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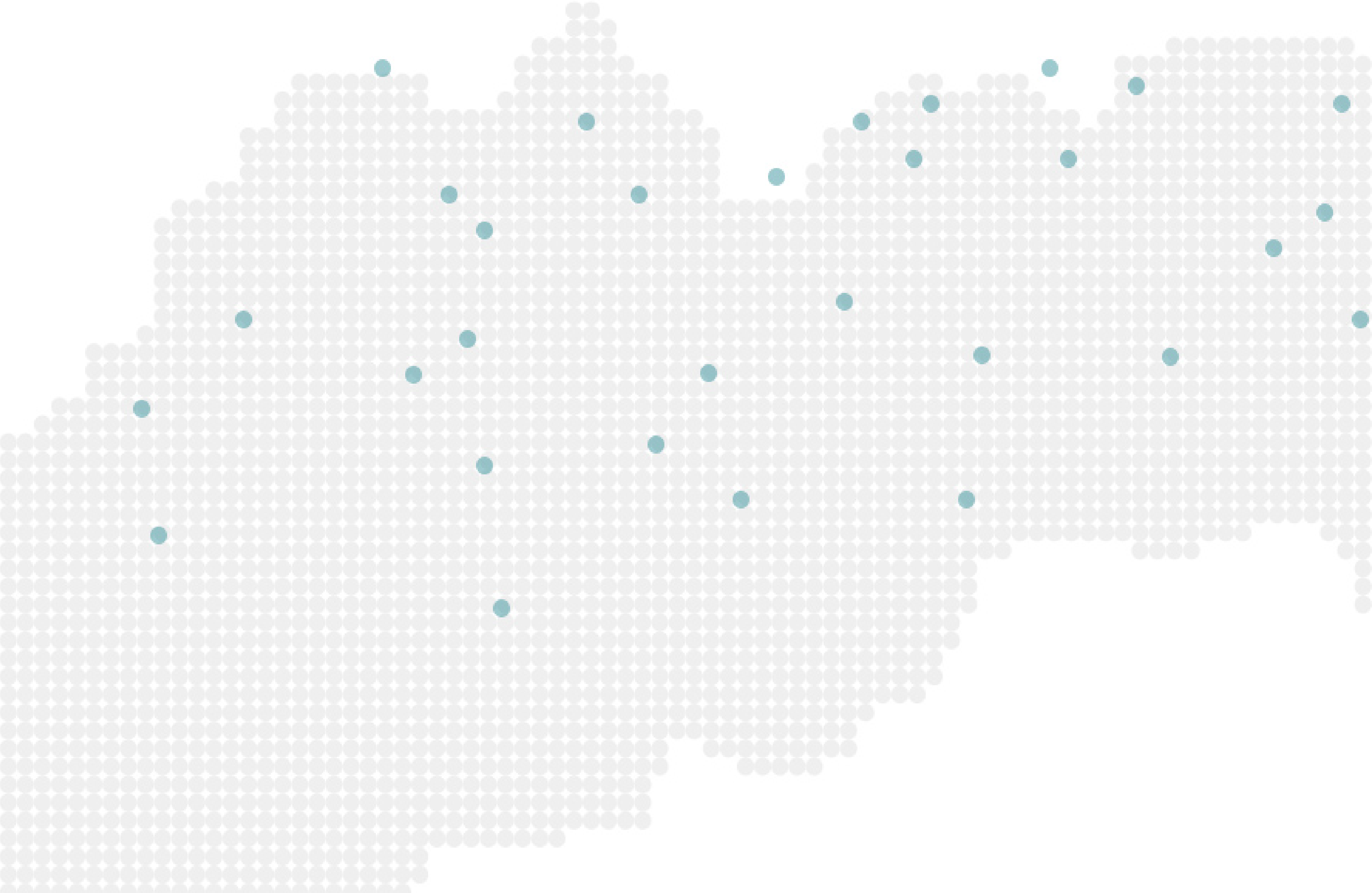

# Report on GHG Emission Projections 2023

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

Bratislava
18. May 2023

# DETAILS OF PREPARATION OF THE SUBMISSION

| **TITLE OF REPORT** | **REPORT ON GHG EMISSION PROJECTION 2023 UNDER THE REGULATION (EU) 2018/1999** |
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| **DATE OF COMPLETION:** | April 30, 2023 |
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In 2023, 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 2023 of the Slovak Republic comprises:

1. National projections of anthropogenic greenhouse gas emissions [2023] – online Tables
2. Report on Emission Projection 2023

This version of the biennial GHG emission projections is the official submission 2023 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 2023 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, 2023.

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 30. April 2023.

Slovakia submitted the latest GHG emissions inventory submission for the years 1990 – 2021 under the Energy Governance on March 15, 2022 and under the UNFCC the same data on April 15, 2023. However, presented emission projections published in this report were estimated based on the previous GHG emissions inventory submission for the years 1990 – 2020 published on October 20, 2022 and therefore the base-year defined for this estimation is 2019, as the latest reviewed inventory year.

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 2019 (submitted in 2022).

# 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 are 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.

## 1.1. Aggregated GHG Emissions

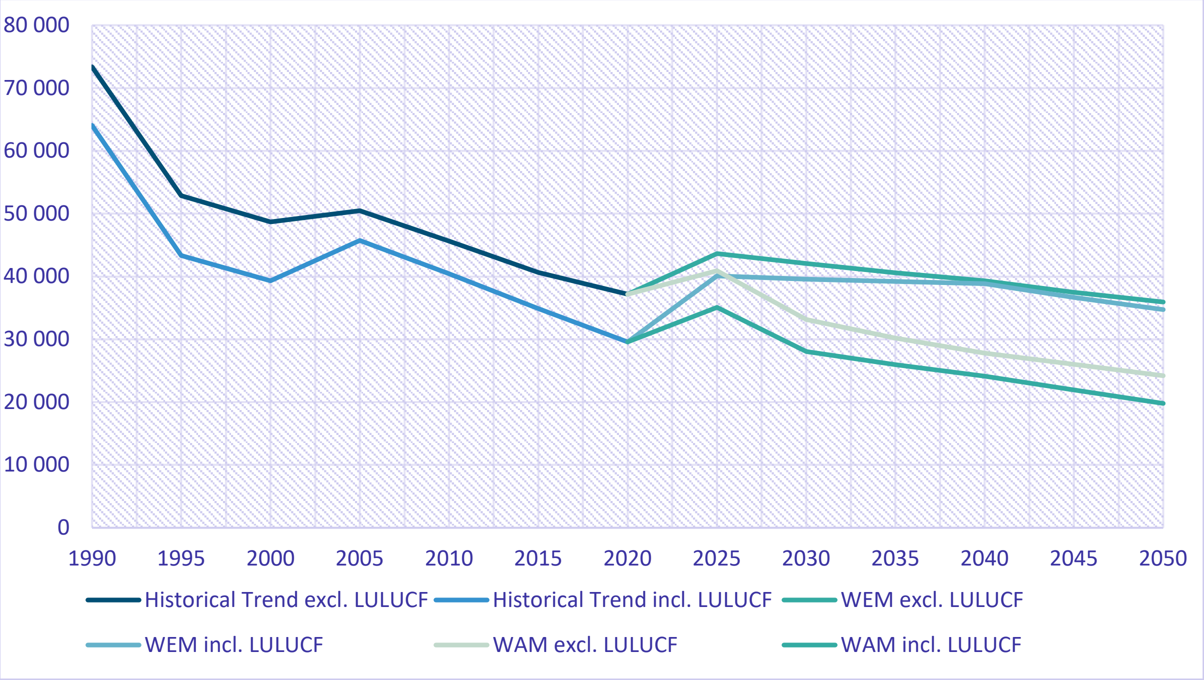
This chapter describes in figures and tables the projections of total aggregate GHG emissions for all monitored sectors of the Slovak economy.

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

| **WEM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
|---|---|---|---|---|---|---|---|---|
| Total excluding LULUCF | 39 957 | 37 179 | 43 643 | 42 065 | 40 563 | 39 329 | 37 473 | 35 934 |
| Total including LULUCF | 34 438 | 29 580 | 40 092 | 39 592 | 39 225 | 38 861 | 36 662 | 34 731 |
| **WAM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| Total excluding LULUCF | 39 957 | 37 179 | 40 911 | 33 142 | 30 172 | 27 818 | 26 003 | 24 204 |
| Total including LULUCF | 34 438 | 29 580 | 35 084 | 28 078 | 25 976 | 24 156 | 21 947 | 19 794 |

** Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Figure 1.1:*** *GHG emission trends and emission projections in Gg of $CO_2$ eq.*



## 1.2. EU ETS/ESD Split

***Table 1.2*** shows detailed split of EU ETS and ESD/ESR GHG emission projections in WEM and WAM scenarios.

***Table 1.2:*** *GHG emission projections split in EU ETS and ESD/ESR by sectors in Gg of $CO_2$ eq.*

| **WEM** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **EU ETS** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| Total excluding LULUCF | 19 903.80 | 18 169.50 | 20 953.60 | 19 234.50 | 19 091.50 | 19 319.60 | 19 169.70 | 19 096.60 |
| 1. Energy | 12 278.60 | 10 996.20 | 12 221.10 | 11 086.90 | 10 897.30 | 11 027.60 | 10 952.50 | 10 917.60 |
| 2. Industrial processes | 7 625.30 | 7 173.30 | 8 732.50 | 8 147.60 | 8 194.10 | 8 292.00 | 8 217.20 | 8 179.00 |
| **ESD/ESR** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| Total excluding LULUCF | 20 051.8 | 19 008.8 | 22 688.1 | 22 829.4 | 21 469.8 | 20 008.1 | 18 302.2 | 16 836.0 |
| 1. Energy | 14 629.9 | 13 669.7 | 17 432.4 | 17 762.0 | 16 966.2 | 15 823.8 | 14 178.7 | 12 757.9 |
| 2. Industrial processes | 1 044.4 | 941.5 | 948.6 | 827.1 | 532.7 | 331.9 | 326.0 | 319.9 |
| 3. Agriculture | 2 541.4 | 2 545.0 | 2 628.1 | 2 701.8 | 2 618.0 | 2 686.0 | 2 722.3 | 2 771.7 |
| 5. Waste | 1 836.1 | 1 852.5 | 1 679.0 | 1 538.4 | 1 352.8 | 1 166.3 | 1 075.2 | 986.5 |

| **WAM** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **EU ETS** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| Total excluding LULUCF | 19 903.8 | 18 169.5 | 20 689.8 | 12 681.0 | 12 291.8 | 12 602.7 | 12 768.6 | 12 438.0 |
| 1. Energy | 12 278.6 | 10 996.2 | 12 136.0 | 7 167.7 | 6 801.4 | 7 017.9 | 7 310.2 | 7 023.7 |
| 2. Industrial processes | 7 625.3 | 7 173.3 | 8 553.8 | 5 513.3 | 5 490.4 | 5 584.8 | 5 458.4 | 5 414.3 |
| **ESD/ESR** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| Total excluding LULUCF | 20 051.8 | 19 008.8 | 20 220.4 | 20 459.5 | 17 878.7 | 15 213.8 | 13 232.9 | 11 764.4 |
| 1. Energy | 14 629.9 | 13 669.7 | 15 370.8 | 16 003.5 | 14 043.3 | 11 749.6 | 9 857.9 | 8 506.4 |
| 2. Industrial processes | 1 044.4 | 941.5 | 947.2 | 818.5 | 500.7 | 285.9 | 272.8 | 259.5 |
| 3. Agriculture | 2 541.4 | 2 545.0 | 2 393.3 | 2 437.9 | 2 313.9 | 2 350.2 | 2 341.2 | 2 303.8 |
| 5. Waste | 1 836.1 | 1 852.5 | 1 509.1 | 1 199.5 | 1 020.8 | 828.0 | 761.0 | 694.7 |

***** *Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

# 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** | 18 959.40 | 16 094.81 | 11 543.22 | 478.98 |
| **1995** | 11 741.91 | 11 809.02 | 7 208.06 | 279.39 |
| **2000** | 12 108.22 | 9 434.03 | 6 713.60 | 147.82 |
| **2005** | 11 761.65 | 8 576.38 | 6 717.37 | 95.72 |
| **2010** | 9 176.81 | 7 664.18 | 6 710.90 | 69.85 |
| **2015** | 7 710.70 | 6 768.99 | 4 944.54 | 63.93 |
| **2019** | 7 065.45 | 6 327.49 | 4 775.36 | 83.68 |
| **2020** | 6 445.24 | 5 930.99 | 4 685.48 | 69.11 |

*Years 1990 – 2020 based on the GHG inventory submission 20. 10. 2022*

***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. Methodologies and Key Assumptions/Trends

Energy and Industry model: TIMES

Input data for the calculation of GHG projections in model TIMES from industry and 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 (format for EU ETS reports).

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.

Fuels data provided by Regulatory Office for Network Industries (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.

RES technologies provided by Ministry of Economy of the Slovak Republic - or with the association of operators of renewable resources accompanied with structure and time development. For individual types of resources, the following data are preliminary:

- 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,
- Biomass - biomass potential in TJ/year according to its type - wood, wood chips, etc.,
- Geothermal - Potential TJ/year in geographical distribution, investment costs EUR/GW.

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

- Sources included in this group are the most significant stationary sources of GHG emissions, primarily $CO_2$.
- The new sets of NIMS tentatively show this trend, especially for sources that will switch from carbon leakage (CL) to nonCL.
- The analysis is based on the data of 2018, for which there are data from files processed for the preparation of NIMS after 2020. 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.

### 2.1.2. Model Description

The main goal of the model TIMES (***Table 2.2***) 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.

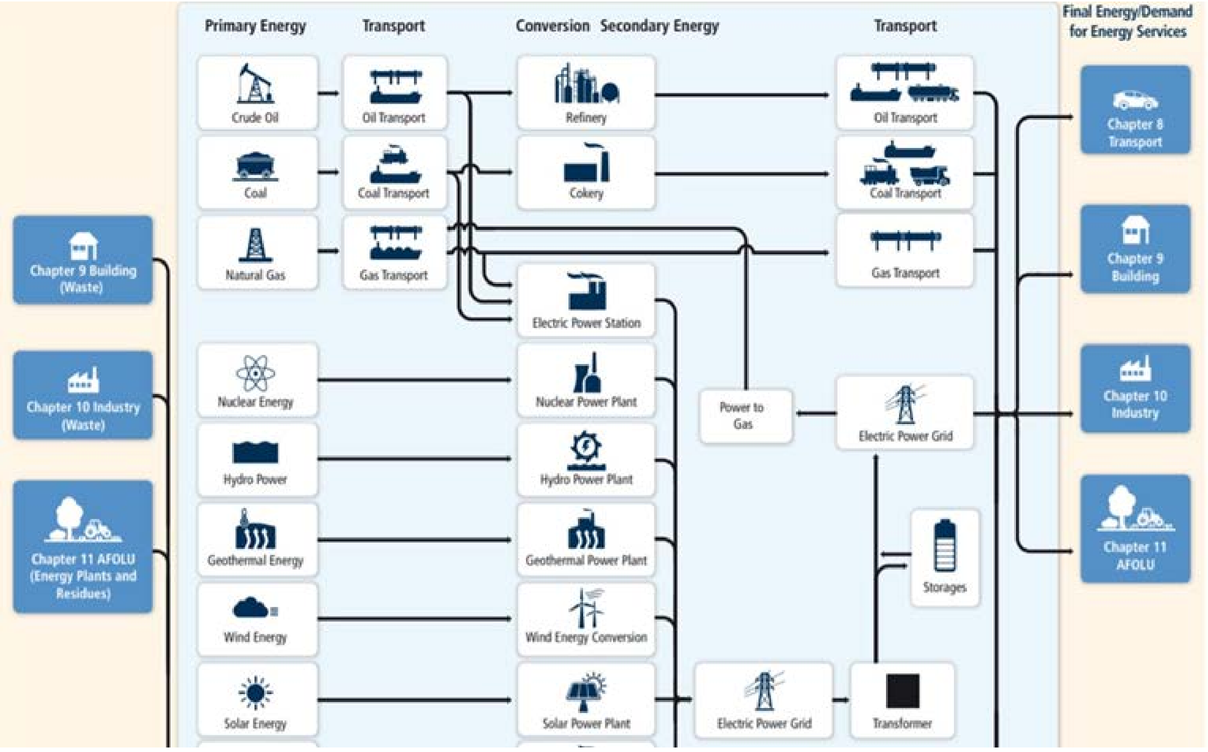
Calculation includes various policies and measures (in numerical formulation) defined according to the WEM and WAM. The model itself operates with several sectors:

- POWER (Public Electricity and Heat Production)
- IRON (Iron and Steel)
- FAT (Food and Tobacco)
- CHE (Chemicals)
- NMM (Non Metallic Mineral)
- NFM (Non Ferrous Metal)
- PPP (Pulp Paper and Print)
- OTH (Other)
- SUPP (Refinery and Petrochemicals)

***Table 2.2:*** *SWOT analysis of the TIMES model*

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

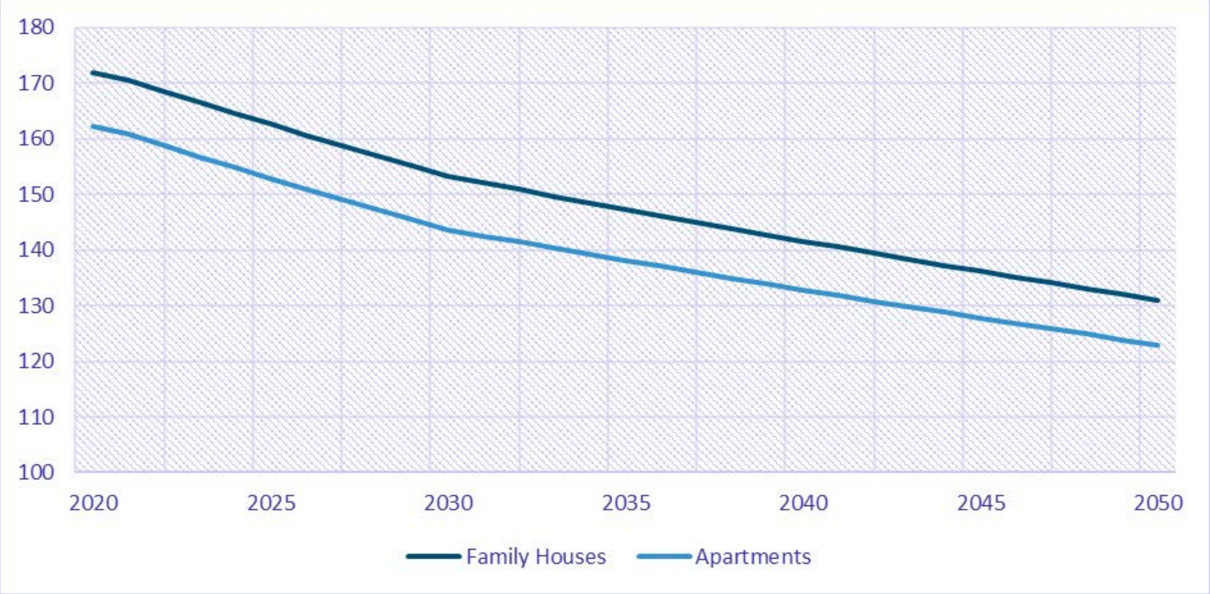
### GHG Emission Projections in Households – Excel Sheet Model

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.

***Figure 2.2:*** *Energy need for heating and hot water in family houses and apartments (kWh/year/m²)*



### 2.1.3. Scenarios, Parameters and PAMs

Base year 2019 was selected for the GHG emission projections in energy sector. Historic years 2019 – 2020 were reported based on the GHG inventory submitted on October, 20. 2022. The GWP from the 5th Assessment Report of the IPCC (AR5) were used for non-$CO_2$ gases. Results from WEM and WAM scenarios are presented in this report in accordance with the tabular format of this reporting.

With Existing Measures scenario (WEM) – scenario is equivalent to the Reference Scenario of the CPS-PRIMES model. It includes policies and measures (PAMs) adopted and implemented at the EU and at the national levels by the end of 2021 and the measures being in place to achieve the national renewables (RES) and energy efficiency targets for the year 2021. Following parameters and PAMs on the EU level were used in the GHG emissions projections of the energy sector:

- Eco-design Framework Directive (Directive 2005/32/EC);
- Energy Labelling Directive (Directive 2010/30/EU);
- Energy Performance of Buildings Directive, Energy Efficiency Directive (Directive 2012/27/EU);
- Completion of the internal energy market, including provisions of the 3rd package (Directive 2009/73/EC, Directive 2009/72/EC) - Regulation (EC) No 715/2009, Regulation (EC) No 714/2009;
- Directive on the promotion of the use of energy from renewable sources - "RES Directive"- incl. amendment on ILUC (Directive 2009/28 EC as amended by Directive (EU) 2015/1513);
- EU ETS Directive 2003/87/EC as amended by Directive 2004/101/EC (international credits), Directive 2008/101/EC (aviation), Directive 2009/29/EC (revision for 2020 climate and energy package), Regulation (EU) No 176/2014 (back-loading), Decision (EU) 2015/1814 (Market Stability Reserve), and implementing Decisions, in particular 2010/384/EU, 2010/634/EU, 2011/389/EU, 2013/448/EU (cap), 2011/278/EU, 2011/638/EU (benchmarking and carbon leakage list);
- Industrial emissions (Recast of Integrated Pollution and Prevention Control Directive 2008/1/EC and Large Combustion Plant Directive 2001/80/EC) - Directive 2010/75/EU.

- 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 buildings, which are regularly reviewed. Measures in the buildings sector represent the most important source of potential energy savings by 2030.
- Optimisation 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 District heating network (DHN), installing innovative district heating technologies, improving the supply of heat from combined heat and power plants)

Apart from above-listed PAMs at the EU level and the national policies needed to implement 2020 obligations, WEM scenario includes following specific national measures:

- Fuel switching of district heating solids-fired plants to biomass and gas;
- Phase out of solids-fired district heating plants from 2025 onwards."

With Additional Measures scenario (WAM) – is equivalent to the scenario “Decarbonization 2” from CPS-PRIMES model. This is consistent with the results presented in the Low Carbon Development Study of the Slovak Republic; however, scenario was updated based on the latest input data and parameters assumption (including consideration of development with the COVID-19 situation).

WAM scenario also considers achievement of the EU's 2050 target for emission reductions. WAM scenario have been designed as contrasting combinations of energy efficiency and renewable targets, representing the trade-offs between targets. Scenario includes Slovakia's participation in the EU ETS, median targets for renewable and energy efficiency involving a construction of new nuclear electricity-generation capacity, what will ensure continuity of the higher share of nuclear energy in the generation mix. To shape a range of possible contributions by the Slovak Republic in the achievement of the EU targets for 2030, at first a summary of possible flexibilities in targets with using several trend-variants was quantified by using the CPS-PRIMES model. The Basic, Median and Ambitious categorisations refer to the possible intensiveness of the policy targets for the year 2030. The specification of WAM scenario relies on the logic of the design of the EU scenarios and in particular, the EUCO30 scenario, which sets the 2030 targets at EU level as follows:

- GHG emissions reduction: -40% in 2030 and -80 to -85% in 2050, compared to 1990;
- EU ETS $CO_2$ emissions reduction: -43% in 2030 and -90% in 2050, compared to 2005, but this is resulting from the EU ETS carbon price trajectories as an outcome of the EU ETS market regulations including the market stability reserve as adopted;
- Non-EU ETS GHG emissions reduction: -30% in 2030 compared to 2005, with specific obligations per country;
- RES share: 27% of gross final energy demand in 2030;
- Energy efficiency: reduction of primary energy by 30% (1 321 Mtoe – excluding non-energy consumption of energy products) in 2030 compared to 2007 baseline;
- Continuing to reduce final energy consumption in all sectors after 2020. 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 2020 for new buildings.

