). At this stage 2055 is being used as a "dummy" year to avoid end of period distortions when obtaining results for 2050.

MS Excel tools were used for modelling emission projections in the sources outside of the EU-ETS system and for F-gases. Emission projections were prepared in accordance with the methodology of the Intergovernmental Panel on Climate Change from 2006, Chapter IV (IPCC 2006 Guidelines). The calculation analysis tool is based on the Excel platform and the calculation includes different policies and measures (in numerical formulation) defined according to the WEM and WAM scenarios. The model that was developed in connection with the implementation of Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU.

3.5. Scenarios, Parameters and PAMs

The IPPU sector allocates greenhouse gas emissions regulated by Directive 2003/87/EC of the European Parliament and of the Council of 13. October 2003 establishing a scheme for greenhouse gas emission allowance trading within the EU and amending Council Directive 96/61/EC28 (hereinafter referred to as EU ETS emissions) and non-EU ETS emissions allocated by Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States of greenhouse gas emissions for the period 2021 to 2030 to contribute to climate action to meet their commitments under the Paris Agreement and amending Regulation (EU) No. 525/201327 (hereinafter referred to as the ESR emissions).

IPPU sector includes GHG emissions allocated under the revised EU ETS Directive and emissions from smaller industrial sources which are not allocated under the Directive.[15] Emissions projections from the non-EU ETS IPPU sources of emissions, mainly CO_2 ETS emissions, are projected together with the emissions from energy sector.

The following sources are considered as taking part in the EU-ETS scheme:

- Central electricity, CHP and heat producers
- Industrial auto-producers (electricity and CHP)
- Large industries: Steel, Cement, Glass, Pulp and Paper
- Process emissions from all industries

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[15] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0410&from=EN

While EU ETS emissions have their reduction mechanisms set by the allocation of allowances at the operator level, ESR emissions are not sectoral regulated and the ESR reduction target is set only at the level of the country as a whole. It is therefore very important to identify potential areas for reduction, regulation or promotion. The report looks at projections of ESR emissions from the IPPU sector. This sector accounts for process (technological) emissions, i.e. not emissions from fossil fuel combustion (which are accounted for in the Energy or Buildings sectors). More on the methodology for allocating greenhouse gas emissions to the EU ETS and the ESR can be found in the report.

The projections of ESR emissions in categories 2.A-2.G were mainly prepared by forecasting the development of value added for the identified industrial category under one scenario WEM = WAM. In the absence of relevant direct policies and measures in these sectors, it is very difficult to predict developments up to 2050. It is likely to be influenced only by the availability of raw materials, energy and material prices, and supply and demand. We foresee regulation mainly at EU level. The nature of process (technological) emissions does not allow much room for manoeuvre for their regulation (they are dependent on chemical reactions and processes).

The base (reference) year for modelling the GHG emissions projection was the latest revised inventory year 2022 in all scenarios. Projections of greenhouse gas emissions for the EU ETS emissions component have been developed for the years 2020 – 2050 under the following scenarios:

Two scenarios, WEM and WAM, have been prepared for the purpose of determining the target for 2030 and subsequently for 2050 in the different categories of industrial activities not included in the EU ETS. Separately for all three groups of IPPU categories, namely CO_2, CH_4 and N_2O emissions in categories 2.A - 2.D, HFCs emissions in category 2.F and N_2O and SF_6 emissions in category 2.G.

The policies and measures taken into account in each scenario are based on a number of national documents:

- Low Carbon Development Strategy of the Slovak Republic until 2030 with a view to 2050 (NUS SR)
- National Air Pollution Control Programme (NAPCP)
- Integrated National Energy and Climate Plan of Slovakia (NECP)

In addition to these documents, separate laws and European legislation also intervene in the preparation of individual scenarios. Act No. 277/2020, which amends Act No. 309/2009 Coll. on the Promotion of Renewable Energy Sources and High Efficiency Combined Production, significantly interferes with the preparation of laws. Within the framework of common European legislation, these are mainly directives setting emission limits and the European Parliament's Energy Union Governance Regulation 2018/1999, complemented by Regulation 2021/1119, which establishes a framework for achieving climate neutrality.

The policies and measures used were taken from the Low Carbon Strategy of the Slovak Republic (LCDS) from the National Air Pollution Control Programme and from the Slovak Recovery Plan.

The reduction potential presented is based on the WEM and WAM scenarios reported for emission projections in 2021 under Regulation (EU) 2018/1999 of the European Parliament and of the Council on the Governance of the Energy Union and Climate Action.

The specification of the WAM scenario according to the Low Carbon Development Strategy of the Slovak Republic depends on the logic of the draft EU scenarios and in particular on the EUCO3030 scenario, which sets the EU target for energy efficiency for 2030 at 30%.

Most of the above measures were applied at the level of the CPS-PRIMES model, from which trends in energy consumption or other parameters were taken for modelling emissions in the TIMES model.

Existing Measures Scenario (WEM) - includes policies and measures adopted and implemented at EU and national level by the end of 2023. In industrial processes, improving energy efficiency is essential for productivity growth, which is part of sustainable growth in added value.

The scenario with additional measures (WAM) - is equivalent to the Dcarb2 scenario of the CPS-PRIMES model, in the IPPU sector the outputs from CPS-PRIMES were used to obtain trends in the different industry types.

Trend of the N_2O and PFCs emissions projections from the sources included in the EU ETS from the CRF categories 2.B and 2.C were prepared according to assumptions of GVA presented in the energy sector (WEM and WAM scenarios).Due to specific character of the emissions produced in the technological process, it is difficult to regulate or mitigate energy demand in these categories of industry. Moreover, the nitric acid production is at its emission limit, therefore, there is no difference between WEM a WAM scenarios). Thus, the trends in emissions strongly depend on the production. Increasing and also decreasing trend in emissions for WEM scenario is caused by the increase in production. Aluminium production finished in 2023, therefore we do not assume the PFC emissions from this source.

The trend of emission projections below the ESR in categories 2.A to 2.D is very complicated to express due to the lack of legislative and market mechanisms. . It is very difficult to influence these emissions by any policies and measures that are influencing the energy demand. The trend of emission projections depends on the technological processes, which are mainly influenced by the EU ETS Directive, therefore emission reductions cannot be expected as production grows. Changes in the trend of emissions projections are therefore caused mainly by changes in production.

Projections of F-Gases emissions were calculated based on the approved EU legislative - Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006, Annex III as follow (***Table 3.8***).

Table 3.8: *Annex III of EU Regulation No 517/2014 of the European Parliament*

Placing on the market prohibitions referred to in Article 11(1) Products and equipment Where relevant, the GWP of mixtures containing fluorinated greenhouse gases shall be calculated in accordance with Annex IV, as provided for in point 6 of Article 2		**Date of prohibition**
1. Non-refillable containers for fluorinated greenhouse gases used to service, maintain or fill refrigeration, air-conditioning or heat-pump equipment, fire protection systems or switchgear, or for use as solvents		4. July 2007
2. Non-confined direct evaporation systems that contain HFCs and PFCs as refrigerant		4. July 2007
3. Fire protection equipment	that contain PFCs	4. July 2007
	that contain HFC-23	1. January 2016
4. Windows for domestic use that contain fluorinated greenhouse gases		4. July 2007
5. Other windows that contain fluorinated greenhouse gases		4. July 2008
6. Footwear that contains fluorinated greenhouse gases		4. July 2006
7. Tyres that contain fluorinated greenhouse gases		4. July 2007
8. One-component foams, except when required to meet national safety standards, that contain fluorinated greenhouse gases with GWP of 150 or more		4. July 2008
9. Aerosol generators marketed and intended for sale to the general public for entertainment and decorative purposes, as listed in point 40 of Annex XVII to Regulation (EC) No 1907/2006, and signal horns, that contain HFCs with GWP of 150 or more		4. July 2009
10. Domestic refrigerators and freezers that contain HFCs with GWP of 150 or more		1. January 2015
11. Refrigerators and freezers for commercial use (hermetically sealed equipment)	that contain HFCs with GWP of 2 500 or more	1. January 2020
	that contain HFCs with GWP of 150 or more	1. January 2022
12. Stationary refrigeration equipment, that contains, or whose functioning relies upon, HFCs with GWP of 2 500 or more except equipment intended for application designed to cool products to temperatures below -50°C		1. January 2020
13. Multipack centralised refrigeration systems for commercial use with a rated capacity of 40 kW or more that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 150 or more,		1. January 2022

Placing on the market prohibitions referred to in Article 11(1) Products and equipment Where relevant, the GWP of mixtures containing fluorinated greenhouse gases shall be calculated in accordance with Annex IV, as provided for in point 6 of Article 2		Date of prohibition
except in the primary refrigerant circuit of cascade systems where fluorinated greenhouse gases with a GWP of less than 1 500 may be used		
14. Movable room air-conditioning equipment (hermetically sealed equipment which is movable between rooms by the end user) that contain HFCs with GWP of 150 or more		1. January 2020
15. Single split air-conditioning systems containing less than 3 kg of fluorinated greenhouse gases, that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 750 or more		1. January 2025
16. Foams that contain HFCs with GWP of 150 or more except when required to meet national safety standard	Extruded polystyrene (XPS)	1. January 2020
	Other foams	1. January 2023
17. Technical aerosols that contain HFCs with GWP of 150 or more, except when required to meet national safety standards or when used for medical applications		1. January 2018

F-Gases emission projections in the category 2.F were prepared according to two scenarios – WEM and WAM.

Emissions projections according to the WEM scenario were followed directly the above-mentioned EU Regulation, Annex III. It was assumed that the gas R404A (GWP 3922) will be replaced with the gases R448A (GWP 1387), R449A (GWP 1397) and R452A (2410). The gas 410A will be replaced with R452B (GWP 698) and the gas R134a will be replaced with the gas R513A (GWP 631). Except of MAC when it will be replaced with the gas R1234YF. Later the gases with the GWP higher than 750 will be replaced with gases with GWP 150.

Emissions projections according to the WAM scenario were following the above-mentioned EU Regulation and in addition with the requirement that gases with the zero GWP (or by the supplementary gases) should replace all refrigerants the after 2033.

SF_6 and N_2O emissions projections in the category 2.G were prepared according to WEM and WAM scenarios. Emissions projections of the SF_6 in the WEM scenario were prepared by the extrapolation of the base year emissions (and considering time series consistency) with the assumption that the phase-out of obsolete equipment started. Emissions projections in the WAM scenario followed the restrictions on the utilisation of SF_6 gas in the new equipment after 2025. Emissions projections of N_2O in the category 2.G.3 were prepared according to extrapolated trend of the last 10 years (WEM). In the WAM scenario, a gradual replacement of N_2O in anaesthesia was assumed.

CCS technology was not considered as one of the real measures in Slovak conditions. Today's main barriers to CCS deployment include the need to demonstrate that geological storage is definitely safe and permanent, the need for international regulatory frameworks, possible social acceptance issues, the high investment and operation costs, and the lack of specific policies (incentives) for emission reduction via CCS. Emission trading system (EU ETS) alone are not enough to promote CCS as the current CO_2 price is low to compensate for the high cost and financial risk in most CCS applications.

3.6. GHG Emission Projections by Categories and Gases

Projections of CO_2 emissions in the IPPU Sector

Carbon dioxide (CO_2) emissions from the Industrial Processes and Product Use (IPPU) sector are primarily driven by emissions subject to the EU Emissions Trading System (EU ETS), particularly those originating from mineral and metal production. Additionally, emissions from the chemical industry and solvent use contribute significantly to the overall CO_2 footprint of the IPPU sector. The projected trends in CO_2 emissions from the IPPU sector, as modelled under the WEM and WAM scenarios, are presented in ***Figure 3.2*** and ***Table 3.9***.

Figure 3.2: Emission projections of CO_2 in Gg in the IPPU sector in WEM and WAM scenarios

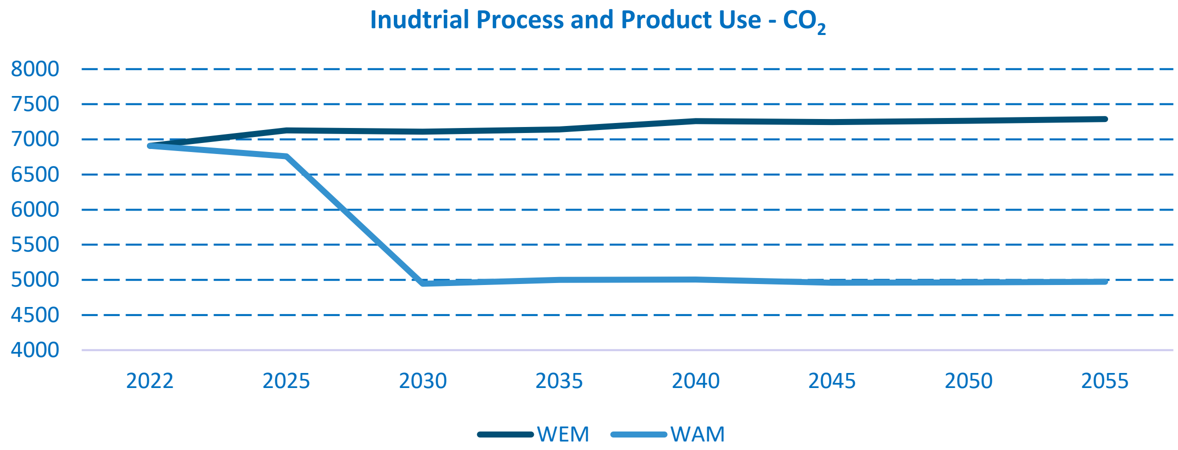


Table 3.9: Emission projections of CO_2 in Gg in the IPPU sector in WEM and WAM scenarios

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
2. Industrial processes	6 908.01	7 128.73	7 111.72	7 141.59	7 258.30	7 245.00	7 266.51	7289.03
A. Mineral processing	2 332.71	2 321.36	2 305.07	2 342.25	2 456.47	2 438.12	2 461.90	2485.64
B. Chemical industry	1 022.93	1 080.69	1 089.99	1 082.33	1 081.46	1 083.42	1 079.76	1077.93
C. Metal industry	3 511.61	3 687.85	3 677.83	3 683.12	3 688.97	3 692.80	3 694.26	3694.98
D. Non-energy use of products	40.77	38.82	38.83	33.88	31.40	30.66	30.59	30.48
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
2. Industrial processes	6 908.01	6 758.09	4 944.83	4 998.54	5 003.14	4 960.89	4 965.94	4972.76
A. Mineral processing	2 332.71	1 932.19	1 919.06	1 949.59	2 044.15	2 029.18	2 049.08	2062.41
B. Chemical industry	1 022.93	1 096.00	1 085.74	1 049.92	994.52	959.04	906.01	880.49
C. Metal industry	3 511.61	3 691.07	1 901.19	1 965.15	1 933.07	1 942.01	1 980.26	1999.38
D. Non-energy use of products	40.77	38.82	38.83	33.88	31.40	30.66	30.59	30.48

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Projections of CH_4 emissions in the IPPU Sector

Methane (CH_4) emissions from the Industrial Processes and Product Use (IPPU) sector are predominantly linked to the production of ammonia and metal compounds. While significant within the IPPU sector, CH_4 emissions from these sources do not contribute substantially to total greenhouse gas emissions. The CH_4 emission projections were developed under a single scenario, WEM = WAM. ***Figure 3.3*** and ***Table 3.10*** present the projected trend in CH_4 emissions from the IPPU sector according to the WEM = WAM scenario.

Figure 3.3: *Emission projections of CH_4 in Gg in the IPPU sector in WEM and WAM scenarios*

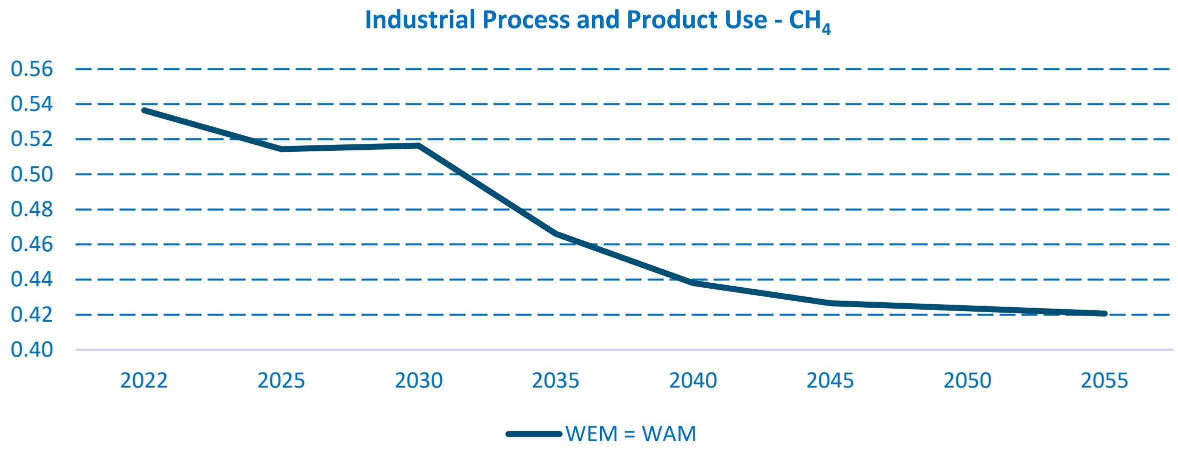


Table 3.10: *Emission projections of CH_4 in Gg in the IPPU sector in WEM and WAM scenarios*

WEM = WAM	2022*	2025	2030	2035	2040	2045	2050	2055
2. Industrial processes	0.54	0.51	0.52	0.47	0.44	0.43	0.42	0.42
B. Chemical industry	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C. Metal industry	0.52	0.50	0.50	0.45	0.43	0.41	0.41	0.41

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Projections of N_2O emissions in the IPPU Sector

N_2O emissions within the IPPU sector originate primarily from the catalytic oxidation of ammonia to nitric acid. This process, essential for the production of fertilizers and other nitrogen-based products, can lead to significant N_2O emissions if not properly controlled. While N_2O emissions from the IPPU sector are relatively small compared to other sectors, such as agriculture, they nonetheless contribute to global warming and ozone depletion. ***Figure 3.4*** and ***Table 3.11*** provide a detailed breakdown of the projected N_2O emissions from the IPPU sector under the WEM and WAM scenarios, highlighting the potential impact of various mitigation strategies.

Figure 3.4: *Emission projections of N_2O in Gg in the IPPU sector in WEM and WAM scenarios*

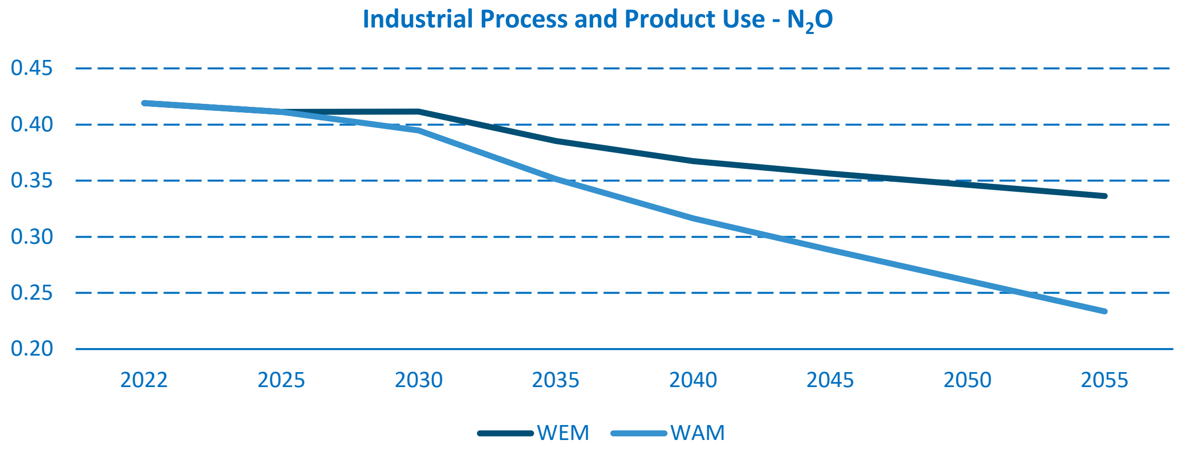


Table 3.11: Emission projections of N_2O in Gg in the IPPU sector in WEM and WAM scenarios

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
2. Industrial processes	0.419	0.411	0.412	0.385	0.367	0.356	0.346	0.336
B. Chemical industry	0.200	0.198	0.207	0.190	0.181	0.179	0.177	0.176
C. Metal industry	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003
G. Other product man. and use	0.215	0.210	0.201	0.193	0.184	0.175	0.166	0.157
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
2. Industrial processes	0.419	0.411	0.395	0.351	0.317	0.288	0.261	0.234
B. Chemical industry	0.200	0.198	0.207	0.190	0.181	0.179	0.177	0.176
C. Metal industry	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003
G. Other product man. and use	0.215	0.210	0.184	0.159	0.133	0.107	0.081	0.054

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Projections of F-Gases emissions in the IPPU Sector

F-gas projections include emissions of PFCs (aluminium production), HFCs (use of refrigerators and air conditioners) and SF_6 (electronics production). They currently account for a relatively significant share but are projected to decrease significantly. The trends according to the WEM and WAM scenarios are provided in the ***Figure 3.5*** and in the ***Table 3.12***.

Figure 3.5: Emission projections of F-gases in Gg of CO_2 eq. in the IPPU sector in WEM and WAM

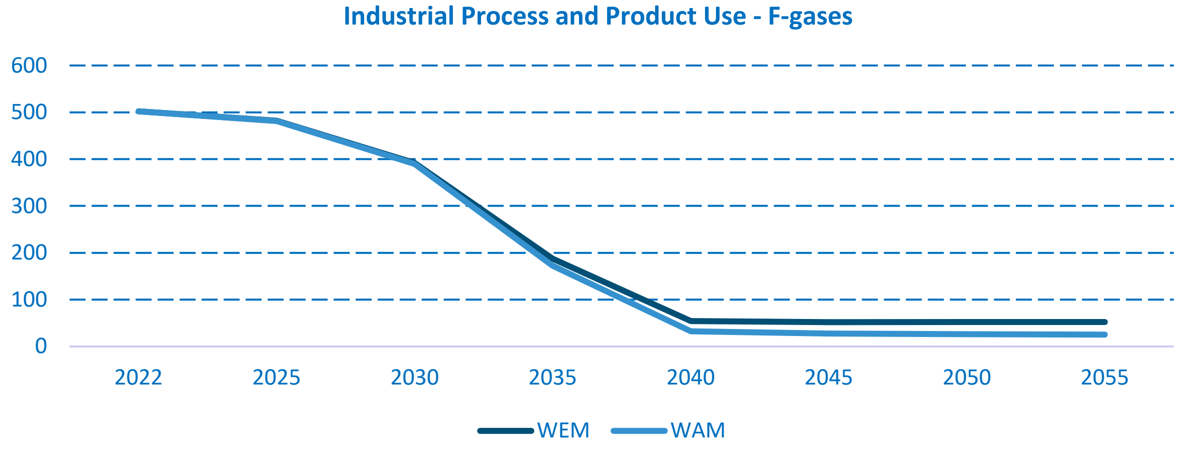


Table 3.12: Emission projections of F-gases in Gg of CO_2 eq. in the IPPU sector in WEM and WAM

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
2. Industrial processes	502.15	481.83	392.12	187.71	54.23	51.93	52.10	52.27
C. Metal industry	5.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F. Use of products to ODS replacements	480.89	466.67	377.92	175.14	42.03	39.73	39.90	40.07
G. Other product man. and use	15.38	15.16	14.20	12.57	12.20	12.20	12.20	12.20
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
2. Industrial processes	502.15	481.60	389.96	172.23	32.16	27.75	26.30	25.36
C. Metal industry	5.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F. Use of products to ODS replacements	480.89	466.62	376.23	160.44	21.02	16.74	15.28	14.34
G. Other product man. and use	15.38	14.98	13.73	11.79	11.14	11.02	11.02	11.02

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

CHAPTER 4. GHG EMISSION PROJECTIONS IN THE AGRICULTURE SECTOR

In preparing the presented projections, long list of measures that have a detectable impact on the estimated emissions were analysed and quantification of their impact on the GHG inventory and pollutant inventory was possible. All other measures that were proposed in the strategies and not implemented in the projections do not have a measurable effect on the inventory but have an impact on agriculture as a whole in relation to the environment. Subsequently, based on literature and expert consultations, the values of key parameters for these measures were determined to best reflect the conditions in Slovakia. A comprehensive list of measures was proposed based on available literature, encompassing measures applicable to both crop and livestock production. In livestock production, the measures were further categorized by animal species: dairy cattle, non-dairy cattle, sheep, poultry, and pigs.