In addition to the national policies included in WAM scenario, following national policies are also included:

- Earlier decommissioning of solid-fired utility power plants: Vojany and Nováky power plants are assumed to decommission in 2025 and 2023 respectively;
- RES support scheme in power generation: Eligible RES technologies are Solar PV, wind onshore turbines and biomass. The scenarios assume a support to 50MW in the period 2021 – 2025, followed by the support of another 500 MW based on auctions;
- Further development of nuclear energy is possible based on economic optimality;
- Carbon capture and storage is excluded;
- 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 - Programme Slovakia, Green renovation;
- Awareness campaign and education on good coal and biomass combustion practices;
- Commissioning of new nuclear power sources: Mochovce unit 3 in 2023 and Mochovce unit 4 after 2025;
- Installation of 2 Electric Arc Furnace (EAF) processing iron scrap;
- Decommissioning of Coke oven battery;
- Decommissioning of Sinter installation;
- Continuous Casting;
- Decommissioning of two blast and oxygen furnace;
- Reduction of energy coal consumption.

***Table 2.3:*** *Fuels consumption for electricity and heat production in CRF category 1.A.1a (in PJ) (excluding nuclear, hydro, solar and wind) according to WEM and WAM scenarios*

| WEM | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Solid | 26.87 | 20.03 | 16.93 | 11.12 | 0.34 | 0.31 | 0.32 | 0.32 |
| Gas | 31.48 | 35.71 | 41.3 | 39.64 | 40.97 | 44.05 | 44.96 | 46.28 |
| Liquid | 0.09 | 0.08 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Biomass | 14.56 | 14.2 | 22.93 | 22.58 | 24.23 | 24.18 | 24.33 | 24.27 |
| Waste | 0 | 0 | 0 | 1.85 | 2.16 | 2.16 | 1.94 | 1.93 |

| WAM | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Solid | 27.44 | 24.03 | 16.93 | 10.6 | 0.35 | 0.32 | 0.27 | 0.22 |
| Gas | 37.91 | 39.48 | 41.3 | 34.45 | 34.17 | 33.46 | 33.71 | 33.88 |
| Liquid | 0.09 | 0.08 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 |
| Biomass | 14.56 | 14.2 | 22.93 | 28.11 | 31.72 | 35.05 | 36.56 | 37.46 |
| Waste | 0 | 0 | 0 | 1.89 | 1.5 | 0.55 | 0.44 | 0.27 |

***** *Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Table 2.3*** shows decreasing trend in using of solid fossil fuels and projected trend in other fuels. In both WEM and WAM scenarios, there is a strong impact of decommissioning of solid-fired power plants.

The change of the fuel mix based in the current CHPs, as main heat producers for the district heating system, is applied in the WEM and WAM scenarios. In some CHP facilities, the so-called fuel blend is available without new technology investments. This applies especially to producers with a fluid boiler, which is capable of co-combustion of biomass together with natural gas or solid fuels such as hard coal and lignite.

Both scenarios also include fuel switch, where there is a complete change of the fuel mix to another. This applies to CHP facilities with combustion of solid fuels. These are the largest producers of district heat included in the EU-ETS.

The most important facilities included in the emissions trading system have a planned fuel mix change in the cities of Košice, Martin, Zvolen, Žilina and Žiar nad Hronom. These cities are geographically situated differently and therefore the availability of biomass is also different. In some cases, it is currently not possible to phase out natural gas as the primary fuel for heat production for the district heating system of buildings. This mainly concerns the two largest cities in Slovakia, Bratislava and Košice and other regional cities where biomass is not available in the required extent. Natural gas is also used for combustion stabilization. As a result of one of the measure in LULUCF category, the domestic availability of biomass is limited in both scenarios and that is the reason why the decline of natural gas consumption is not so significant.

Use of alternative fuels (TAP) in heat production facilities are also expected to a greater extent. However, the share in the total mix is limited due to the lack of input data such as price and availability.

In the future, the implementation of a geothermal energy use in the city of Košice is planned. However, the current WAM scenario still provides insufficient technical data for modelling.

As a part of reducing dependence on fossil fuels, a project to use waste heat from a nearby municipal solid waste incinerator has begun to be prepared in the capital city.

Based on the result of model TIMES, Slovakia would become electricity exporter in the WEM scenario, based on projections of electricity consumption provided by the SEPS (Slovak Electricity Transmission System) in individual sectors such as households, services, industry, agriculture and transport, after commissioning two new nuclear reactors in 2023 and 2026.

As a result of the increasing demand for electricity in all sectors and decommissioning of the Nováky and Vojany power plants in 2023 respectively 2030, this trend of electricity exports will drop to zero in 2040. After this year, Slovakia will have to import electricity again due to the increase in demand for electricity until 2050. Both sources are partially replaced by combined gas cycle power plant in Malženice. In the WEM scenario, the production from renewable energy sources (RES) (solar, wind, hydro) will not change significantly due to limiting factors such as the actual technical life, the availability factor in our region.

Hydro power plants are not so strongly dependent on these factors, therefore the production of electricity is more stable and more or less constant throughout the year. Changes in production for these types of sources are on a seasonal basis, not day and night like solar and wind power plants.

In any case, in the WEM scenario, capacity expansion is not planned, therefore, electricity production from solar, wind and hydro is constant throughout the entire period.

In the WAM scenario, the export of electricity is higher due to the measure of installing new capacities in the RES category. Wind and Solar capacity increase from 0.0032 GW to 0.46 GW respectively from 0.400 GW to 4.4 GW. Capacity increase is based on more ambitious potential availability factors from PRIMES model for Slovakia.

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

***Table 2.4*** 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. A shorter decrease in emissions is expected in industrial energy. The increase in emissions compared to 2019 and 2020 is due to the recovery of production after the crisis years.

***Table 2.4:*** *Trend of GHG emission projections in Gg of $CO_2$ eq. by categories in the WEM and WAM scenarios 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 |
|---|---|---|---|---|
| | | **WEM** | | |
| **2019*** | 7 065.45 | 6 327.49 | 4 775.36 | 83.68 |
| **2020*** | 6 445.24 | 5 930.99 | 4 685.48 | 69.11 |
| **2025** | 6 166.78 | 7 568.39 | 4 671.36 | 88.80 |
| **2030** | 5 572.33 | 7 032.14 | 4 381.12 | 90.71 |
| **2035** | 5 362.75 | 7 051.90 | 4 187.17 | 91.03 |
| **2040** | 5 434.80 | 7 113.74 | 3 932.30 | 90.06 |
| **2045** | 5 419.86 | 7 095.25 | 3 770.30 | 88.24 |
| **2050** | 5 413.41 | 7 057.91 | 3 608.31 | 86.43 |

| YEAR | 1.A.1 ENERGY INDUSTRIES | 1.A.2 MAN. INDUSTRIES AND CONST. | 1.A.4 OTHER SECTORS | 1.A.5 OTHER |
|---|---|---|---|---|
| | | **WAM** | | |
| **2019*** | 7 065.45 | 6 327.49 | 4 775.36 | 83.68 |
| **2020*** | 6 445.24 | 5 930.99 | 4 685.48 | 69.11 |
| **2025** | 6 163.56 | 7 302.78 | 4 556.31 | 88.80 |
| **2030** | 3 367.30 | 6 802.04 | 4 218.64 | 90.71 |
| **2035** | 3 006.36 | 6 821.98 | 3 935.09 | 91.03 |
| **2040** | 3 183.36 | 6 884.10 | 3 619.47 | 90.06 |
| **2045** | 3 547.65 | 6 866.97 | 3 395.95 | 88.24 |
| **2050** | 3 303.29 | 6 831.00 | 3 172.44 | 86.43 |

*** Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

## 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 (0.01%)
- 1.A.3.b Road transport (96.38%)
- 1.A.3.c Rail transport (1.15%)
- 1.A.3.d Water transport (0.08%)
- 1.A.3.e Other mode of transport (e.g. pipeline transport) (2.38%)

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 97% of all emissions in 2019 came from road transport, including pipeline transport. If pipeline transport, which is included in the EU ETS emissions trading system, were not counted, this would account for almost 99% of all transport emissions. 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 2.3***, ***Table 2.5***), with the WAM scenario peaking as early as 2023, followed by a slow and gradual decline in GHG emissions, which are only 10% 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 7% above 1990 levels in 2050. 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.

***Figure 2.3:*** *Evolution of greenhouse gas emissions in Gg $CO_2$ equivalents under the WEM and WAM scenarios*

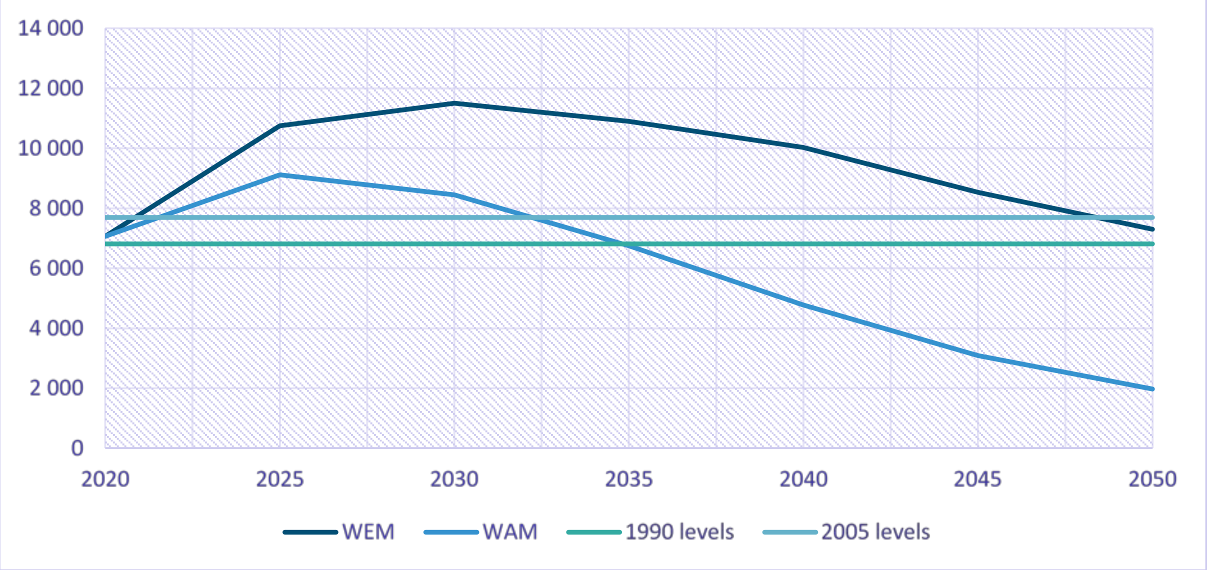


***Table 2.5:** Overall trend of GHG emissions (1990 – 2020) and emission projections in Gg of $CO_2$ eq. in WEM and WAM scenarios in the transport sector (1.A.3)*

| YEAR | WEM | WAM |
|---|---|---|
| **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 |
| **2019** | 8 123.05 | 8 123.05 |
| **2020** | 7 061.50 | 7 061.50 |
| **2025** | 10 747.15 | 9 120.54 |
| **2030** | 11 502.98 | 8 451.44 |
| **2035** | 10 898.07 | 6 750.67 |
| **2040** | 10 027.19 | 4 777.30 |
| **2045** | 8 535.96 | 3 092.81 |
| **2050** | 7 299.58 | 1 974.33 |

*Base year 2019; 1990-2020 based on the GHG inventory submission 20. 10. 2022*

### 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 of the Ministry of Environment of the Slovak Republic (IEP MŽP SR). 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[1] 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

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

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 - 2019. The data for this time period were obtained from IS EVO as a by product of a project[2]. 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".

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 2.4*** (WEM scenario) and ***Figure 2.5*** for (WAM scenario).

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[2] 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

*Figure 2.4:* *Fleet development by fuel types in WEM scenario*

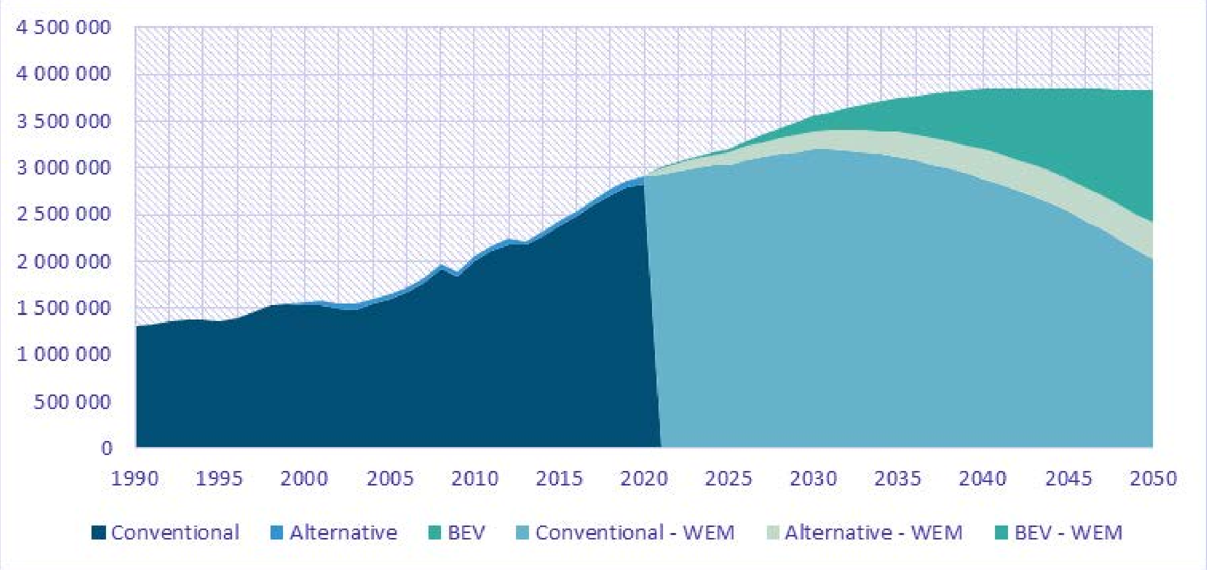
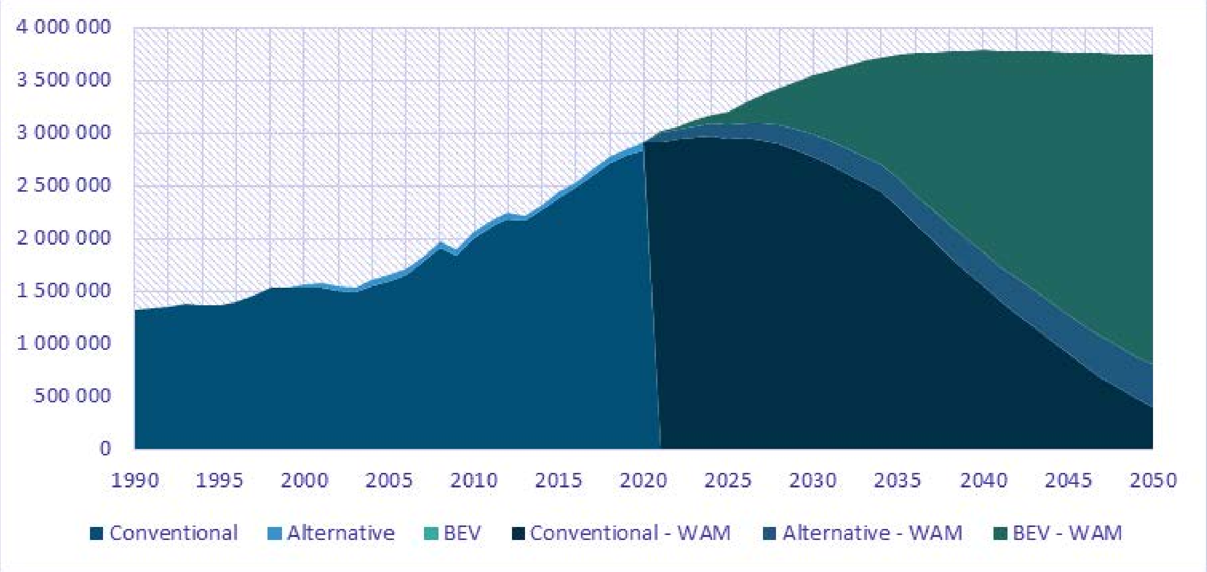


*Figure 2.5:* *Fleet development by fuel types in WAM scenario*



### 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 the 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 2.6***). In the case of the WAM scenario, this peak could happen earlier, sometime around the year 2024. For alternative engines, there is a slightly lower increase in the WAM (***Figure 2.7***) and this is due to the greater weight given to BEV in the fleet development for this scenario (***Figure 2.8***), which have exponential growth up to 2050.

**Figure 2.6:** *Development of conventional fuel passenger cars in WEM and WAM scenarios*

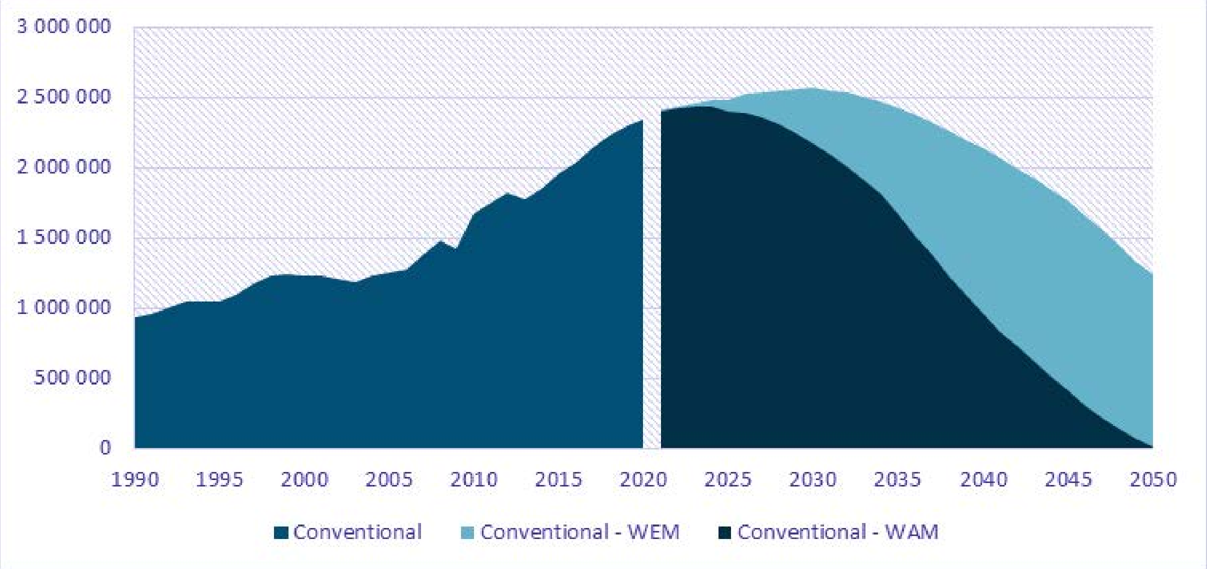


**Figure 2.7:** *Development of alternative fuel passenger vehicles (CNG, LPG, LNG and hybrid) in WEM and WAM scenarios*

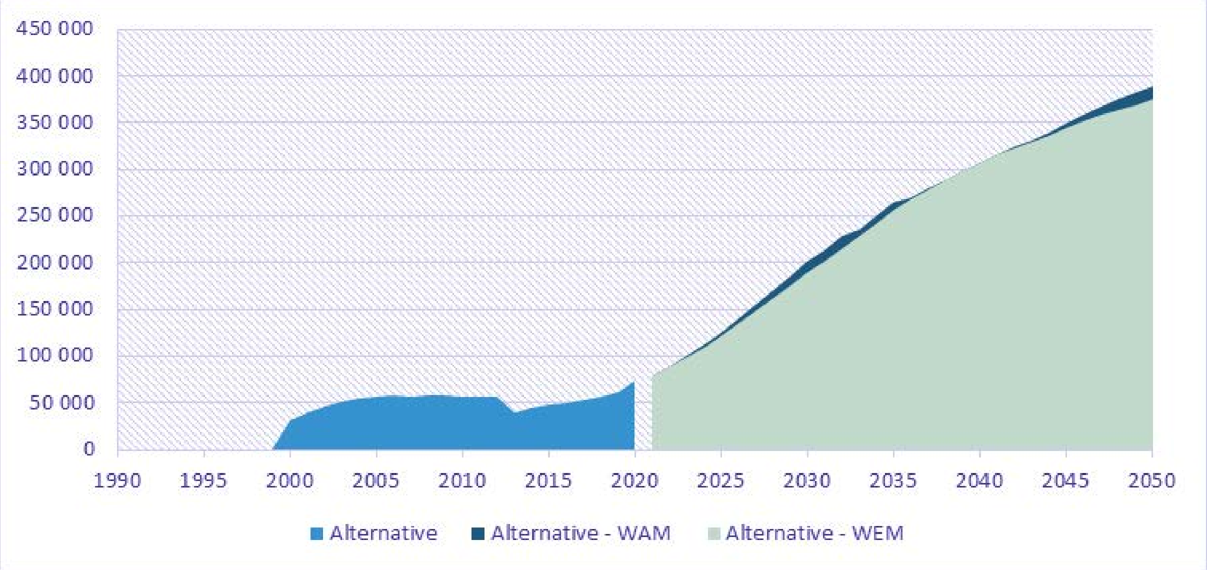
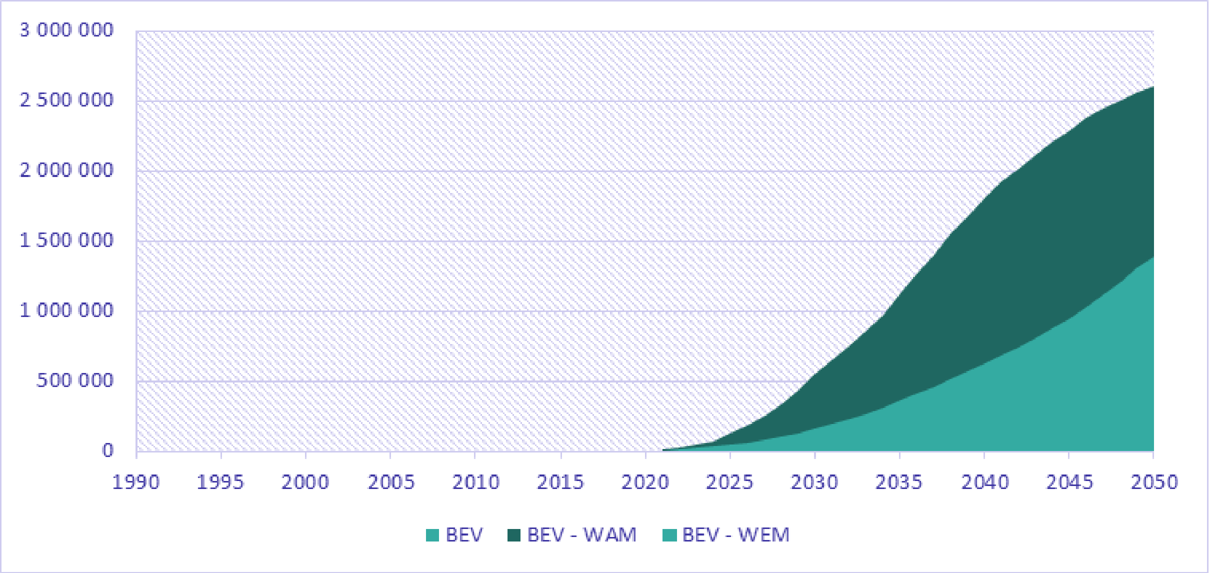


***Figure 2.8:*** *Development of electric and hydrogen powered passenger cars in WEM and WAM scenarios*



## 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 450,000 vehicles in 2050 (***Figure 2.9***). For LCVs, there is little expectation of a turnover to alternative fuels as there would be a reduction in transport space (***Figure 2.10***) 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 (***Figure 2.11***).

***Figure 2.9:*** *Development of light-commercial vehicles with conventional in WEM and WAM scenarios*

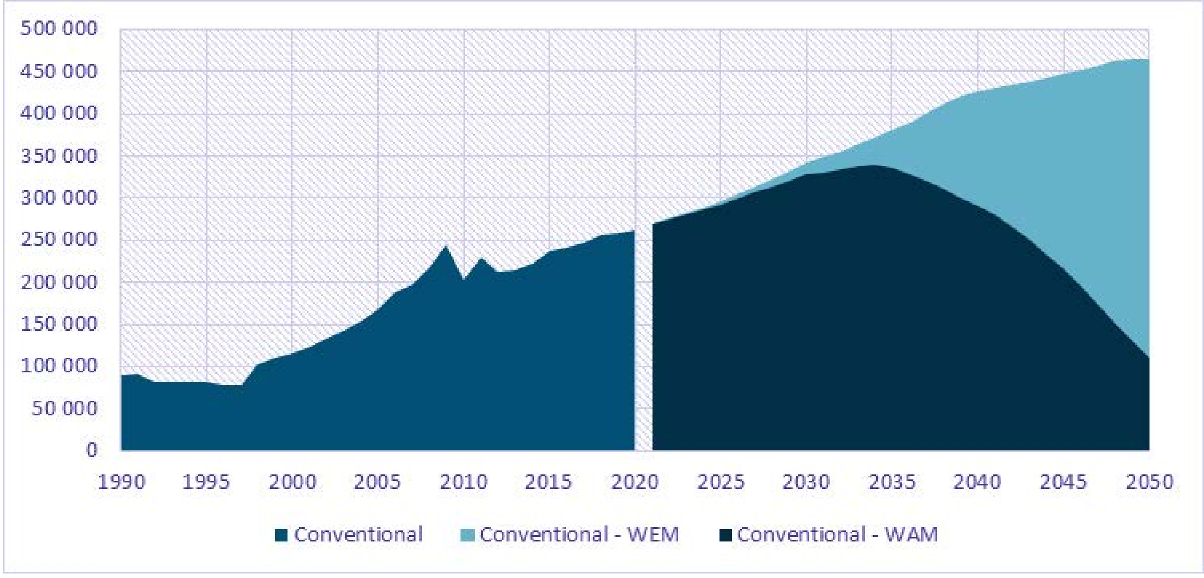


***Figure 2.10:*** *Development of light-commercial vehicles with alternative propulsion in WEM and WAM scenarios*

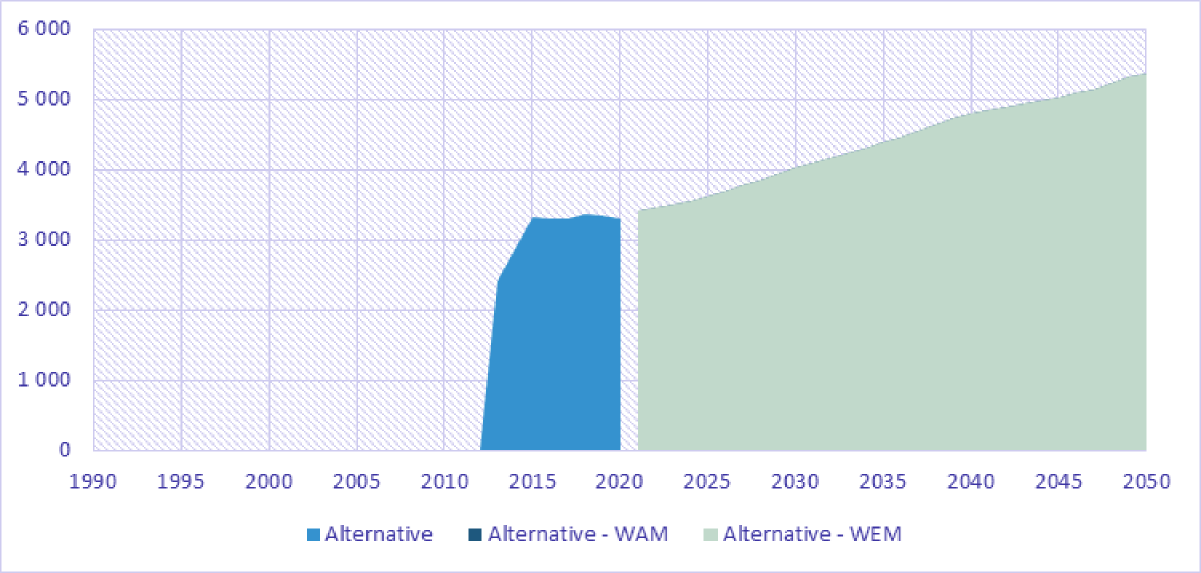
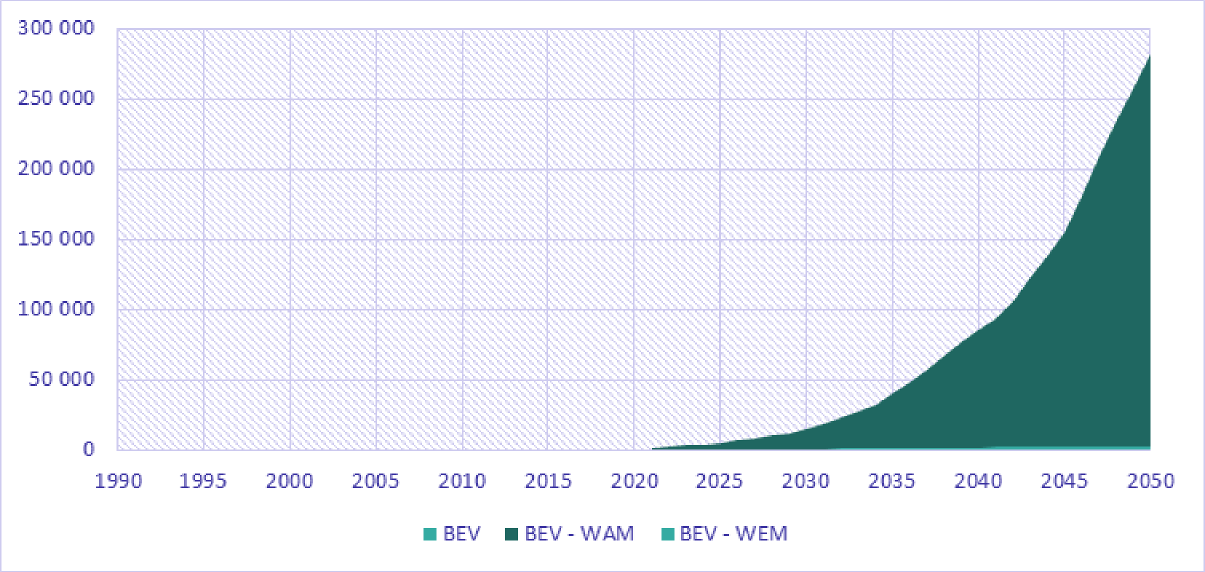


***Figure 2.11:*** *Development of electric and hydrogen light-commercial vehicles in WEM and WAM scenarios*



### 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. At the same time, these projections yet do not reflect the European Commission’s latest proposal to end the sales of GHG-emitting HDV around the year 2040.

In the WEM scenario, there is a steady increase in the number of HDVs (***Figure 2.12***) 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 (***Figure 2.13***) 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 (***Figure 2.14***). This is limited, as for the other categories, only by the production capacities of the car manufacturers.

**Figure 2.12:** *Development of HDV fleet with conventional engine in WEM and WAM scenarios*

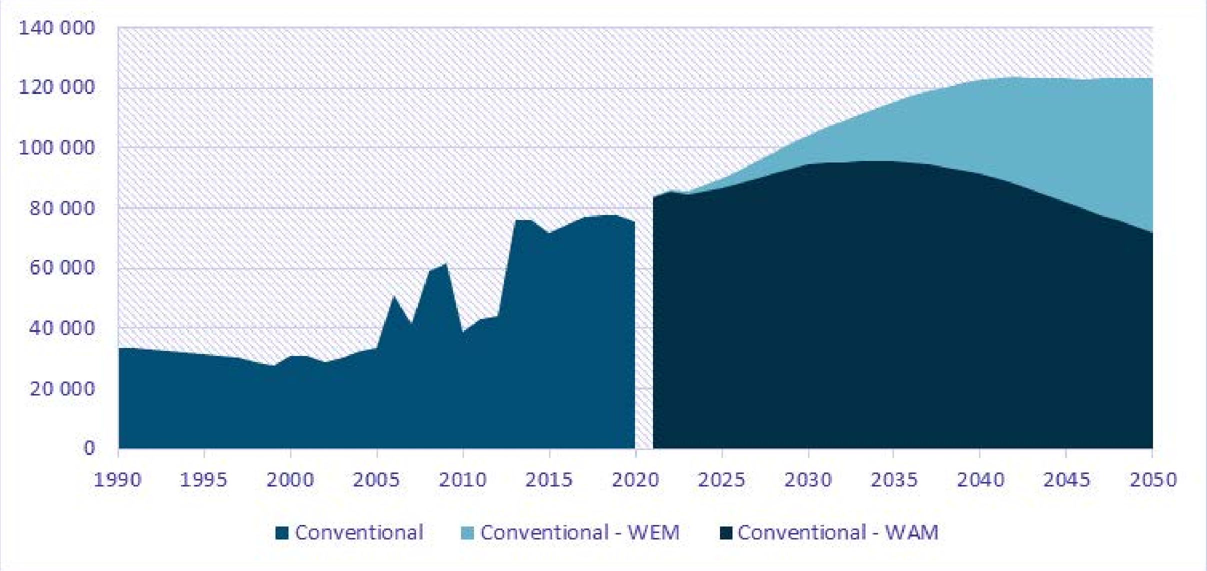


**Figure 2.13:** *Development of alternative fuel HDV fleet in WEM and WAM scenarios*

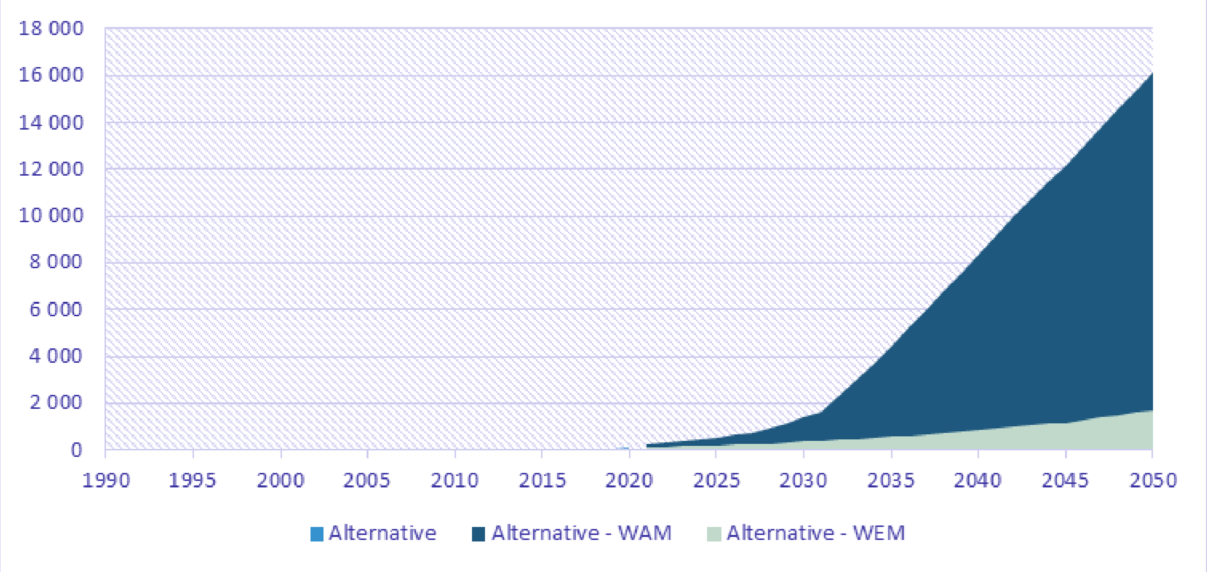
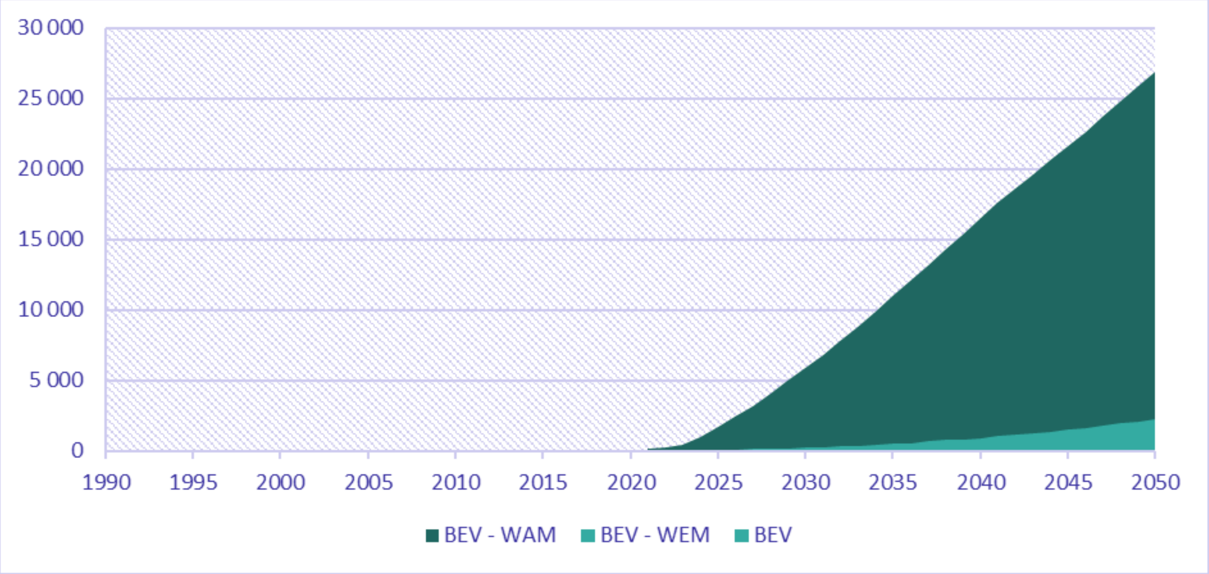


***Figure 2.14:*** *Electric and hydrogen HDV fleet development in WEM and WAM scenarios*



## 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. 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. In the WEM scenario, emissions from PPT account for about 3.1% of total emissions, and in the WAM scenario, they are projected to account for about 3.7% in 2030 after annual rise of mileage. Given the small share in road transport, no major interventions in the form of measures to change the bus fleet 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 conventional fuel buses in WEM and WAM scenarios*

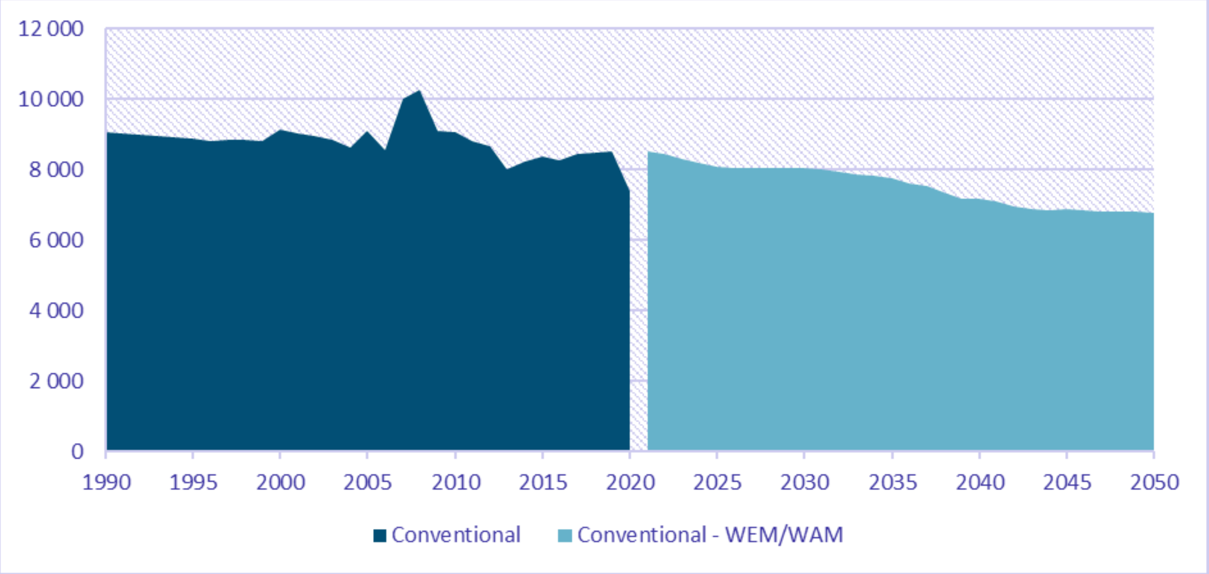


**Figure 2.16:** *Development of alternative fuel buses in WEM and WAM scenarios*

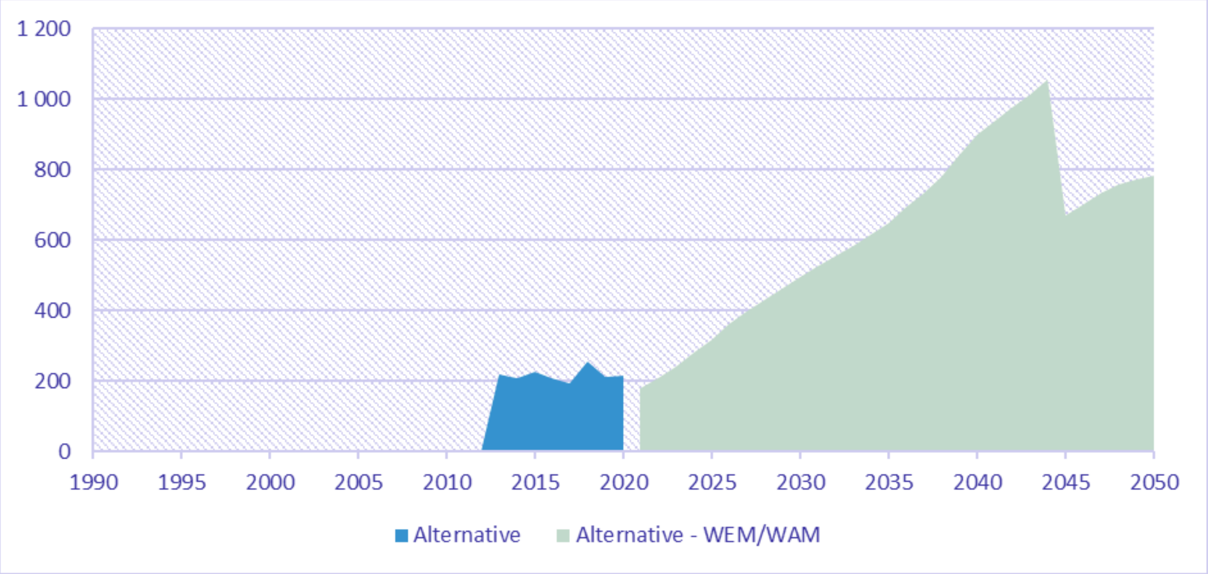
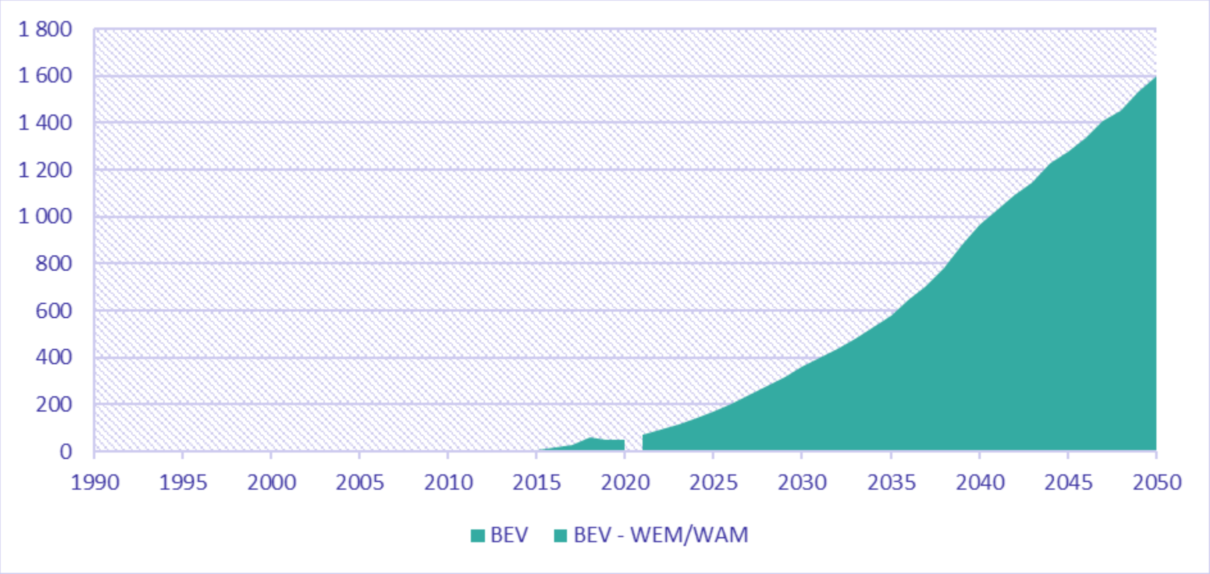


**Figure 2.17:** *Development of electric and hydrogen buses in WEM and WAM scenarios*



### L-category (L1 toL7)

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.