From this broader list, measures expected to be applicable in Slovakia for each animal species or land type were selected after consultations with experts from the National Agricultural and Food Centre (NPPC), the Slovak Hydrometeorological Institute (SHMÚ), and the Ministry of Agriculture and Rural Development (MPRV SR). Results of preparation revised projections consist into two scenarios were prepared for the development of emissions from agriculture after 2022: a scenario with existing measures (WEM scenario) and a scenario with additional measures (WAM scenario). The results of the emission projection modelling are presented in ***Figure 4.1*** and ***Table 4.1.***

In the WEM scenario, measures adopted by 2022 were implemented, while the WAM scenario included additional planned or discussed measures. The effect of the implemented measures is evident in the reduction of emission projections by 2050, with a 68% reduction in the WEM scenario and a 75% reduction in the WAM scenario compared to 1990. According to the WEM scenario, emissions in 2050 will increase by 27%, whereas in the WAM scenario, they will decrease by 49% compared to 2005.

To set national legislation, it is important to establish an emission reduction target for the agriculture sector for 2030, with 2005 as the base year. Emission projections for 2030 show an increase of 0.5% in the WEM scenario and a decrease of 6.8% in the WAM scenario compared to 2005.

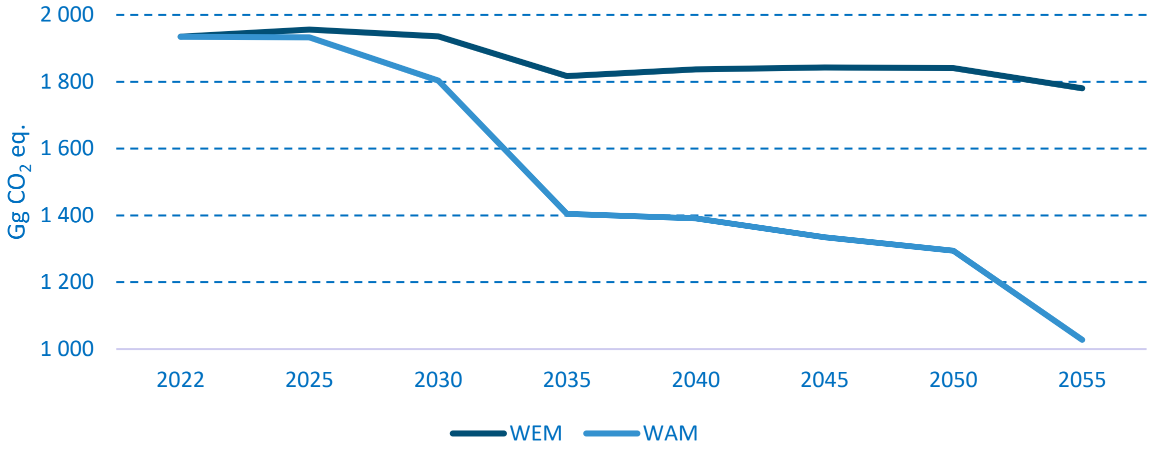
Table 4.1 and ***Figure 4.1*** show aggregated data on GHG emission projections in the agriculture sector.

Table 4.1: *GHG emission projections in Gg of CO_2 eq. in WEM and WAM scenario in Agriculture*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
3. Agriculture	1 934.43	1 956.11	1 935.36	1 816.59	1 836.69	1 843.13	1 841.10	1780.39
3.A Enteric fermentation	1 028.92	1 037.82	1 021.80	938.48	967.14	983.46	1 004.36	960.53
3.B.1 Manure management	100.79	99.04	98.23	87.80	88.67	87.60	87.27	80.91
3.B.2 Manure management	179.11	106.35	107.70	98.29	100.33	100.79	101.96	158.59
3.D Agricultural soils	564.77	553.56	541.64	523.25	504.60	492.58	466.65	452.17
3.G Limestone and dolomite	3.334	1.772	1.705	2.349	2.684	2.906	2.839	33.07
3.H Use of urea	56.62	73.73	79.36	81.61	86.11	87.23	87.23	95.12
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
3. Agriculture	1 934.43	1 932.89	1 803.84	1 404.42	1 390.64	1 334.53	1 294.36	1027.54
3.A Enteric fermentation	1 028.92	1 037.82	979.26	642.87	644.04	613.72	610.25	409.87
3.B.1 Manure management	100.79	99.04	98.23	86.47	87.37	86.33	85.88	78.91
3.B.2 Manure management	179.11	162.61	163.67	149.71	152.00	151.63	152.44	142.58
3.D Agricultural soils	564.77	540.75	470.28	436.38	420.83	410.80	389.18	340.38
3.G Limestone and dolomite	3.334	1.772	1.705	2.349	2.684	2.906	2.839	33.07
3.H Use of urea	56.62	73.73	71.42	65.29	60.28	43.62	26.17	22.74

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Figure 4.1: GHG emission projections in the Agriculture sector in WEM and WAM scenarios up to 2055



4.1. Input Parameters for Emission Projections

To properly prepare the model for agricultural emissions projections, it is necessary to obtain a wide range of input data and parameters along with their historical time series. The available time series of input data have varied lengths (the longest covering the period 1970 – 2022, the shortest covering the period 2003 – 2022) and were obtained from various sources (Green Report of the Slovak Republic, Statistical Office of the Slovak Republic, situational and outlook reports of NPPC-VÚEPP, Central Control and Testing Institute of Agriculture - ÚKSUP).

The input data required for the preparation of projections are as follows:

- Number of cattle in the head (data available by regions for the period 1990-2020, source: Statistical Office of the Slovak Republic - ŠÚ SR)
- Number of pigs in the head (1990 – 2022, ŠÚ SR)
- Number of sheep in the head (1990 – 2022, ŠÚ SR)
- Number of poultry in the head (1990 – 2022, ŠÚ SR)
- Number of goats in head (1990 – 2022, ŠÚ SR)
- Number of horses in the head (1990 – 2022, ŠÚ SR)
- Milk yield per cow - average annual milk yield per dairy cow in kilograms (1990 – 2022, ŠÚ SR)
- Milk yield per ewe - average annual milk yield per dairy ewe in kilograms (1990 – 2022, ŠÚ SR)
- Consumption of nitrogen fertilizers in tons (1990 – 2022, sources: IFASTAT and ÚKSUP), data available for Slovakia by types
- Consumption of urea in tons (2000 – 2020, source: ÚKSUP)
- Consumption of ground limestone and dolomite in tons (2000 – 2020, source: ÚKSUP)

The input data for the given time period were subsequently processed for use in preparing projections of parameters in Slovak agriculture for 2020 – 2040. The exponential smoothing model SAS 9.3 was modelled at the Research Institute of Agricultural and Food Economics in Bratislava (NPPC-VÚEPP). Subsequently, projections of input parameters such as livestock populations and quantities of applied organic and mineral fertilizers were calculated until 2040-2050 at the Slovak Hydrometeorological Institute (SHMÚ) using the exponential smoothing function in MS Excel's forecasting tool, Projections. The principle of exponential smoothing is an adaptive method for forecasting time series, which means that the values of parameters in the model change over time. The forecast is based on smoothing weights that assign different importance to individual observations. The most recent observations have the highest weight, exponentially decreasing to the past. The values of the weights are optimized by the statistical software itself.

Slovakia still uses the Grade 1 method for estimating future livestock numbers due to the unavailability of public policies and strategies. In terms of data revision, SHMÚ conducted a review of livestock numbers and fertilizer consumption using exponential smoothing. The results underwent a thorough review process involving relevant ministries (Ministry of Environment of SR, Ministry of Agriculture and Rural Development of SR), research institutes (National Agriculture and Food System, Institute of Environmental Policy), and other entities such as breeding unions and NGOs.

The input from breeding unions provided a more accurate view of the development of livestock numbers in Slovakia. Furthermore, it is mentioned that future Common Agricultural Policy (CAP) measures are expected to impact increasing the mentioned livestock species, particularly through increased grazing breeding. Additionally, the consumption of inorganic fertilizers was modified based on planned European Farm to Fork Strategies and national measures to reduce urea use.

4.2. Methodologies and Key Assumptions/Trends

The list of measures was used as input for modelling in a model that simulated the use of individual measures based on the following assumptions:

- Baseline Emission Factors: The basic emission factors for each activity (e.g., pig farming) were determined based on the data from the 2023 Greenhouse Gas Emission reporting by 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter IV.
- Cost-Effectiveness Adjustments: The year of full availability for a measure is adjusted so that the cost per ton of emissions saved is lower than the carbon price in that year. Consequently, some measures may not be utilized at all.
- Application Potential Growth: The application potential of measures increases from zero to the maximum application potential linearly over five years, reaching the maximum in the year of full availability.
- Mutually Exclusive Measures: Measures that cannot be applied simultaneously (e.g., different feed additives) are not used together.
- Combined Measures: In cases where multiple measures are combined, the reduction potential of all measures, except the one with the highest potential, is reduced by 20% to account for possible overlap in effects.

4.3. Model Description

The model has been developed by E3-modelling with funding from the European Commission in order to provide analytical support to the Slovakian authorities, particularly with regard to the economics of climate change.

The GEM-E3-AGR is a satellite module designed to calculate GHG emissions and identify abatement options within the agricultural sector. This model assesses emissions from agriculture and determines the most cost-effective adoption of abatement technologies to meet specific emission reduction targets. Key outputs include GHG emissions, abatement technologies, and the total and unit costs of emission reduction.

The model accounts for GHG emissions from both animals and crops. It derives the demand for agricultural products from the GEM-E3 model and then employs a nested structure to represent substitution possibilities between different agricultural products. At the base level, all products are identified separately, and abatement technologies are chosen based on GHG emission reduction targets or carbon values.

Specifically, the model addresses the following GHG emissions: i) For animals, CH_4 and N_2O emissions from enteric fermentation and manure management, and ii) For crops, N_2O emissions from fertilizer application.

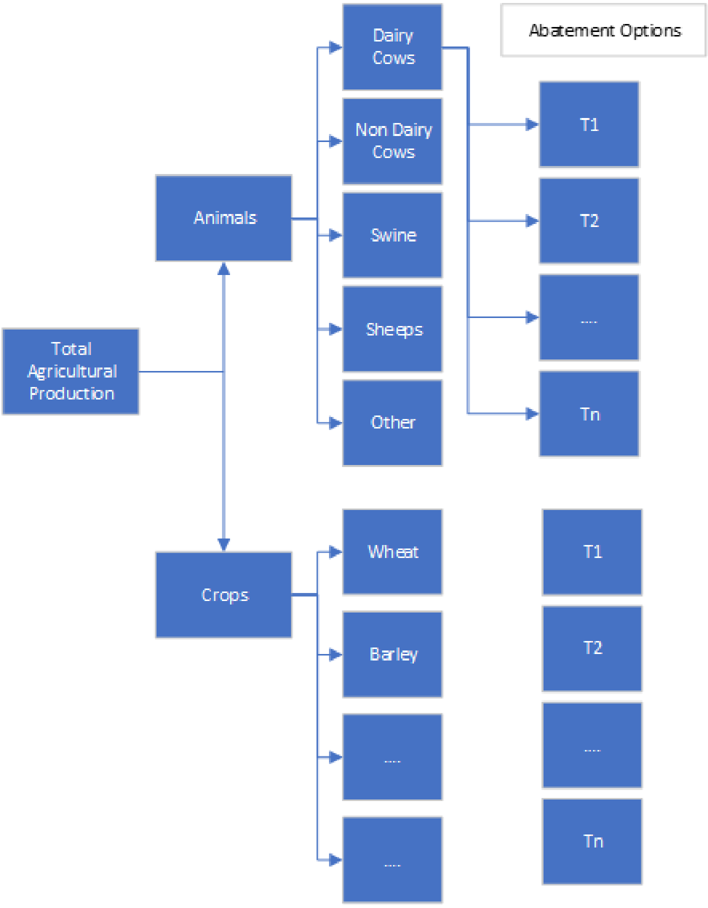
The structure of the model consists of three levels: The first level includes the combined production of all animals and crops. The second level differentiates between total animal production and total crop production. The third level details the production of each specific animal and crop. Abatement options are then calculated for each product.

The GEM-E3-SK model is written in GAMS while supported by scripts in R and visual basic macro commands.

Table 4.2: *SWAT analysis of the GEM-E3-AGR*

Strengths	Opportunities
Compatibility with emission model for emission inventories The national database used is compatible with EÚ data Data consistencies in the projection and estimation process	Incorporate to the model new technologies Versatile use of time-series
Treats	**Weakness**
Easy data entry Non-free Software licence Connected from macroeconomic models	Missing measurable indicators in national policies and strategies

The model in the agricultural sector optimizes the cost-effective selection of measures, including their mutual interactions in application, and calculates the reduction of greenhouse gas emissions until 2050. The measures were selected based on literature and consultations with national experts. Each measure has several basic parameters that determine the scope of possible implementation, the effect on emission reduction, and the cost. From the list of measures, the model selects based on two main factors – the availability of the measure (i.e., the earliest possible date when the measure can be applied) and the cost per ton of emissions saved, which includes all associated application costs and is compared with the price of emission allowances. Two scenarios are modelled – the reference (WEM) and the decarbonisation (WAM), which mainly differ in the availability and scope of measure application and the assumed price of emission allowances.



4.4. Scenarios, Parameters and PAMs

Data collection was undertaken in two steps. First, cost and mitigation data from existing literature was compiled. Second, a Slovak expert from the government adapted the mitigation estimates for some of the measures. To make these adjustments transparent, we provide in the below tables both data from literature and from expert judgment, when these differ. The estimates provided by the Slovak expert take into account the applicability of the measure (% of units to which the measure could realistically be applied), whereas the literature estimates do not.

For all measures, prices have been converted to euros and correlated with price from the 2015 year to ensure consistency. Mitigation potential is given per unit (head for livestock measures, hectares for crop measures) and total (per year, and for livestock measures based on number of heads for the year 2022).

The measures are divided 3.A and 3.B categories (Animal species) and 3.D Agriculture soils (Crop measures). For the former category, the specific livestock type to which the measure applies is specified.

Best practice examples were included alongside the description of the measure, where relevant.

- The WOM (BAU) scenario is identical to the scenario with existing WEM measures.
- The WEM scenario is a scenario with measures that include projections of anthropogenic emissions from agricultural sources, after taking into account the effects of policies and measures adopted by the end of 2022.

The WEM Scenario (With Existing Measures) is a scenario with measures that include projections of anthropogenic emissions from agricultural sources, after taking into account the effects of policies and measures adopted by the end of 2022 reference scenario utilizing measures that are currently partially implemented. The basic assumptions of the scenario are as follows:

The maximum application potential of many measures from the list is significantly limited or even zero, meaning some measures are not used at all.

The assumed carbon price increases only slightly (based on the European Commission's assumptions for the WEM scenario), resulting in a gradual implementation of measures, or their current application will not expand at all by 2050.

The WEM scenario took into account policies and measures from national strategies published in the past. The list of policies and measures used was taken from the National Programme for Pollutant Emission Reduction and the Low Carbon Strategy of the Slovak Republic. The stagnation (oil plants, soya, potato) in emission projections for the WEM scenarios after 2005 is due to the projected stagnating (potato, or decreasing (cereals, lantern) in hectare yields in the crop production part, which puts pressure on higher consumption of applied nitrogen fertilisers; the offsetting of organic matter and nutrients to the soil in the form of applied plant matter will also increase. Emissions will also rise in the livestock sector, particularly in beef cattle, sheep and goat farming. Other livestock species are projected to stagnate or decline. In the WEM scenario was also included anaerobic digesters for cattle, poultry and swine. This technic is very effective for reduction of emission from 3.B Manure management.

Daily removal of manure from animal housing systems and covering storage of manure and slurry in the form of isolation of excreta from the surrounding environment and by preventing soil contamination and nitrogen leaching from the stored waste, while contributing to the avoidance of NH_3 and N_2O emissions. This measure is reflected in both the WEM scenario and the WAM scenario. This measure can be found in several strategic documents and legislation, in particular in the Decree of the Ministry of the Environment of the Slovak Republic No. 146/2023 Coll.

The following measures are focused on reducing greenhouse gas emissions in livestock farming through various techniques applicable to dairy cattle, non-dairy cattle, and sheep thy were included into WEM and WAM scenario. These abatements can effectively reduce methane and N_2O emissions. Improved Animal Longevity aims to extend the lifespan of livestock by reducing mortality rates and delaying the culling date. It applies to dairy cattle, non-dairy cattle, and sheep, and can be implemented by livestock farmers through improved management practices such as enhancing animal health, well-being, and living conditions. Also lead to higher productivity by increasing the number of calves/lambs These improvements include ensuring sufficient space, better bedding quality, heat management, and hygiene. Improved Beef Live Weight Gains is designed to increase the live weight gains of beef cattle, primarily through genetic improvements such as crossbreeding. The use of sexed semen and cross-breeding in dairy cattle and sheep aims to improve productivity by increasing the ratio of female calves and sheep.

The WAM Scenario (With Additional Measures) is a decarbonisation scenario highlighting the potential for emission reduction through measures selected based on their increasing cost-effectiveness. The basic assumptions of the scenario are as follows:

The maximum application potential of measures is not limited; all measures that can be applied and are cost-effective are utilized each year (i.e., at least five years before reaching full availability).

The assumed carbon price increases based on the European Commission's assumptions for the WAM scenario, leading to an earlier year of full availability compared to the WEM scenario, and thus an accelerated implementation of individual measures compared to the WEM scenario.

Each measure is characterized by several parameters. Since these parameters are interconnected, only some were used as input parameters for each measure, while the others were calculated based on data on the number of individual species of animals or the extent of land:

- Reduction potential: Percentage reduction of emissions when using the measure.
- Unit reduction potential: Reduction of emissions (in kg) when using the measure at the unit level (per animal or hectare of agricultural land).

- Annual unit costs: Annual costs for implementing the measure at the unit level.
- Price per ton of emissions saved: Calculated as annual unit costs divided by unit reduction potential.
- Maximum application potential: The share of units for which the measure can be used, representing additional use beyond the current application scope.
- Application potential: The share of units for which the measure can be used in a given year.
- Year of full availability: The earliest year in which it is possible to reach the maximum application potential.
- Applied reduction potential: Calculated as reduction potential multiplied by application potential.
- Total reduction potential: Calculated as unit reduction potential multiplied by application potential and the number of units in the given category (e.g., number of animals).

Example of Measure Selection in the Model

In the list of measures for dairy cattle, the following three measures are included:

1. Addition of Nitrates as a Feed Additive:

Cost: 20.75 EUR per ton of emissions saved. Application potential: 30%. Reduction potential: 12%. Year of full availability: 2030.

2. Addition of 3-Nitrooxypropanol as a Feed Additive:

Cost: 123.15 EUR per ton of emissions saved. Application potential: 90%. Reduction potential: 20%. Year of full availability: 2025

3. Addition of Concentrate as a Feed Additive:

Cost: 150.33 EUR per ton of emissions saved. Application potential: 70%. Reduction potential: 10%. Year of full availability: 2032

Based on the assumed carbon price in the WAM scenario, the year of full availability for measure 2 is shifted to 2031 and for measure 3 to 2033.

Therefore, measure 1 is first activated in 2026. Subsequently, measure 2 is first activated in 2027. Since the use of different feed additives is mutually exclusive, only one of these measures can be activated. Given that the reduction potential of measure 2 is higher, measure 1 is deactivated.

Methane emissions from enteric fermentation in the WAM scenario were modelled by taking into account the measure proposed in the long list of measures. One of the measures in the Low Carbon Strategy is the use of additives (nitrates, tannins, lipids and fatty acids, 3-Nitrooxypropanol and amino acids) to reduce methane and nitrogen emissions. This measure impacts category 3.A Enteric Fermentation, 3.B Nitrous Oxide from manure and slurry management and has a partial impact on nitrous oxide emissions from category 3.D Agricultural soils.

Into WAM scenario was also included Zero Emissions Livestock Project (ZELP) Cattle Wearable Technology. This measure involves equipping cattle with a wearable device designed to neutralize methane emissions from exhalation, reducing methane emissions from 3.A Enteric fermentation.

Nitrous oxide and ammonia emissions from manure and slurry management (more efficient manure and slurry storage - Storage and covering of manure and slurry, Daily removal of manure from animal housing systems, low emission housing) in the WAM scenario. The measures are not included on all farms. Maximum application potential was taking into account the measure of introducing requirements to reduce emissions from livestock farms due to economic limitation of sector.

The Common Agricultural Policy (EU CAP) will support the fight against climate change through the Whole Farm Eco-Scheme intervention (31.1), which will ensure the improvement of the structure of arable land, expand unproductive areas in the grassland and grassy inter-rows in orchards and vineyards. The intervention Investments on farms to reduce greenhouse gas and ammonia emissions will support investments in reducing greenhouse gas and ammonia emissions on farms in the form of the intervention Animal welfare - Pastoral farming (31.2). Non-productive investments necessary for introducing measures in agricultural production will also be supported. The intervention "Precision Fertilization of Arable Land - Protection of Water Resources (70.05)" will optimise fertilization rates based on soil analyses and reduce nutrient leaching into groundwater (especially phosphorus and nitrogen). The Slovak Republic has, under Act No. 305/2015 Coll. on Protected Areas of Natural Accumulation, established protected water management areas. The share of utilized agricultural area (UAA) under-supported commitments related to better nutrient management is 16.87%. Precision farming aims to optimise returns on inputs while preserving resources. As this managerial system enables the farmer to, among other things, make better use of fertilisers and fuel use, it also directly contributes to reducing GHG.

The need to increase the share of the use of renewable energy sources in the total volume of energy in agriculture will be addressed by the intervention of Productive investments in agricultural holdings by investing in technologies and related construction investments aimed at energy transformation, in particular of agricultural by-products and biodegradable waste. Investments in equipment for the production of energy from other renewable sources to use all the energy produced on the farm or holding will also contribute to increasing the share of the use of renewable energy sources.

Another implemented measure that has an impact on N_2O and CH_4 emissions in category 3.B Manure and slurry management was the use of slurry and manure as feedstock in anaerobic digesters. This measure impacts emissions reductions through two main pathways - reducing fossil fuel carbon emissions through the production of energy sources and reducing direct nitrous oxide emissions from manure and slurry storage. Although anaerobic digestion does produce methane, it is captured and used in energy production, which has a positive impact on increasing the share of energy from renewable sources.

Additional measures were applied to the WAM scenario to reduce emissions from the categories 3.D.1 and 3.D.2, which include direct and indirect N_2O emissions from agricultural soils as well as ammonia emissions. Slovakia generates more emissions from agricultural soils than from livestock farming, making it necessary to implement more measures aimed at reducing N_2O emissions from the 3.D.1 and 3.D.2 categories. The Strategic Plan of the Common Agricultural Policy has allocated funds through a subsidy scheme for so-called Precision Agriculture, a management strategy based on observing, measuring, and responding to temporal and spatial variability to enhance the sustainability of agricultural production. This includes techniques such as integrated nutrient management. Other measures include the use of denitrification inhibitors. When urea is applied to soil, it dissolves rapidly, reacting ammonia (NH_3) and carbon dioxide (CO_2), and is then nitrified to NO^{3-}. The release of N_2O can also occur, primarily through nitrification and denitrification processes. Nitrification inhibitors can be used to slow down the conversion of ammonium into other forms that lead to nitrogen losses and negatively impact the environment. Both measures lead to a decrease in GHG emissions as with less nitrogen losses, and hence also to a reduction in fertiliser use. Urease inhibitors help reduce greenhouse gas emissions from these processes. Last measures in 3.D Agricultural soils is switch to other organic fertilizers at the expense of inorganic N- fertilizers. Compost, manure and sewage sludge, when properly incorporated into the soil, lead to less emissions than the application of inorganic fertilisers and removes emissions associated with the production of inorganic fertilisers. In addition, organic fertilisers improve soil health and biodiversity (in soil and on land), improve nutrient cycling, and decrease emissions from other stages of the value chain.

4.5. GHG Emission Projections by Categories and Gases

Projections of CO_2 emissions in the Agriculture sector

CO_2 emissions in Agriculture sector arise from categories 3.G - Liming and 3.H – Urea application, accounting for only 3% of total GHG emissions in 2022. Projections according to WEM and WAM scenarios are presented in ***Figure 4.2*** and ***Table 4.3***.