***Figure 2.18:*** *Evolution of L-category conventionally powered vehicles in scenarios WEM = WAM*

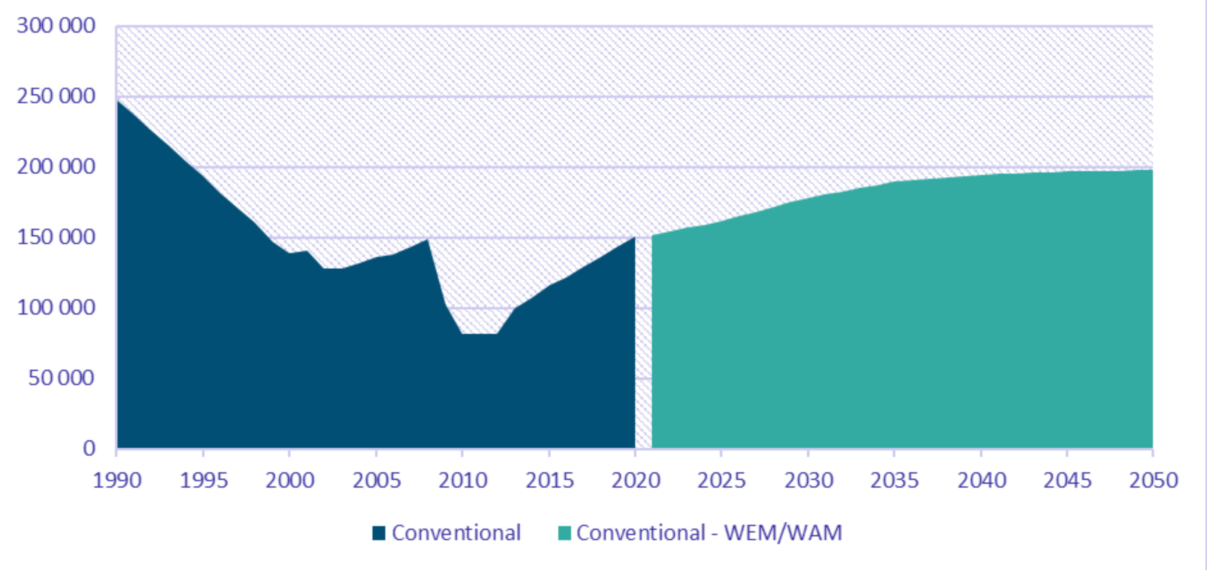
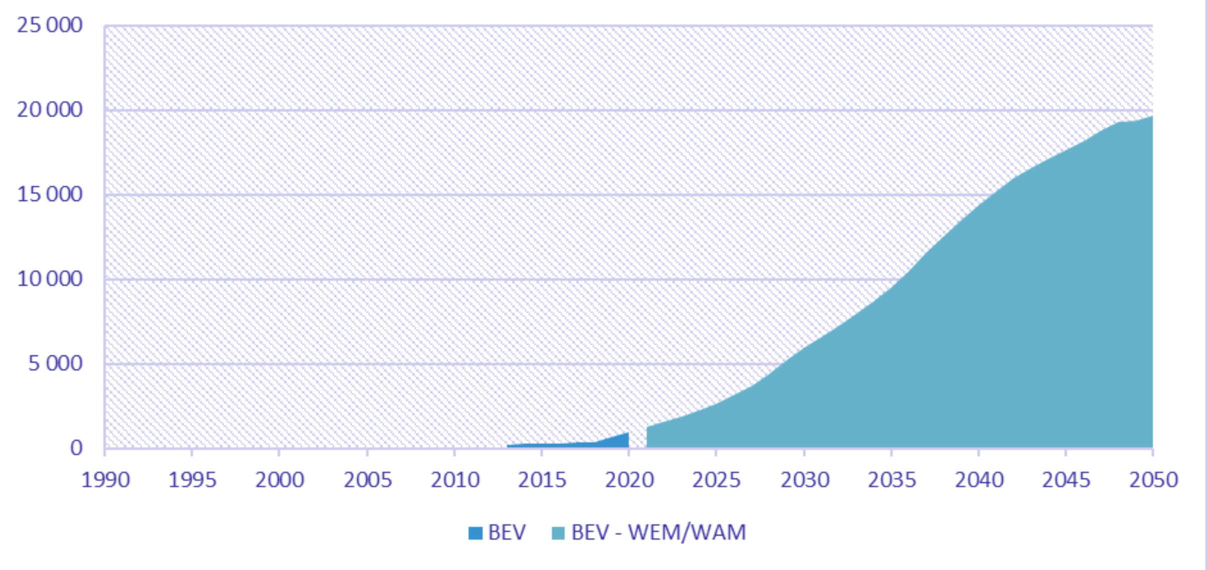


***Figure 2.19:*** *Development of electric and hydrogen L-category vehicles in scenarios WEM = WAM*



## 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 – 2020. 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 – 2020, 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 2.6:*** *SWOT analysis of the COPERT CLI model*

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

Estimates for the period 2021 – 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 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 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 2020 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 2020.

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 2019 (the year 2020 was excluded as a pandemic year and thus unusual year).

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 2020. All measures are contained directly in the Low Carbon Strategy of the Slovak Republic (NUS SR) and subsequently in the National Energy and Climate Plan (NECP) or the NECP directly refers to other strategies where these measures are found. 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 Directive (EU) 2018/2001 of the European Parliament and of the Council (RED II) 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 (electric cars)
- Energy efficiency
- Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO2 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 CO2 emission performance standards for new heavy-duty vehicles

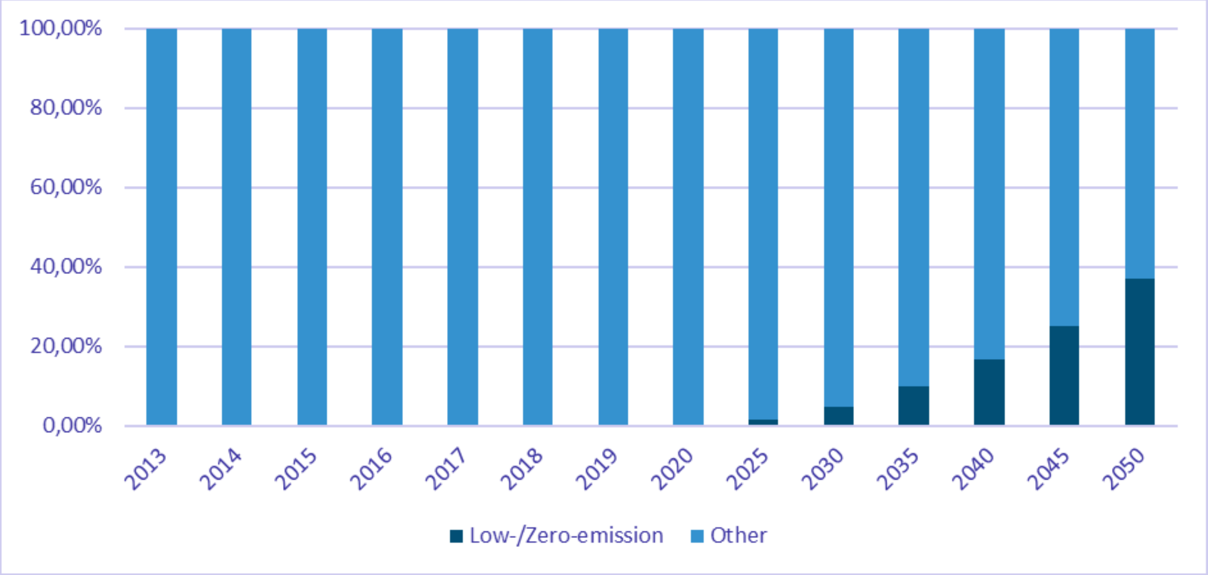
The RED II Directive on the promotion and use of energy from renewable sources is currently still not fully transposed into national legislation (to be done in the course of 2022). Its validity and inclusion in the WEM scenario was necessary and mandatory based on the scenario preparation framework. The revised RED II Directive sets new targets for the blending of renewable fuels (biofuels) into fossil fuels. The new, increased targets are:

| 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|
| 7.6% | 8.0% | 8.2% | 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 promotion of electromobility can be seen in ***Figures 2.16*** and ***2.19***. The projected share of low- and zero-emission vehicles (BEV) in the fleet can be seen in the ***Figure 2.20***. Passenger cars account for the largest share of electromobility, accounting for 89% in 2020, 98% in 2025 and up to 99% of all electric vehicles on the road in 2030.

***Figure 2.20:*** *Share of low- and zero-emission vehicles in the total vehicle fleet of the Slovak Republic - historical development and projections to 2050*



The estimated percentage of electric vehicles (EVs) in the passenger car category is shown in ***Table 2.7***. This is a more conservative estimate of the number of EVs in 2030 than in the EU Reference Scenario. According to the EU Reference Scenario, the share of EVs in the EU as a whole is expected to reach 25% in 2030.

***Table 2.7:*** *Share of electric vehicles in the passenger car fleet according to historical data and projected development*

| Years | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| EV share on passenger cars | 0.01% | 0.08% | 1.58% | 5.40% | 11.74% | 20.18% | 30.53% | 45.47% |
| Number of EV (pcs) | 194 | 2 644 | 41 844 | 157 304 | 357 644 | 619 698 | 930 934 | 1 366 982 |

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. ***Table 2.8*** shows the coefficient used for selected vehicle groups in the model for new vehicles.

**Table 2.8:** *Energy efficiency coefficients for selected groups of new vehicles*

| Years/Category | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| Passenger vehicles | 0.6% | 1.9% | 3.4% | 4.5% | 5.2% | 5.7% | 6.1% |
| Light-commercial vehicles | 0.9% | 2.8% | 4.6% | 6.1% | 7.2% | 8.2% | 9.2% |
| Heavy-duty vehicles | 0.7% | 3.0% | 5.2% | 6.7% | 7.8% | 8.6% | 9.3% |
| Buses | 0.6% | 2.9% | 5.1% | 6.6% | 7.6% | 8.4% | 9.1% |
| L-category | 0.7% | 2.8% | 4.7% | 5.9% | 6.4% | 6.8% | 7.3% |

### 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 2020. The list of policies and measures used is summarised in ***Table 2.9***.

**Table 2.9:** *List of policies and measures used in WAM scenario*

| PAMS | Source (strategy, action plan, etc.) | Quantifiable (yes/no) |
|---|---|---|
| Continued direct support for the use of low-emission vehicles | Action plan for the development of electric vehicles in the Slovak Republic | Yes |
| Long-term financial mechanism to support the development of charging infrastructure | Action plan for the development of electric vehicles in the Slovak Republic | No, supporting |
| Setting stricter requirements for periodic technical inspections of vehicles | National Air Pollution Control Program | Yes |
| Vehicle registration fee based on g $CO_2$/km emissions | Act in preparation at the Ministry of Finance of the Slovak Republic | Yes |
| Information campaign | Action plan for the development of electric vehicles in the Slovak Republic | No, supporting |
| Education in schools; awareness of new skills and knowledge in education | Review and update of the National Policy Framework for the Development of the Alternative Fuels Market | No, supporting |
| Modal shift in passenger transport | Strategic Transport Development Plan 2030 | yes |
| Modal shift in the transport of goods | Strategic Transport Development Plan 2030 | Yes |
| Introduction and promotion of hydrogen powered vehicles (FCEV) | European Hydrogen Strategy | Yes |
| Addition of biomethane to CNG and LNG | RED II, Act No 309/2009 Coll. (adopted in 2022) | yes |

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. It is expected that further significant subsidy schemes will be introduced and that the share of electric vehicles will increase to 65% between 2025 and 2050. ***Table 2.10*** shows how the more significant increase is reflected in the number of EVs in the fleet.

**Table 2.10:** *Share of electric vehicles in the passenger car fleet after the introduction of the measure "Continued direct support for the use of low-emission vehicles"*

| Years | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| Share of electric vehicles in the passenger car fleet | 0.19% | 3.80% | 13.88% | 26.78% | 39.67% | 52.57% | 65.47% |
| Number of electric vehicles (pcs) | 4 544 | 100 427 | 404 332 | 815 529 | 1 218 148 | 1 603 241 | 1 968 268 |

A suggested indicator of the implementation of this measure and also an indicator for the trajectory of the reduction of $CO_2$ emissions from new passenger vehicles is the share of new battery electric vehicles (BEVs) in the total sales of new passenger vehicles. The share that would need to be met each year to meet the 55% reduction target in g $CO_2$/km for newly registered vehicles by 2030 and was agreed as part of the Fit for 55 package. This share can be seen in ***Table 2.11***. Legislation limiting emissions from new vehicles to 100% comes into force in 2035.

***Table 2.11:*** *Indicator of progress towards the Fit for 55 target*

| Years | Share of new BEV | Share of subsidised BEV Of new BEV |
|---|---|---|
| **2021** | 8.38% | 27.8% |
| **2022** | 11.69% | 100.0% |
| **2023** | 19.46% | 14.1% |
| **2024** | 23.57% | 26.7% |
| **2025** | 37.05% | 71.3% |
| **2026** | 43.89% | 67.2% |
| **2027** | 47.96% | 66.4% |
| **2028** | 49.64% | 74.4% |
| **2029** | 65.01% | 55.5% |
| **2030** | 62.69% | 64.0% |
| **2031** | 65.15% | 57.7% |
| **2032** | 64.66% | 60.1% |
| **2033** | 69.10% | 51.3% |
| **2034** | 67.23% | 56.1% |
| **2035** | 64.22% | 63.8% |

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 expert estimates, the introduction of additional inspection mechanisms could help to phase out between 0.01% and 0.05% of vehicles older than 15 years per year. 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.

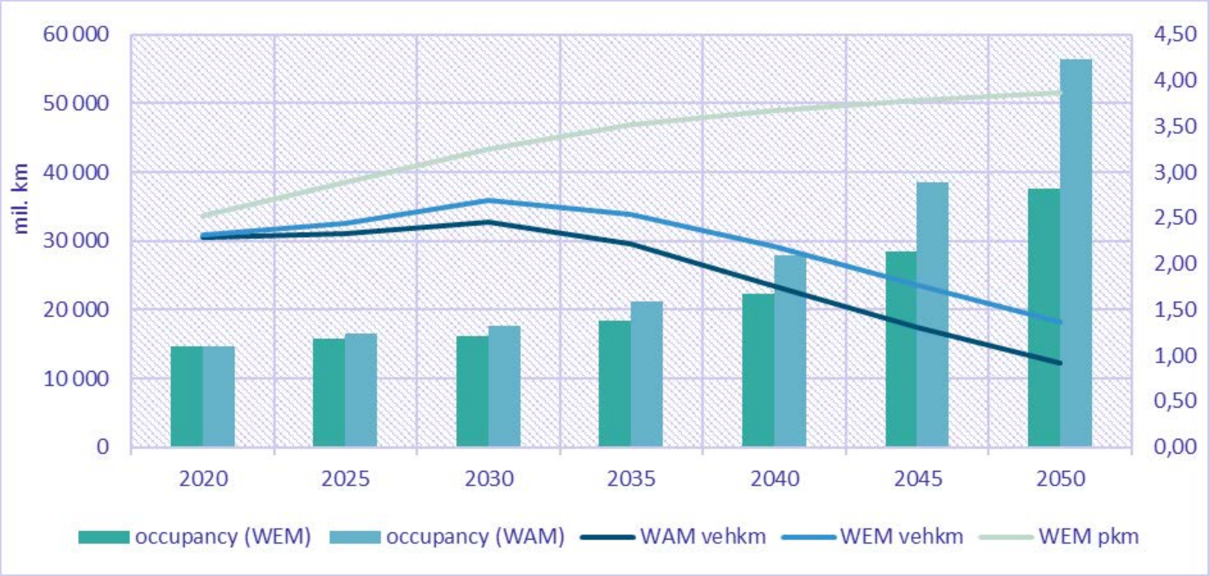
The introduction of a new registration fee, or "environmental tax", takes into account the production of $CO_2$ emissions by passenger cars and is expertly estimated at between 0.1% and 0.3% of the end-of-life passenger cars with the highest emissions. These are mostly older vehicles, as are the technical and emissions inspections. The effect of this measure is reflected in the model in the change in the age structure of passenger cars. A gradual fading will also be observed for this measure.

Modal shift in passenger transport implies a shift of passengers from passenger vehicle transport to public passenger transport (PPT). As a result, the occupancy rate of passenger vehicles is expected to increase by 50% compared to 2020, reducing in particular the amount 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 2.21***).

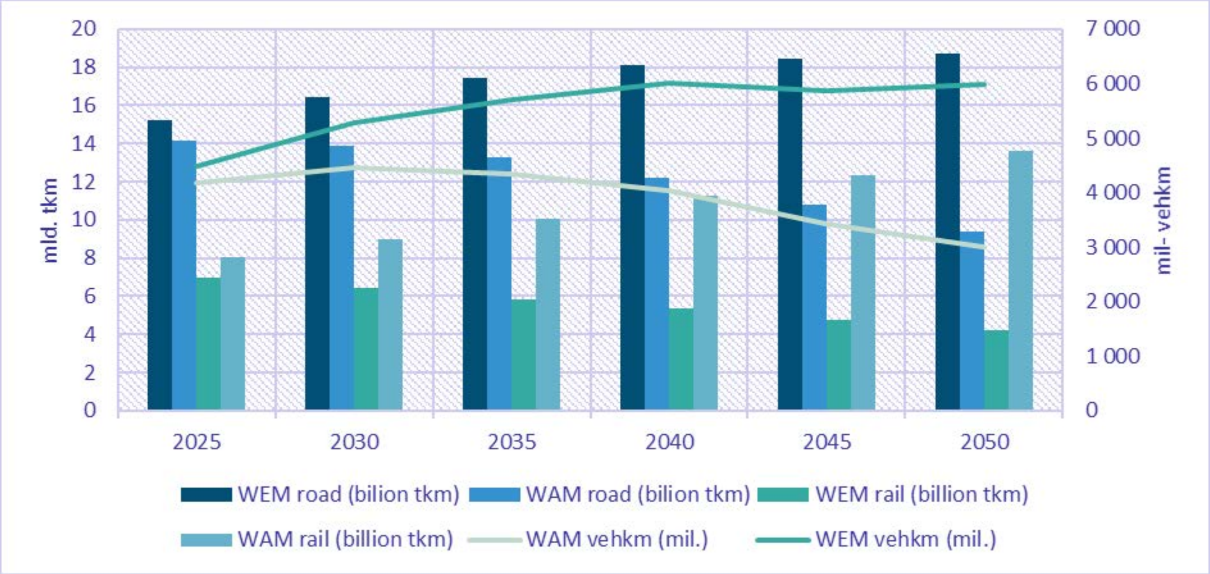
***Figure 2.21:*** *Changes in passenger vehicle occupancy, annual passenger vehicle miles travelled, and passenger vehicle miles travelled by CPS+ model*



<u>Modal shift in freight transport</u> 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 2.22***).

***Figure 2.22:*** *Changes in freight transport, annual boarding and goods transported by road and rail (billion tkm)*

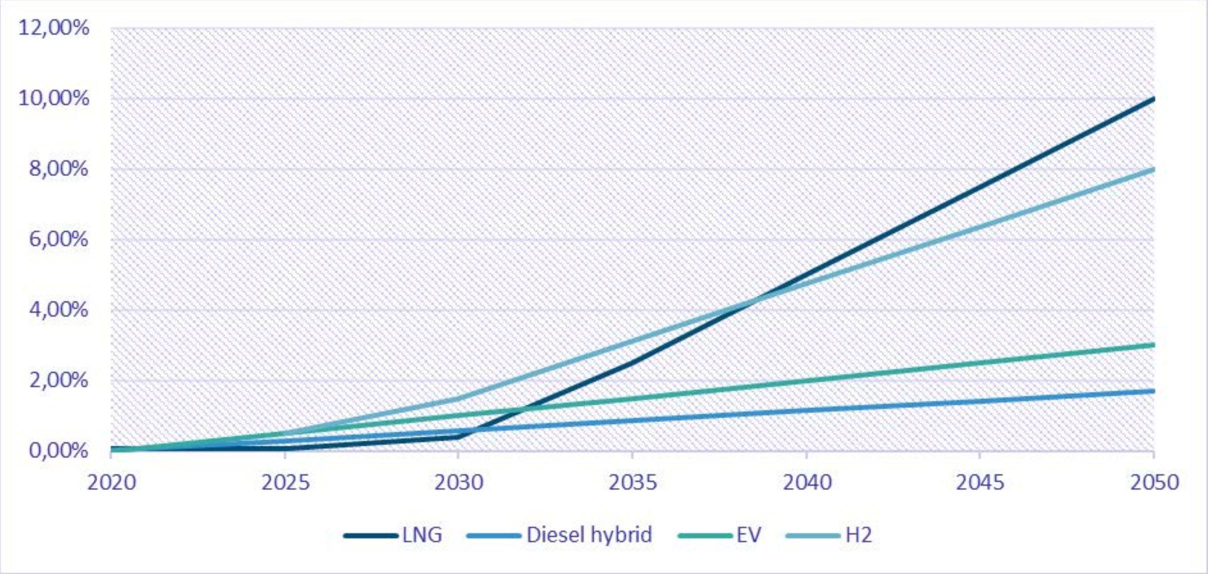


The most effective measure in this scenario appears to be the phasing out of fossil fuelled cars and light-commercial vehicles and their replacement by electric and hydrogen vehicles, especially for last mile goods movements. A complete ban on the sale of these pure fossil fuel vehicles (diesel and petrol) 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 could also facilitate the introduction of low emission zones in cities. The low emission zones measure is not part of the package of measures for the WAM scenario as the quantification of such a measure would be difficult and burdened with high uncertainty due to regional differences.

Similarly, traditional fossil fuel trucks are expected to be phased out and replaced by hybrid, electric, hydrogen or LNG vehicles. To support this measure, the same subsidy mechanism will need to be put in place as for passenger cars. The uptake of these engines is generally slow and only becomes apparent after the year 2030. In the case of hydrogen engines, the European Hydrogen Strategy mentions of a maximum hydrogen deployment rate of 16% by 2050 within heavy-duty vehicles. In Slovakia, this level is set at 8% in the WAM scenario, based on a consensus of experts in the field. Hybrid and electric motorisation is at 4.7% by 2050. The uptake of LNG vehicles is projected at 10% by 2050 (***Figure 2.23***). This growth is assumed to be in addition to the natural growth of alternative and zero-emission trucks.

***Figure 2.23:*** *Percentage growth of additional trucks using alternative and BEV fuels*



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.

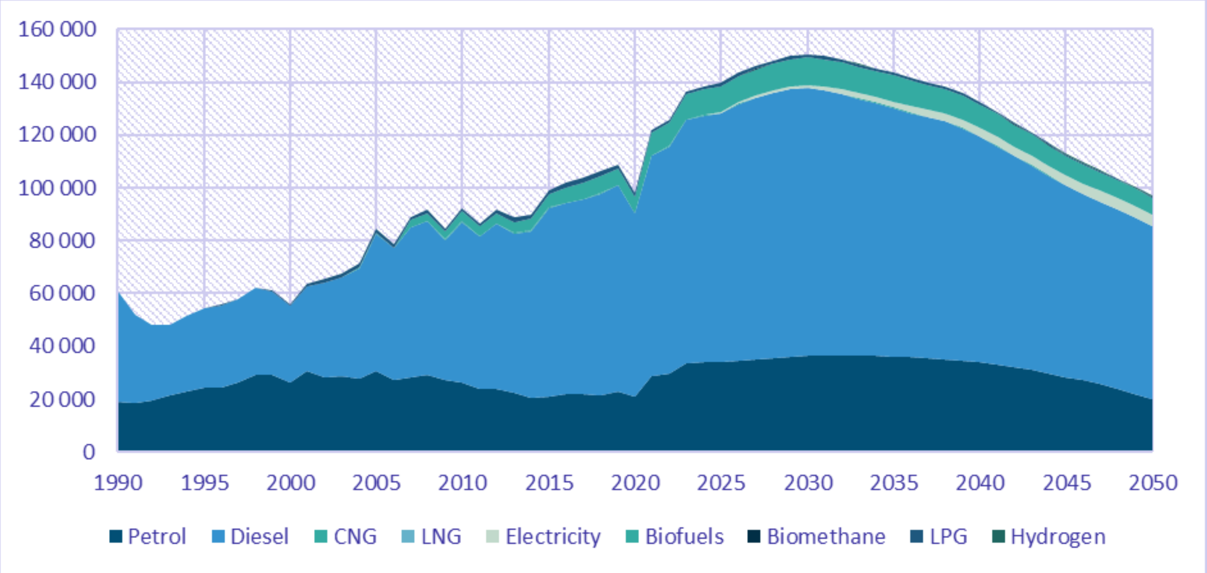
The addition of bio-based methane (bio-methane) to vehicle fuels is now common practice in other EU countries. In Slovakia, this obligation will be introduced by the amendment of Act No. 309/2009 on the Promotion of Renewable Energy Sources and High Efficiency Combined Production. As the amendment was not adopted before 31 December 2019, it could not be implemented as a WEM scenario measure. 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.