Figure 4.2: *CO_2 emission projections in Gg in the Agriculture sector in WEM and WAM scenarios up to 2055*

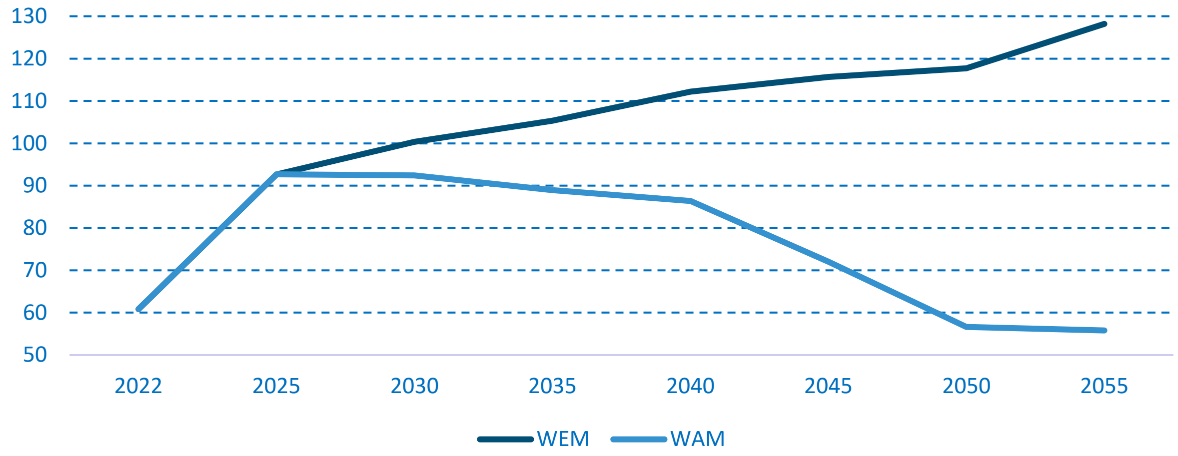


Table 4.3: *CO_2 emission projections in Gg in the Agriculture sector in WEM and WAM scenarios up to 2055*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
3. Agriculture	60.84	92.68	100.33	105.31	112.23	115.66	117.68	128.19
3.G Limestone and dolomite	4.22	18.95	20.97	23.70	26.12	28.43	30.44	33.07
3.H Use of urea	56.62	73.73	79.36	81.61	86.11	87.23	87.23	95.12
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
3. Agriculture	60.84	92.68	92.39	88.98	86.40	72.04	56.61	55.81
3.G Limestone and dolomite	4.22	18.95	20.97	23.70	26.12	28.43	30.44	33.07
3.H Use of urea	56.62	73.73	71.42	65.29	60.28	43.62	26.17	22.74

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Projections of CH_4 emissions in the Agriculture sector

CH_4 emissions in Agriculture sector arise from categories 3.A – Enteric fermentation and 3.B.1 – Manure management, accounting for 56% of total GHG emissions in 2022. Projections according to WEM and WAM scenarios are presented in ***Figure 4.3*** and ***Table 4.4***.

Figure 4.3: *CH_4 emission projections in Gg in the Agriculture sector in WEM and WAM scenarios up to 2055*

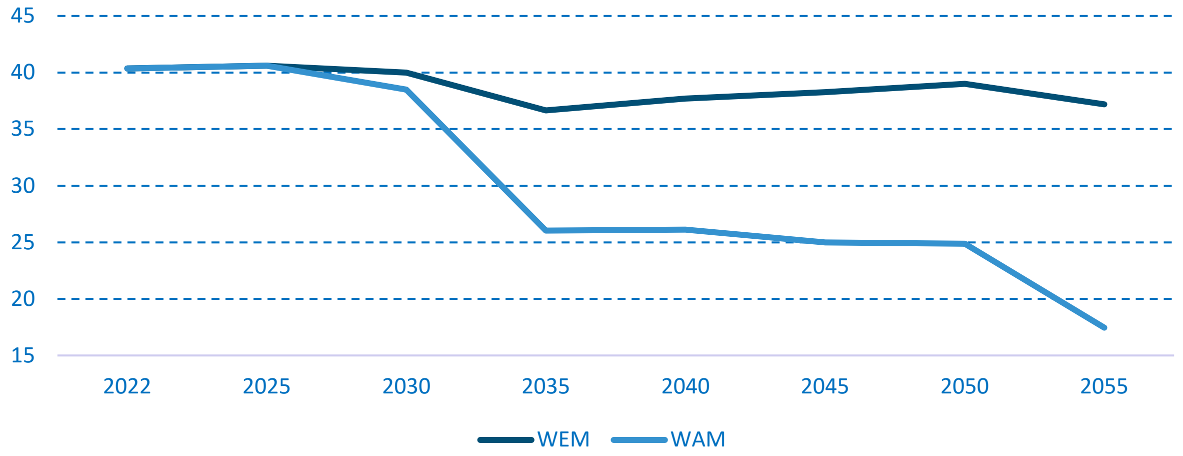


Table 4.4: *CH_4 emission projections in Gg in the Agriculture sector in WEM and WAM scenarios up to 2055*

WEM	2022*	2025	2030	2035	2040	2045	2050	2055
3. Agriculture	40.35	40.60	40.00	36.65	37.71	38.25	38.99	37.19
3.A Enteric fermentation	36.75	37.06	36.49	33.52	34.54	35.12	35.87	34.30
3.B.1 Manure management	3.60	3.54	3.51	3.14	3.17	3.13	3.12	2.89
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
3. Agriculture	40.35	40.60	38.48	26.05	26.12	25.00	24.86	17.46
3.A Enteric fermentation	36.75	37.06	34.97	22.96	23.00	21.92	21.79	14.64
3.B.1 Manure management	3.60	3.54	3.51	3.09	3.12	3.08	3.07	2.82

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Projections of N_2O emissions in the Agriculture sector

N_2O emissions in Agriculture sector arise from categories 3.B.2 – Manure management and 3.D – Agricultural soils, accounting for 41% of total GHG emissions in 2022. Projections according to WEM and WAM scenarios are presented in ***Figure 4.4*** and ***Table 4.5***.

Figure 4.4: *N_2O emission projections in Gg in the Agriculture sector in WEM and WAM scenarios up to 2055*

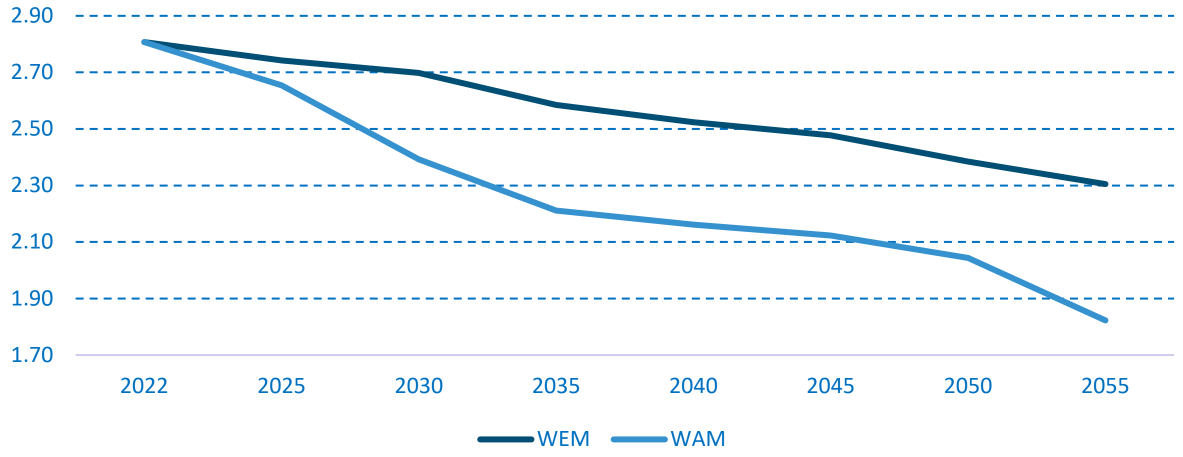


Table 4.5: *N_2O emission projections in Gg in the Agriculture sector in WEM and WAM scenarios up to 2055*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
3. Agriculture	2.81	2.74	2.70	2.58	2.52	2.48	2.38	2.30
3.B.2 Manure management	0.68	0.65	0.65	0.61	0.62	0.62	0.62	0.60
3.D Agricultural soils	2.13	2.09	2.04	1.97	1.90	1.86	1.76	1.71
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
3. Agriculture	2.81	2.65	2.39	2.21	2.16	2.12	2.04	1.82
3.B.2 Manure management	0.68	0.61	0.62	0.56	0.57	0.57	0.58	0.54
3.D Agricultural soils	2.13	2.04	1.77	1.65	1.59	1.55	1.47	1.28

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

CHAPTER 5. GHG EMISSION PROJECTIONS IN THE LULUCF SECTOR

This chapter discusses the effect of adopted, implemented and planned measures and policies and analyses their impact on projections of emissions/removals (CO_2, CH_4 and N_2O) of greenhouse gases (GHGs) in each land use category 4.A Forest Land, 4. B Cropland, 4.C Grassland, 4.D Wetlands, 4.E Settlements, 4.F Other Land and 4.G Harvested Wood Products (HWP), but also across the LULUCF sector.

The LULUCF sector is unique in terms of climate change, as it can primarily capture GHG emissions, and is only a small producer of GHG emissions. The latest published results of the GHG inventory in Slovakia for the year 2022 indicate that 37 012.71 Gg CO_2 eq. was produced. The LULUCF sector captured -7233.43 Gg CO_2 eq., representing 23.6% of all emissions produced. Forests are the most important category within LULUCF in Slovakia, accounting for more than 2/3 of the CO_2 sequestered in this sector. In addition to this category, the categories of Cropland and Grassland, as well as Harvested wood products, also show CO_2 sinks, but are much less significant from a balance sheet perspective. In contrast, CO_2, CH_4 and N_2O emissions are produced in the categories Settlements and Other land, also from biomass burning after forest harvesting, from forest fires, as well as from land mineralisation due to land use changes.

Figure 5.1: *GHG emissions/removals trend and projections in Gg of CO2 eq. in the LULUCF sector in WEM and WAM scenarios up to 2055*

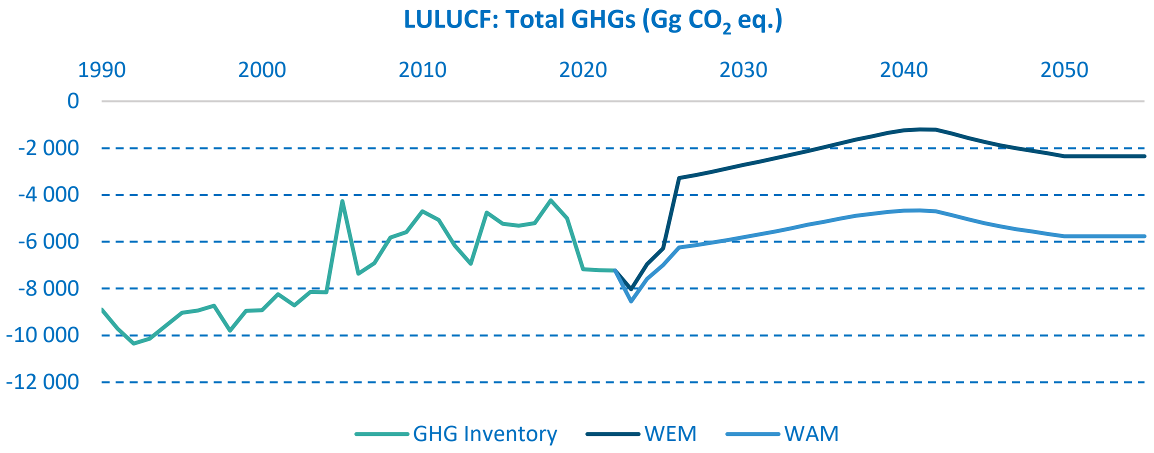


Table 5.1: *GHG emissions/removals trend and projections in the LULUCF sector in WEM and WAM scenarios up to 2050*

Year	WEM	WAM
	Gg CO_2 equivalents	
1990*	-8 892.53	-8 892.53
1995*	-9 030.43	-9 030.43
2000*	-8 922.53	-8 922.53
2005*	-4 264.77	-4 264.77
2010*	-4 704.36	-4 704.36
2015*	-5 234.27	-5 234.27
2020*	-7 178.98	-7 178.98
2022*	-7 225.74	-7 225.74
2025	-6 284.27	-6 991.20
2030	-2 722.09	-5 800.67

Year	WEM	WAM
	Gg CO_2 equivalents	
2035	-1 967.99	-5 144.82
2040	-1 246.95	-4 671.43
2045	-1 733.18	-5 202.89
2050	-2 342.86	-5 770.24
2055	-2 342.86	-5 770.24

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

The modelling results above show that both scenarios show a reduction in removals from 1990 levels in 2030 and, conversely, the scenarios show a reduction in removals by 2055.

5.1. Input Parameters for Emission Projections

Projections of the main input parameters - area and changes in areas in each land use category in the LULUCF sector for the period 2023 – 2050 were determined either through the exponential smoothing function of MS Excel, in the Forecast tool (dynamic projections), or as average values from historical data (static projections). In particular for the WEM scenario, a stable development of the areas (or areas of transfers between categories) based on average values over the period 1990 – 2022 was considered. If there is a significant break in development or intensity during this period and the current value of transfers (e.g. in the last decade) is significantly different than the average over the whole period, the calculation of the average was based only on the last decade or period with the current, new level of values.

In addition, outputs from the FCarbon model, which was developed in the context of the implementation of Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the integration of greenhouse gas emissions and removals from land use, land-use change and forestry into the 2030[16] Framework for Climate and Energy Policies , amending Regulation (EU) No. 525/2013 and Decision No. 529/2013/EU, were used for the projection of input parameters in the Forests category. The main reasons for the development of the FCarbon[17] model were the requirements for consistency with GHG emissions/removals reporting and the inclusion of age-related forest dynamic characteristics.

This model simulating the future development of forests in Slovakia was developed at NLC according to the methodology proposed.[18] The model is able to simulate in each simulation step, which is 1 year, the development of the age structure of forests, stock changes through normal annual increments and harvesting rates (harvesting percentages). It is possible to model bare-root and understorey management. The simulation of forest growth in the FCarbon model is based on growth tables[19], which determine the increments of wood volume in m^3 for the main tree species in Slovakia (spruce, fir, pine, beech, oak and selected poplars). The volumes of clearance and recovery are calculated on the basis of the specified percentages of extraction from the stock. The model is optionally able to simulate changes in the area of trees and thus changes in the total forest area. The model requires the following input data (broken down by species and age class): stock (m^3), area (ha), suitability and harvesting percentage for thinning and regeneration (mean and standard deviation).

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[16] https://eur-lex.europa.eu/legal-content/SK/ALL/?uri=CELEX%3A32018R0841

[17] https://web.nlcsk.org/cafmocc-fcarbon/

[18] Grassi, G.; Pilli, R. 2017. Projecting forest GHG emissions and removals based on the “continuation of current forest management”: the JRC method. EUR 28623 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2017. doi:10.2760/844243. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC106814/jrc_report_frl.pdf; Forsell, N.; Korosuo, A.; Federici, S.; Gusti, M.; Rincón-Cristóbal, J.J.; Rüter, S.; Sánchez-Jiménez, B.; Dore, C.; Brajterman, O.; Gardiner, J. 2018. Guidance on developing and reporting Forest Reference Levels in accordance with Regulation (EU) 2018/841

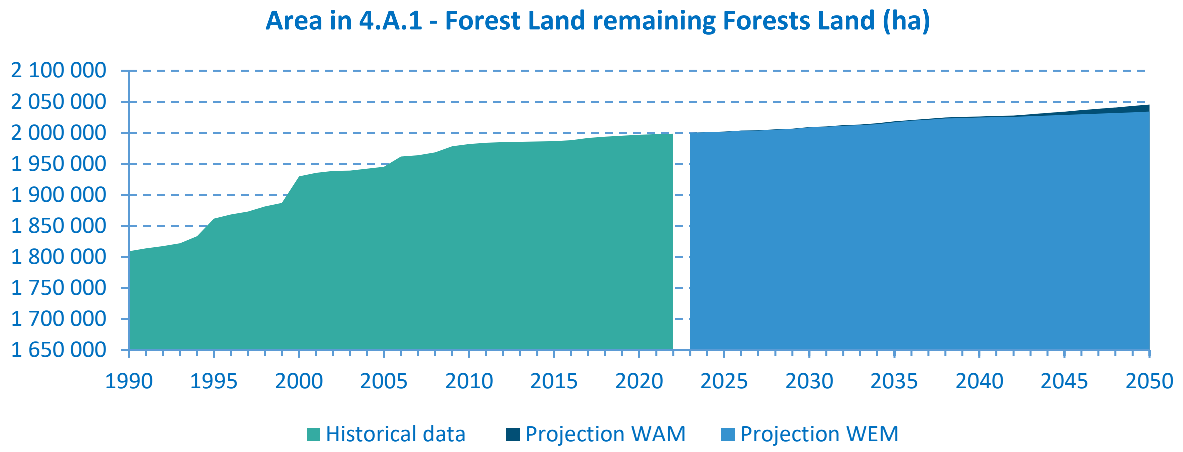
[19] Halaj, J.; Petráš, R. 1998: Rastové tabuľky hlavných drevín/Yield tables of main tree species. Bratislava, Slovak Academic Press, 325 p.

As input data for the simulation of the future development of Slovak forests were used summaries from central forestry databases, prepared for one calendar year (capturing the state at the end of the year), stratified by tree species and 10-year age stages. These summaries contained information on the area of each tree species and age class, stock (in m^3 of rough), stunting, stock rating, total normal increment and planned harvesting volume (educational and regeneration). The information from the Forest Economic Record (FER) on actual timber harvesting was broken down according to the Decree of the Ministry of Agriculture and Rural Development of the Slovak Republic No. 297/2011 Coll. on Forest Economic Record (FER) into deliberate (educational and restoration), extraordinary and accidental (executed, with timber left in the forest stand and not executed).

Area of the category Forest Land remaining Forest Land (4.A.1) - forest area and its trend are among the basic indicators of sustainable forest management. Society's demands on forests, which play an important role in mitigating climate change, conserving biodiversity, protecting water resources, preventing floods, providing timber and non-timber forest products as well as other ecosystem services, are constantly increasing. Maintaining and increasing forest cover is therefore highly desirable. According to data from the Summary Information on the State of Forests (FIS source), there is a long-term trend of its increase. Since 1990, the area of forest cover has increased by 28.3 thousand ha, or 1.47%. The increase of approximately 975 ha per year over the period is mainly due to the change in land type. The total area of forest land in 2020 was 2 027 852 ha and has increased by 46.6 thousand ha since 1990 (i.e. by 2.36%). On average, it increased by 1 607 ha per year over the period. Forest cover, calculated as a percentage of the area of forest land in the total area of the Slovak Republic (4.903 million ha, including water areas), reached 41.3% in 2020. It has increased by 1.0% since 1990. There are 0.36 ha of forest per inhabitant of the Slovak Republic.

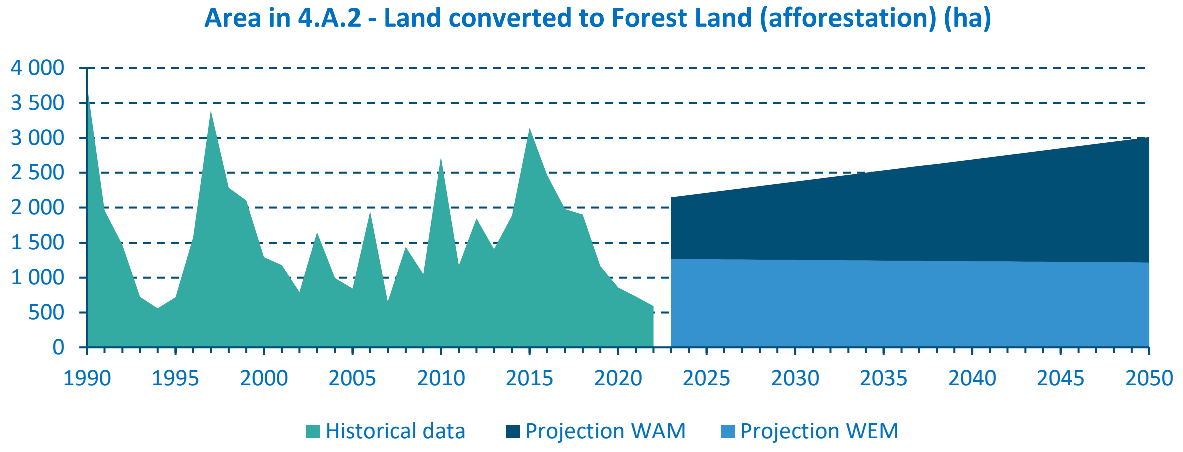
The development of acreage in the category Forest Land remaining Forest Land follows the above-mentioned trend of increasing acreage of forests in the Slovak Republic. For this reason, the projection assumes an increase in forest area after 2020, both in the WEM and WAM scenarios (***Figure 5.2***).

Figure 5.2: *Trend and projections of area in ha in 4.A.1 - Forest Land remaining Forests Land in WEM and WAM scenarios up to 2050*



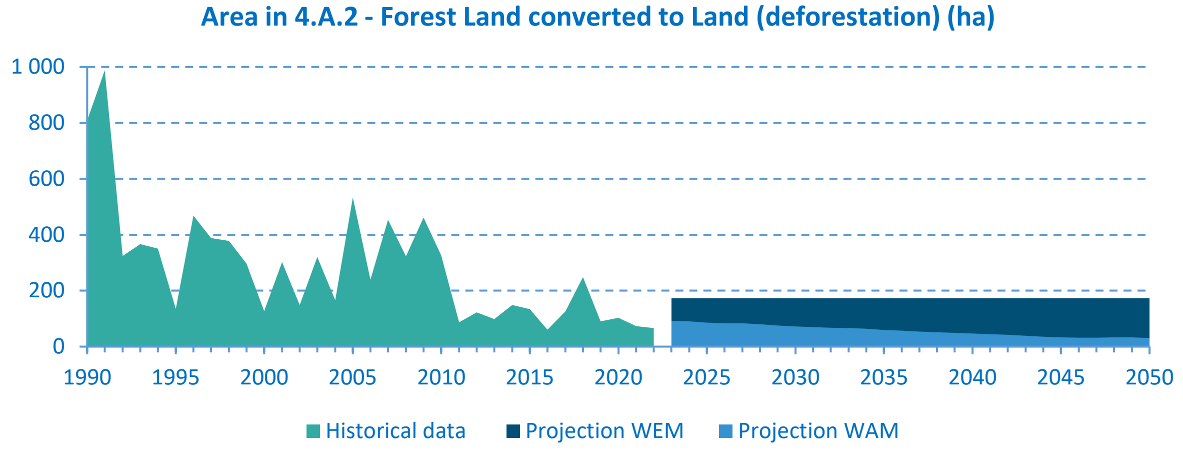
Area of the category Land converted to Forest Land (afforestation) (4.A.2) - historical acreage in this category shows a divergent pattern throughout the 1990 – 2020 period. The highest acreage value was recorded in 1990 at 3 770 ha and the lowest at 559 ha in 1994. The average value was 1 670 ha. The future trend shows a slightly decreasing trend (WEM) and an increasing trend (WAM) (***Figure 5.3***).

Figure 5.3: *Trend and projections of area in ha in 4.A.2 - Land converted to Forest Land (afforestation) in WEM and WAM scenarios up to 2050*



Area of the category Forests converted to Land (deforestation) (4.A.2) - historical acreage in this category shows a divergent pattern throughout the 1990 – 2020 period. The highest acreage value was recorded in 1991 at 988 ha and the lowest at 61 ha in 2016. The average value was 301 ha. The future development shows a balanced trend (WEM) and a slightly decreasing trend (WAM) (***Figure 5.4***).

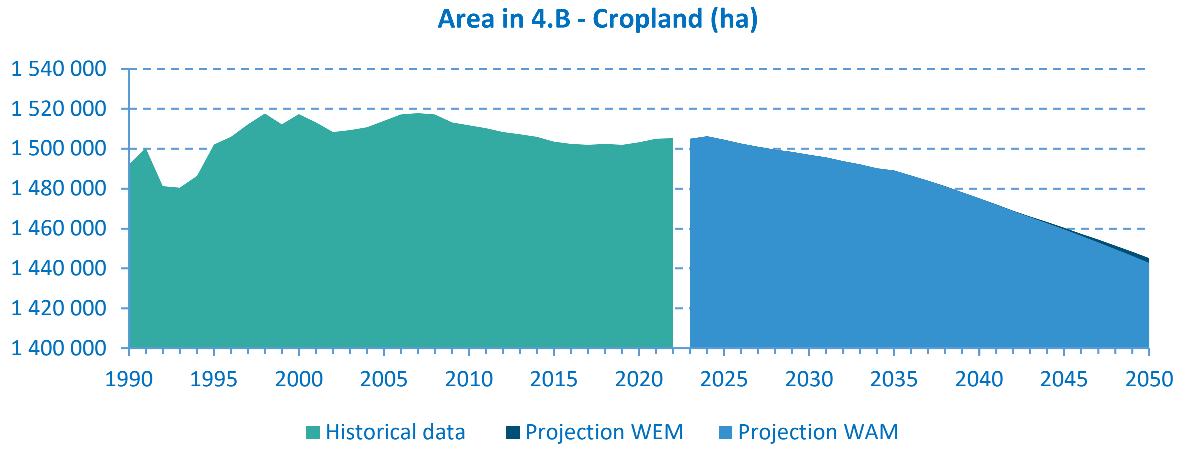
Figure 5.4: *Trend and projections of area in ha in 4.A.2 - Forest Land converted to Land (deforestation) in WEM and WAM scenarios up to 2050*



Area of the category Cropland (4.B) - historical area in this category shows a slightly fluctuating pattern throughout the 1990-2020 period and a steadily declining trend since 1998. The projected future development of the cropland category includes the fact that there will be conflicting factors influencing the development of areas in the coming years, which are likely to intensify over time. On the one hand, there will be pressure for the encroachment and development of cropland for residential areas, industrial, commercial and logistics centres, as well as roads. On the other hand, there will be increasing pressure to preserve cropland, to strengthen its productive functions, especially in relation to at least partially increased food self-sufficiency, and in particular to strengthen the non-productive functions of land, such as water storage in the land, erosion protection, biodiversity, land formation, and also mitigation of the negative impacts of change and adaptation to climate change. Significant positive impacts of this category are also envisaged in relation to emissions capture and carbon sequestration. Not only the EU's Common Agricultural Policy, but also other, particularly environmentally oriented EU policies such as the European Green Deal, are working towards this.

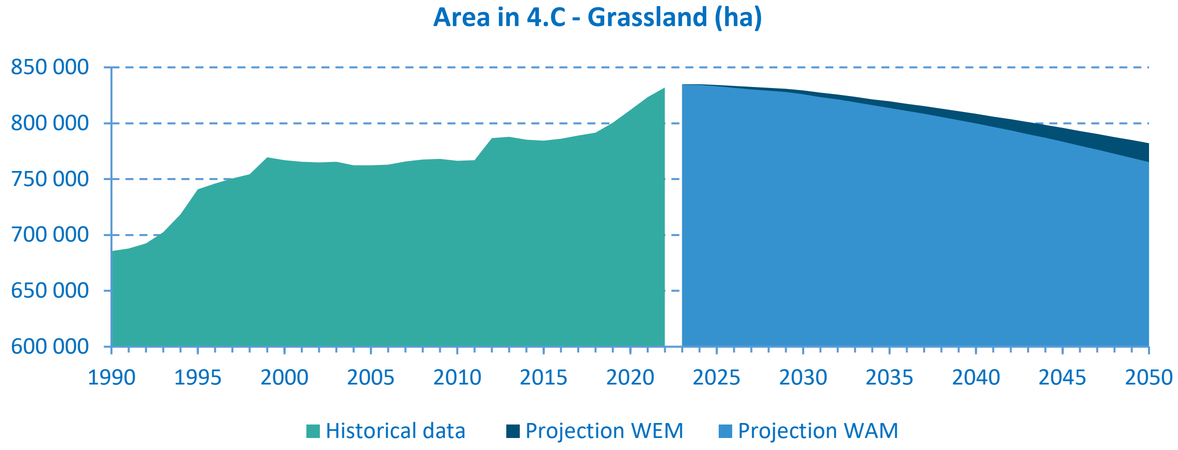
On the basis of the above, it is possible to assume a stabilisation of the area in this category, or a very slight decrease. As regards the internal structure, an increase in the area of individual permanent crops is expected, particularly orchards, vineyards and, it would be appropriate, hop-growing, since the products of all these crops make up a negative balance in the economic balance, and, in addition, in terms of GHG emissions, these crops show relatively high CO_2 removals. Alongside this, it is expected that within the arable sub-category there will be an increase in the proportion of land features and non-forest woody vegetation in the form of tree lines, borders, solitudes and trees in groups, which will enhance the fulfilment of the non-productive functions of the cropland and land. Future trends in cropland area show a declining trend (WEM) and a slightly declining trend (WAM) (***Figure 5.5***).

Figure 5.5: *Trend and projections of area in ha in 4.B – Cropland in WEM and WAM scenarios up to 2050*



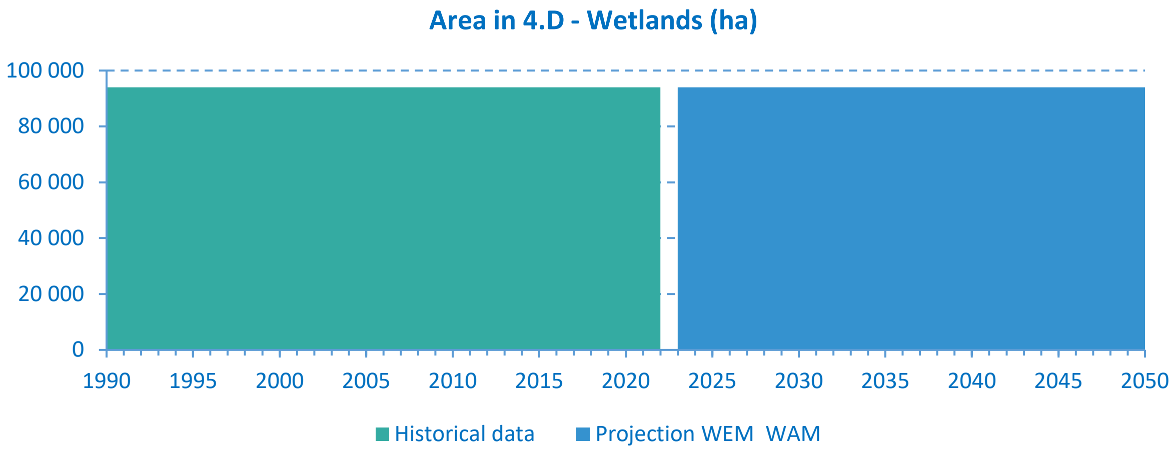
Area of the category Grassland (4.C) - the set trend gives an outlook that most probably the gradual reduction of the area of permanent grasslands will continue, mainly due to the transfer of unused and abandoned grasslands to the forest fund, ecological and water protection restrictions, the introduction of forest-pastoral systems, the transfer of land under the administration of national parks. If appropriate socio-economic and ecosystem measures or payments are introduced and applied in the land, the area in this category could be stabilised and its use improved. The trend of permanent grassland area in the future shows a decreasing trend for all scenarios (WEM and WAM) (***Figure 5.6***).

Figure 5.6: *Trend and projections of area in ha in 4.C – Grassland in WEM and WAM scenarios up to 2050*



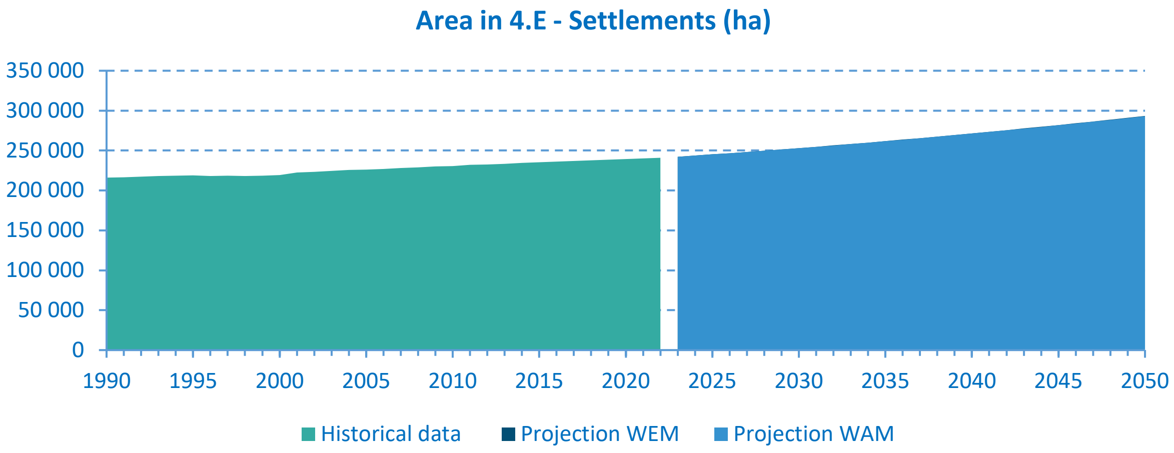
Area of the category Wetlands (4.D) - Slovakia shows no change in this category in the long term. It is realistic to assume that this will remain the case in the future, which is why the acreages for the WEM and WAM scenarios are identical (***Figure 5.7***).

Figure 5.7: *Trend and projections of area in ha in 4.D – Wetlands in WEM and WAM scenarios up to 2050*



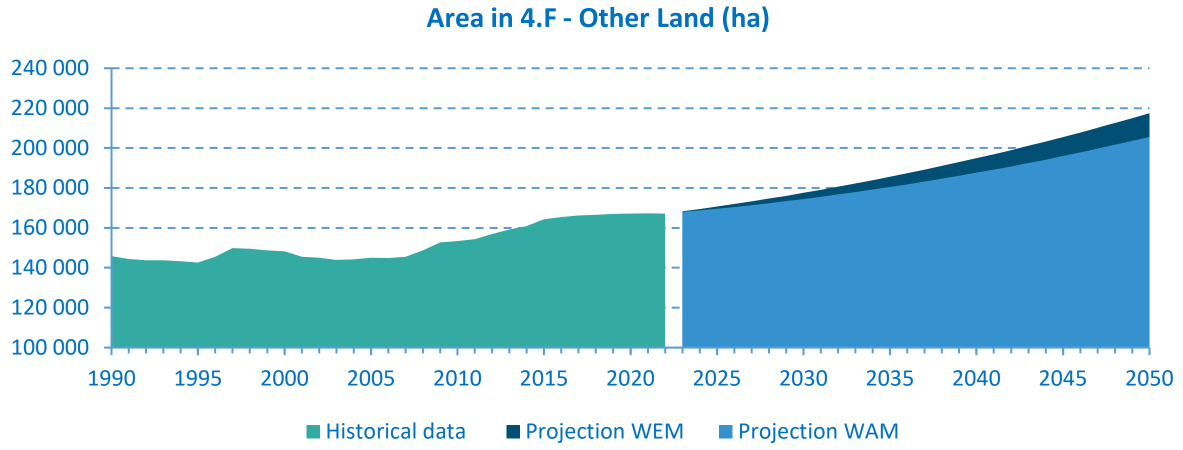
Area of the category Settlements (4.E) - the area of this land use category has shown a steadily increasing trend throughout the period. This situation is mostly due to the development of transport infrastructure, industrial areas, the development of towns and villages, the increase in the area of various infrastructure in the countryside. In Slovakia, it is very often associated with a decrease in the area of the category of cropland, as it is related to the occupation of good quality arable land. Future developments show an increasing trend for all scenarios (***Figure 5.8***).

Figure 5.8: *Trend and projections of area in ha in 4.E – Settlements in WEM and WAM scenarios up to 2050*



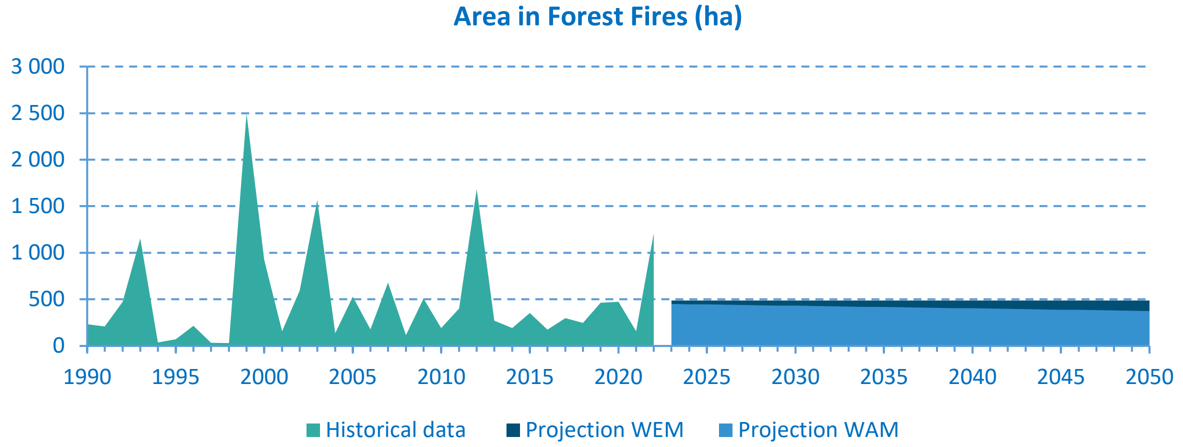
Area of the category Other Land (4.F) - the area of this land use category has shown a steadily increasing trend throughout the period. This situation is mostly due to the degradation of cropland, but also due to leaving the territory of Slovakia without active management. Future developments show an increasing trend for all scenarios are identical (***Figure 5.9***).

Figure 5.9: *Trend and projections of area in ha in 4.F – Other Land in WEM and WAM scenarios up to 2050*



Area of the category Forest Fires - historical forest fire acreage shows a discontinuous pattern throughout the period. The highest acreage value was recorded in 1999 at 2 496 ha and the lowest at 32 ha in 1998. The average value was 488 ha. The future development shows a steady trend (WEM) and a slightly decreasing trend in the WAM scenario (***Figure 5.10***).

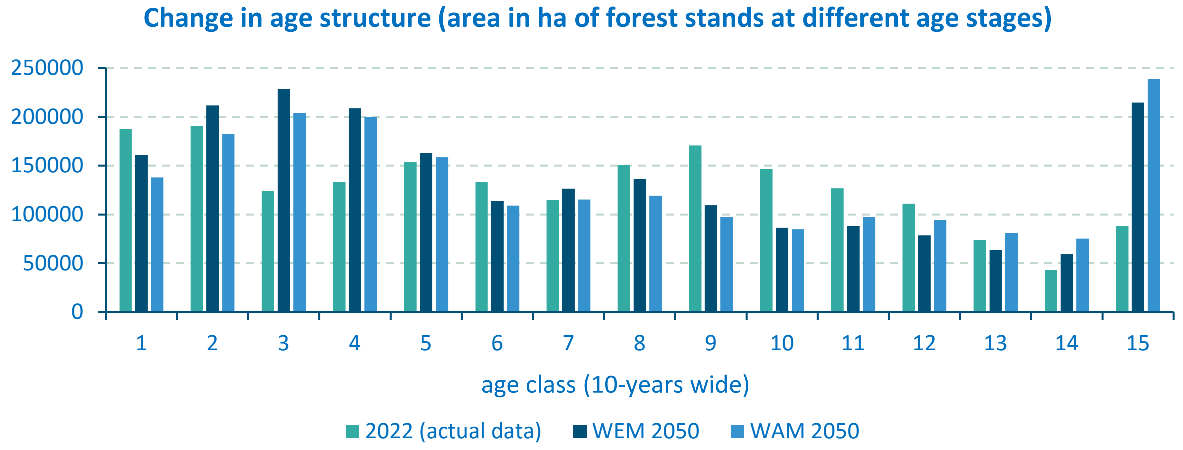
Figure 5.10: *Trend and projections of area in ha in Forest Fires in WEM and WAM scenarios up to 2050*



Trend of age structure, increments and timber harvests - future forest development was simulated using the FCarbon model for the period 2023 – 2050. Input data on forest condition were based on the summarised stand characteristics of individual tree species (age structure, stock (m^3), area (ha) and suitability) for the year 2022. The projections were refined for the years 2023-2025 based on the latest harvest data on 2023 and a realistic estimate for the near future. The estimate of the future amount of timber harvesting for the years 2024 and 2025 is based on current trends in timber harvesting, imports, exports and timber demand.

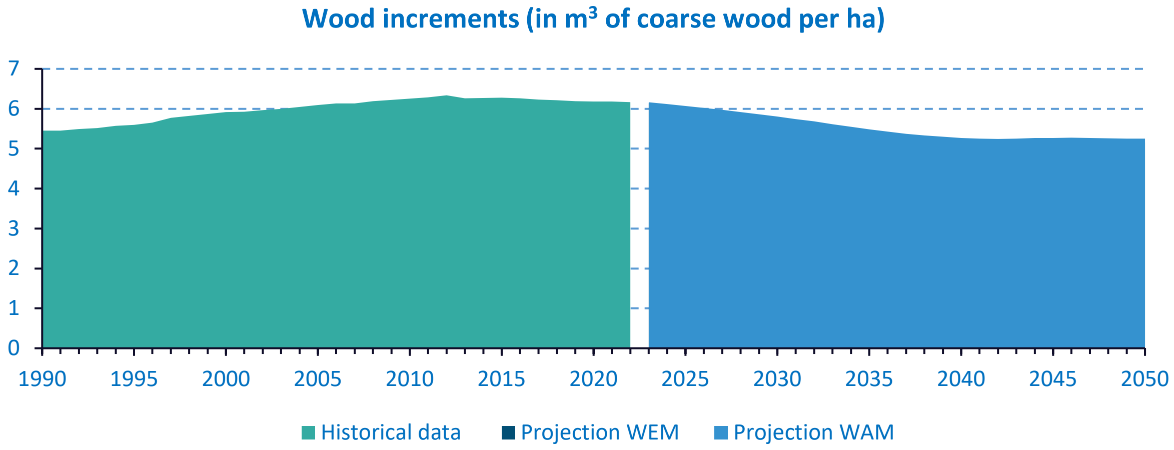
Harvesting percentages (percentage of annual coarse harvest of total stock) were derived from data for the period 2013 – 2022, which capture the current level of stand regeneration. They were determined separately for planned and actual harvests (***Figure 5.11***).

Figure 5.11: *Change in age structure (area in ha of forest stands at different age stages) in WEM and WAM scenarios from 2018 up to 2050*



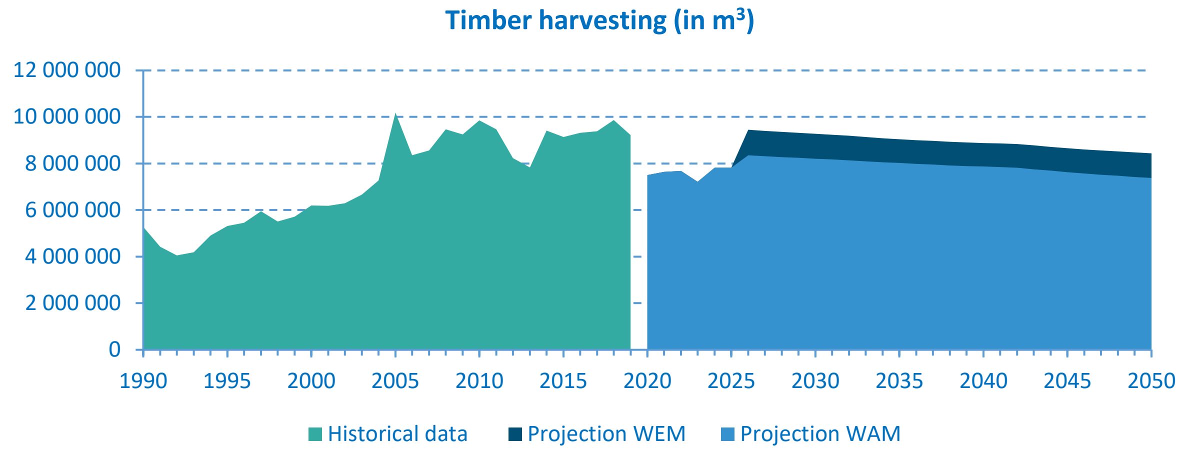
Based on these inputs, the FCarbon model calculated, at each time step (1 year) during the simulation, the trend of the age structure of the forest (by increasing the age, by transferring harvested areas to the youngest categories; (***Figure 5.11***), stock changes using current annual increments (***Figure 5.12***), and timber harvesting (via harvesting percentages; (***Figure 5.13***).

Figure 5.12: *Trend and projections of wood increments (in m3 of coarse wood per hectare) in WEM and WAM scenarios up to 2050*



Depending on the species of tree species, the management method was also simulated, namely: holm oak (mainly pine and spruce in case of calamities), but mainly understorey method (the ratio of both methods determined on the basis of the proportion of natural regeneration from the Forest Management Plans). The FCarbon model also accounted for changes in tree cover (and also in tree composition) and thus changes in total forest area under the WAM and WEM scenarios. The calculated wood mass gains and losses served as input for the calculations of carbon stock changes (***Figure 5.13***).

Figure 5.13: *Trend and projections of timber harvesting (in m3) in WEM and WAM scenarios up to 2050*



5.2. Methodologies and Key Assumptions/Trends

The National Forestry Centre (NLC) - Forestry Research Institute (FRI) in cooperation with the National Agricultural and Food Centre, the Research Institute of Soil Science and Soil Protection (NPPC-SRI) and the Research Institute of Grasslands and Mountain Agriculture (NPPC-SRI) have developed two scenarios for the development of emissions from 2022 to 2050 on the basis of available information, the scenario with existing measures (WEM) and the scenario with additional measures (WAM). The result of the modelling of the GHG emission/removals projections is presented in ***Figure 5.1*** and ***Table 5.1***. In the WEM scenario, the measures adopted and implemented up to 2022 have been implemented, these measures have not prevented a decrease in GHG removals of -74% compared to 1990. The WEM scenario took into account policies and measures from official national strategic documents and programmes valid in Slovakia until 2022, mainly from the National Forestry Programme of the Slovak Republic 2014 – 2020[20], Rural Development Programmes 2007 – 2013, 2014 – 2020[21] and from the Low Carbon Development Strategy of the Slovak Republic until 2030 with a view to 2050. The WAM scenario incorporates measures from available official national strategic documents and programmes valid in Slovakia after 2022[1] and the Environmental Policy Strategy of the Slovak Republic 2030. When additional measures were implemented in the WAM scenario, removals decreased by -35% compared to 1990.

Historically, the lowest CO_2 removals in the LULUCF sector were recorded in 2005, with the Forests category contributing significantly due to a major wind calamity in the High Tatras. Both the WEM and WAM scenarios show decreasing removals compared to 2005 (63% for the WEM scenario and 10% for the WAM scenario). The more pronounced decrease in projected removals after 2022 in the WEM scenario, compared to the WAM scenario, is due to a higher decrease in removals in the Forest, Cropland and Grassland categories and an increase in emissions from the Settlements and Other Land categories.

Projections of emissions/removals of GHGs in the LULUCF sector were modelled for the 6 main land use categories (Forest Land, Cropland, Grassland, Wetlands, Settlements, Other Land) and the

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[20] Ministry of Agriculture and Rural Development. "Forest Strategy 2030." [Online]. https://data.consilium.europa.eu/doc/document/ST-13537-2021-INIT/sk/pdf

[21] Ministry of Agriculture and Rural Development. "Rural development programme 2014-2020 extended until 2023". [Online]. https://agriculture.ec.europa.eu/common-agricultural-policy/rural-development_sk; Ministry of Agriculture and Rural Development. "Rural Development Programme 2023-2027. [Online]. https://agriculture.ec.europa.eu/common-agricultural-policy/rural-development_sk

Harvested Wood Products category, as well as for the different GHG emission gases (CO_2, CH_4, N_2O). The available time series of input data for the period 1990-2022 were used, which were obtained from various sources (Office of Geodesy Cartography and Cadastre, NLC, Statistical Office of the Slovak Republic, National Agriculture and Food Centre-Soil Science and Conservation Research Institute, National Agriculture and Food Centre-Grassland and Mountain Agriculture Research Institute, Fire Technical and Expert Institute of the Ministry of the Interior of the Slovak Republic, FAO database). All input data entering the accounting of GHGs emissions/removals in the LULUCF sector were used as input data for the projections.

Input data needed in the preparation of projections:

- acreages of individual land use categories - forests, cropland, permanent grasslands, wetlands, settlements, other land, (data for the period 1970 – 2022, source Statistical Yearbook of the Land Fund of the Slovak Republic, Office of Geodesy Cartography and Cadastre[22]), data available by regions, districts and cadastral territories,
- changes in acreage into and out of each land use category - forests, cropland, permanent grassland, wetlands, settlements, other land (data for the period 1970-2022), data available by county, district and cadastral area,
- annual tree growth in m^3/ha (1990 – 2022, source Summary Information on the State of Forests (SISL), as part of the Forestry Information System [23](FIS), data available by county,
- annual timber harvest in m^3 (1990 – 2022, source FIS), data available for Slovakia by tree species,
- area of individual trees in ha (1990 – 2022, source FIS), data available by county,
- representation of individual tree species in ha (1990-2022, source SFIS), data available by county,
- age structure of forests in ha (2014 – 2022, source FIS),
- area of forest fires in ha (1990 – 2022, source NLC in cooperation with the Fire Technical and Expertise Institute of the Ministry of the Interior of the Slovak Republic),
- Inputs for harvested wood products (1990 – 2022, source FAO database).

5.3. Model Description

GHG emission/removal projections in the LULUCF sector were prepared for 6 main land use categories (Forest land, Cropland, Grassland, Wetlands, Settlements, Other land) and category Harvested Wood Products, as well as for various greenhouse gas emissions (CO_2, CH_4, N_2O). Available time series of input data for the period 1990 – 2022 were used, which were obtained from official sources: Office of Geodesy of Cartography and Cadastre (Cadastre), National Forest Centre (NFC), Statistical Office of the Slovak Republic (SOSR), National Agricultural and Food Centre (NPPC), Fire Engineering and Expertise Institute of the Ministry of the Interior (FEEI), FAO database.