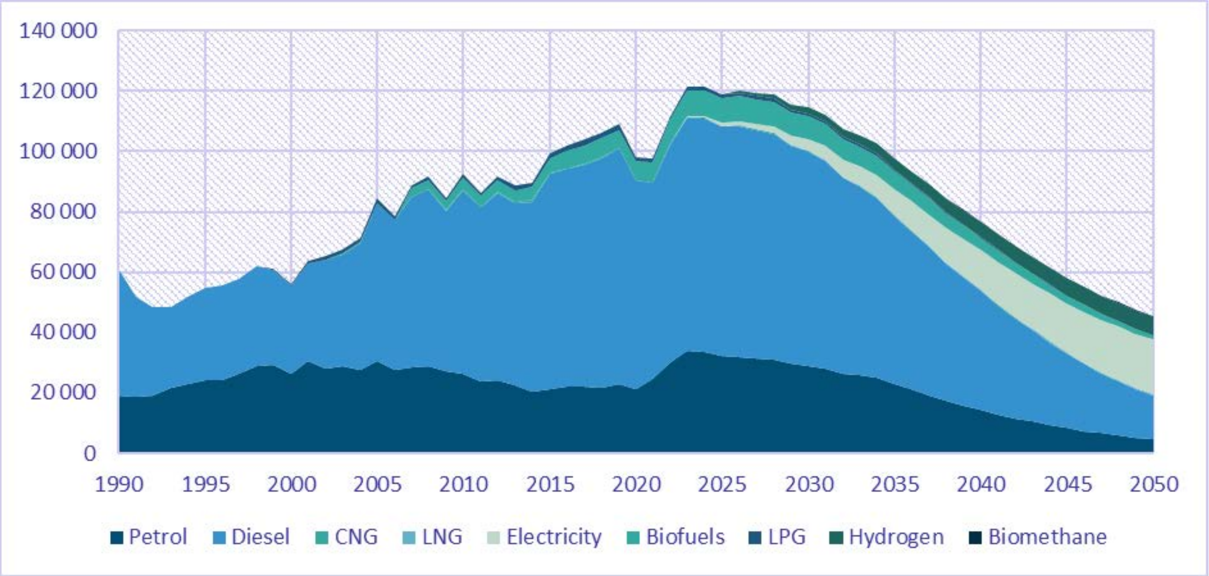
Energy consumption: in terms of energy, according to the WEM scenario, in Slovakia will dominate consumption of diesel oil until 2050. Its consumption will slowly decrease in this scenario but will still account for up to 67% of the total energy consumption of road transport in 2050. From other alternative fuels will be the most dominant electricity consumption, rising gradually from a share of 1% (1 200 TJ or 330 GWh) in 2030 to around 5% (4 450 TJ or 1 230 GWh) in 2050 (***Figure 2.24***).

***Figure 2.24:*** *Historical evolution of the energy demand for road transport for the years 1990 – 2020 and WEM scenario 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 3% (4 000 TJ or 1 100 GWh) in 2030 and up to 40% (18 300 TJ or 5 000 GWh) of the total energy demand in 2050 (***Figure 2.25***). Diesel oil will still have a similarly important but significantly smaller share, with a share of 62% in 2030, falling to half (31%) in 2050. This significant share, despite strong decarbonisation, is mainly due to the truck category, which is extremely difficult to decarbonise while maintaining the parameters required of them.

**Figure 2.25:** *Historical evolution of the energy demand for road transport for the years 1990 – 2020 and assumed evolution under the WAM 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 2.26***) also follow the trend of GHG emissions expressed in $CO_2$ equivalents.

**Figure 2.26:** *Historical trends of $CO_2$ emissions in Gg from road transport for the years 1990 – 2020*
*and emission projections in the WEM and WAM scenarios*

### $CH_4$ and $N_2O$ emission projections

$CH_4$ and $N_2O$ emissions (***Figure 2.27*** and ***2.28***) 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 2.27:*** *Historical trends of $CH_4$ emissions in Gg of $CO_2$ eq. from road transport for the years 1990 – 2020 and emission projections in WEM and WAM scenarios*

***Figure 2.28:*** *Historical trends of $N_2O$ emissions in Gg of $CO_2$ eq. from road transport for the years 1990 – 2020 and emission projections in WEM and WAM scenarios*

### Aggregated GHG emission projections from road transport

The WEM scenario (***Table 2.12***) results in a 78% increase in GHG emissions in $CO_2$ equivalents, in 2030 compared to 2005. Passenger car and light-commercial vehicle segments account for the largest share of this increase. In contrast, heavy-duty vehicle will only contribute around 5% to this increase.

***Table 2.12:*** *GHG emission projections in Gg of $CO_2$ eq. in road transport 1.A.3.b according to WEM scenario*

| 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| 7 636.69 | 6 813.31 | 10 353.73 | 11 111.36 | 10 506.91 | 9 621.01 | 8 130.79 | 6 893.02 |
| 7 549.99 | 6 743.79 | 10 250.83 | 10 996.67 | 10 391.68 | 9 509.59 | 8 031.03 | 6 799.79 |
| 0.20 | 0.17 | 0.34 | 0.34 | 0.34 | 0.33 | 0.28 | 0.21 |
| 0.27 | 0.22 | 0.32 | 0.36 | 0.36 | 0.35 | 0.31 | 0.29 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

WAM scenario (***Table 2.13***), which is already extremely ambitious at this point, shows some dimming of the increase in GHG emissions. The increase in 2030 will be 29% compared to 2005, and in 2050 the measures introduced in this scenario will make it possible to achieve $CO_2$ emission reductions around 75% compared to 2005 levels. In this case, it should be noted that the strongest measure will be the obligation for manufacturers to reduce $CO_2$ emissions from new vehicles by 100% after 2035. If this deadline is postponed, it will have a significant impact on future emissions by 2050 and it is very likely that Slovakia will not be able to meet its carbon neutrality commitment because of road transport.

***Table 2.13:*** *GHG emission projections in Gg of $CO_2$ eq. in road transport 1.A.3.b according to WAM scenario*

| 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| 8 132.58 | 7 069.21 | 9 128.53 | 8 459.12 | 6 757.27 | 4 782.58 | 3 097.50 | 1 978.40 |
| 8 035.30 | 6 990.37 | 9 039.66 | 8 374.98 | 6 685.06 | 4 725.45 | 3 049.17 | 1 937.04 |
| 0.22 | 0.18 | 0.32 | 0.28 | 0.24 | 0.18 | 0.12 | 0.09 |
| 0.31 | 0.25 | 0.27 | 0.26 | 0.22 | 0.18 | 0.15 | 0.13 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

Total GHG emission projections from road transport in Slovakia in the WAM scenario increase by +29% in 2030 compared to 2005 but decrease by -81% in 2050 compared to 2005 (***Table 2.13***).

### 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 2.14***).

***Table 2.14:*** *GHG emission projections by gases in non-road transport for the WEM scenario*

| Gases | Transport Sector | Unit | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ | Air transport | kt | 1.83 | 0.88 | 1.25 | 1.34 | 1.34 | 1.34 | 1.34 | 1.38 |
| | Rail transport | | 81.02 | 72.53 | 97.85 | 100.97 | 104.41 | 108.06 | 115.21 | 120.50 |
| | Navigation transport | | 4.17 | 5.35 | 2.64 | 2.25 | 2.06 | 1.87 | 1.02 | 0.52 |
| | Pipeline transport | | 398.28 | 167.83 | 290.91 | 287.28 | 283.28 | 294.08 | 280.53 | 274.13 |
| $CH_4$ | Air transport | t | 0.04 | 0.02 | 0.031 | 0.031 | 0.031 | 0.031 | 0.031 | 0.032 |
| | Rail transport | | 4.87 | 4.36 | 5.50 | 5.70 | 5.90 | 6.10 | 6.34 | 6.57 |

| Gases | Transport Sector | Unit | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Navigation transport |  | 0.40 | 0.51 | 0.30 | 0.30 | 0.30 | 0.30 | 0.25 | 0.23 |
|  | Pipeline transport |  | 7.14 | 3.03 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.005 |
| $N_2O$ | Air transport |  | 0.05 | 0.02 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.020 |
|  | Rail transport |  | 33.58 | 30.10 | 37.80 | 39.00 | 40.40 | 41.80 | 61.61 | 71.38 |
|  | Navigation transport |  | 0.11 | 0.14 | 0.06 | 0.06 | 0.06 | 0.06 | 0.04 | 0.03 |
|  | Pipeline transport |  | 7.14 | 0.30ň | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0005 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

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

Fugitive emissions from the mining and post-mining activities of brown coal and production, transmission and distribution of crude oil and natural gas (NG) what were projected, are methane and $CO_2$. 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 (less than 2%).

### 2.3.1. Methodologies and Key Assumptions/Trends

Mining and post-mining

A gradual decline in coal mining activities in Slovakia in connection with the completed closure of the Dolina mine in 2015 and the closure of the Cígeľ mine (HBP, a. s.) in 2017 is expected also in the next years.

The HBP, a. s. company has in its portfolio, in addition to the mines Nováky and Handlová situated in the Horná Nitra region, also the Čáry mine situated in Záhorie region. In connection with the cessation of state subsidies and the planned declining in mining activities in the Slovak Republic, it is assumed that the Čáry mine will end its activities in 2023. Due to the characteristics of brown coal mined here (also used in agriculture), it is possible, that the production will continue in limited range after 2023, as envisaged in the "EU Reference scenario (EU REF2020)".Fugitive methane emissions from underground coal mining and subsequent post-mining activities in the Slovak Republic were calculated from the following data:

- Data on coal production in 2019 from individual underground mines were obtained from official sources - from HBP, a. s. and the Statistical Office of the Slovak Republic.
- Data on projected coal production in 2020-2050 were obtained from sources: EU reference scenario for Slovakia for 2020 – 2050 (EU REF 2020).
- Government Resolution No. 580/2018, point B.3 - timeframe for the gradual closure of the Handlová and Nováky mining fields belonging to HBP, a. s.
- Emission factors from the 2006 IPCC Guidelines for National GHG Inventories - Chapter 4: Fugitive emissions.

***Table 2.15:*** *Coal production and projected mining activity in Slovakia according to the WEM scenario to 2050*

| Mine | Units | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Cigeľ | kt | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Handlová | kt | 236 | 174 | 0 | 0 | 0 | 0 | 0 |
| Nováky | kt | 925 | 595 | 0 | 0 | 0 | 0 | 0 |
| HBP, a. s. total | kt | 1 161 | 769 | 0 | 0 | 0 | 0 | 0 |
| BD, a. s. | kt | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BČ, a. s. | kt | 270 | 212 | 483 | 31 | 21 | 17 | 10 |
| Slovakia Total | kt | 1 431 | 981 | 483 | 31 | 21 | 17 | 10 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Table 2.16:*** *Coal production and projected mining activity in Slovakia according to the WAM scenario to 2050*

| Mine | Units | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Cigeľ | kt | 0 | 0 | **0** | **0** | **0** | **0** | 0 |
| Handlová | kt | 236 | 174 | **0** | **0** | **0** | **0** | 0 |
| Nováky | kt | 925 | 595 | **0** | **0** | **0** | **0** | 0 |
| HBP, a. s. total | kt | 1 161 | 769 | **0** | **0** | **0** | **0** | 0 |
| BD, a. s. | kt | 0 | 0 | **0** | **0** | **0** | **0** | 0 |
| BČ, a. s. | kt | 270 | 212 | **0** | **0** | **0** | **0** | 0 |
| Slovakia Total | kt | 1 431 | 981 | **0** | **0** | **0** | **0** | 0 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

## 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 CH4 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 2020 will be stopped, while the extraction of gas will continue until 2045 without significant changes.

Ministry of Economy – Integrated National Energy and Climate Plan 2021 – 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.

Data for the calculation of fugitive emissions for 2020 – 2050 were obtained from sources:

- EU Reference Scenario for Slovakia for 2020 – 2050 (EU REF 2020);
- Integrated National Energy and Climate Plan 2021 – 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;
- IPCC Guidelines on best practices and management of unpredictability in national GHG inventories - Fugitive emissions from oil and gas operations.

***Table 2.17:*** *Projected production, transmission and distribution of oil and gas in the Slovak Republic according to WEM scenario in 2020 – 2050*

| Activity | Units | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Oil production | t | 6 328 | 4 431 | 0 | 0 | 0 | 0 | 0 |
| Oil processing | t | 5 109.0 | 6 437.9 | 5 558.4 | 5 562.8 | 5 453.2 | 5 171.2 | 4 484.3 |
| Natural gas production | million $m^3$ | 124 | 70 | 74 | 77 | 99 | 89 | 0 |
| Long-distance transmission of NG | million $m^3$ | 69 060 | 56 980 | 67 882 | 67 036 | 66 102 | 68 623 | 63 966 |
| Natural gas distribution | million $m^3$ | 4 841 | 5 004 | 5 115 | 4 637 | 4 988 | 4 632 | 3 927 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Table 2.18:*** *Projected production, transmission and distribution of oil and gas in the Slovak Republic according to WAM scenario in 2020 – 2050*

| Activity | Units | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Oil production | t | 6 328 | 4 431 | 0 | 0 | 0 | 0 | 0 |
| Oil processing | t | 5 109.0 | 6 437.9 | 5 558.4 | 5 562.8 | 5 453.2 | 5 171.2 | 4 484.3 |
| Natural gas production | million $m^3$ | 124 | 70 | 74 | 77 | 99 | 89 | 0 |
| Long-distance transmission of NG | million $m^3$ | 69 060 | 56 980 | 66 400 | 63 400 | 60 400 | 57 400 | 51 400 |
| Natural gas distribution | million $m^3$ | 4 841 | 5 004 | 5 115 | 4 637 | 4 988 | 4 632 | 3 927 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

### 2.3.2. Model Description

Projections of emissions were prepared in accordance with the methodology of the Intergovernmental Panel on Climate Change from the year of IPCC 2006 Guidelines, 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.

### 2.3.3. Scenarios, Parameters and PAMs

Reference year for the projections preparation was the year 2019, projections were prepared until 2050. In the sector 1.B.1 Solid fuels were prepared two scenarios based on two scenarios from the Low-Carbon Development Strategy of the Slovak Republic:

- WEM scenario – with measures already in place (adopted) by the end of 2021;
- WAM scenario – with additional measures (optimistic).

For the period from 2023 onwards, all mines are categorised as "closed mines", except for the Čáry mine (WEM scenario) and for the period from 2023 onwards, all mines are categorised as "closed mines"

(WAM scenario), The emission factor for fugitive methane emissions from abandoned mines was estimated by exponential regression to 2050.

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 – 2019. The intensity and mitigation of fugitive emissions are at the same level as it is average of the years 2015 – 2019. 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 assumes that, the SK-PL (Slovak-Poland) gas pipeline with a new metering station will be 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. The scenario is also considering the future installation of new equipment for capturing of the NG ($CH_4$) emissions. The intensity and method of reducing emissions is planned to be on a higher level than at present, with the eliminating of approximately 90% of NG ($CH_4$) emissions by 2050 compared to 2020. The scenario assumes that, the SK-PL (Slovak-Poland) gas pipeline with a new metering station will be put into operation in 2022.

### 2.3.4. Emission Projections in Energy Sector – Fugitive Emissions (1.B)

Based on the provided information on trends in the mining activity in Slovakia, the following emissions projections based on the WEM and WAM scenario was calculated. Emissions from mining include also post-mining activities and abandoned mines.

***Table 2.19:*** *Fugitive emissions of $CH_4$ and $CO_2$ from coal mining and abandoned mines for the years 2020 – 2050 according to the WEM scenario in the Slovak Republic*

| Year | Brown coal (t) | $CH_4$ emissions (t) | $CO_2$ emissions (t) | $CO_2$ eq. emissions (Gg) |
|---|---|---|---|---|
| **2019*** | 1 431 000 | 9 822 | 17 891 | 292.90 |
| **2020*** | 980 500 | 7 142 | 12 261 | 212.25 |
| **2025** | 483 211 | 5 672 | 8 567 | 167.38 |
| **2030** | 30 563 | 1 555 | 2 994 | 46.53 |
| **2035** | 20 592 | 1 335 | 2 605 | 39.99 |
| **2040** | 17 305 | 1 201 | 2 353 | 35.98 |
| **2045** | 11 780 | 1 069 | 2 155 | 32.05 |
| **2050** | 10 041 | 984 | 1 952 | 29.50 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Table 2.20:*** *Fugitive emissions $CH_4$ and $CO_2$ from coal mining and abandoned mines for the years 2020 – 2050 according to the WAM scenario in the Slovak Republic*

| Year | Brown coal (t) | $CH_4$ emissions (t) | $CO_2$ emissions (t) | $CO_2$ eq. emissions (Gg) |
|---|---|---|---|---|
| **2019*** | 1 431 000 | 9 822 | 17 891 | 292.90 |
| **2020*** | 980 500 | 7 142 | 12 261 | 212.25 |
| **2025** | 0 | 1 465 | 3 028 | 44.05 |
| **2030** | 0 | 1 287 | 2 658 | 38.69 |
| **2035** | 0 | 1 153 | 2 381 | 34.67 |
| **2040** | 0 | 1 048 | 2 164 | 31.51 |
| **2045** | 0 | 963 | 1 990 | 28.95 |
| **2050** | 0 | 893 | 1 846 | 26.85 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

Based on the provided information on trends in the oil and NG activity in Slovakia, the following emissions projections based on the WEM and WAM scenario were calculated. Emissions includes transmission, distribution, production, and venting and flaring activities for NG and oil.

Fugitive emissions projections for $N_2O$ originated from flaring were estimated only for one scenario, which means, that the WEM is equal to WAM scenario. Due to cancelation of the oil and NG production after 2045 and flaring by production, no $N_2O$ emissions projections occurred in the 2050.

***Table 2.21:*** *Fugitive GHG emission projections calculated in the Slovak Republic in the years 2020 – 2050 (WEM scenario)*

| Year | $CO_2$ emissions (t) | $CH_4$ emissions (t) | $N_2O$ emissions (t) | $CO_2$ eq. emissions (Gg) |
|---|---|---|---|---|
| **2019*** | 1 189 | 8 614 | 0.0097 | 242.39 |
| **2020*** | 907 | 9 334 | 0.0061 | 262.27 |
| **2025** | 788 | 8 719 | 0.0017 | 244.92 |
| **2030** | 768 | 7 988 | 0.0018 | 224.42 |
| **2035** | 858 | 8 326 | 0.0023 | 233.99 |
| **2040** | 818 | 7 781 | 0.0021 | 218.69 |
| **2045** | 721 | 6 789 | 0.0019 | 190.81 |
| **2050** | 459 | 6 473 | 0.0018 | 181.70 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Table 2.22:*** *Fugitive GHG emission projections calculated in the Slovak Republic in the years 2020 – 2050 (WAM scenario)*

| Year | $CO_2$ emissions (t) | $CH_4$ emissions (t) | $N_2O$ emissions (t) | $CO_2$ eq. emissions (Gg) |
|---|---|---|---|---|
| **2019*** | 1 189 | 8 614 | 0.0097 | 242.39 |
| **2020*** | 907 | 9 334 | 0.0061 | 262.27 |
| **2025** | 782 | 8 259 | 0.0017 | 232.04 |
| **2030** | 754 | 7 251 | 0.0018 | 203.80 |
| **2035** | 835 | 7 334 | 0.0023 | 206.19 |
| **2040** | 773 | 6 508 | 0.0021 | 182.99 |
| **2045** | 677 | 5 291 | 0.0019 | 148.82 |
| **2050** | 409 | 4 883 | 0.0018 | 137.12 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Figure 2.29:*** *Trend of $CO_2$ fugitive emission projections in tons from oil and NG activities in years 2020 – 2050 in the Slovak Republic according to WEM and WAM scenarios*

**Figure 30:** *Trend of $CH_4$ fugitive emission projections in tons from oil and NG activities in years 2020 – 2050 in the Slovak Republic according to WEM and WAM scenarios*

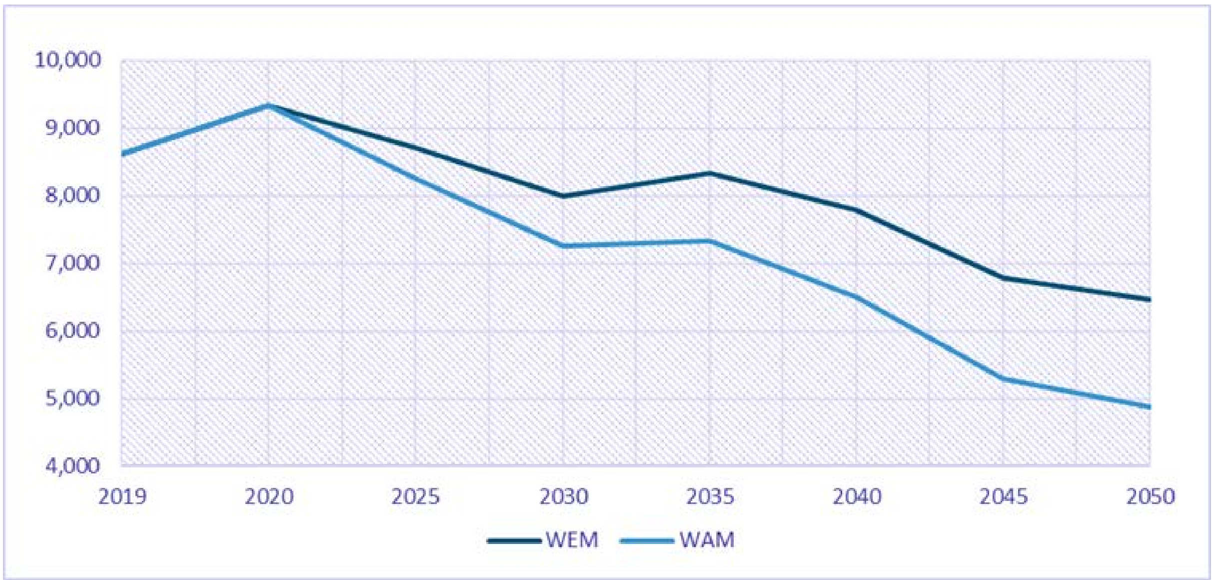
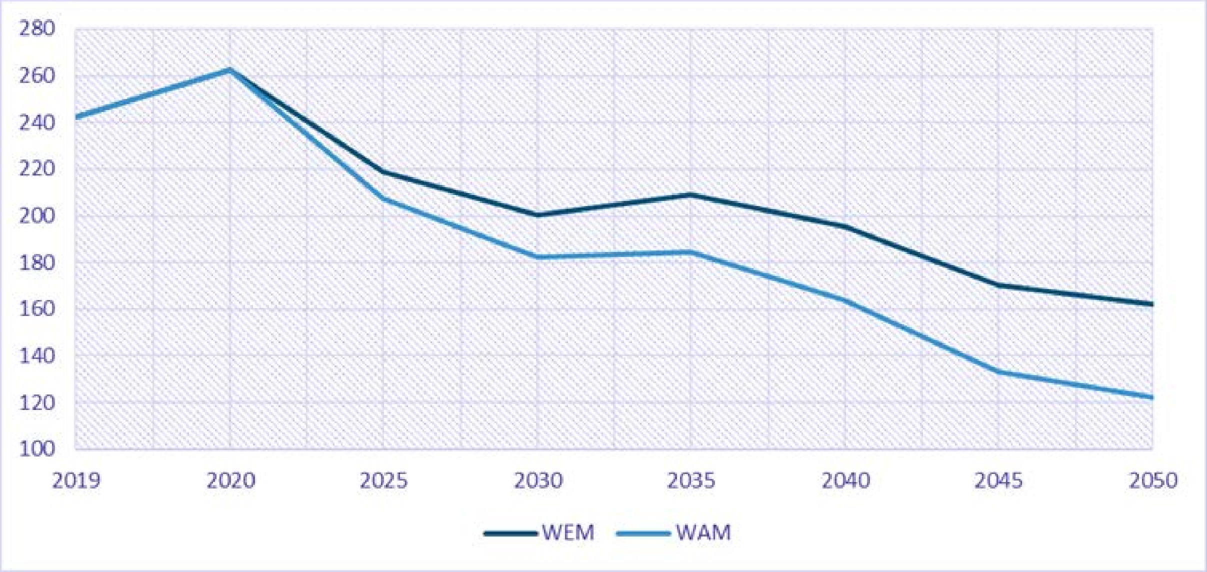


**Figure 2.31:** *Trend of $N_2O$ fugitive emission projections in tons from oil and NG activities in years 2020 – 2050 in the Slovak Republic according to WEM and WAM scenarios*



## 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 2.23*** shows the aggregated projections of GHG emissions in the energy sector. ***Figure 2.32*** 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 12% and in the WAM scenario by 42%. 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 85%. A significant decrease is also recorded in the category of electricity and heat production by 53%. 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 2.23*** shows the aggregated projections of GHG emissions in the energy sector. ***Figure 2.32*** shows a comparison of projected emissions in the energy sector in eq. $CO_2$ by 2050 for all scenarios.