Input data needed for the preparation of projections:

- areas of individual LU categories, including the changes in areas and transitions between the LU categories (1970 – 2022; Cadastre data available by region, districts and cadastral areas),

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[22] Statistical Yearbook on the Land Fund of the Slovak Republic, Office of Geodesy Cartography and Cadastre. https://www.skgeodesy.sk/sk/ugkk/kataster-nehnutelnosti/sumarne-udaje-katastra-podnom-fonde/

[23] https://gis.nlcsk.org/islhp/

- current annual increment in m^3 ha^{-1} (NFC data available by region),
- annual harvested volume in m^3 (NFC data available for Slovakia by tree species),
- area of individual tree species in ha (NFC data available by regions),
- individual tree species composition in ha (NFC data available by regions),
- age structure of forests in ha (2014 – 2022; NFC data),
- area of forest fires in ha (NFC in cooperation with the FEEI),
- inputs for harvested timber products (FAO database).

Projections of the main input parameters - areas and changes in areas in individual land use categories in the LULUCF sector for the period 2022 – 2050 were determined either through the exponential balancing function in MS Excel (the Forecast tool) or as average values from historical data.

In addition, the outputs of the FCarbon forest growth model were used to project forest characteristics, used as the input parameters for GHG emissions/removals quantification in the Forest land category. This model simulating the future development of forests in Slovakia was developed in NFC according to the methodology proposed by Grassi & Pilli (2017) and Forsell et al. (2018).

The main reason for the development of the model was to fulfil the requirements for consistency with the reporting of GHG emissions/removals within the Slovak national emission inventory and also the inclusion of dynamics in forest growth through characteristics related to age structure. The model is able to simulate on an annual basis the development of the age structure of forests and growing stock changes, using annual increments and harvesting rates (logging percentages). It is possible to model the clear-cutting and shelter-wood forest management systems. The simulation of forest growth in the FCarbon model is based on yield tables (Halaj & Petráš 1998), which determine the current annual increments of growing stock in m^3 for the main tree species in Slovakia (spruce, fir, pine, beech, oak and breeding poplars). Harvested wood volumes (thinning, planned harvest and sanitary felling) are calculated applying harvesting rates (percentages set out according to extraction of wood volume from the growing stock in reference period). The model is optionally able to simulate changes in the area of tree species, as well as changes in the total forested area. The model requires the following input data (stratified by trees species and age classes): growing stock (m^3), area (ha), yield class, thinning and harvesting rate (average value and standard deviation, in %). These data were prepared by summarizing inputs from central forestry databases from the years 2013 – 2022. The whole procedure of simulation in the FCarbon model and calculation of CO_2 emissions is programmed in the Python language with data stored in the SQLite database.

Table 5.2: *SWAT analysis of the LULUCF-model*

Strengths	**Opportunities**
Compatibility with emission inventories Detailed data break down Database used is compatible with national data	Incorporate to the model new technologies Versatile use of time-series
Treats	**Weakness**
Bugs can be introduced if changes in the code are not thoroughly verified	Absence of user interface (set of scripts) Model not sensitive to climate change (based on empirical yield-tables)

The projections of emission/removals were prepared in accordance with the methodology of the Intergovernmental Panel on Climate Change of 2006 (IPCC 2006). The applied methodology is consistent with the methodology for estimating emissions under Article 26 of Regulation (EU) 2018/1999. The computational analytical tool is based on the MS Excel platform and the calculation includes various policies and measures (in numerical formulation) defined according to the WEM and WAM scenarios. Outputs of the FCarbon model, developed in connection with the application of Regulation (EU) 2018/841, are used for projections in the Forest land category. The FCarbon model was calibrated using data for the years 2014 – 2019, because the first usable data on the condition of forest stands from the reference period were valid at the end of 2013. The aim of the calibration was to increase the accuracy of the simulation process to be able to reproduce the resulting GHGs emissions/removals as accurately as possible. The calibrated model was used to simulate the development of the age structure of forests, increments and harvesting in the period 2022 – 2050.

The "Gain-Loss" method was used to quantify GHG emissions/removals in each land use category. This is based on estimates of the year-on-year change in biomass from the difference between its gains and losses, where gains represent an annual increase in carbon stocks due to biomass growth and losses represent an annual decrease in carbon stocks due to biomass removal (extraction). The simulation results for individual trees are summarized within each step and CO_2 emissions/removals in living biomass are calculated from the summary data.

The annual increment (m^3) is converted to biomass gain (dry weight) using wood density, biomass conversion expansion factor (BCEFI) and root-to-shoot ratio (R). The annual increase in carbon stocks is calculated by multiplying the dry weight by the average carbon content of the dry matter (50% for conifers and 49% for broadleaves; IPCC 2006 GL). Inter-annual losses in carbon stocks due to biomass loss are calculated from annual harvest volume (m^3), conversion and expansion factor (BCEFR), above-ground and underground biomass ratio (R) and average dry matter carbon content (IPCC 2006 GL). The resulting changes in carbon stocks (gains minus losses) are converted to CO_2 emissions/removals by multiplying the mass of carbon by -44/12. More detailed information on the methodology of emissions/removals calculations is published in the National Inventory Report (Szemesová et al. 2022).

5.4. Sensitivity Analysis

Emission projections were prepared in accordance with the 2006 Intergovernmental Panel on Climate Change Methodology, Chapter IV (IPCC 2006 Guidelines). The computational analytical tool is based on the MS Excel platform and the calculation includes various policies and measures (in numerical formulation) defined according to the WEM and WAM scenarios. The projections of emissions and removals in the Forest category used outputs from the FCarbon, model, which was developed in the context of the implementation of Regulation (EU) 2018/841 of the European Parliament and of the Council. The main reasons for the model development were the requirements for consistency with the reporting of GHG emissions and removals in national emission inventories and also the inclusion of forest dynamics through characteristics related to the age structure of the forest. The whole procedure of simulating the FCarbon model and calculating emission and sink projections is programmed in Python and the data are stored in an SQLite database.

In the context of a very exceptional situation in the LULUCF sector in 2020, caused by low extraction, dampened by anti-pandemic measures during the first wave of COVID-19, increased removals, and 2020 being an exceptional year outside of the long-term trend of high removals, the emission projections were calibrated to the 2014-2019 time period. This allowed to reduce the fluctuation of the emission projections and to relate them to the previous trend.

The model was calibrated using data for 2014 – 2019, as the first usable forest cover condition data from the reference period were valid at the end of 2013. The aim of the calibration was to increase the accuracy of the simulation process so that it is able to reproduce the resulting emissions and removals as faithfully as possible and to track the actual development of forest stands during the reference period. For each year of the simulation, deviations from the mean values of the thinning and harvesting percentages (both positive and negative, in %) were specified, so that the sum of the deviations over the calibration period was zero. After the first run of the model, total carbon stock gains and losses were calculated. It was found that the resulting average value of the increments (5 141.1 kt C) was higher by

2.68% and the average value of the simulated removals (-3 874.5 kt C) was lower by 0.05% compared to the average values of the national GHG emissions and removals inventory (5 006.9 kt C and -3 872.5 kt C, respectively). Carbon increments were compared by tree species and ratios of simulated to actual values were calculated. These ratios were used as multipliers to the volume increments determined from the tree-by-tree growth tables to adjust the total simulated biomass increments. The calibrated model was used to simulate the trend of forest age structure, increments and harvests over the period 2022 – 2050. Forest condition data valid at the end of 2022 were used as inputs to the model.

The "gains-losses" method was used to quantify emissions and removals in each category. This is based on estimates of the year-on-year change in biomass from the difference in biomass gains and losses, where gains represent the annual increase in carbon stocks due to biomass growth and losses represent the annual decrease in carbon stocks due to biomass removal (harvesting). The simulation results for each tree species are summarized within each step and the emissions and removals in living biomass are calculated from the summarized data. The annual increment of coarse biomass (m^3) is converted to biomass increment (dry weight) using wood density, Biomass Conversion Expansion Factor (BCEFI) and Root-to-Shoot Ratio (R). The annual carbon stock gain is calculated by multiplying the dry weight by the average dry carbon content (50% for conifers and 49% for broadleaves). The annual loss of carbon stocks due to biomass loss is calculated from the annual harvest volume (m^3), the conversion and expansion factor (BCEFR), the ratio of aboveground to belowground biomass (R), and the average dry carbon content. The resulting carbon stock changes (additions minus removals) are converted to CO_2 emissions and removals by multiplying the carbon mass by -44/12. More detailed information on the methodology for calculating emissions and removals is published in the National Inventory Report 2022.[24]

For category 4.A.1 Forest land remaining forest land, the projections have been treated as a continuation of forest management in the so-called reference period 2014-2019 for all scenarios.

In the WEM scenario, the trend of increments - gains, modelled on the basis of a scenario with dynamically increasing forest area (1 996 758 ha in 2020 to 2 024 599 ha in 2040 and 2 034 266 ha in 2050) and dynamically changing tree species composition for example a decrease of spruce from 22% in 2020 to 17% in 2040 and 15% in 2050, was assumed, beech increases from 35% in 2020 to 39% in 2040 and 41% in 2050). As for the losses, these have been modelled through harvesting. In the WEM scenario, the so-called planned harvests were modelled (6-8% higher than the realised harvests).

- Category 4.A.2 Land converted to forest land (afforestation):

The area and tree species composition were projected as static - the average value from historical data 1990-2022 was used (GL/FL - 836 ha, CL/FL - 83 ha, OL/FL - 353 ha) sm - 34%, bo - 15%, bk - 44%, db - 8%.

- Category 4.A.2 Forest land converted to other land (deforestation):

Both area and tree species composition were projected as static - the average value from historical data 1990-2022 was used (FL/GL - 22 ha, FL/CL - 2 ha, FL/S 45 ha, FL/OL - 104 ha. The average hectare stock was modelled as a dynamic variable.

- Category 4.B.1 Cropland:

The area of CLA/CLP (annual cropland/perennial cropland) and CLP/CLA (perennial cropland/annual cropland) transfers was projected as static and the average value from 1990-2022 historical data was used (CLA/CLP - 6 ha, CLP/CLA - 354 ha). The area of each sub-category of perennial cropland (orchards, gardens, vineyards and hop gardens) was projected as dynamic - determined using the exponential smoothing function of MS Excel, in the Forecast tool. The areas in the remaining categories (grassland, settlements, other land) were projected as dynamic. The harvested wood products (HWP)

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[24] https://oeab.shmu.sk/app/cmsSiteBoxAttachment.php?ID=105&cmsDataID=0

category was projected based on the volume of timber harvest calculated for the WEM and WAM scenarios, by the FCarbon model, with the distribution of harvest volume among the different product categories based on the current, realistic distribution (realistic model).

For category 4.A.1 Forest land remaining forest land, the projections have been treated as a continuation of forest management in the so-called reference period 2014-2019 for all scenarios.

In the WAM scenario, the projected development of gains was modelled on the basis of a scenario with dynamically increasing forest area (1 996 758 ha in 2020 to 2 026 463 ha in 2040 and 2 045 507 ha in 2050) as a result of afforestation (i.e. afforestation of formerly mainly cropland, its transfer to category 4.A.2 Land converted to forest land, after a 20-year period, to category 4.A.1 Forest land remaining forest land). The WAM scenario is also characterised by a dynamically changing tree species composition. As for the losses - losses, these were modelled through harvesting. In the WAM scenario, actual realised harvests were modelled (6-8% lower than planned).

- Category 4.A.2 Land converted to forest land (afforestation):

Area and tree species composition were projected as a combination of a static approach and a dynamic approach - the acreage determined by the exponential smoothing function of MS Excel was used, in the Forecast tool (GL/FL - from 639 ha in 2020 to 2224 ha in 2050, CL/FL - from 46 ha to 122 ha in 2050, OL/FL - 665 ha), spruce - from 46% in 2020 to 32% in 2040 to 29% in 2050, pine - from 18% in 2020 to 13% in 2040 to 14% in 2050, beech - from 33% in 2020 to 49% in 2040 to 49% in 2050, oak - from 3% in 2020 to 6% in 2040 to 7% in 2050, beech - from 33% in 2020 to 49% in 2040 to 49% in 2050.

- Category 4.A.2 Forest land converted to other land (deforestation):

Both area and tree species composition were projected as dynamic - the value determined by the MS Excel exponential smoothing function in the Forecast tool was used (FL/GL - 0 ha, FL/CL - from 2 ha in 2020 to 1 ha in 2050, FL/S - from 36 ha in 2020 to 31 ha in 2050, FL/OL - from 62 ha in 2020 to 0 ha in 2050. The average hectare stock was modelled as a dynamic variable.

- Category 4.B.1 Cropland:

The area of CLA/CLP (annual CL/perennial CL) and CLP/CLA (perennial CL/annual CL) transfers was projected as dynamic - using the value determined by the exponential smoothing function of MS Excel, in the Forecast tool (CLA/CLP from 27 hectares in 2020, through 48 hectares in 2040, to 59 hectares in 2050, CLP/CLA from 162 hectares in 2020, through 99 hectares in 2040, to 67 hectares in 2050). The area of the individual subcategories of perennial cropland (orchards, gardens, vineyards and hop gardens) was projected as dynamic - determined through the exponential smoothing function of MS Excel, in the forecast tool (dynamic projections). Acreages in the remaining categories (grassland, settlements, other land) were projected as dynamic. The harvested wood products (HWP) category was projected based on the timber harvest volume calculated for the WAM scenario by the FCarbon model, with the distribution of harvest volume among the different product categories based on an ideal distribution.[25]

5.5. Scenarios, Parameters and PAMs

In its conclusions of 23 and 24 October 2014, the European Council endorsed a binding target to reduce domestic greenhouse gas emissions across the economy by at least 40% by 2030 compared to 1990 levels, as part of its 2030 climate and energy policies. However, the current target is -55%, which has been increased through the European Green Deal. The implementation of Regulation (EU) 2023/839 as well as Regulation (EU) 2018/841 by individual Member States should also contribute to achieving this

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[25] Forsell, N.; Korosuo, A.; Federici, S.; Gusti, M.; Rincón-Cristóbal, J.J.; Rüter, S.; Sánchez-Jiménez, B.; Dore, C.; Brajterman, O.; Gardiner, J. 2018. Guidance on developing and reporting Forest Reference Levels in accordance with Regulation (EU) 2018/841

objective. This Regulation is part of the implementation of the Union's commitments under the Paris Agreement adopted under the United Nations Framework Convention on Climate Change (UNFCCC). The Union should continue to reduce its greenhouse gas emissions and increase removals in line with the Paris Agreement to the UNFCCC. Therefore, the condition of Regulation (EU) 2023/839 and Regulation (EU) 2018/841 of the EP and Council of the EU that each Member State shall ensure that emissions do not exceed removals (zero emissions) in the period 2021 to 2025 and 2026 to 2030, taking into account the flexibility instruments provided for in Articles 12 and 13, has also been incorporated in the development of GHG emission/removal projections for the LULUCF sector. Projections of emissions and removals were prepared for the two required scenarios of WEM and WAM development. The measures listed in ***Table 5.3*** were taken into account in the preparation of the LULUCF sector projections.

The scenario with existing measures (WEM) includes policies and measures adopted by the end of 2022 and their effect on LULUCF emissions/removals from 2022 onwards. As afforestation of cropland has a high carbon sequestration potential, this measure has been implemented under the individual RDP. In the first RDP 2004 – 2006, afforestation of unused cropland was supported by 15 projects with a total result of 100 ha of afforestation. In the following years, afforestation continued under the RDP 2007 – 2013 (28 projects with a total area of 133.35 ha) and the annual report on the RDP 2014 – 2020 for 2019 states that during the last two previous programming periods, planting of forest trees on cropland with a total area of 332 ha was carried out in Slovakia. In addition, a project was implemented for the establishment of fast-growing tree plantations on 35 ha of cropland. According to the Annual Report 2008 of the RDP 2004 – 2006, 29 320 ha of arable land had been grassed in Slovakia by the end of 2008.

Scenario with additional measures (WAM) represents scenarios of LULUCF development with applied measures expected after 2022. For forestry, no new specific measures (quantification) are currently known. In 2019, the Ministry of Forests of the Slovak Republic started the preparation of a new strategic document - the National Forestry Programme of the Slovak Republic for the period 2022 – 2030 (measure 5.30.3), which follows the evaluation of the implementation of the National Forestry Programme of the Slovak Republic and the government-approved document. On this basis, the new National Forestry Programme of the Slovak Republic focus on the key societal themes of increasing the role of forests and the Slovak Forestry in the fight against climate change, the green economy, and the development of employment in rural areas. The National Forestry Programme of the Slovak Republic for the period 2022-2030 includes monitoring indicators (qualitative and quantitative), which will then enable their incorporation into future projections. The Low carbon strategy states that support for increasing sinks in the LULUCF sector in the short term will be mainly implemented through the Common Agricultural Policy and through adaptation measures under the 2nd programming priority in Slovakia funded from the EU budget.

As regards the other categories (cropland and permanent grassland), EU countries implement the 2023 - 27 Common Agricultural Policy (CAP) through tailored national CAP Strategic Plans, targeting local needs while supporting EU objectives and the European Green Deal.

A list of the policies and measures that have been taken into account in the projections of GHG emissions/removals in the LULUCF sector under each scenario and their effect is presented in ***Table 5.3*.**

Table 5.3: *List of policies and measures implemented in the projections of GHG emissions/removals in LULUCF sector*

PAM	Scenario	Gas/Category	Measure	Effect of Measure
National Forestry Programme RDP Low carbon strategy	WEM	CO_2 / forest land, cropland, permanent grassland	Afforestation of unused cropland, establishment of stands of fast-growing trees on cropland, afforestation of cropland, measures to reduce fires	synergic
National Forestry Programme	WEM	CO_2 / forest land	Prevention of deforestation (as an integrated part of sustainable forest management)	Synergic
National Forestry Programme RDP	WEM	CO_2 / forest land	Protection of existing forests against natural disturbances (as an integrated part of sustainable forest management)	Synergic
National Forestry Programme Adaptation strategy[26]	WAM	CO_2 / forest land	Promote measures to increase carbon sinks as part of sustainable forest management. Adjust tree species composition to increase the resilience of stands to drought and reduce vulnerability to biotic and abiotic agents.	Synergic
Low carbon strategy Envirostrategy	WAM	CO_2 / forest land	Increasing forest cover through afforestation of agriculturally unused land while maintaining the diversity of non-forest habitats Create conditions for the settlement of the status of the so-called white areas	synergic
Low carbon strategy	WAM	CO_2 / forest land	Maintaining vital forests by limiting the negative impacts of climate change on forests through measures aimed at forest adaptation (support for the use of alternative management models to adjust tree species composition, use of suitable provenances).	synergic
Low carbon strategy	WAM	CO_2 / Products of harvested wood	Increasing the share of long-life wood products (HWP), including for construction purposes.	synergic
Low carbon strategy	WAM	CO_2 / cropland	Implementation of measures to increase carbon sequestration in agricultural soils and maintain high levels of organic carbon in carbon-rich soils.	synergic
Low carbon strategy	WAM	CO_2 / permanent grassland	Maintenance and restoration of grasslands.	synergic

5.6. GHG Emission Projections by Categories and Gases

Projections of emissions and removals in Forest Land Remaining Forest Land - in this category, projections of emissions and removals of CO_2, CH_4, N_2O (Gg CO_2 eq.) were calculated for the WEM and WAM scenarios (***Figure 5.14***). CO_2 sinks are mainly from forest management, CH_4, N_2O emissions from forest fires. Assuming that forests are managed as they have been for the last 8 years (WEM), we can expect a significant decrease in CO_2 sinks between now and 2050. The cause is the current age structure of forest stands. Older stands are beginning to predominate in the forests, with lower annual wood mass growth compared to younger, fast-growing stands. The results of the WAM scenario based on harvesting of stands so far would lead to a higher level of CO_2 storage by living biomass in Slovak forests over the whole simulated period, despite an expected decrease in sinks from the current level of ~ -7 200 Gg CO_2 to ~ -4 700 by 2040 and a subsequent slight increase to ~ -5 800 Gg CO_2 in 2050. The WEM scenario is based on the implementation of planned extraction and may result in a larger decrease in CO_2 sinks, peaking in 2040 at ~ -1 200 Gg CO_2, followed by a slight increase to ~ -2 300 Gg CO_2 in 2050. Changes in the tree species composition of forests have a more pronounced effect on

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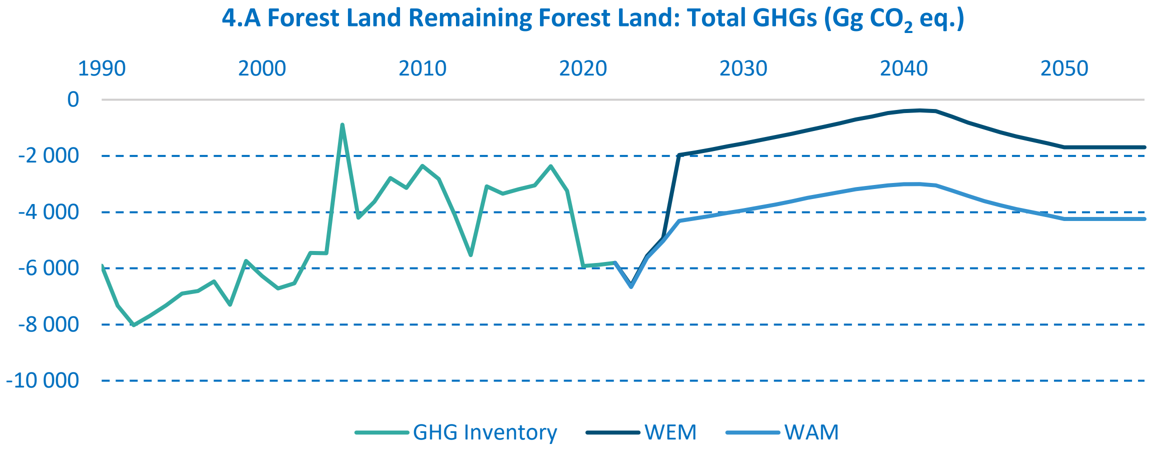
[26] Ministry of the Environment of the Slovak Republic, 2018: "Climate Change Adaptation Strategy - Update", Bratislava: s.n 2018. [Online]. http://www.minzp.sk/files/odbor-politiky-zmeny-klimy/strategia-adaptacie-sr-zmenu-klimy-aktualizacia.pdf

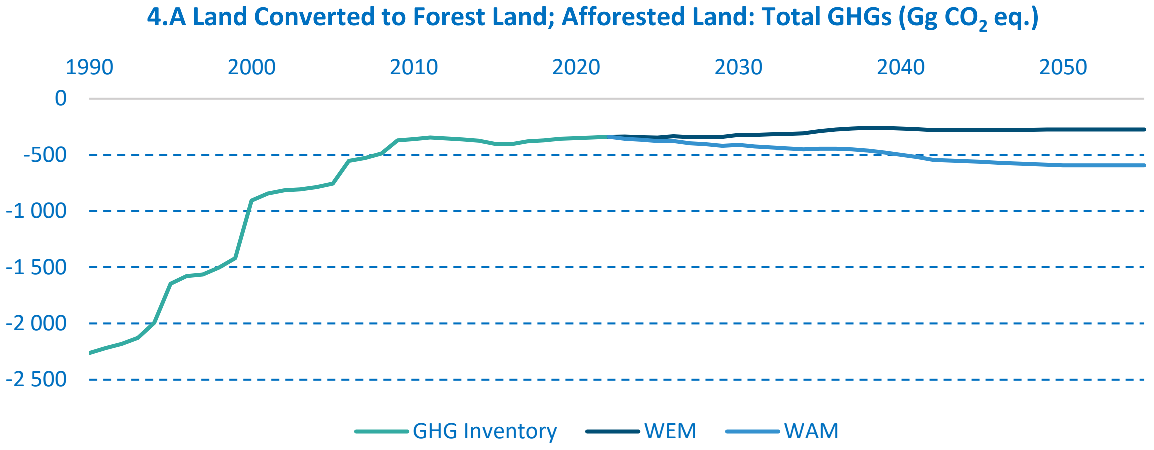
CO_2 sinks, compared to increasing forest area. In the WEM scenario, lower sinks occur due to lower forest area, unchanged tree species composition and also higher CH_4 and N_2O emissions from forest fires. The WAM scenario shows higher CO_2 removals due to higher forest area, more favourable tree species composition and lower CH_4 and N_2O emissions from forest fires.

Figure 5.14: *Trend and projections of GHG emissions and removals in Gg of CO_2 eq. in 4.A.1 - Forest Land remaining Forest Land in WEM and WAM scenarios up to 2055*



Projections of emissions/removals in Land Converted to Forest Land - in this category, projections of emissions and removals of CO_2, CH_4, N_2O (Gg CO_2 eq.) were calculated for the WEM and WAM scenarios (***Figure 5.15***). When land is converted to forest (afforestation), significant carbon sequestration or CO_2 sinks occur, mainly through new forest biomass. In the WEM scenario, there are lower sinks due to decreasing area under afforestation, unchanged tree species composition and also higher emissions from forest fires. The WAM scenario shows higher removals mainly due to higher forest cover, more favourable tree species composition and assumed lower emissions from forest fires.