***Table 2.23:*** *GHG emission projections in Gg of $CO_2$ eq. in the Energy sector by categories*

| WEM | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| 1. Energy | 26 910 | 24 667 | 29 655 | 28 850 | 27 865 | 26 853 | 25 132 | 23 677 |
| 1.A. Fuel combustion | 26 375 | 24 192 | 29 242 | 28 579 | 27 591 | 26 598 | 24 910 | 23 466 |
| 1.A.1. Energy industries | 7 065 | 6 445 | 6 167 | 5 572 | 5 363 | 5 435 | 5 420 | 5 413 |
| 1.A.2. Manufacturing industries | 6 327 | 5 931 | 7 568 | 7 032 | 7 052 | 7 114 | 7 095 | 7 058 |
| 1.A.3. Transport | 8 123 | 7 061 | 10 747 | 11 503 | 10 898 | 10 027 | 8 536 | 7 300 |
| 1.A.4. Other sectors | 4 775 | 4 685 | 4 671 | 4 381 | 4 187 | 3 932 | 3 770 | 3 608 |
| 1.A.5. Other | 84 | 69 | 89 | 91 | 91 | 90 | 88 | 86 |
| 1.B. Fugitive emissions from fuels | 535 | 475 | 412 | 271 | 274 | 255 | 223 | 211 |
| **WAM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| 1. Energy | 26 910 | 24 667 | 27 508 | 23 173 | 20 846 | 18 769 | 17 169 | 15 531 |
| 1.A. Fuel combustion | 26 375 | 24 192 | 27 232 | 22 930 | 20 605 | 18 554 | 16 992 | 15 367 |
| 1.A.1. Energy industries | 7 065 | 6 445 | 6 164 | 3 367 | 3 006 | 3 183 | 3 548 | 3 303 |
| 1.A.2. Manufacturing industries | 6 327 | 5 931 | 7 303 | 6 802 | 6 822 | 6 884 | 6 867 | 6 831 |
| 1.A.3. Transport | 8 123 | 7 061 | 9 121 | 8 451 | 6 751 | 4 777 | 3 093 | 1 974 |
| 1.A.4. Other sectors | 4 775 | 4 685 | 4 556 | 4 219 | 3 935 | 3 619 | 3 396 | 3 172 |
| 1.A.5. Other | 84 | 69 | 89 | 91 | 91 | 90 | 88 | 86 |
| 1.B. Fugitive emissions from fuels | 535 | 475 | 276 | 242 | 241 | 214 | 178 | 164 |

** Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Figure 2.32:*** *GHG emission projections in Gg of $CO_2$ eq. in the Energy sector by categories in WEM and WAM scenarios*

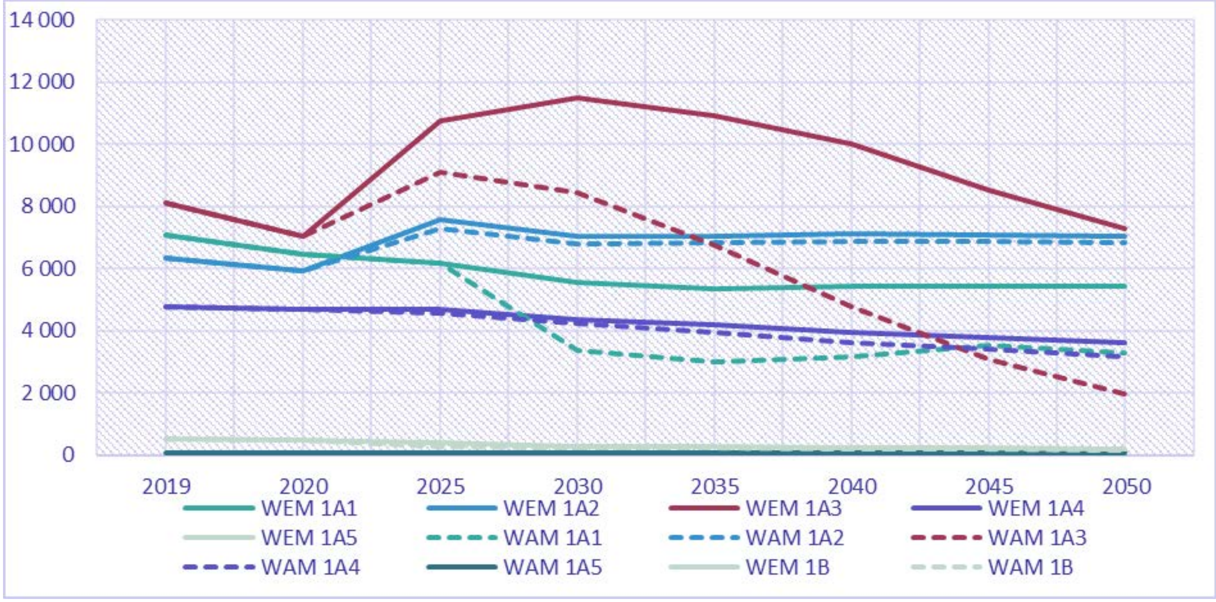


***Figure 2.33*** and ***Table 2.24*** shows the results of modelling projections of $CO_2$ emissions under the relevant scenarios. The projected economic growth dynamics will lead to an increase in $CO_2$ emissions. The impact of the included measures resulted in emission reductions in the WEM and WAM scenarios.

***Figure 2.33:*** *GHG emission projections in Gg of $CO_2$ eq. in the Energy sector according to WEM and WAM scenarios uo to 2050*

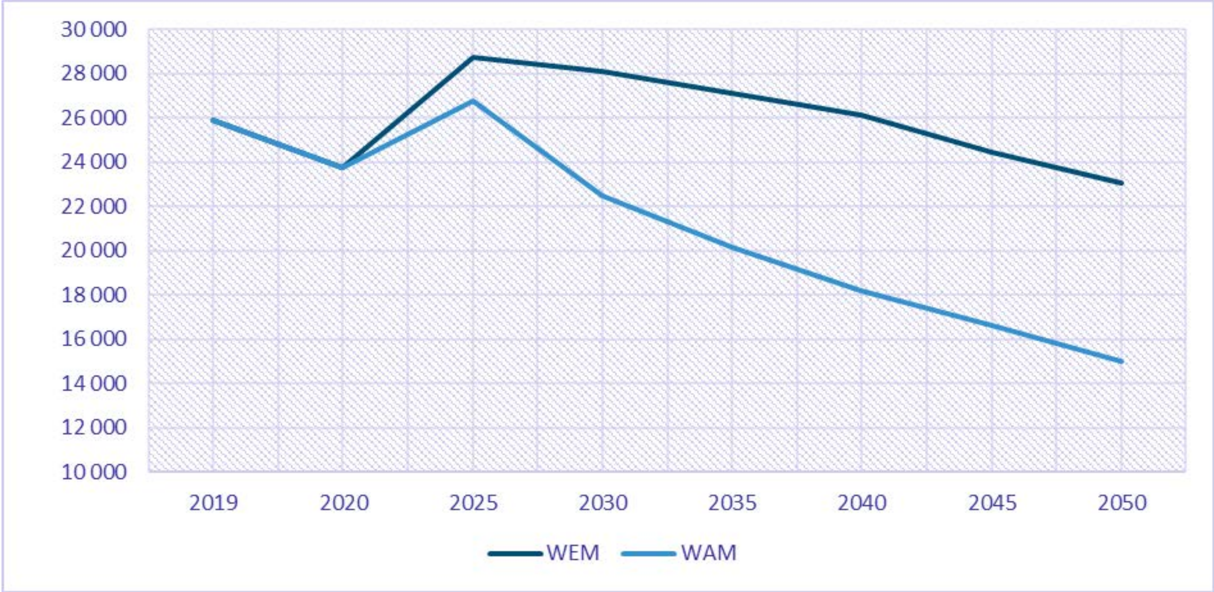


***Table 2.24****: $CO_2$ emission projections in Gg of $CO_2$ in the Energy sector by categories*

| **WEM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
|---|---|---|---|---|---|---|---|---|
| 1. Energy | 25 912 | 23 737 | 28 748 | 28 098 | 27 127 | 26 151 | 24 476 | 23 048 |
| 1.A. Fuel combustion | 25 893 | 23 724 | 28 738 | 28 094 | 27 123 | 26 148 | 24 474 | 23 045 |
| 1.A.1. Energy industries | 7 020 | 6 404 | 6 128 | 5 537 | 5 333 | 5 405 | 5 387 | 5 380 |
| 1.A.2. Manufacturing industries & cons. | 6 279 | 5 882 | 7 506 | 6 974 | 6 994 | 7 055 | 7 037 | 7 000 |
| 1.A.3. Transport | 8 035 | 6 990 | 10 643 | 11 389 | 10 783 | 9 915 | 8 429 | 7 196 |
| 1.A.4. Other sectors | 4 476 | 4 379 | 4 372 | 4 105 | 3 924 | 3 683 | 3 533 | 3 383 |
| 1.A.5. Other | 83 | 68 | 88 | 90 | 90 | 90 | 88 | 86 |
| 1.B. Fugitive emissions from fuels | 19 | 13 | 9 | 4 | 3 | 3 | 3 | 2 |
| **WAM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| 1. Energy | 25 912 | 23 737 | 26 744 | 22 475 | 20 176 | 18 157 | 16 619 | 15 015 |
| 1.A. Fuel combustion | 25 893 | 23 724 | 26 740 | 22 472 | 20 173 | 18 154 | 16 616 | 15 013 |
| 1.A.1. Energy industries | 7 020 | 6 404 | 6 128 | 3 340 | 2 986 | 3 168 | 3 536 | 3 295 |
| 1.A.2. Manufacturing industries & cons. | 6 279 | 5 882 | 7 240 | 6 744 | 6 764 | 6 825 | 6 809 | 6 773 |
| 1.A.3. Transport | 8 035 | 6 990 | 9 040 | 8 375 | 6 685 | 4 725 | 3 049 | 1 937 |
| 1.A.4. Other sectors | 4 476 | 4 379 | 4 244 | 3 922 | 3 648 | 3 346 | 3 134 | 2 922 |
| 1.A.5. Other | 83 | 68 | 88 | 90 | 90 | 90 | 88 | 86 |
| 1.B. Fugitive emissions from fuels | 19 | 13 | 4 | 3 | 3 | 3 | 3 | 2 |

*** *Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

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 2.25**: $CH_4$ emission projections in Gg of $CH_4$ in the Energy sector by categories*

| WEM | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| 1. Energy | 28.70 | 26.84 | 24.74 | 19.22 | 19.00 | 17.87 | 16.39 | 15.55 |
| 1.A. Fuel combustion | 10.26 | 10.36 | 10.35 | 9.68 | 9.34 | 8.89 | 8.53 | 8.10 |
| 1.A.1. Energy industries | 0.57 | 0.55 | 0.54 | 0.61 | 0.69 | 0.69 | 0.76 | 0.77 |
| 1.A.2. Manufacturing industries & cons. | 0.68 | 0.67 | 0.86 | 0.80 | 0.80 | 0.81 | 0.81 | 0.80 |
| 1.A.3. Transport | 0.22 | 0.18 | 0.35 | 0.34 | 0.34 | 0.33 | 0.28 | 0.22 |
| 1.A.4. Other sectors | 8.77 | 8.94 | 8.60 | 7.92 | 7.50 | 7.05 | 6.68 | 6.30 |
| 1.A.5. Other | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1.B. Fugitive emissions from fuels | 18.44 | 16.48 | 14.39 | 9.54 | 9.66 | 8.98 | 7.86 | 7.46 |
| **WAM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| 1. Energy | 28.70 | 26.84 | 20.45 | 18.61 | 18.24 | 16.67 | 14.84 | 13.89 |
| 1.A. Fuel combustion | 10.26 | 10.36 | 10.73 | 10.07 | 9.75 | 9.12 | 8.58 | 8.11 |
| 1.A.1. Energy industries | 0.57 | 0.55 | 0.50 | 0.48 | 0.47 | 0.35 | 0.25 | 0.18 |
| 1.A.2. Manufacturing industries & cons. | 0.68 | 0.67 | 0.86 | 0.80 | 0.80 | 0.81 | 0.81 | 0.80 |
| 1.A.3. Transport | 0.22 | 0.18 | 0.32 | 0.28 | 0.24 | 0.18 | 0.12 | 0.09 |
| 1.A.4. Other sectors | 8.77 | 8.94 | 9.05 | 8.51 | 8.23 | 7.77 | 7.40 | 7.04 |
| 1.A.5. Other | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1.B. Fugitive emissions from fuels | 18.44 | 16.48 | 9.72 | 8.54 | 8.49 | 7.56 | 6.25 | 5.78 |

** Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

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. 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 2.26**: $N_2O$ emission projections in Gg of $N_2O$ in the Energy sector by categories*

| WEM | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| 1. Energy | 0.73 | 0.67 | 0.81 | 0.81 | 0.78 | 0.76 | 0.74 | 0.73 |
| 1.A. Fuel combustion | 0.73 | 0.67 | 0.81 | 0.81 | 0.78 | 0.76 | 0.74 | 0.73 |
| 1.A.1. Energy industries | 0.11 | 0.10 | 0.09 | 0.07 | 0.04 | 0.04 | 0.04 | 0.04 |
| 1.A.2. Manufacturing industries & cons. | 0.11 | 0.11 | 0.14 | 0.13 | 0.13 | 0.14 | 0.14 | 0.13 |
| 1.A.3. Transport | 0.31 | 0.25 | 0.35 | 0.40 | 0.40 | 0.39 | 0.37 | 0.37 |
| 1.A.4. Other sectors | 0.20 | 0.21 | 0.22 | 0.21 | 0.20 | 0.19 | 0.19 | 0.18 |
| 1.A.5. Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.B. Fugitive emissions from fuels | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **WAM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| 1. Energy | 0.73 | 0.67 | 0.72 | 0.66 | 0.60 | 0.55 | 0.51 | 0.48 |
| 1.A. Fuel combustion | 0.73 | 0.67 | 0.72 | 0.66 | 0.60 | 0.55 | 0.51 | 0.48 |
| 1.A.1. Energy industries | 0.11 | 0.10 | 0.08 | 0.05 | 0.03 | 0.02 | 0.02 | 0.01 |
| 1.A.2. Manufacturing industries & cons. | 0.11 | 0.11 | 0.14 | 0.13 | 0.13 | 0.14 | 0.14 | 0.13 |
| 1.A.3. Transport | 0.31 | 0.25 | 0.27 | 0.26 | 0.22 | 0.18 | 0.15 | 0.13 |
| 1.A.4. Other sectors | 0.20 | 0.21 | 0.22 | 0.22 | 0.21 | 0.21 | 0.21 | 0.20 |
| 1.A.5. Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.B. Fugitive emissions from fuels | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

** Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

## 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 2.27*** shows that the projected GHG emissions from these categories are negligible compared to other sources.

***Table 2.27:*** *GHG emission projections in Gg of $CO_2$ eq. from international transport in the WEM=WAM scenario*

| Item | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|
| International air transport | 186.99 | 55.08 | 186.99 | 186.99 | 186.99 | 186.99 | 186.99 |
| International maritime transport | 15.95 | 14.98 | 15.95 | 15.95 | 15.95 | 15.95 | 15.95 |
| International transport | 202.94 | 70.06 | 202.94 | 202.94 | 202.94 | 202.94 | 202.94 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

# CHAPTER 3. GHG EMISSION PROJECTIONS IN THE IPPU SECTOR

Although the EU ETS Directive has been in force since 2005 and is now in its fourth phase (2021-2030), the ESR Regulation has been in force since 2013-2020, with a base year of 2005 (the year from which emission reductions under the ESR are calculated). Another difference between the two systems is the application of their obligations. While the EU ETS does not contain country-specific commitments, but annual trajectories of emission cap reductions, under the ESR the commitment is valid at the country level. Emissions under both schemes are subject to annual international verifications.

## 3.1. Methodologies and Key Assumptions/Trends

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. 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.

Metal production has a long history in Slovakia and a decline in production is not expected. However, iron and steel production reflects the economic situation. After the COVID-19 crisis in 2020, there is a clear decline in production (-40%) and thus in emissions produced. However, the amount of iron and steel produced has increased after 2020 and the intention is to maintain it in the future.

Issues in the IPPU generally reflect any economic crisis. This can also be seen in steel production in 2020, when iron and steel production declined due to the COVID-19 pandemic. However, no major changes in production are expected in the coming years.

In the iron and steel sector, it is possible to reduce $CO_2$ emissions by reducing the consumption of coke as a fuel for energy processes and as a reducing agent in blast furnaces. However, this would result in a reduction in steel production and hence economic problems for the region. One of the most recent measures in the iron and steel sector is electric arc furnaces. The current set of measures foresees investments in technology, which should lead to significant emission savings in the sector.

The share of enterprises in the non-metallic and chemical industries is also significant.

One of the most effective measures in reducing emissions in the non-metallic industry is waste recovery. Specific waste mineral wastes can, by their chemical composition, replace natural raw materials such as limestone or clay that have to be extracted from nature. Many of them also contribute to reducing $CO_2$ emissions.

The trend in the chemical industry is influenced by various segments. Slovakia has a strong tradition in all major segments of the chemical industry including oil refining, fertilizer production, rubber and plastics. The product portfolio is also influenced by the strong automotive and electronics sectors in Slovakia, which serve as regular high-capacity clients for various companies in the chemicals and plastics industries.

No closure of existing chemical facilities is currently anticipated or planned. As regards the trend in emissions from the chemical industry, it is expected to be fairly constant and no significant decrease is foreseen. However, the largest reductions in this sector could be due to reductions in the production or consumption of fuels by cars and trucks, or reductions in the consumption of artificial fertilisers in agriculture. By transforming the production of petroleum-based fuels to the production of green hydrogen as a fuel using RES, or by producing more advanced biofuels and bioplastics.

## 3.2. Model Description

Model description used for the EU ETS part of IPPU emissions (large sources of technological emissions) is provided in the **Chapter 2.1.2**. 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.

## 3.3. 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).

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 2019 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 2021. 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.

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, which are mainly driven by energy policy. The trend of emission projections depends on the technologies used, 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 in the WEM scenario is due to changes in production, also the WAM scenario. In this case, WEM=WAM. The WAM scenario could not be prepared due to missing measures. The impact of electromobility on the reduction of $CO_2$ emissions from urea used as a reagent in nitrogen oxide abatement technologies cannot yet be estimated.

Projections of emissions of F-gases (HFCs) in category 2.F were prepared under two scenarios, WEM and WAM. The emission projections under the WEM scenario replicate 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. According to Annex III of this Regulation, the gas designated R404A (GWP 3922) shall be replaced by R448A (GWP 1387), R449A (GWP 1397) and R452A (2410). R410A gas shall be replaced by R452B gas (GWP 698) and R134a gas shall be replaced by R513A gas (GWP 631). In addition, R134a will be replaced by R1234YF gas in the MAC. Newer gases with a GWP higher than 750 shall be replaced with gases with a maximum GWP of 150.

The emissions projections under the WAM scenario took into account Regulation No. 517/2014 together with the assumption of an obligation to include zero GWP gases (as supplementary gases) in new installations to replace gases used in refrigeration after 2033.

The projections of $SF_6$ and $N_2O$ emissions in category 2.G were prepared under two scenarios, WEM and WAM. The projections of $SF_6$ emissions in the WEM scenario were prepared by extrapolating the base year taking into account the time series since 1990. The mitigation measure in the scenario was the assumption of decommissioning of obsolete facilities.

The emissions projections in the WAM scenario took into account restrictions on the use of $SF_6$ gas in new installations after 2025. The projections of $N_2O$ emissions in category 2.G.3 were prepared by extrapolating the time series over the last 10 years (WEM scenario). Under the WAM scenario, there is a gradual substitution of the driving gas $N_2O$ in anaesthesia.

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.

## 3.4. GHG Emission Projections in the IPPU Sector

### 3.4.1. Emission Projections of $CO_2$ in the IPPU Sector

The $CO_2$ emission projections in the IPPU sector are mostly driven with the EU ETS emissions from mineral production and metal production, in addition with the chemical industry and solvent use emissions. The trends according to the WEM and WAM scenarios are provided in the ***Figure 3.1*** and in the ***Table 3.1***.

***Figure 3.1:*** *Emission projections of $CO_2$ in Gg in the IPPU sector in WEM and WAM scenarios up to 2050*

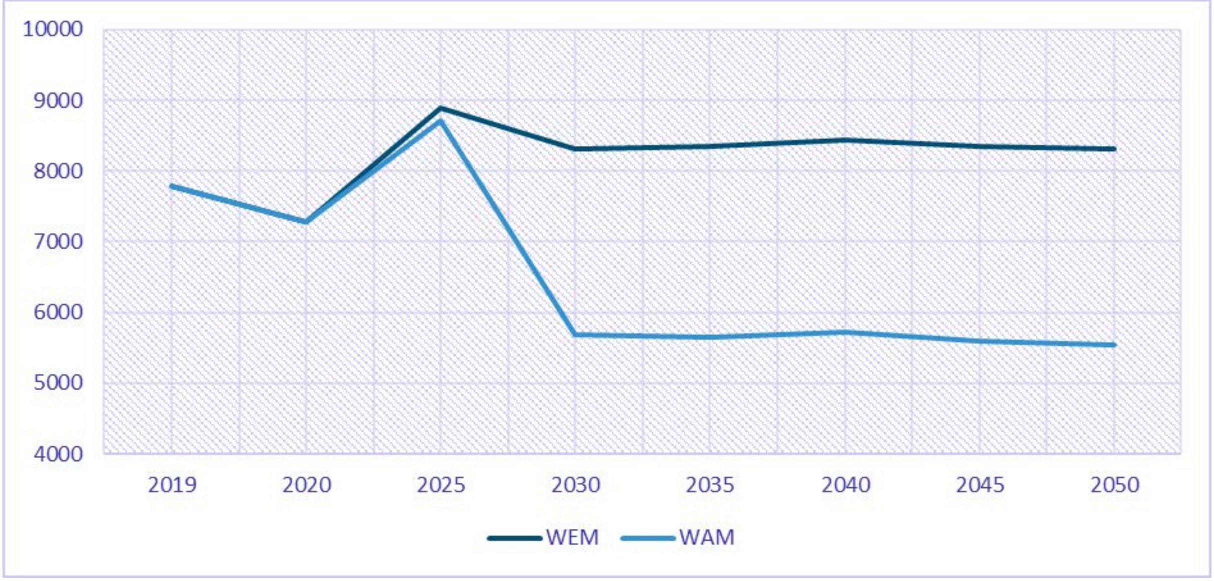


**Table 3.1:** *Emission projections of $CO_2$ in Gg in the IPPU sector in WEM and WAM scenarios up to 2050*

| WEM | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| 2. Industrial processes | 7 795.0 | 7 284.9 | 8 900.3 | 8 318.5 | 8 351.8 | 8 433.9 | 8 356.9 | 8 316.1 |
| A. Mineral processing | 2 285.0 | 2 218.7 | 2 206.9 | 2 189.5 | 2 223.9 | 2 332.7 | 2 314.0 | 2 335.8 |
| B. Chemical industry | 1 407.0 | 1 437.2 | 1 534.5 | 1 577.8 | 1 593.4 | 1 582.7 | 1 560.7 | 1 537.2 |
| C. Metal industry | 4 068.1 | 3 599.1 | 5 121.8 | 4 513.9 | 4 501.9 | 4 492.2 | 4 455.9 | 4 416.9 |
| D. Non-energy use of products | 35.0 | 29.8 | 37.2 | 37.2 | 32.5 | 26.4 | 26.3 | 26.2 |
| **WAM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| 2. Industrial processes | 7 795.0 | 7 284.9 | 8 719.1 | 5 681.8 | 5 645.6 | 5 724.3 | 5 595.5 | 5 549.0 |
| A. Mineral processing | 2 285.0 | 2 218.7 | 2 053.2 | 2 133.8 | 2 070.0 | 2 172.6 | 2 173.4 | 2 174.3 |
| B. Chemical industry | 1 407.0 | 1 437.2 | 1 507.0 | 1 551.2 | 1 566.5 | 1 555.5 | 1 533.1 | 1 509.2 |
| C. Metal industry | 4 068.1 | 3 599.1 | 5 121.7 | 1 959.5 | 1 976.5 | 1 969.9 | 1 862.7 | 1 839.2 |
| D. Non-energy use of products | 35.0 | 29.8 | 37.2 | 37.2 | 32.5 | 26.4 | 26.3 | 26.2 |

***** *Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

### Decarbonising of steel production

As part of reducing emissions in the iron and steel production sector, the WAM scenario includes measures to decarbonize of steel production in the biggest iron and steel producer. Currently, the steel mill is one of the largest producers of $CO_2$ in Slovakia and at the same time the most energy-intensive consumer. The decarbonisation scenario consists of the decommissioning of the coking battery, where the average annual production is 1 300 kt/$CO_2$. Decommissioning of sinter production and two blast furnaces.

Replacements of two blast furnaces is planned in WAM scenario after 2026 with two electric arc furnaces and equipment for endless casting and rolling with a capacity of about 3 million tons per year.

The consumption of iron scrap, natural gas and electricity will increase significantly. Average annual electricity consumption will increase from 4.5 PJ to 13 PJ. Increase of natural gas consumption is due to shortage of coke oven gas produced in coking battery. And also blast furnace gas and oxygen furnace gas production decrease due to decommissioning of two blast furnaces.

The decrease in $CO_2$ emissions due to the applied of decarbonisation measures is significant. A decrease of approximately 60% can be expected while maintaining average steel production.

With the current conditions of the EU ETS when purchasing EUA, it has dropped from approx. 2.2 mil. tons per year to 0.4 million tons per year.

## 3.4.2. Emission Projections of $CH_4$ in the IPPU Sector

$CH_4$ emission projections in the IPPU sector arise mainly from the production of ammonia and from the production of metal compounds, making up only a small proportion of total emissions. The trends according to the WEM and WAM scenarios are provided in the ***Table 3.2***.

**Table 3.2:** *Emission projections of $CH_4$ in Gg in the IPPU sector in WEM and WAM scenarios up to 2050*

| WEM | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| 2. Industrial processes | 0.057 | 0.058 | 0.058 | 0.058 | 0.053 | 0.050 | 0.050 | 0.049 |
| B. Chemical industry | 0.020 | 0.021 | 0.022 | 0.023 | 0.021 | 0.020 | 0.020 | 0.020 |
| C. Metal industry | 0.037 | 0.037 | 0.035 | 0.036 | 0.032 | 0.030 | 0.030 | 0.029 |

| WAM | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| 2. Industrial processes | 0.057 | 0.058 | 0.058 | 0.058 | 0.053 | 0.050 | 0.050 | 0.049 |
| B. Chemical industry | 0.020 | 0.021 | 0.022 | 0.023 | 0.021 | 0.020 | 0.020 | 0.020 |
| C. Metal industry | 0.037 | 0.037 | 0.035 | 0.036 | 0.032 | 0.030 | 0.030 | 0.029 |

** Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

### 3.4.3. Emission Projections of $N_2O$ in the IPPU Sector

$N_2O$ emissions in the IPPU sector arise mainly from the production of nitric acid but also do not form a significant part of total emissions. The trends according to the WEM and WAM scenarios are provided in the ***Figure 3.2*** and in the ***Table 3.3***.

***Figure 3.2:*** *Emission projections of $N_2O$ in Gg in the IPPU sector in WEM and WAM scenarios up to 2050*

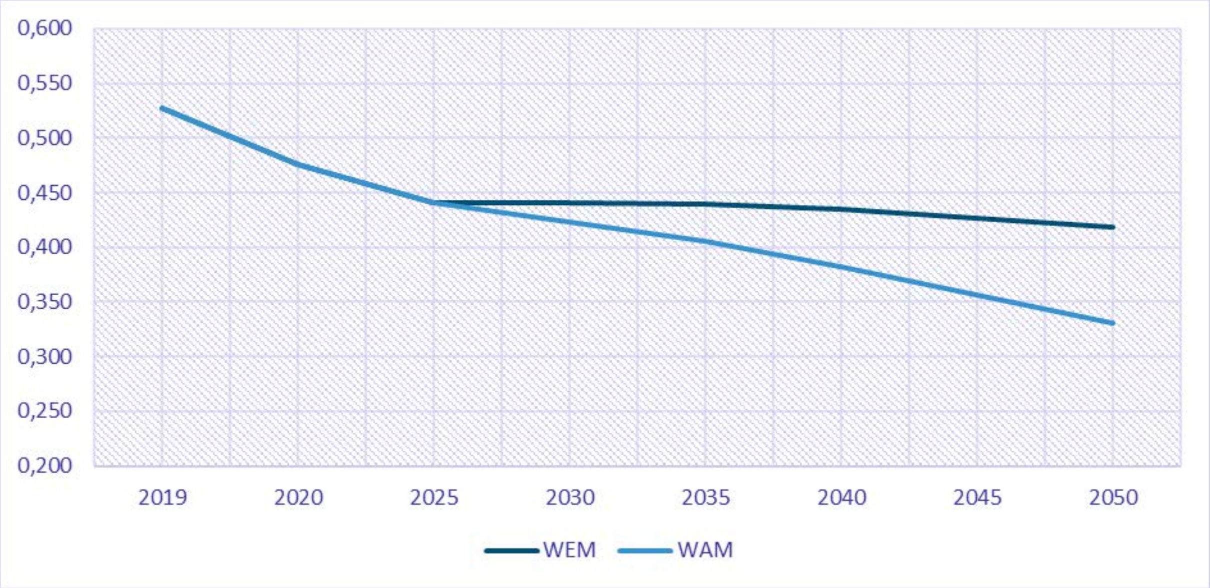


***Table 3.3:*** *Emission projections of $N_2O$ in Gg in the IPPU sector in WEM and WAM scenarios up to 2050*

| WEM | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| 2. Industrial processes | 0.527 | 0.476 | 0.441 | 0.441 | 0.440 | 0.434 | 0.426 | 0.418 |
| B. Chemical industry | 0.306 | 0.257 | 0.227 | 0.236 | 0.243 | 0.247 | 0.248 | 0.249 |
| G. Other product man. and use | 0.221 | 0.219 | 0.214 | 0.205 | 0.196 | 0.187 | 0.178 | 0.169 |
| **WAM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| 2. Industrial processes | 0.527 | 0.476 | 0.441 | 0.424 | 0.405 | 0.383 | 0.357 | 0.331 |
| B. Chemical industry | 0.306 | 0.257 | 0.227 | 0.236 | 0.243 | 0.247 | 0.248 | 0.249 |
| G. Other product man. and use | 0.221 | 0.219 | 0.214 | 0.188 | 0.162 | 0.136 | 0.109 | 0.082 |

** Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

### 3.4.4. Emission Projections of F-Gases 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 3.3*** and in the ***Table 3.4***.

***Figure 3.3:*** *Emission projections of F-gases in Gg of $CO_2$ eq. in the IPPU sector in WEM and WAM scenarios up to 2050*

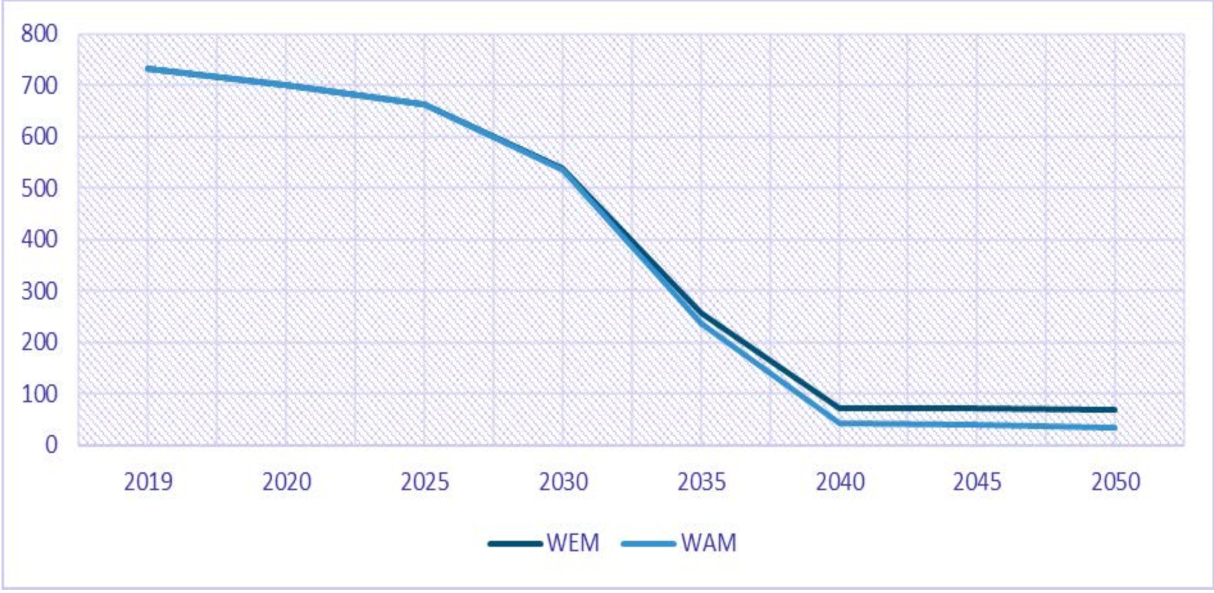


***Table 3.4:*** *Emission projections of F-gases in Gg of $CO_2$ eq. in the IPPU sector in WEM and WAM scenarios up to 2050*

| WEM | 2019* | 2020* | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| 2. Industrial processes | 733.3 | 702.2 | 662.3 | 537.8 | 257.1 | 73.4 | 72.0 | 70.5 |
| C. Metal industry - PFC | 5.2 | 5.6 | 6.9 | 5.5 | 5.7 | 5.8 | 5.8 | 5.8 |
| F. Use of products to ODS replacements-HFC | 719.0 | 678.9 | 643.3 | 521.0 | 241.4 | 57.9 | 56.5 | 55.0 |
| G. Other processing and uses - $SF_6$ | 9.1 | 17.7 | 12.1 | 11.3 | 10.0 | 9.7 | 9.7 | 9.7 |
| **WAM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| 2. Industrial processes | 733.3 | 702.2 | 663.4 | 536.1 | 236.7 | 43.7 | 39.7 | 35.6 |
| C. Metal industry - PFC | 5.2 | 5.6 | 6.9 | 5.5 | 5.7 | 5.8 | 5.8 | 5.8 |
| F. Use of products to ODS replacements-HFC | 719.0 | 678.9 | 644.6 | 519.7 | 221.6 | 29.0 | 25.1 | 21.1 |
| G. Other processing and uses - $SF_6$ | 9.1 | 17.7 | 11.9 | 10.9 | 9.4 | 8.9 | 8.8 | 8.8 |

** Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

### 3.4.5. GHG Emission Projections in the IPPU Sector

The trends according to the WEM and WAM scenarios are provided in the ***Figure 3.4*** and in the ***Table 3.5***. The overall trend most closely reflects the impact of steel production. The WEM scenario represents only a slightly decreasing trend in emissions. In the WAM scenario, there is a decrease of 35% mainly due to measures in the steel industry. Emissions from mineral production and the chemical industry have a stable trend due to the unavailability of better technologies in given industrial processes and also due to the trend of industrial production.

***Figure 3.4:*** *GHG emission projections in Gg of $CO_2$ eq. in the IPPU sector in WEM and WAM scenarios up to 2050*

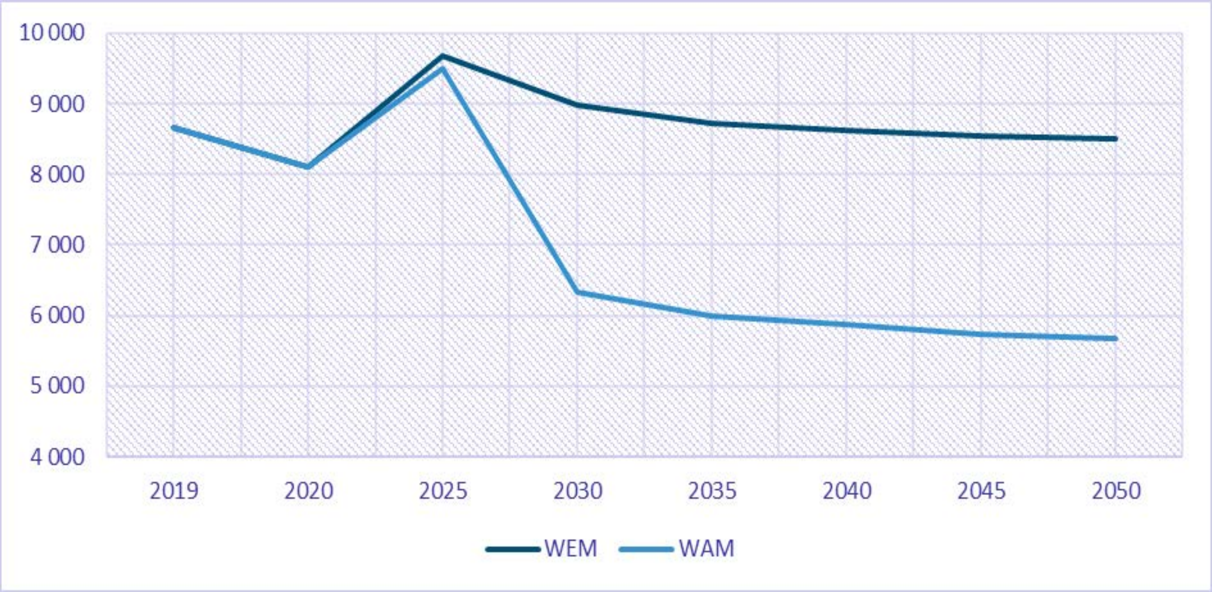


***Table 3.5:*** *GHG emission projections in Gg of $CO_2$ eq. in the IPPU sector in WEM and WAM scenarios up to 2050*

| **WEM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
|---|---|---|---|---|---|---|---|---|
| 2. Industrial processes | 8 670 | 8 115 | 9 681 | 8 975 | 8 727 | 8 624 | 8 543 | 8 499 |
| 2.A. Mineral Industry | 2 285 | 2 219 | 2 207 | 2 189 | 2 224 | 2 333 | 2 314 | 2 336 |
| 2.B. Chemical industry | 1 489 | 1 506 | 1 595 | 1 641 | 1 658 | 1 649 | 1 627 | 1 604 |
| 2.C. Metal industry | 4 074 | 3 606 | 5 130 | 4 520 | 4 509 | 4 499 | 4 463 | 4 424 |
| 2.D. Non-energy products | 35 | 30 | 37 | 37 | 33 | 26 | 26 | 26 |
| 2.E. Electronics industry | NO | NO | NO | NO | NO | NO | NO | NO |
| 2.F. Product uses as subs. for ODS | 719 | 679 | 643 | 521 | 241 | 58 | 56 | 55 |
| 2.G. Other product man. and use | 68 | 76 | 69 | 66 | 62 | 59 | 57 | 55 |
| 2.H. Other | NO | NO | NO | NO | NO | NO | NO | NO |
| **WAM** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| 2. Industrial processes | 8 670 | 8 115 | 9 501 | 6 332 | 5 991 | 5 871 | 5 731 | 5 674 |
| 2.A. Mineral Industry | 2 285 | 2 219 | 2 053 | 2 134 | 2 070 | 2 173 | 2 173 | 2 174 |
| 2.B. Chemical industry | 1 489 | 1 506 | 1 568 | 1 614 | 1 632 | 1 621 | 1 599 | 1 576 |
| 2.C. Metal industry | 4 074 | 3 606 | 5 130 | 1 966 | 1 983 | 1 977 | 1 869 | 1 846 |
| 2.D. Non-energy products | 35 | 30 | 37 | 37 | 33 | 26 | 26 | 26 |
| 2.E. Electronics industry | NO | NO | NO | NO | NO | NO | NO | NO |
| 2.F. Product uses as subs. for ODS | 719 | 679 | 645 | 520 | 222 | 29 | 25 | 21 |
| 2.G. Other product man. and use | 68 | 76 | 69 | 61 | 52 | 45 | 38 | 31 |
| 2.H. Other | NO | NO | NO | NO | NO | NO | NO | NO |

*** Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022***

# CHAPTER 4. GHG EMISSION PROJECTIONS IN THE AGRICULTURE SECTOR

In preparing the projections, selected 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.

## 4.1. Methodologies and Key Assumptions/Trends

Based on the qualification of the likely impact of mitigation measures on emission inventories, we distinguish:

- Measures that have a detectable impact on emissions. This impact can be specifically attributed to the implementation of the mitigation measure. These measures are measurable and effective; this type of measure has been used in the preparation of emission projections.
- Measures that have an impact on emissions are reported in inventories, but this impact cannot be specifically attributed to a particular mitigation measure. These include measures that are difficult to measure and have different, often synergistic or antagonistic effects.
- Measures whose impact on emissions are reported in inventories are possible because there is a visible reduction in emissions. The effect of these measures depends on other factors.
- Measures that do not have a direct impact on emissions but may have a positive impact on farmers' actions or the environment in the sector.

The list of policies and measures implemented in the agricultural projections was taken from the National Programme for the Reduction of Pollutant Emissions, the Low Carbon Strategy of the Slovak Republic and the strategic document " Farm to Fork".[3] The forthcoming EU food strategy aims to reduce the use of pesticides, fertilisers and antibiotics in agriculture. By 2030, the consumption of hazardous pesticides should be reduced by 50% and the consumption of inorganic fertilisers should fall by 20%. The targets are set for the whole European Union, the Slovak Republic does not have a binding reduction resulting from the Farm to Fork Strategy, the European targets have been implemented in the projections.

The Low Carbon Strategy aims to identify measures, including additional ones, to achieve climate neutrality in the Slovak Republic in 2050 and a 55% reduction in emissions in 2030 compared to 1990. This ambitious target was only formally defined at the last stage of the Low Carbon Strategy preparation, and therefore other, less ambitious emission reduction scenarios are analysed in detail.

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 the introduction of measures in agricultural production will also be supported.

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[3] A Farm to Fork Strategy for a fair, healthy and environmentally friendly food system EK, "A Farm to Fork strategy for an equitable, healthy and environmentally friendly food system," European Commission, Brussels, 2020. [Online]. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381

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 in order 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.

## 4.2. Model Description

Emissions projections were prepared in accordance with the 2006 Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines, Chapter IV. 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.

For the projections of emissions in the Agriculture category, the model developed in the context of the implementation of Regulation (EU) 2018/841 of the European Parliament and of the Council was used. The computational analytical tool used 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.

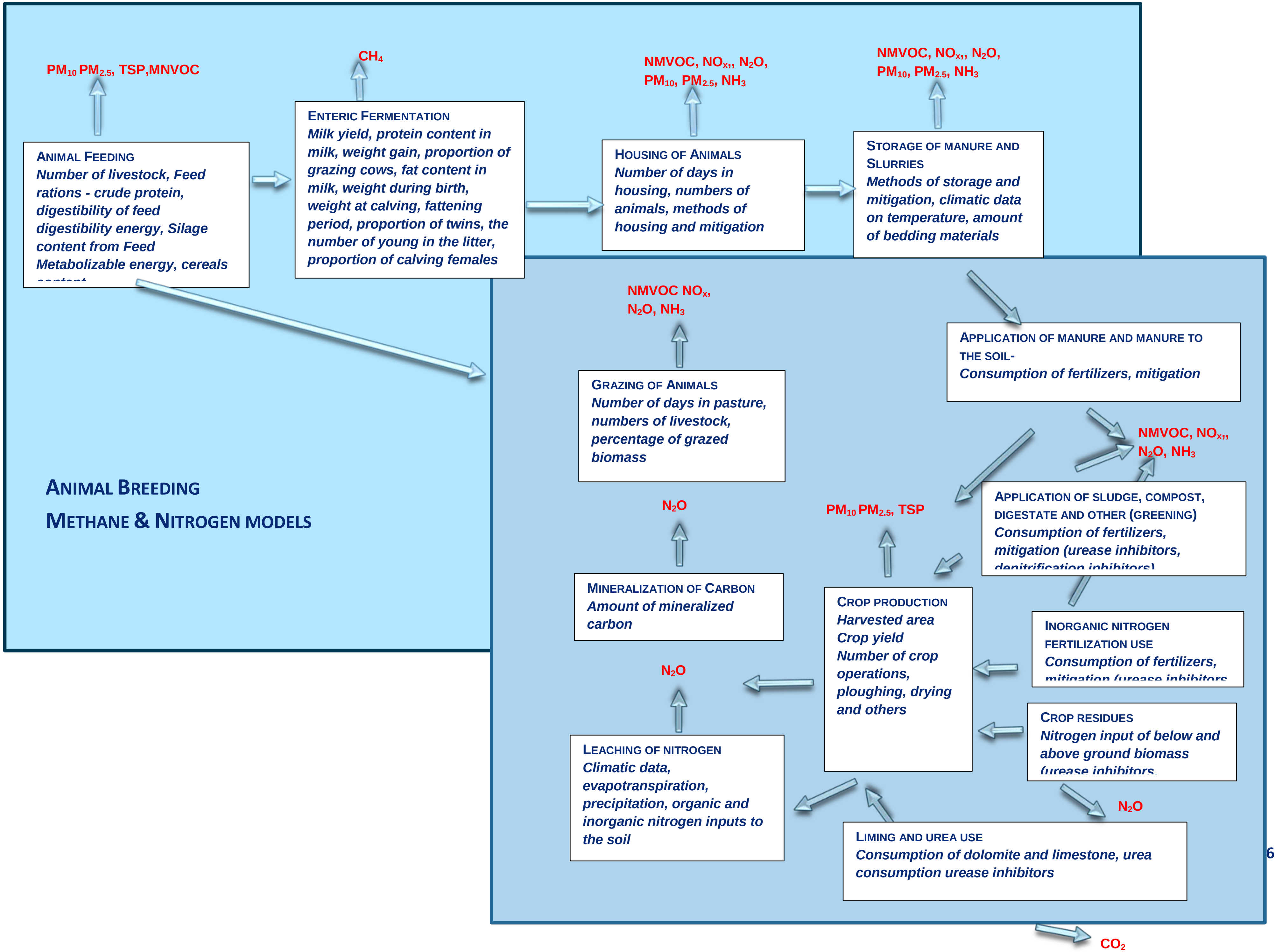
The calculation model is based on regional differences, which means the input parameters and number of livestock was modelled on a regional (district) level. After, this redistribution was implement to calculate emission projections. Projection of $CH_4$ emissions are calculated separately for each animal sub-category. For categories 3.B and 3.D, $N_2O$ emissions are calculated based on an N-flow concept. In categories 3.G and 3.H, $CO_2$ emissions are estimated for liming and urea application in line with the IPCC 2006 GL Please see ***Table 4.1*** and ***Figure*** below.