Figure 5.15: *Trend and projections of GHG emissions and removals in Gg of CO_2 eq. in 4.A.2 - Land converted to Forest Land in WEM and WAM scenarios up to 2055*



Projections of emissions/removals in the Cropland - this category shows net GHG sinks (Gg) for all scenarios (***Figure 5.16*** and ***Figure 5.17***). The CO_2 sinks occur mainly in the permanent crops category and are due to additions of woody biomass in orchards, vineyards and gardens. Also, mineral soil represents a CO_2 sink in this category. CO_2 emissions in this category occur when forests are converted to cropland (deforestation) and N_2O emissions occur when soils are mineralised as a result of land-use change. Deforestation removes tree biomass and also releases carbon sequestered in fallout and forest soil. The WEM scenario shows lower removals, due to lower areas of permanent crops, higher CO_2

emissions from deforestation and N_2O emissions from soil mineralisation, compared to the WAM scenario.

Figure 5.16: *Trend and projections of GHG emissions and removals in Gg of CO_2 eq. in 4.B.1 - Cropland remaining Cropland in WEM and WAM scenarios up to 2055*

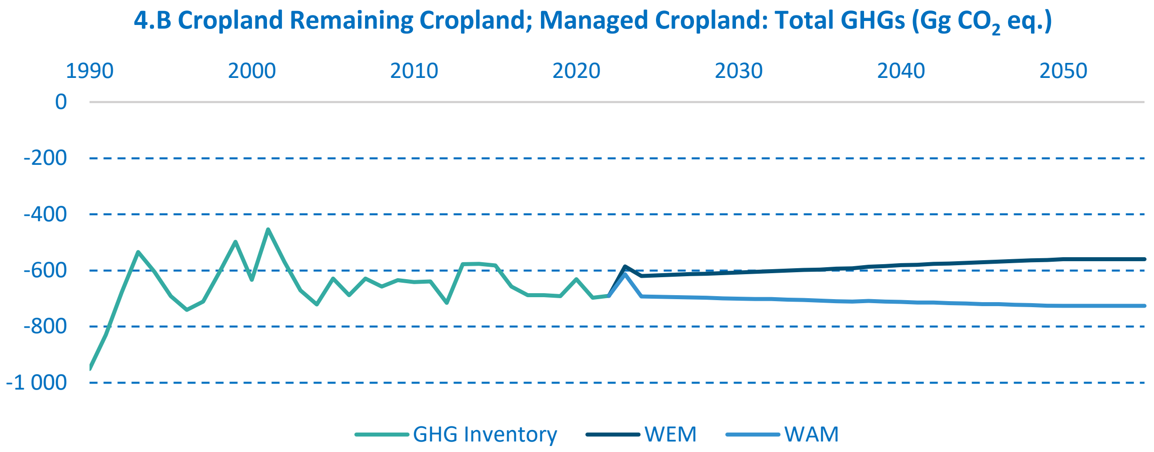
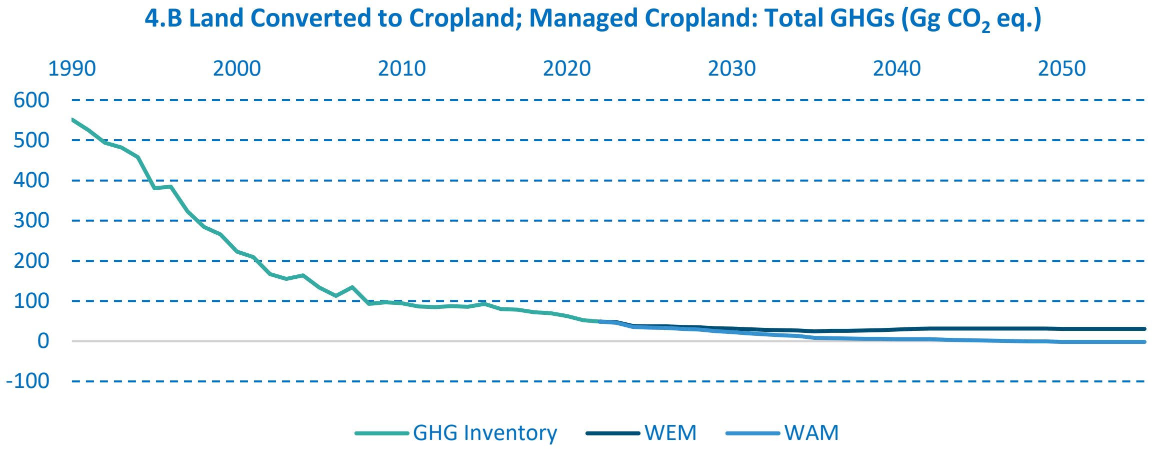
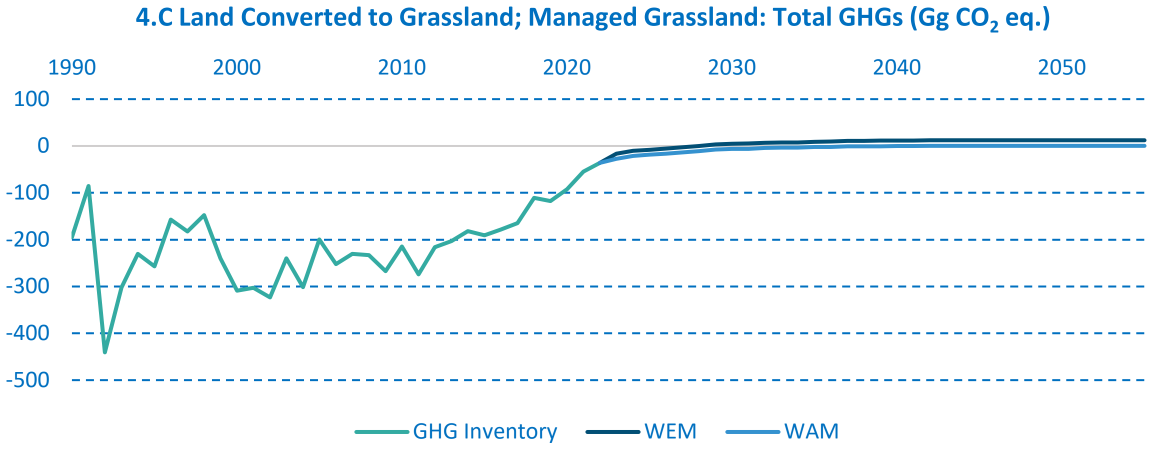


Figure 5.17: *Trend and projections of GHG emissions and removals in Gg of CO_2 eq. in 4.B.2 – Land converted to Cropland in WEM and WAM scenarios up to 2055*



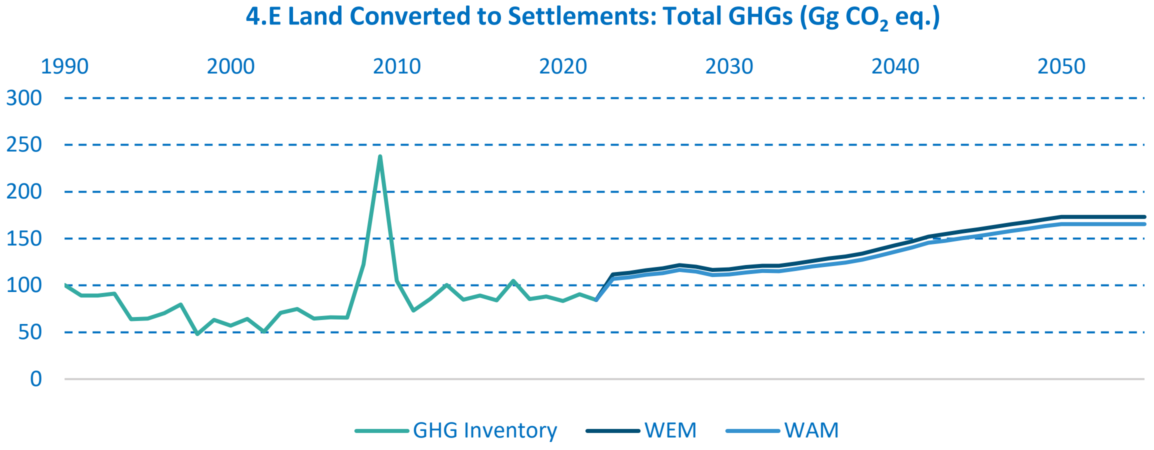
Projections of emissions/removals in Grassland - in this category, projections of CO_2 emissions and sinks (Gg) were determined for all scenarios, with the scenarios (***Figure 5.18***). Both scenarios show CO_2 sinks by 2050, but a significant decrease in sinks can be expected compared to historical data, mainly due to a decrease in acreage in this category. The WEM scenario shows slightly lower removals, due to lower areas of permanent grassland, higher CO_2 emissions from deforestation and N_2O from soil mineralisation, compared to the WAM scenario. However, the differences in removals between the two scenarios are minimal.

Figure 5.18: *Trend and projections of GHG emissions and removals in Gg of CO_2 eq. in 4.C – Grassland in WEM and WAM scenarios up to 2055*



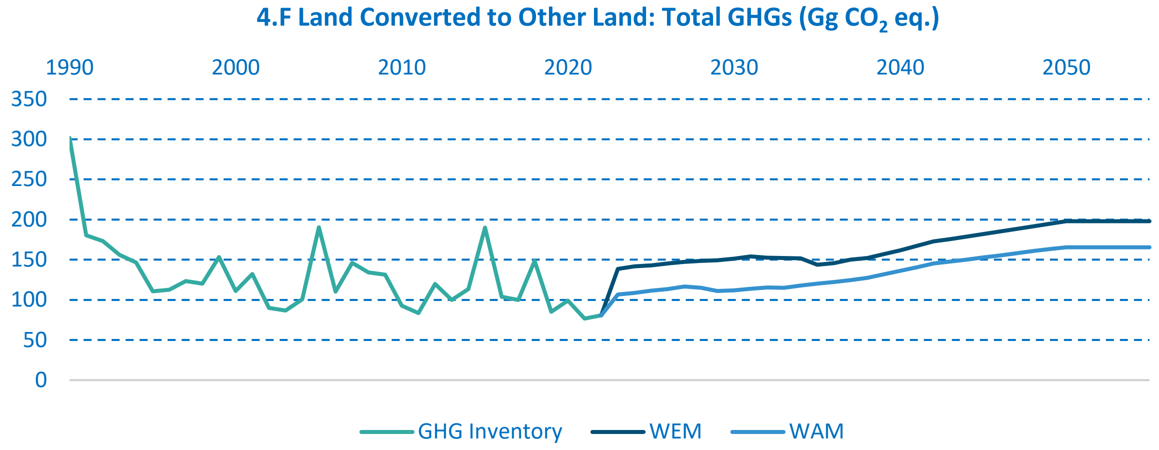
Projections of emissions/removals in Settlements - in this category, projections of CO_2 emissions (Gg) were determined for the WEM and WAM scenarios (***Figure 5.19***). Both scenarios show CO_2 emissions up to 2050 and can be expected to increase compared to historical data, mainly due to the increase in acreage in this category. This situation is mostly due to the development of transport infrastructure, industrial areas, urban and municipal development and the increase in the acreage of various infrastructure in the land. The WEM scenario shows slightly higher CO_2 emissions compared to the WAM scenario. Higher CO_2 emissions from deforestation and N_2O emissions from soil mineralisation contribute to this.

Figure 5.19: *Trend and projections of GHG emissions and removals in Gg of CO_2 eq. in 4.E – Settlements in WEM and WAM scenarios up to 2055*



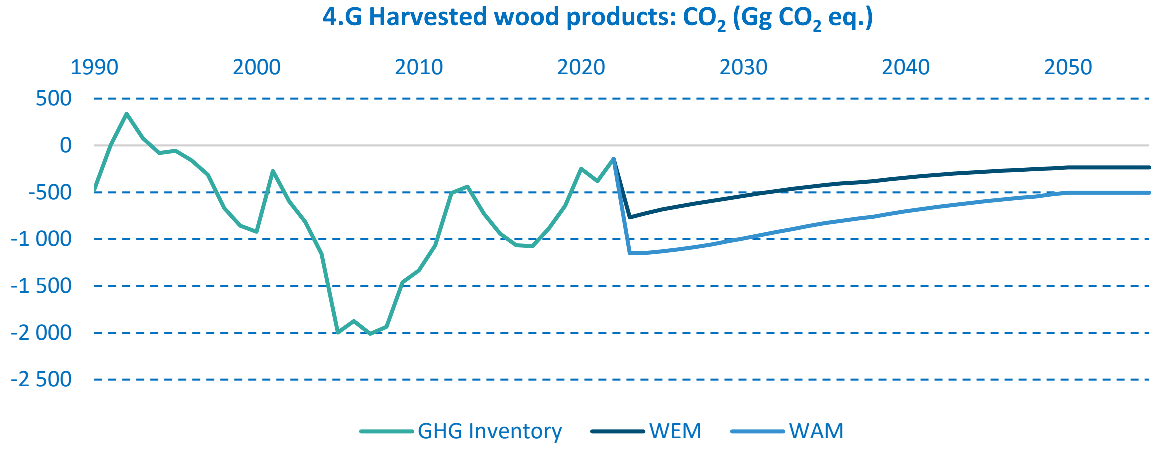
Projections of emissions/removals in Other Land - in this category, projections of CO_2 emissions (Gg) were determined for the WEM and WAM scenarios (***Figure 5.20***). Both scenarios show emissions up to 2050, an increase in emissions can be expected compared to historical data, mainly due to the increase in acreage in this category. This situation is mostly due to degradation of cropland, but also to an increase in the acreage of various infrastructure in the land. The WEM scenario shows higher CO_2 emissions compared to the WAM scenario. Higher CO_2 emissions from deforestation and N_2O emissions from soil mineralisation also contribute to this.

__Figure 5.20:__ Trend and projections of GHG emissions and removals in Gg of CO_2 eq. in 4.F – Other Land in WEM and WAM scenarios up to 2055



Projections of emissions/removals in Harvested Wood Products - increased sustainable use of harvested wood products can significantly reduce emissions through substitution effects and improve the removal of greenhouse gases from the atmosphere. This category shows CO_2 removals (Gg) for the WEM and WAM scenarios (***Figure 5.21***). CO_2 sequestration occurs through carbon sequestration in the different wood product groups. While the storage period for paper products is 2 years, it is 25 years in wood panels and up to 35 years in lumber. The WEM scenario shows lower removals compared to the WAM scenario, mainly due to the higher share of products with shorter carbon storage times.

__Figure 5.21:__ Trend and projections of CO_2 removals p in Gg in 4.G - Harvested Wood Products in WEM and WAM scenarios up to 2055



CHAPTER 6. GHG EMISSION PROJECTIONS IN THE WASTE SECTOR

In general, the more waste we produce, the more we have to get rid of. Some waste disposal methods release both pollutants and greenhouse gases into the air. Recycling is one method of reducing the impact of waste disposal on the air and the climate. However, there are also ways of managing waste that are more environmentally friendly.

The waste management sector consists of the following categories:

- 5.A Solid waste Disposal Sites
- 5.B Biological Treatment of Solid Waste
- 5.C Waste Incineration
- 5.D Wastewater Treatment

The most common disposal methods are landfill and, to a lesser extent, incineration. When waste from landfills decomposes, non-methane volatile organic compounds (NMVOCs) and methane are released into the air, and particulate emissions are released when waste is handled (PM).

Incineration is the second most common method of waste disposal in the Slovak Republic. In the past energy from incineration was not often used and waste was only disposed of. Modern plants now use waste as a fuel in the production of energy or heat, and waste is also recovered in this way. In this case, the emissions from incineration are classified in the energy sector. In our country, waste incineration contributes significantly to the number of dioxins and furans (PCDDs/PCDFs) that are emitted into the air. Since dioxins are virtually unbreakable in nature and can persist for hundreds of years, they are deposited in animal tissues and thus enter the human food chain. Dietary intake, especially of meat, fish, eggs, milk and fats, is the most important route of entry of dioxins into the human body. Incineration of waste also releases high levels of heavy metal emissions into the air. Modern waste incineration plants capture these pollutants efficiently, but this was not common practice in the past. Heavy metals are deposited in the soil and subsequently in organisms, from which they are difficult to break down. Through the food chain, contamination of organisms gradually increases. Animals at the end of the food chain, and therefore humans, are particularly at risk from heavy metals. The risk is particularly higher in coastal areas, where seafood consumption is generally higher.

Recycling is not the only sustainable way to recover waste. Composting any organic waste, such as food and garden waste, is one of them. Organic waste decomposes into mulch in a matter of weeks, which can be used as fertilizer for the soil. Many households practise small-scale composting, large-scale composting systems are also being developed with the collection of organic waste from parks and urban amenities. Similar types of organic waste can also be treated in biogas plants. Unlike composting, here the waste is decomposed anaerobically (without air access) and biogas is produced which can be further burned to generate energy that can be used for heating.

This sector also includes cremations of human and animal remains, which are also a source of air pollution through emissions of heavy metals and POPs.

Wastewater treatment also releases pollutants and greenhouse gases (both CH_4 and N_2O). In general, emissions of POPs as well as NMVOCs, CO and NH_3 occur in wastewater treatment plants, but in most cases, these are negligible amounts.

The waste sector is the most important source of methane emissions, accounting for almost 46% of total emissions in 2022. Methane emissions from this sector have increased by more than 35% compared to 1990 due to the use of a new cumulative methodology (FOD) in the solid waste landfilling category instead of the original annual methodology (Zero Order). Landfilling of waste is a significant source of methane emissions, which is released in the form of landfill gas. The volume of emissions from landfills strongly depends on the amount of landfilled waste, the content of organically degradable carbon (DOC) in this waste, and also on the capture and use of landfill gas. Methane production from landfills takes place over a period of 10 - 30 years, depending on the half-life of organic carbon in the waste. Since only very few landfills in Slovakia (11 establishments) have a built-in system for capturing and recovering landfill gas, it is released directly into the atmosphere at most landfills.

The trend in emissions from waste management has been balanced over the entire period under review since 1990. Methane is the most important gas, accounting for more than 89% of the sector's GHG emissions, followed by N_2O with almost 11%. Most emissions come from landfilling, followed by wastewater.

The Waste sector accounted for over 5% of total greenhouse gas emissions in 2022. According to WEM scenario, it can be concluded that after recalculating all four main waste treatment categories, there will be a 6% increase in GHG emissions in 2030 compared to 2005 and a 22% increase compared to 1990. Compared to 1990 a 10% increase is expected in emissions from the waste sector in 2050. In the WAM scenario there will be a 1% reduction in GHG emissions by 2030 compared to 2005 and a 14% increase compared to 1990. In 2050 a 22% reduction is expected in emissions from the waste sector compared to 1990. The trends according to the WEM and WAM scenarios are provided in the ***Table 6.1*, *Figures 6.1*** and ***6.2***.

Table 6.1: *Trend and projections of GHG emissions in Gg od CO2 eq. for Waste sector in WEM and WAM scenarios up to 2055*

Sector 5 - Waste								
WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
	Gg CO_2 eq.							
	1 929.92	1 827.68	1 704.41	1 641.37	1 567.32	1 574.55	1 528.04	1474.34

Sector 5 - Waste								
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
	Gg CO_2 eq.							
	1 929.92	1 783.95	1 590.79	1 446.58	1 342.05	1 287.03	1 250.70	1198.03

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Figure 6.1: *Trend and projections of GHG emissions in Gg of CO2 eq. for Waste sector by categories in WEM scenario up to 2055*

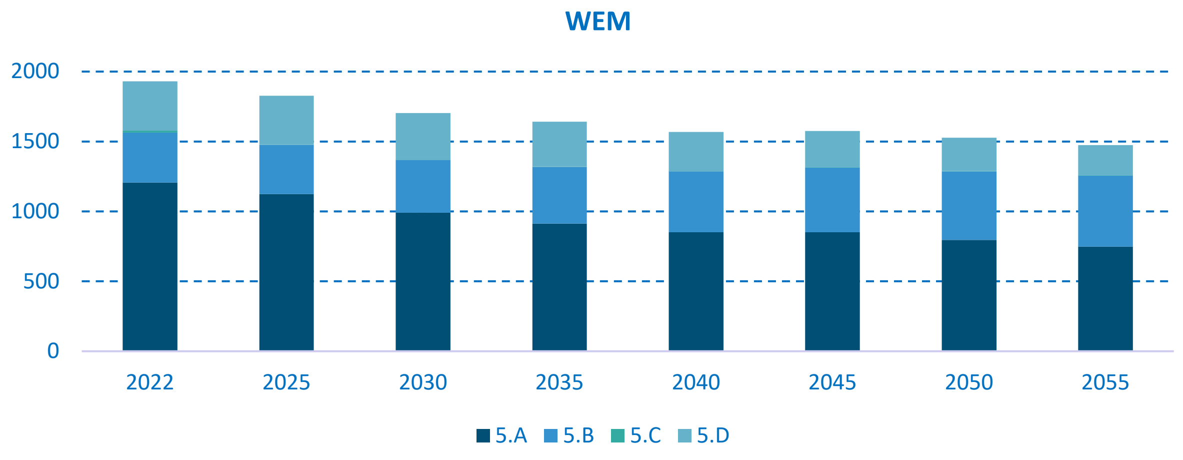
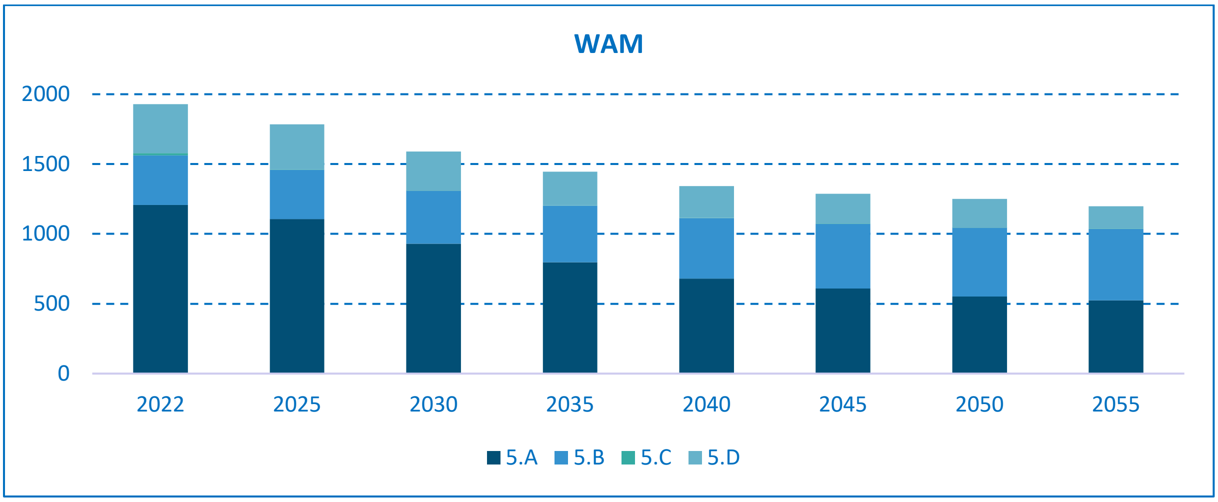


__Figure 6.2:__ Trend and projections of GHG emissions in Gg of CO2 eq. for Waste sector by categories in WAM scenario up to 2055



6.1. Historical Data of Input Parameters for Projections in Waste Sector

Municipal solid waste (MSW) production - When determining methane emissions from municipal waste landfills, according to the IPCC 2006 Guidelines methodology, key input parameters are defined as follows:

- Number of inhabitants of the country for the monitored period
- Municipal waste production in kg per inhabitant per year
- Share of landfilled waste in the total production of municipal waste per year
- Composition of landfilled municipal waste and its DOC content

The first value represents the so-called average state per year, the other two values are exactly given by calculation and the last value is more or less empirical.

The development of the population in Slovakia since 1990, together with the forecast of development until 2050, are the basic input parameters for determining greenhouse gas emissions in this category. ***Table 6.2*** shows the historical data used in the emission inventory from 1990 – 2022 according to the documents provided by the Slovak Ministry of Education.

__Table 6.2:__ Statistical information on the population of Slovakia for the years 1990 – 2022

Year	1990	1995	2000	2005	2010	2015	2020	2022
Number of inhabitants	5 297 774	5 363 676	5 400 679	5 387 285	5 431 024	5 423 800	5 460 136	5 428 792

According to the IPCC 2006 methodology, the second important data for calculating emissions from landfilling is municipal waste production. In general, according to the IPCC methodology, it is recalculated according to the country's GDP data. For Slovakia, where the data is directly tracked statistically, we start from the database of the ŠÚ SR. In the calculations, we take statistical data on the total amount of municipal waste produced in Slovakia. ***Table 6.3*** shows the data converted into kilograms per person per year.

Table 6.3: *Statistical information on the production of municipal waste for the years 1990 – 2022*

Year	Unit	1990	1995	2000	2005	2010	2015	2020	2022
Unit production MSW	kg/capita	287	236	248	289	333	348	476	479

With the growing environmental awareness of the population and the improving economic situation, there is a shift from landfilling to the recovery of municipal waste, either through material recycling, energy recovery or classic composting. This progress is best signalled by the decrease in the share of landfilled municipal waste to the total production of this waste. The amount of landfilled waste is evaluated by the ŠÚ SR on the basis of documents from the Ministry of the Environment of the Slovak Republic according to the records of individual landfill operators. ***Table 6.4*** shows data on the percentage share of landfilled municipal waste for a given year as a ratio of produced waste and landfilled waste according to the ŠÚ SR.

Table 6.4: *Share of landfilled municipal solid waste in total MSW production for the years 1990 – 2022*

Year	1990	1995	2000	2005	2010	2015	2020	2022
Proportion of landfilling from MSW	90%	88%	79%	79%	78%	69%	41%	39%

The last important data for determining emissions from landfilling is the composition of the landfilled waste and the resulting value of DOC - degradable organic carbon. Due to the small number of analyses of the composition of municipal waste from the past, which are not sufficiently representative of the entire landfilled amount of MSW, this value was more or less only estimated. ***Table 6.5*** shows the DOC values of landfilled municipal waste for a given year.

Table 6.5: *DOC value of landfilled MSW for the years 1990 – 2022*

Year	1990	1995	2000	2005	2010	2015	2020	2022
DOC value	0.124	0.124	0.141	0.141	0.143	0.129	0.120	0.120

Industrial solid waste (ISW) production - Similar to municipal waste, the input data for the calculation of emissions from industrial waste landfills are the following parameters:

- Production of industrial waste in tons per year
- The share of landfilled waste in the total production of industrial waste per year
- Amount of landfilled industrial waste with DOC content > 0

Even though the production of ISW represents a much more significant amount of waste in Slovakia than MSW (10 593 124 t / 2 597 457 t in 2022), their share in landfilling is much lower. According to data from the Waste Information System (IS Odpady), administered by the Ministry of the Environment of the Slovak Republic, over the past 15 years, solid waste has made up around 81 to 89% of the total amount of waste produced in Slovakia. Since 2014, the amount of landfilled industrial waste has decreased significantly from the original 46% to the current 16% (2022) of the total amount of ISW produced. ***Table 6.6*** shows the amounts of landfilled industrial waste for a given year.

Table 6.6: *Total production of industrial waste and amount of landfilled industrial waste for the years 2005 – 2022 (t/y)*

Year	2005	2010	2015	2020	2022
Amount of ISW	9 346 816	7 814887	8 782 522	10 516 841	10 593 124
Amount of landfilled ISW	2 888 366	2 483 878	2 707 543	1 832 869	1 721 583

For the calculation of emissions from landfilling of industrial waste, only those types of industrial waste that have a non-zero content of DOC - degradable organic carbon are important. Based on exact knowledge, individual types of waste were selected from the entire Waste Catalogue, which were assigned to individual groups according to the IPCC breakdown - Food, Wood, Paper, Textile, Sludge, Mix_package, C+D_waste. The group Wood, for example, includes all landfilled wood from individual subgroups 03 +15 +17 +19 of the Waste Catalogue. Landfill industrial wastes with a DOC content > 0 form only a minimal share of the total production of ISW and their share gradually decreases from the original 4% to the current approx. 1%. ***Table 6.7*** shows the amounts of landfilled industrial waste with a DOC content > 0 for a given year.

Table 6.7: *Amount of landfilled industrial waste with DOC > 0 for the years 1990 – 2022*

Year	1990	1995	2000	2005	2010	2015	2020	2022
Σ (t/y):	212 825	223 681	235 091	191 407	209 183	157 388	129 265	65 898

Wastewater - The development of the population in Slovakia, together with the share of connections to wastewater treatment plants since 1990, are the basic input parameters for determining greenhouse gas emissions in this category. The distribution of the population according to additional methods of wastewater management is also important. ***Table 6.8*** presents the historical data used in the emission inventory from 1990 – 2022.

Table 6.8: *Statistical information on the distribution of wastewater treatment for the years 1990 – 2022*

Year	Demography	Connected to public sewerage*	Connected to public sewerage and WWTP	Public sewerage (not connected to the WWTP)	Cesspools	Domestic WWTP	Latrines
1990	5 297 774	2 688 800	2 283 800	405 000	1 923 700	-	685 274
1995	5 363 676	2 817 800	2 592 700	225 100	1 922 699	-	623 177
2000	5 400 679	2 956 300	2 695 900	260 400	1 921 661	-	522 718
2005	5 387 285	3 075 500	2 971 400	104 100	1 845 112	26 883	439 790
2010	5 431 024	3 281 700	3 202 900	78 800	1 749 686	61 298	338 340
2015	5 423 800	3 534 341	3 495 177	39 164	1 654 260	87 453	147 745
2020	5 460 136	3 805 330	3 782 220	23 110	1 538 834	109 938	6 034
2022	5 428 792	3 856 104	3 839 074	17 030	1 455 800	112 850	4 038

6.2. Projections of Input Data and Parameters

Projections of emissions are based on the assumption of the demographic development of the Slovak population according to the Aging report for the years 2023 to 2050. According to this scenario, the population of Slovakia will decrease by 2% in 2030, by 4% in 2040 and by 7% in 2050. ***Table 6.9*** shows the assumption of demographic development in Slovakia.

Table 6.9: *Projections of demographic development in Slovakia up to 2050*

Year	2022	2025	2030	2035	2040	2045	2050
Total (median state)	5 428 792	5 410 167	5 339 138	5 260 065	5 194 922	5 135 372	5 075 429

Source: Ageing report 2024

Municipal solid waste (MSW) production per capita/year in kg - for the purposes of forecasting the average production of municipal solid waste, the standard model of the annual increase in municipal waste according to the OECD was used, which is highly correlated with GDP growth (0.69% of GDP). For Slovakia, we used the GDP growth forecast in the Aging report for the years 2023 to 2050 (potential growth rate GDP). The municipal waste production forecast for the emissions projection is in ***Table 6.10***. It should be noted that this forecast is highly debatable and uncertain, as it is based on only one indicator (GDP). Published knowledge on the growth of municipal waste points to a higher correlation of MSW with the growth of household final consumption than only with the growth of GDP. However, we do not have a forecast of this data until 2050. Secondly, it should be noted that in the years 2016 - 2021, the production of municipal waste in Slovakia grew by approximately 66 000 t per year, mainly due to significant economic growth (GDP ≈ +6% per year). According to the NBS, the gross annual income of a typical Slovak household increased by up to 31% between 2017 and 2021, which was reflected in the increase in the production of municipal waste by 27%. The second reason for the growth of MSW was also some administrative changes in the classification of waste. For the years 2024 – 2050, the annual GDP growth is only in the range of 1.50% - 2.15%. This results in the assumption of annual growth of municipal waste in the given period to a maximum of 30 000 t/y. Considering the knowledge from the last economic crisis and COVID, one can even expect a decrease or stagnation in the creation of KO or real year-on-year growth of only up to 10 000 t/y until 2040. It then follows that the specific production of MSW could be significantly lower - for the year 2030 only 493 kg/capita and for the year 2040 only 536 kg/capita.

Table 6.10: *Specific production of MSW in Slovakia by 2050*

Year	Unit	2022	2025	2030	2035	2040	2045	2050
Unit production MSW	kg/capita	480	479	515	560	604	623	635*

**the value represents only an expert estimate*

Share of landfilled municipal solid waste in total MSW production - in the years 2005 – 2012, Slovakia maintained the amount of landfilled MSW at a level of approx. 1.3 million tons per year. It was only after 2018 that the amount of landfilled MSW began to decrease to the level of approximately 1.0 million tons per year. The share of landfilled municipal waste thus fell from the original 75% to the current 39%. The forecast for the years 2025 – 2050 is very uncertain and represents only an expert estimate (***Table 6.11***).

Table 6.11: *Projections of the development of the MSW landfill fraction in Slovakia until 2050*

Year	2022	2025	2030	2035	2040	2045	2050
Proportion of landfilling from MSW	39%	36%	31%	26%	21%	16%	11%

MSW composition and degradable organic carbon (DOC) content of landfilled waste - based on the available data on the representation of biodegradable components in MSW in Slovakia, the expected DOC values for the next period were determined. The calculated DOC values are presented in ***Table 6.12***.

Table 6.12: *Projections of DOC value of landfilled MSW until 2050*

Year	2022	2025	2030	2035	2040	2045	2050
DOC value	0.120	0.107	0.107	0.107	0.107	0.107	0.107

When projecting methane emissions from landfilling of ISW waste in Slovakia, the key calculation parameters are defined by the following indicators:

GDP (economic development of a country as an indicator of waste production) – trend in GDP is generally considered to be a basic indicator of waste production - as GDP increases, the amount of waste increases. According to the OECD it is characteristic for developing countries (where Slovakia still belongs) that for every 1% increase in GDP, MSW production increases by 0.69%. However, COVID-19 and its associated measures have apparently brought a change in this paradigm. GDP growth has slowed to a halt over the last two years, yet for some types of waste (sanitary, medical, packaging) there has been a significant increase in their production or a change in the way they are managed (D1 > R1). One possible explanation is that some recycling plants were not functioning properly, or that the sharp increase in specific wastes was dealt with in the cheapest economic way (landfilling instead of recycling).

It is very difficult to predict how GDP will develop in Slovakia in the years 2025 – 2030 (2050) in connection with the current energy crisis or changes in the structure of the economy (automotive industry), as well as the consequences of some climate measures. The recession will probably dampen the growth of industrial waste production. Based on these facts, we expect the production of ISW in Slovakia to be stabilized or only very slightly growing in the coming years.

Based on these facts, we assume that ISW production in Slovakia will be stable or slightly increasing in the coming years. From the current approx. 10.6 million tonnes, we expect a stagnant state by 2030 and an increase to approx. 11.0 million tons by 2040 and 2050.

SWDS (share of landfilled ISW in total industrial waste production) - SWDS is an indicator of how much of the waste generated ends up in landfills. Despite the significantly larger production of industrial waste, the share of landfilled ISW is significantly lower than that of MSW. In Slovakia, the share of landfilled ISW has been significantly reduced from 31 - 46% in 2005 – 2015 to less than 16% today. In terms of weight, this represents a decrease in ISW landfilling from the original 2.5 to 4.3 million tons to the current approx. 1.637 million tons. In the next period, we do not expect a significant decrease in the share of landfilling, which will probably stabilize at the level of approx. 16%, which will represent about 1.718 million tons per year.

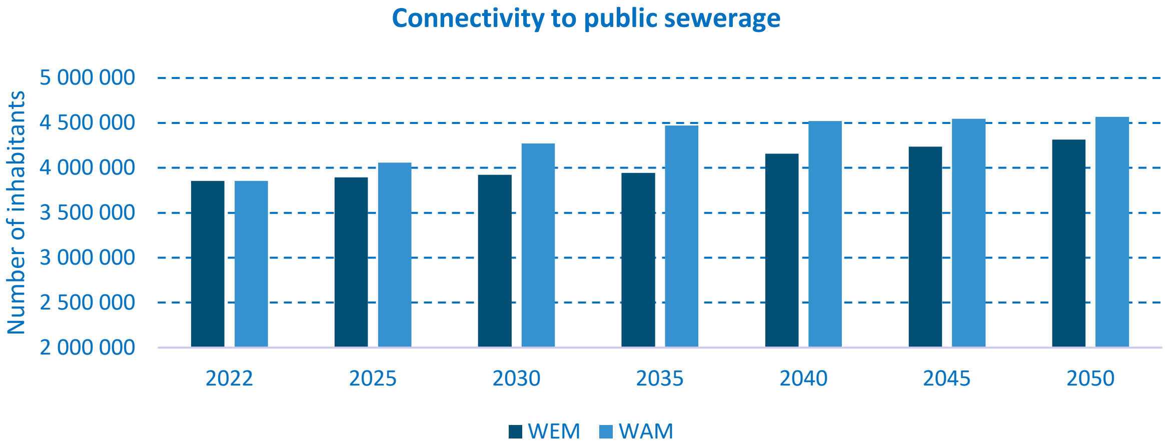
SWDS + DOC>0 (share of landfilled industrial waste containing biodegradable carbon) - SWDS + DOC > 0 represents only that part of landfilled industrial wastes which, due to their organic degradable carbon content, contribute directly to methane emissions from landfilling. In Slovakia, these types of MSW represent only a relatively small proportion of the total amount of MSW produced. The maximum of 4% was in 2009, the share has fallen below 3% since 2012 and below 2% since 2014. It has remained just above 1% since 2017. In absolute terms, this represents a decrease from the original approx. 290 000 t/y to the current approx. 100 000 t/y, although in the last three years it has even dropped below 70 000 t/y. We assume that the total amount of landfilled ISW with DOC > 0 will stabilize at around 92 000 t per year for the years 2025 to 2050.

A very important input parameter for the correct estimation of GHG emissions projections from wastewater is the proportion of households connected to public sewerage and wastewater treatment plants. These estimates under the two scenarios are shown in ***Figure 6.3***.

Table 6.13: *Projections of demographic development in Slovakia until 2050*

Year	Demography	Connected to public sewerage*	Connected to public sewerage and WWTP	Public sewerage (not connected to the WWTP)	Cesspools	Domestic WWTP	Latrines
Source	**EU REF 2024**	**Water Research Institute/Blue Report. expert estimates**					
			WEM				
2022	5 428 792	3 856 104	3 839 074	17 030	1 455 800	112 850	4 038
2025	5 410 167	3 895 400	3 876 400	19 000	1 393 700	117 700	3 367
2030	5 339 138	3 924 300	3 907 300	17 000	1 293 900	118 000	2 938
2035	5 260 065	3 945 100	3 930 100	15 000	1 192 200	120 000	2 765
2040	5 194 922	4 156 000	4 142 000	14 000	911 800	125 000	2 122
2045	5 135 372	4 236 700	4 223 700	13 000	769 800	127 000	1 872
2050	5 075 429	4 314 200	4 302 200	12 000	631 200	128 300	1 729
			WAM				
2022	5 428 792	3 856 104	3 839 074	17 030	1 455 800	112 850	4 038
2025	5 410 167	4 057 700	4 038 700	19 000	1 231 000	118 000	3 467
2030	5 339 138	4 271 400	4 255 400	16 000	943 400	121 000	3 338
2035	5 260 065	4 471 100	4 457 100	14 000	663 900	122 000	3 065
2040	5 194 922	4 519 600	4 507 600	12 000	546 600	126 000	2 722
2045	5 135 372	4 544 900	4 533 900	11 000	460 100	128 000	2 372
2050	5 075 429	4 567 900	4 557 900	10 000	375 600	130 800	1 129

__Figure 6.3:__ Trend of the number of connections to public sewerage in WEM and WAM scenarios up to 2050



6.3. Methodologies, Key Assumptions/Trends and Model Description

Projections of emissions were prepared in accordance with the methodology of the Intergovernmental Panel on Climate Change from 2006 IPCC Guidelines 2006, the methodology is consistent with the methodology for estimating emissions under Article 26 par. 3 of Regulation (EU) 2018/1999. The calculation analysis tool is based on the MS Excel platform and the calculation includes various policies and measures (in numerical formulation) defined according to the WEM and WAM scenarios. Detailed calculations of emissions projections of individual gases were carried out according to the new modified methodology "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories – Chapter 6 Wastewater Treatment and discharge". By changing the methodology for calculating emissions of methane and nitrous oxide, both the initial and future projections of both greenhouse gases were changed. Therefore, virtually all relevant data is different (usually higher) compared to the 2022 report.

There are several specially developed mathematical models for the preparation of emission projections, but due to the need for complex input data including economic and energy indicators, it is currently not possible to use them for the purposes of reporting national projections. The small Slovak economy would need its own model developed exactly for our conditions.

Further improvements in the preparation of emissions projections from the waste sector should enable the entire calculation process to be automated, which should reduce the calculation time and create space for the creation of a larger number of scenarios and the processing of sensitivity analysis.

From the previous description of the key parameters for calculating methane emissions from landfilling, it follows that two of them are of an objective nature - the development of the population over the monitored period as well as the total production of waste. These parameters are influenced by social and economic factors, which we still do not know how to regulate or guide significantly. Their future values for the monitored period are therefore relatively difficult to predict and burdened with a relatively high degree of uncertainty. The other three parameters (proportion of landfilled waste, composition of waste, capture and use of methane) are more or less subjective in nature and can be influenced by external interventions and state policies. Some of these parameters may (but may not) act synergistically and increase their impact on overall methane emissions from landfilling. For example, the construction and operation of additional waste-to-energy facilities ("incinerators" = WtE) will in any case contribute to a decrease in the amount of landfilled waste as we can see, for example, in the data from BSK and

KSK. More intensive separation of waste components will lead to a decrease of DOC in landfilled waste. The construction and operation of new MBU facilities will combine both of these parameters. However, it should be noted that the residue from MBU facilities (ending up in landfills) has a higher DOC > 0 than the residue from WtE (DOC < 0). The resulting impact of the measures on these parameters will depend on the capacity of the new facilities and their operational efficiency. However, from a time point of view, it is necessary to think with a horizon of at least 5 - 10 years, so that these policies are also reflected at the output. The last parameter - "Recovery methane" is probably also a very important and underappreciated component. Based on knowledge from European countries, where there has already been a shift away from landfilling, it is clear that the production of landfill gas and thus the amount of usable methane from landfills will subsequently decrease. On the other hand, according to the EEA report from May 2021, Slovakia is among the EU27 countries with the lowest use of landfill gas (only 5%), while the EU average is around 39%. Due to the lack of data, it is not possible to more precisely quantify the total potential of usable methane from landfills and the current efficiency of its capture and processing.

When describing the preparation of emission projections, it should be noted that according to the methodology of the IPCC 2006 Guidelines, emissions from landfilling are calculated according to the components of the landfilled waste (food, wood, paper, textiles, sludge...) and not according to the type of landfills in the sense of the Directive on landfills (2018/850 or 1999/31/EC). Considering the different development and production of municipal and industrial waste in Slovakia, as well as the requirement in previous revisions of the national inventory, emission projections were calculated separately with industrial waste = ISW (sk. 01 to 19 EWC) and separately with municipal waste = MSW (sk. 20 EWC). The resulting emission projections from the waste landfill category (5.A) are then the sum of both sub-categories.

Table 6.14: *SWAT analysis of the Waste-model*

Strengths	**Opportunities**
Compatibility with emission inventories Detailed data break down Database used is compatible with national data Model is free of charge	Incorporate to the model new technologies Versatile use of time-series
Treats	**Weakness**
Bugs can be introduced if data is incorporated manually Lack of input data introduce high uncertainty	Disconnected from macroeconomic models Too much pre-calculations needed Missing measurable indicators in national policies and strategies Data consistencies in the projection estimation process

6.4. Scenarios, Parameters and PAMs

Two scenarios have been prepared to model the emission projections for categories 5.A - Landfills and 5.D - Wastewater:

- WEM – scenario with existing measures (realistic)
- WAM – scenario with additional measures (optimistic)

For the modelling of emission projections from categories 5.B - Composting of non-biogenic waste and 5.C - Incineration of waste without energy recovery, only one scenario was prepared, namely WEM = WAM, due to the lack of relevant PAMs.

The scenario with existing measures (realistic) scenario, or also called BAU = Business as Usual, is based on the expectation that developments in solid waste landfill management will continue as observed in other EU countries undergoing economic transition.

Municipal waste production - the WEM scenario presents a projection of methane emissions from MSW with the continuation of current trends and policies in waste management in Slovakia without taking into account more significant externalities or radical economic collapses. The production of municipal waste for the years 2023 – 2050 copies the expected development of GDP with annual growth in the range of 1.48%-1.03%. At the same time, we assume that the current significant decrease in the share of landfilled waste to the total production of MSW (-3.1% per year or -40 300 t/y) will slow down and stabilize at 1% per year (-20 000 t/y). Methane emissions from landfilling of municipal waste are shown in ***Table 6.15*** below.

Table 6.15: *Trend and projections of parameters and methane emissions from MSW in WEM scenario up to 2050*

Year	Unit	2022*	2025	2030	2035	2040	2045	2050
MSW	kilo tonnes	2 597.46	2 592.79	2 750.77	2 943.83	3 137.35	3 196.77	3 524.17
MSW-> SWDS	kilo tonnes	1 021.58	941.97	861.82	775.12	669.20	521.07	400.29
CH_4 Emissions	Gg	37.94	35.26	30.87	28.40	26.45	26.51	24.59

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Production of industrial waste - the WEM scenario represents a projection with a continuation of the current trends given by the policies and measures in the waste management in Slovakia without taking into account more significant externalities or radical economic collapses. The amount of landfilled industrial waste containing biodegradable carbon stabilises at around 92 000 t/year. Methane emissions from landfilling of industrial waste are shown in ***Table 6.16*** below.

Table 6.16: *Trend and projections of parameters and methane emissions from ISW in WEM scenario up to 2050*

Year	Unit	2022*	2025	2030	2035	2040	2045	2050
ISW -> SWDS	kilo tonnes	65.90	90.27	89.40	91.14	92.02	93.61	95.07
CH_4 emissions	Gg	5.18	4.84	4.49	4.22	3.98	3.89	3.81

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

The WAM scenario presents a projection of the future development of methane emissions from waste landfills in Slovakia when new policies in waste management are introduced and applied without taking into account significant external influences (economic crisis, war, another pandemic, etc.). The scenario with additional measures (optimistic) is based on the expectation that additional supporting measures will be implemented in the waste management sector in Slovakia to increase the rate of waste recovery and reduce the amount of landfilled waste (MBU, WtE, etc.).

Municipal waste production – in the WAM scenario is expected a decrease of the “FOOD” component in municipal waste due to separate collection of kitchen waste. Similarly, the separate collection of textiles from 1.1.2025 will contribute to the reduction of this component in the MSW landfilled. Further intensification of separate collection, support of composting and aerobic digestion will also bring a decrease in the components of paper and garden waste in landfilled MSW. The deposit system of returnable packaging will probably be reflected in the reduction of the production of mixed packaging, which represents a significant share of landfilled waste. The introduction of mandatory treatment of municipal waste before landfilling and an increase in the share of waste that can be used for energy will also have a significant impact on reducing the amount of landfilled municipal waste. By 2050, there could thus be a substantial decrease in landfilled bio-degradable carbon, which also represents an adequate decrease in the DOC value by about 35% and, ultimately, a decrease in methane production from landfills. This scenario assumes a significant decrease in the amount of landfilled municipal waste, i.e. diversion of mixed MSW to other (new) facilities gradually by approx. 80 000 t per year until 2050.

In accordance with goals of European Commission for waste management, the goal for 2035 is set: landfill less than 10% of MSW and recover more than 60% MSW. The 2030 environmental strategy has a set goal for the year 2030 to landfill max. 25% and evaluate min. 60%. The WAM scenario envisages reaching the landfill goal of max. 25% in 2030 and max. 15% of MSW in 2035 with a gradual reduction of landfilled MSW from 2023 by approx. 42 000 tons per year. Methane emissions from landfilling of municipal waste are shown in the following ***Table 6.17***.

Table 6.17: *Trend and projections of parameters and methane emissions from MSW in WAM scenario up to 2050*

Year	**Unit**	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
MSW	kilo tonnes	2 597.46	2 592.79	2 750.77	2 943.83	3 137.35	3 196.77	3 524.17
MSW-> SWDS	kilo tonnes	1 021.58	886.22	684.61	482.99	281.38	206.11	146.97
CH_4 Emissions	Gg	37.94	34.81	28.83	24.38	20.43	18.37	16.75

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Production of industrial waste - WAM scenario represents a projection of the future development of methane emissions from landfilling of industrial waste in Slovakia with a slight decrease in the amount of landfilled ISW. Methane emissions from landfilling of industrial waste are shown in the following ***Table 6.18***.

Table 6.18: *Trend and projections of parameters and methane emissions from ISW in WAM scenario up to 2050*

Year	**Unit**	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
ISW -> SWDS	kilo tonnes	65.90	66.55	77.18	72.67	69.66	66.13	62.87
CH_4 emissions	Gg	5.18	4.69	4.35	4.10	3.86	3.40	2.97

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Wastewater treatment (5.D) – the scenario with existing measures (realistic) or also called BAU = Business as Usual, is based on the expectation that wastewater management developments will continue as observed over the last decade. According to these assumptions, the development of the wastewater sector is characterized by an increase in the share of the population covered by sewerage systems, with the aim of reaching 85% coverage in 2050. This scenario corresponds with the information from the Envirostrategy 2030[27], as well as with the recently adopted document "Concept of water policy of the Slovak Republic until 2030 with a view to 2050"[28]. Similar visions are also declared in the Plan for the Development of Public Sewers for the Slovak Republic[29]. This goal is also indirectly stated in the frequent statements that all agglomerations with population of over 2000 and half of the agglomerations with population of up to 2000 are planned to be part of sewage network, which in total gives the value of about 85% of population connected to sewage system. This development can be characterised by the continuous development of sewerage systems and the modernisation of wastewater treatment plants to meet the requirements of the EU water sector strategies.

The scenario assumes that the number of inhabitants using storage tanks (cesspools) will decrease (from 26% in 2022 to 12% in 2050) due to the expansion of the sewerage network from 71 to 85% and also by increasing the number of domestic wastewater treatment plants from the current 2 to 3%.

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[27] https://www.minzp.sk/files/iep/03_vlastny_material_envirostrategia2030_def.pdf

[28] https://www.minzp.sk/files/sekcia-vod/koncepcia-vodnej-politiky/koncepcia-vodnej-politiky.pdf

[29] https://www.minzp.sk/voda/verejne-vodovody-verejne-kanalizacie/

The scenario with additional measures (optimistic) is based on the expectation that developments in the wastewater sector will continue with increased financial support from the Slovak government as well as EU support under the Recovery Plan for Europe. This development is characterised by an accelerated increase in the share of the population connected to sewerage systems, with a target of 90% connection in 2050. This scenario corresponds to the aspiration to achieve a level of sewerage connection as high as in the developed Western European countries (at least 90% connection to sewers and wastewater treatment plants).

The scenario assumes that the number of inhabitants using septic tanks will decrease (from 26% in 2022 to 7% in 2050) as a result of the intensive expansion of sewerage from 71 to 90% and the construction of decentralised domestic wastewater treatment plants from 2 to 3%. This strategy corresponds to the strict requirement of the European Commission, as stated in procedure No 2016/2191, for non-compliance with certain articles of Council Regulation 91/271/EEC of 21 May 1991 concerning urban wastewater treatment. These measures are expected to contribute to a reduction of methane emissions in the municipal sector by almost 70% and in the industrial sector by 76% in 2050 compared to 2005.

6.5. GHG Emission Projections by Categories and Gases

Methane from category 5.A – waste landfills had until recently an annual upward trend due to changes in the way landfills are operated (controlled anaerobic landfills) and the increasing amount of landfilled waste. It was only after 2010 that the amount of landfilled waste with a non-zero DOC content decreased, which was manifested with a time delay of 8 years (decomposition half-time) by stopping the growth of total methane emissions from landfills. From 2021, there is already a decrease in these emissions.

In order to be able to draw up a projection of emissions, in accordance with the IPCC 2019 methodology for emissions from landfills, we need to know the following variables: demographic development and population, economic growth (GDP) and related waste production (t/y), share of landfilling (%) on overall waste management and the content of biodegradable components in landfilled waste (DOC). Each of these components is more or less independent, and its development for the projected period is conditioned by many external factors, which may be very difficult to decipher and forecast. In addition to GDP growth (and the related growth in waste production), all other factors will probably show a decline in the projected period.

These changes will lead to a decrease in methane emissions from landfills in Slovakia (together expressed as greenhouse gas emissions in CO_2 eq.).

Landfilling is a significant source of methane emissions, which are released as landfill gas. As very few landfills in Slovakia have sophisticated landfill gas capture and recovery systems, landfill gas is released directly into the atmosphere. Methane also escapes from closed landfills, from layers of waste stored for up to about 30 years, so it is very important to prevent landfilling.

Total CH_4 gas emissions from landfills in the WEM scenario reach a reduction of 3% in 2030 compared to 2005 and 22% in 2050 compared to 2005 (***Table 6.19***).

Table 6.19: *Trend and projections of methane emissions from category 5.A - SWDS in WEM scenario up to 2055*

WEM Scenario	**UNIT**	**2005***	**2022***	**2025**	**2030**	**2035**	**2040**	**2050**	**2055**
Emissions from MSW	Gg	29.36	37.94	35.26	30.87	28.40	26.45	24.59	23.31
Emissions from ISW	Gg	7.11	5.18	4.84	4.49	4.22	3.98	3.81	3.39
Emissions ΣCH_4	Gg	36.47	43.11	40.09	35.36	32.62	30.43	28.40	26.70

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Total CH_4 gas emissions from landfills in the WAM scenario reach a reduction of 9% in 2030 compared to 2005 and 46% in 2050 compared to 2005 (***Table 6.20***).

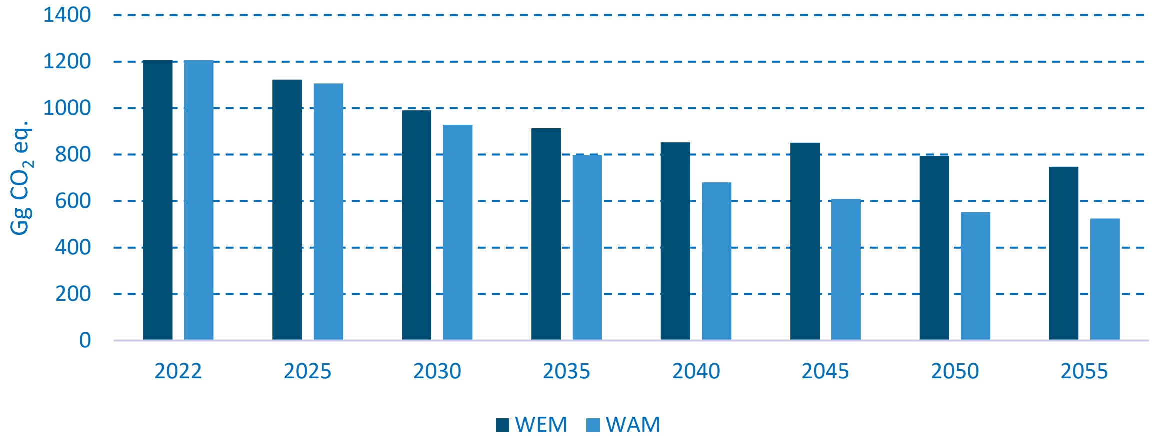
Table 6.20: *Trend and projections of methane emissions from category 5.A - SWDS in WAM scenario up to 2055*

WAM Scenario	UNIT	2005*	2022*	2025	2030	2035	2040	2050	2055
Emissions from MSW	Gg	29.36	37.94	34.81	28.83	24.38	20.43	16.75	16.19
Emissions from ISW	Gg	7.11	5.18	4.69	4.35	4.10	3.86	2.97	2.57
Emissions ΣCH_4	Gg	36.47	43.11	39.50	33.18	28.47	24.28	19.72	18.77

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Trends of total GHG emission projections according to WEM and WAM scenarios in category 5.A – Solid waste disposal are provided in ***Figure 6.4***.

Figure 6.4: *Projections of GHG emissions in 5.A - SWDS in WEM and WAM scenarios up to 2055*



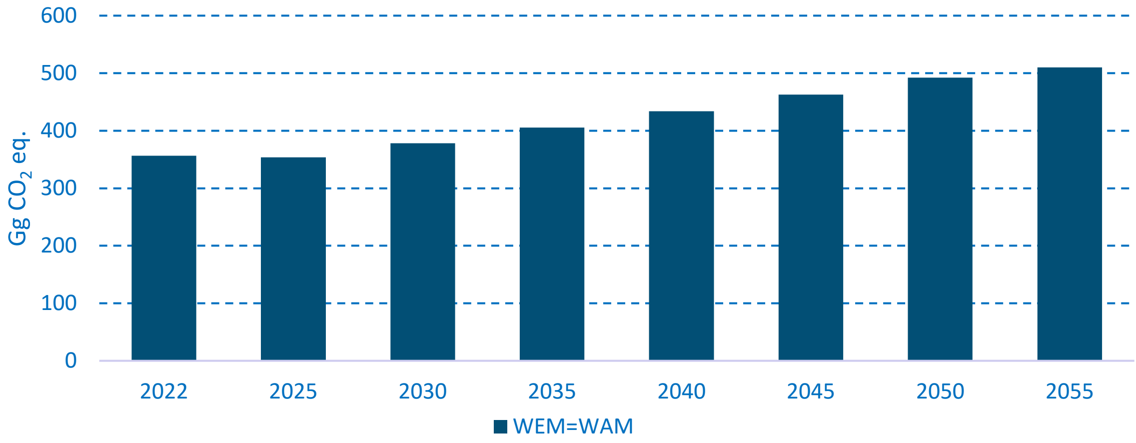
Total GHG emissions from 5.B – Biological treatment of solid waste in the WEM = WAM scenario reach an increase of 200% in 2030 compared to 2005 and an increase of 290% in 2050 compared to 2005 (***Figure 6.5***, ***Table 6.21***). Compared to the 1990 base year, they will increase by 232% in 2030 and 332% in 2050.

Table 6.21: *GHG emission projections in Gg of CO_2 eq. in 5.B - Biological treatment of solid waste in WEM = WAM scenario up to 2055*

5.B – Biological treatment of solid waste								
5.B	2022*	2025	2030	2035	2040	2045	2050	2055
	Gg CO_2 eq.							
	356.31	353.91	378.36	405.48	433.74	462.66	492.02	509.88

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Figure 6.5: *Trend and projections of GHG emissions in 5.B – Biological treatment of solid waste in WEM = WAM scenario up to 2055*



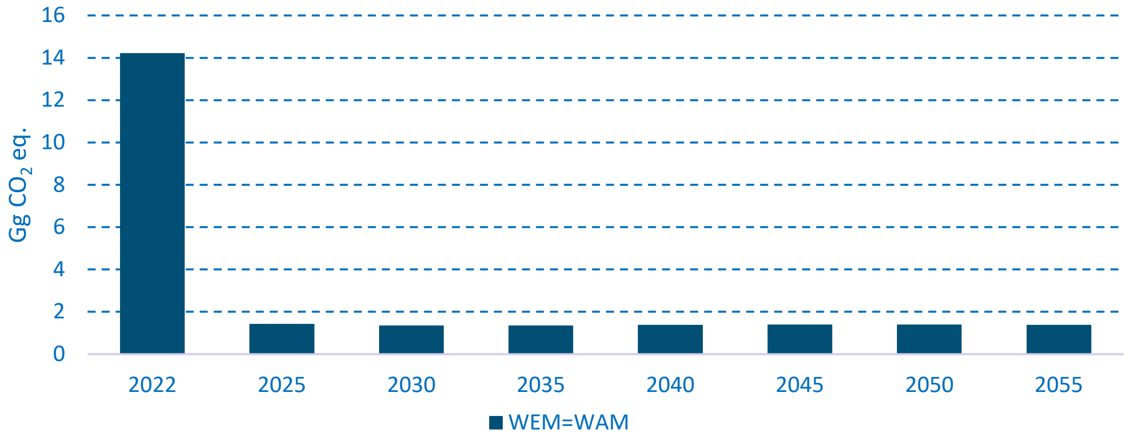
The trends of total GHG emissions from 5.C – Incineration and open burning of waste in the WEM = WAM scenario are provided in ***Figure 6.6*** and ***Table 6.22***.

Table 6.22: *GHG emission projections in Gg of CO_2 eq. in 5.B - Biological treatment of solid waste in WEM = WAM scenario up to 2055*

5.C – Incineration and Open Burning of Waste								
5.C	2022*	2025	2030	2035	2040	2045	2050	2055
	Gg CO_2 eq.							
	14.22	1.43	1.36	1.36	1.38	1.40	1.40	1.39

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Figure 6.6: *Trend and projections of GHG emissions in 5.C – Incineration and open burning of waste in WEM = WAM scenario up to 2055*



The most well-known greenhouse gases that arise when handling wastewater are methane (CH_4) and nitrous oxide (N_2O). Methane is mainly produced by the accumulation of wastewater in cesspools and septic tanks, as well as in the anaerobic digestion of sewage sludge in the production of biogas. Nitrous oxide is produced by processes of nitrogen removal from wastewater in nitrification-denitrification processes. Emissions of these gases from wastewater treatment are influenced by demographics, the level of sewerage connections and the way a country's wastewater is handled and treated.

The presented long-term projections of methane emissions from wastewater are based on the gradually increasing number of people connected to public sewerage in the near future and, on the other hand, on the reduction of the share of residents using individual systems, mainly septic tanks and cesspools. This development is implemented within the framework of financing by municipalities or water companies as operators of wastewater treatment plants. Significant aid is provided by the Government of the Slovak Republic through the Envirofond, while this aid has grown significantly especially in recent years (from 10 - 15 million to 40 million per year). Between 2020 and 2023, the Environmental Fund of Slovakia allocated considerable funds for the construction of sewerage and wastewater treatment plants. In 2021 alone, around €11.6 million has been made available through the Cohesion Fund, with a total of €96 million expected for wastewater and water infrastructure projects. These funds were part of a larger Operational Program Environmental Quality (OP KŽP) aimed at solving the urgent infrastructure needs of the country. In addition, under the new funding rounds for 2021 – 2027, almost EUR 160 million will be allocated to such projects.

These changes should lead to a significant decrease in methane emissions and N_2O emissions from wastewater treatment in Slovakia (together expressed as greenhouse gas emissions in CO_2 eq.).

Total emissions from category 5.D Wastewater expressed as CO_2 eq. for the year 2050 show a decrease of 38% in the WEM scenario compared to 2005, compared to 1990 it is even a decrease of 47%. Total greenhouse gas emissions in the WAM scenario will reach a reduction of 28% in 2030 compared to 2005 and 46% in 2050 compared to 2005.

The WEM scenario will reduce municipal water methane emissions (CRF category 5.D.1) by 29% in 2030 compared to 2005 and by approximately 58% in 2050 compared to 2005. Methane emissions from industrial wastewater (CRT category 5.D.2) are currently significantly lower than methane emissions from municipal wastewater, yet we expect further reductions in methane emissions in 2030 of approximately 71% compared to 2005 and in 2050 by approximately 74% compared to 2005. The reduction is expected mainly due to the recycling of wastewater and the reduction of organic pollution production in industrial production. N_2O emissions from households as well as from the industrial wastewater sector are relatively low, but we still expect emissions to decrease by 24% in 2030 and by approximately 24% in 2050 compared to 2005 in the WEM scenario. N_2O emissions have a slightly increasing trend, which is caused by the application of a new methodology (IPCC 2019 Refinement), which also includes the formation of nitrous oxide in the process of nitrogen removal (nitrification-denitrification) in the biological stage of the WWTP.

The WAM will reduce municipal water methane emissions (CRT category 5.D.1) by 45% in 2030 compared to 2005 and by approximately 70% in 2050 compared to 2005. From industrial wastewater (CRF category 5.D.2) we expect further reductions in methane emissions in 2030 of approximately 28% compared to 2005 and in 2050 by approximately 46% compared to 2005.

In the WAM scenario, we expect an increase in N_2O emissions from the municipal as well as the industrial wastewater sector by 54% in 2030 and by about 66% in 2050 compared to 2005. This increase is caused by the already mentioned inclusion of N_2O production in the process of biological nitrogen removal at the WWTP.

The trends according to the WEM and WAM scenarios are provided in the ***Figure 6.7*** and in the ***Table 6.23***.

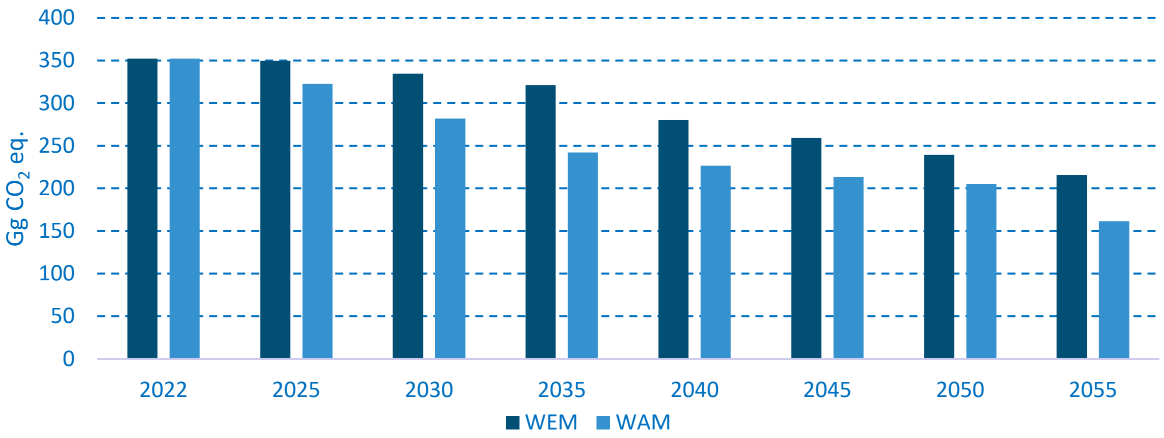
Table 6.23: *GHG emission projections in Gg of CO_2 eq. from Wastewater treatment and discharge in WEM and WAM scenarios up to 2055*

5.D – Wastewater treatment								
WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
	Gg CO_2 eq.							
	352.31	349.53	334.61	321.17	280.17	259.30	239.42	215.61

WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
	Gg CO_2 eq.							
	352.31	322.61	282.03	242.30	226.82	213.42	205.11	161.34

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Figure 6.7: *GHG emission projections in Gg of CO_2 eq. from Wastewater treatment and discharge in WEM and WAM scenarios up to 2055*



Projections of CO_2 Emissions in the Waste Sector

The only source of CO_2 emissions in Waste sector is category 5.C – Incineration and open burning of waste. In 2022 CO_2 emissions accounted only for less than 1% of total GHG emissions in the Waste sector. The trends according to the WEM and WAM scenarios are provided in the ***Table 6.24***.

Table 6.24: *Emission projections of CO_2 in Gg in the Waste sector in WEM and WAM scenarios up to 2055*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
5. Waste	3.02	3.02	0.67	0.65	0.66	0.66	0.67	0.67
C. Incineration and open burning of waste	3.02	3.02	0.67	0.65	0.66	0.66	0.67	0.67
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
5. Waste	3.02	3.02	0.67	0.65	0.66	0.66	0.67	0.67
C. Incineration and open burning of waste	3.02	3.02	0.67	0.65	0.66	0.66	0.67	0.67

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Projections of CH_4 Emissions in the Waste Sector

Methane CH_4 is the most important greenhouse gas in the Waste sector accounting for more than 89% of total GHG emissions in 2022. In the WEM scenario, methane emissions will reach 1% decrease in 2030 and 15% decrease in 2050 compared to year 2005. Compared to 1990 emissions will increase by 16% in 2030 and decrease by 1% in 2050. In the WAM scenario, methane emissions will reach 8% decrease in 2030 and 34% decrease in 2050 compared to year 2005. Compared to 1990 emissions will increase by 7% in 2030 and decrease by 23% in 2050. The trends according to the WEM and WAM scenarios are provided in the ***Figure 6.8*** and in the ***Table 6.25***.

Figure 6.8: *Emission projections of CH_4 in Gg in the Waste sector in WEM and WAM scenarios up to 2055*

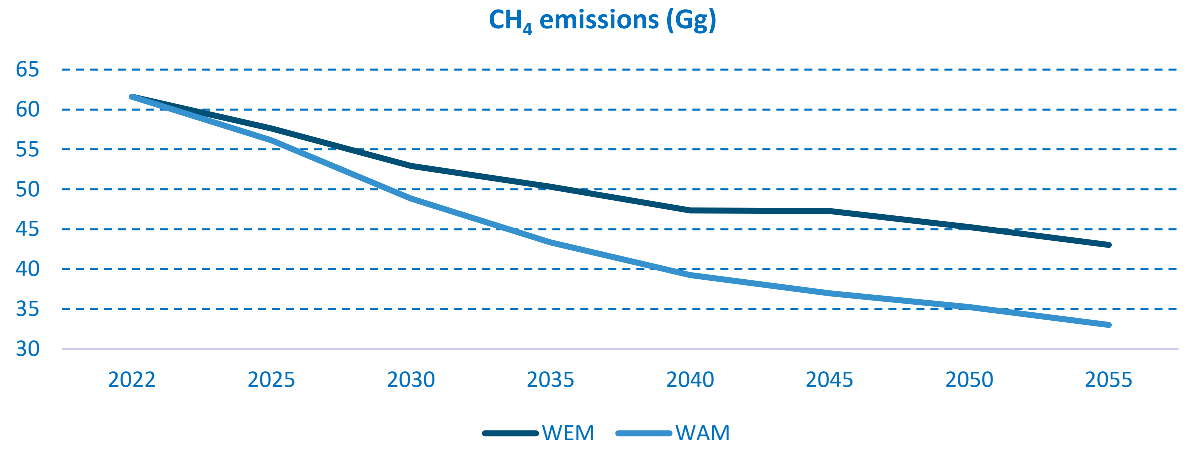


Table 6.25: *Emission projections of CH_4 in Gg in the Waste sector in WEM and WAM scenarios up to 2055*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
5. Waste	61.60	57.64	52.92	50.32	47.34	47.28	45.29	43.04
A. Solid waste disposal	43.11	40.10	35.36	32.62	30.43	30.40	28.40	26.70
B. Biological treatment of solid waste	8.56	8.29	8.87	9.54	10.25	10.99	11.74	12.08
C. Incineration and open burning of waste	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Wastewater treatment and discharge	9.54	9.24	8.69	8.16	6.66	5.89	5.14	4.26
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
5. Waste	61.60	56.13	48.85	43.34	39.24	36.99	35.26	33.01
A. Solid waste disposal	43.11	39.50	33.18	28.48	24.29	21.77	19.72	18.77
B. Biological treatment of solid waste	8.56	8.29	8.87	9.54	10.25	10.99	11.74	12.08
C. Incineration and open burning of waste	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Wastewater treatment and discharge	9.54	8.33	6.80	5.32	4.69	4.23	3.79	2.16

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*

Projections of N_2O Emissions in the Waste Sector

N_2O emissions in the Waste sector arise mostly from biological treatment of solid waste and wastewater treatment and discharge. The trends according to the WEM and WAM scenarios are provided in the ***Figure 6.9*** and in the ***Table 6.26***.

Figure 6.9: *Emission projections of N_2O in Gg in the Waste sector in WEM and WAM scenarios up to 2055*

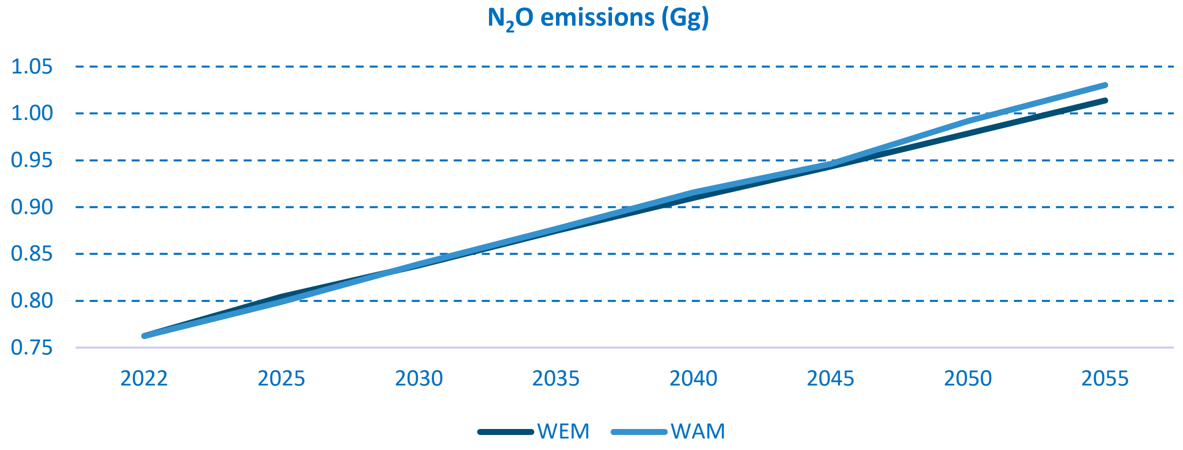


Table 6.26: *Emission projections of N_2O in Gg in the Waste sector in WEM and WAM scenarios up to 2055*

WEM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
5. Waste	0.76	0.80	0.84	0.87	0.91	0.94	0.98	1.01
B. Biological treatment of solid waste	0.44	0.46	0.49	0.52	0.55	0.58	0.62	0.65
C. Incineration and open burning of waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Wastewater treatment and discharge	0.32	0.34	0.34	0.35	0.35	0.36	0.36	0.36
WAM	**2022***	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
5. Waste	0.76	0.80	0.84	0.88	0.92	0.95	0.99	1.03
B. Biological treatment of solid waste	0.44	0.46	0.49	0.52	0.55	0.58	0.62	0.65
C. Incineration and open burning of waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Wastewater treatment and discharge	0.32	0.34	0.35	0.35	0.36	0.36	0.37	0.38

**Base year 2022; 2022 based on the GHG inventory submission 15. 3. 2024*