***Table 4.1:*** *SWOT analysis of the Agri-model*

| **Strengths** | **Opportunities** |
|---|---|
| Compatibility with emission model for emission inventories<br>Detailed data break down<br>National database used is compatible with EU data | Incorporate to the model new technologies<br>Versatile use of time-series |
| **Treats** | **Weakness** |
| Easy data entry<br>Basic software is free | Disconnected from macroeconomic models<br>Too much pre-calculations needed<br>Missing measurable indicators in national policies and strategies<br>Data consistencies in the projection estimation process |

Most implemented measures have a measurable effect on the emission inventory. List of policies and measures taken into account in emissions by individual scenarios and their effect (antagonistic, synergic). The limiting factor during the preparation of projections was the lack of details of the measures and their implementation plans within the Agriculture sector. Lack of information makes it difficult to implement and evaluate their impact. For this reason, an expert estimate of selected parameters was used during the preparation of the projections or European goals were used. It is therefore necessary to supplement the further specification of measures in the future for a more correct setting of models:

- Mechanism of implementation;
- Supporting resources requirements.
- Monitoring of implemented measures at the farm level, respectively. business entity



$PM_{10}$ $PM_{2.5}$, TSP,MNVOC

**ANIMAL FEEDING**
*Number of livestock, Feed rations - crude protein, digestibility of feed digestibility energy, Silage content from Feed Metabolizable energy, cereals content*

$CH_4$

**ENTERIC FERMENTATION**
*Milk yield, protein content in milk, weight gain, proportion of grazing cows, fat content in milk, weight during birth, weight at calving, fattening period, proportion of twins, the number of young in the litter, proportion of calving females*

NMVOC, $NO_x$,, $N_2O$, $PM_{10}$, $PM_{2.5}$, $NH_3$

**HOUSING OF ANIMALS**
*Number of days in housing, numbers of animals, methods of housing and mitigation*

NMVOC, $NO_x$,, $N_2O$, $PM_{10}$, $PM_{2.5}$, $NH_3$

**STORAGE OF MANURE AND SLURRIES**
*Methods of storage and mitigation, climatic data on temperature, amount of bedding materials*

NMVOC $NO_x$,
$N_2O$, $NH_3$

**GRAZING OF ANIMALS**
*Number of days in pasture, numbers of livestock, percentage of grazed biomass*

**APPLICATION OF MANURE AND MANURE TO THE SOIL-**
*Consumption of fertilizers, mitigation*

NMVOC, $NO_x$,,
$N_2O$, $NH_3$

## ANIMAL BREEDING
## METHANE & NITROGEN MODELS

$N_2O$

**MINERALIZATION OF CARBON**
*Amount of mineralized carbon*

$PM_{10}$ $PM_{2.5}$, TSP

**APPLICATION OF SLUDGE, COMPOST, DIGESTATE AND OTHER (GREENING)**
*Consumption of fertilizers, mitigation (urease inhibitors, denitrification inhibitors)*

**CROP PRODUCTION**
*Harvested area*
*Crop yield*
*Number of crop operations, ploughing, drying and others*

**INORGANIC NITROGEN FERTILIZATION USE**
*Consumption of fertilizers, mitigation (urease inhibitors*

$N_2O$

**CROP RESIDUES**
*Nitrogen input of below and above ground biomass (urease inhibitors,*

**LEACHING OF NITROGEN**
*Climatic data, evapotranspiration, precipitation, organic and inorganic nitrogen inputs to the soil*

$N_2O$

**LIMING AND UREA USE**
*Consumption of dolomite and limestone, urea consumption urease inhibitors*

$CO_2$

## 4.3. Scenarios, Parameters and PAMs

- 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 2020.
- The WAM 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 after 2020.

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 increase in emission projections for the WEM scenarios after 2005 is due to the projected increase 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.

More efficient storage of manure and slurry in the form of isolation of excreta from the surrounding environment 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. The WEM takes into account the current occurrence of the measure on farms that have been reported in the National Emissions Information System. 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. 410/2012 Coll., which implements certain provisions of the Air Act.[4] The implementation of this measure has an impact on ammonia nitrous oxide and methane emissions from category 3.B Manure and slurry management.

The WAM scenario is a scenario with additional measures, it contains projections of emissions from agricultural sources that include the effects of policies and measures that will be adopted and implemented after 2020. The WAM scenario was modelled on the basis of strategic documents developed by the MŽP SR in cooperation with the Ministry of Agriculture and Rural Development of the Slovak Republic and strategic documents developed by the Ministry of Agriculture and Rural Development.

Methane emissions from enteric fermentation in the WAM scenario were modelled by taking into account the measure proposed in the Low Carbon Strategy. One of the measures in the Low Carbon Strategy is the use of additives 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. Methane from agriculture, waste and energy should also be reduced under the so-called Methane Strategy.[5] The strategy will help the European Union on its path to more ambitious emissions targets by 2030 and ultimately to carbon neutrality by 2050. The Strategy also proposes measures to improve data collection and monitoring of emissions. It also promises to invest in research and to put in place a mechanism for sharing useful

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[4] Decree of the Ministry of the Environment of the Slovak Republic implementing certain provisions of the Air Act, https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2012/410/

[5] Methane strategy. Communication from the Commission to the EP, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU strategy to reduce methane emissions. [Online]. https://ec.europa.eu/energy/sites/ener/files/eu_methane_strategy.pdf

practices between Member States. Measurable measures to reduce methane emissions include changing the way animals are fattened.

Nitrous oxide and ammonia emissions from manure and slurry management (more efficient manure and slurry storage) in the WAM scenario have been modelled by taking into account the measure of introducing requirements to reduce emissions from livestock farms classified as a medium source of air emissions. This measure was proposed in the National Emission Reduction Program and implemented in the calculation of $NH_3$ and $N_2O$ emissions by implementing low-emission manure and slurry storage systems. This measure has an impact on category 3.B Manure and slurry management.

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 biogas plants. 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.

Nitrous oxide and carbon dioxide emissions from the application of inorganic nitrogen fertilisers (category 3.D Agricultural Soils) were modelled in the WAM scenario based on a measure that was implemented from the Low Carbon Strategy of the Slovak Republic. This measure recommends a switch to, or legislative restriction on, the application of urea-based nitrogen fertilisers. The implementation of this measure has an impact on the reduction of ammonia emissions, mainly due to the high volatility of ammonia from urea fertilisers. At the same time, by limiting urea consumption, carbon dioxide emissions are avoided. Nitrous oxide emissions are limited on the basis of a reduction in the total consumption of inorganic fertilisers in the resulting consumption totals.

The last measure implemented was taken from the European Green Deal, as set out in the Farm to Fork Strategy. This measure provides for a 20% reduction in the consumption of inorganic fertilisers by 2030. This measure impacts emission categories 3.D.1 and 3.D.2 direct and indirect $N_2O$ emissions from agricultural soils and ammonia emissions. A list of the policies and measures that have been taken into account in the emission projections under each scenario and their effect is presented in ***Table 4.2***.

***Table 4.2:*** *List of policies and measures implemented in the projections by scenario*

| Strategy Document Legislation | Scenario | Gas/Category | Measure | Effect of the Measure |
|---|---|---|---|---|
| Code of good agricultural practice<br>National Air Pollution Control Programme<br>Low carbon strategy<br>Decree of the Ministry of the Environment of the Slovak Republic no. 410/201 2 Coll.<br>CAP Strategic Plan 2023-2027 | WEM, WAM | $N_2O$, $NH_3$ - storage of manure and slurry | Efficient storage of animal waste, specifically storage of liquids in tanks isolated from the surroundings or in tanks with access to oxygen and storage of manure in plastic sheeting with no or minimal addition of water. | Synergistic |
| Low Carbon Strategy | WAM | $CH_4$ - enteric fermentation<br>$N_2O$, $NH_3$ - storage of manure and slurry | Animal feeding interventions to reduce emissions, such as intensive feeding of actives, impact on methane emissions | Synergistic |
| National Air Pollution Control Program | WAM | $N_2O$, $NH_3$ - cropland | Obligation to comply with measures to reduce ammonia emissions also at medium pollution sources | Synergistic |
| Low Carbon Strategy | WAM | $N_2O$ - storage of manure and slurry | Process animal waste efficiently and use biogas, especially as a local energy source | Synergistic |
| Low Carbon Strategy | WAM | $CH_4$ - storage of manure and slurry | Process animal waste efficiently and use biogas, especially as a local energy source | antagonistic |

| Strategy Document Legislation | Scenario | Gas/Category | Measure | Effect of the Measure |
|---|---|---|---|---|
| Low Carbon Strategy | WAM | $N_2O$, $NH_3$, $CO_2$ - cropland | Increasing the use of nitrogen fertilisers with stabilised nitrogen at the expense of the use of urea | Synergistic |
| Farm To Fork Strategy | WAM | $N_2O$, $NH_3$ - cropland | Reduction of inorganic nitrogen fertilisers by 20% compared to 2030 | Synergistic |
| Methane Strategy | WAM | $CH_4$ - enteric fermentation | Improving the quality of animal feed (innovating compound feed), feed additives and feeding techniques | Synergistic |
| Methane Strategy | WAM | $N_2O$, $NH_3$ - cropland | Recover waste and residue streams from agriculture through anaerobic digestion | Synergistic |
| Methane Strategy | WAM | $CH_4$ | Monitoring methane emissions at farm level | informative |
| Strategic Plan Cap 2023-2027 | WAM | $CH_4$, $N_2O$ | Pastoral rearing of cattle, sheep and goats | Antagonistic |

## 4.4. Projections of Methane Emissions from Enteric Fermentation and Manure and Slurry Management (3.A and 3.B)

One effective way to reduce methane emissions from livestock is to optimize animal diets and change animal feeding schedules to reduce methane and nitrous oxide emissions. After 1990, there has been a clear decline in livestock numbers and an increase in animal performance, such as milk yield. The trend of increasing performance and decreasing numbers of animals will continue after 2020. There is currently no official national strategy to guide the future development of animal numbers and performance management. In modelling the data for the future, historical trends were assessed and corrected in the form of expert estimates with collaborating institutions, in particular the National Agricultural and Food Centre.

Methane is balanced based on the 2006 IPCC methodology. The calculation methodology is based on a common model for calculating methane from enteric fermentation and methane from manure and slurry management. In particular, the trend of cattle numbers is key, with cattle accounting for approximately 80% of total methane emissions in categories 3.A and 3.B.1. The second significant source of methane emissions is the management of manure and slurry from pig farming. The calculation model for these categories was at tier 2 level, which means the use of emission factors and parameters specific to the Slovak Republic in accordance with the 2006 IPCC methodology.

Projections of methane emissions from categories 3.A and 3.B.1 were prepared in the WEM and WAM scenarios. The WEM scenario takes into account the current state of utility. It is assumed that the trend of increasing productivity and decreasing animal numbers (pigs, poultry) since 1990 will continue after 2020. This scenario is sensitive to the change in livestock numbers, which is one of the most important parameters for the preparation of emission projections. The trend of increasing livestock performance will influence the increase in methane emissions. The above is likely to continue in the case of dairy cattle, especially in dairy cow herds. However, in the case of beef cattle, the tendency is for their numbers to increase. There are plenty of permanent grassland in the country that is not grazed and is suitable for cattle grazing. Meat cattle are easy to care for compared to dairy cattle. There is no need for special stables or milking parlours, but shelters are sufficient as these cattle are often grazed all year round.

The WAM scenario takes into account feeding measures, in particular easily digestible compound feeds, amino acids and other supplements that reduce methane emissions, and a measure from the Strategic Plan for the Common Agricultural Policy 2023 – 2027, which also includes a switch to pastoral livestock farming, in particular for beef cattle and sheep. At the same time, the increase in numbers of beef cattle, goats and sheep was taken into account. In this measure, the grazing of meadow and grassland is included in the feed ration, as well as the use of rotational grazing of animals due to the nature of the permanent grassland (different stages of maturity of the different grasses). In this scenario, the upper limit of digestibility of the ration is a maximum of 70%. It would also be possible to increase the digestibility of the ration during the winter period when the animals are housed by adding kernels and silage and other additives. In the case of dairy cattle, it is possible to increase the digestibility of the ration by increasing the proportion of cereals (up to a maximum of 50% of the dry matter of the feed) or by adding additives such as amino acids to reduce nitrogen excretion or to inhibit methanogenic bacteria in the compound stomach of ruminants. At the same time, it was confirmed from modelling that lower digestibility of feed ration is consequently reflected in increased methane production, i.e. the emission factor for methane EF (the amount of methane emission produced by 1 animal over a period of 1 year) was higher in all categories of beef cattle (lower digestibility of feed ration) than in dairy cattle, except for the category of dairy cows and dairy heifer calves.

It is also possible to reduce methane emissions from enteric fermentation by adding additives to the ration (3-hydroxypropionic acid, rapeseed oil, algae, etc.). The use of the additive 3-nitrooxypropanol (3-NOP) was included in the measures included in the modelling of emissions in the WAM scenario. Its use was implemented in the scenario on the recommendation of the National Agricultural and Food Centre - Research Institute of Animal Production. The maximum recommended level is an admixture into the ration at 100 mg$^3$-NOP/kg DM. Methane is produced by the microbiota naturally present in the compound stomach. 3-NOP acts as an inhibitor of methane production by interfering with the ability of this microbiota to produce methane. Based on this property, a reduction factor was introduced into the emission factor. The mitigating effect of this substance was taken from an EFSA publication of 2021 at 20% compared to a feed ration that did not contain the additive. The implementation of such a measure is limited due to the high acquisition cost of the additive and the possible shortage on the market.[6] In the projections it was included only in economically strong regions such as Bratislava, Trnava, Trenčín, Nitra, which is an expert estimate of the measure. The introduction of this measure in the projections is gradual and will require support at departmental level. The timetable for the introduction of the measures applied in the WAM scenario is presented in ***Table 4.3***.

***Table 4.3:*** *Timetable for the introduction of 3-NOP - expert estimate*

| Animal species | The effectiveness of the measure |
|---|---|
| Dairy cow | Since 2023 |
| Dairy cattle species | Since 2030 |
| Beef cattle species | Since 2030 |
| Sheep | Since 2030 |

The WAM scenario also takes into account the processing of manure and slurry as feedstock for the biogas production process, which can be used as a local energy source. This measure is relevant for cattle and pigs mainly because of the high emission production. The recovery of manure and slurry from cattle has caused a slight increase in methane emissions, particularly during storage prior to recovery. Methane emissions during manure storage are lower (MCF[7] 2%) than for slurry (10-15% on average in temperate climates). In other types of livestock the production of solid waste - manure is predominant, in pig farms the production of liquid waste - slurry is predominant.

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[6] EEDAP, „Safety and efficacy of a feed additive consisting of 3-nitrooxypropanol (Bovaer®10) for ruminants for milk production and reproduction (DSM Nutritional Products Ltd),“ 2021

[7] Methane conversion factor

Under planned measures in the Common Agricultural Policy (CAP) after 2023, subsidies will be provided to farmers in the form of direct payments to improve animal welfare and to increase the proportion of grazing in selected animal species.[8]

Subsidies can be obtained per animal under the CAP if the following criteria are met:

- During the grazing season, at least from 1 May to 31 October (excluding days with adverse weather conditions), ensure grazing for a minimum of 120 days for sheep from 12 months of age (all animals per selected species per holding - farm, except for permitted exceptions, e.g. animals shortly before and after birth, sick animals, etc.). A value of 180 days was used in the calculation of the projections.
- During the grazing season, at least from 1 May to 31 October (except for days with adverse weather conditions), provide grazing for a minimum of 120 days for dairy cows (all animals per holding - farm, except for permitted exceptions, e.g. animals shortly before and after birth, sick animals, etc.). A value of 200 days was used in the calculation of the projections.
- During the grazing season, at least from 1 May to 31 October (except for days with adverse weather conditions), ensure grazing for a minimum of 150 days for heifers from 12 months of age (all animals per selected species and category per breeding-farm). The value of 150 days was used in the calculation of the projections.

This measure will cause an increase in emissions from enteric fermentation, mainly due to the predominance of roughage in the ration, which has a negative effect on the mitigation of GHG emissions due to lower digestibility. Based on the 2006 IPCC Methodological Manual, when cattle are predominantly grazing, the digestibility of the feed ration is at 55-75% (page 10.14 Table 10.2), but when it comes to emissions from manure management, the situation is reversed. Emissions from cattle grazing have a lower potential for methane formation (MCF 1%) than, for example, slurry storage (on average 10-15% in temperate climates) or manure storage (MCF 2%). Final feed rations need to be adjusted so that we can effectively reduce emissions from both categories.

## 4.5. Projections of Nitrous Oxide Emissions from Manure and Slurry Management (3.B)

The potential for reducing nitrous oxide emissions in agriculture is mainly related to the efficiency of manure management, in particular the handling and storage of manure and slurry and their application to the soil in a low-emission manner. Some measures are included in Decree No. 410/2012 Coll. of the Ministry of the Environment of the Slovak Republic and are also valid for farms classified under Act No. 39/2013 Coll. on Integrated Pollution Prevention and Control. Mitigation measures included in the current legislation have been included in the WEM scenario. Currently, a revision of the Decree of the MŽP SR No. 410/2012 Coll. is underway, as well as an amendment to the Air Act No. 137/2010 Coll., in order to introduce the obligation to comply with the principles of Good Agricultural Practice also in medium-sized agricultural units. ***Table 4.4*** shows the percentage distribution of farms that have been reported in the National Emissions Information System.

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[8] Ministry of Agriculture and Rural Development, "Strategic Plan of the Common Agricultural Policy for 2023-2027," Bratislava, Ministry of Agriculture and Rural Development, 2022. [Online]. https://www.mpsr.sk/spolocna-polnohospodarska-politika-2023-2027/462

***Table 4.4:** Percentage distribution of medium, large and small farms in the Slovak Republic in 2020*

| Species of animal | Pigs | Poultry | Cattle | Sheep | Horses | Goats |
|---|---|---|---|---|---|---|
| Share of large farms | 2% | 30% | 3% | 0% | 0% | 0% |
| Share of medium-sized farms | 2% | 20% | 5% | 10% | 1% | 0% |
| Share of small farms | 96% | 50% | 92% | 90% | 99% | 100% |

*Source: National Emissions Information System*

The WEM scenario includes mitigation measures resulting from the Decree of the MŽP SR No. 410/2012 Coll., namely the storage of manure and slurry in tanks and manure pits isolated from the surroundings. Information on existing measures and their percentage share in the reduction of nitrogen emissions was taken from the National Emission Information System.[9]

The WAM scenario contains measures that are synergistic and can be implemented in a computational model. This is the use of amino acids in the ration reducing the nitrogen excretion of the animals, in the model it has been implemented through a more precise optimization of the nitrogen in the ration. The measure was used in the estimation of nitrogen excretion per animal per year in cattle. Based on a meta-analysis, the estimate of mitigation potential compared to the reference value ranged from 17±6% Nex.

In the WAM scenario, the processing of animal waste in biogas plants to produce biogas that can be used as a local energy source has also been implemented. This measure was included in the Low Carbon Strategy of the Slovak Republic and the Methane Strategy does not include details such as animal species, percentages of waste recovered and others that would provide measurable indicators potentially usable in the calculation of emission projections. In the preparation of the emission projections, this information was additionally expertly estimated. For the purposes of this analysis, it was assumed that 10% of organic waste - manure from cattle and pigs - would be recovered in biogas plants. Cattle and pigs are the key animal categories with the greatest potential to generate emissions from waste. Biogas from biogas plants is a promising source of renewable electricity and heat that can be used locally. Emission mitigation achieved through the inclusion and increased potential for animal waste treatment in biogas plants will be accounted for in the Energy sector. The nitrogen input data for biogas plants is balanced based on a percentage estimate from the pool. In the future it will be necessary to collect these data on an annual basis, mainly due to the lack of detailed statistics. Inaccurate data overestimates GHG and pollutant emissions.

Another measure from the National Air Pollution Control Program, which was included in the WAM scenario, is the obligation to comply with measures to reduce ammonia emissions also at medium sources of air pollution. The measure is primarily designed to reduce ammonia, but also has an impact on reducing $N_2O$ emissions. The measure will also be implemented in the amendment of the Air Act No. 137/2020 Coll. and Decree No. 410/2012 Coll. of the MŽP SR. The projections assume compliance with the isolation of slurry and manure from the surroundings on medium and large farms (sources of air pollution). These data were also compared with the database of the Central Livestock Register. As can be seen in the table, the majority of farms are included in the category of small farms. As exact figures on the percentage of farms that will be affected by this change in legislation were not available, it was assumed in the preparation of the emission projections that all medium and large farms would benefit from emission reduction measures from manure and slurry management. This measure has a minimal impact on the reduction of nitrous oxide emissions. In the WAM scenario, the measures are assumed to be implemented immediately after 2021.

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[9] National Emissions Information System: http://www.air.sk/neis.php

## 4.6. Projections of Nitrous Oxide Emissions from Cropland (3.D)

Between 2016 and 2020, we have seen a recovery in crop production, which has put pressure on the consumption of mineral nitrogen fertilizers, the application of compost, digestate, and other organic nitrogen fertilizers. The recovery may have been stimulated by direct payments for selected crops used for human and animal nutrition and biofuel production.

The WEM scenario assumes an estimated trend in the consumption of organic and inorganic nitrogen fertilisers based on exponential smoothing by analysing past emission trends. The WEM scenario has an increasing trend in the projections of nitrous oxide emissions, mainly due to the assumed continued recovery of crop production in Slovakia. After 2020, inorganic fertiliser consumption is expected to increase by 79% compared to 2005. We project an increase in the consumption of inorganic fertilizers, which will be needed to compensate for the shortage of organic nitrogen due to declining livestock numbers by 2050. $N_2O$ emissions from livestock grazing are projected to follow an increasing trend until 2030, with a gradual stabilization of grazing emissions projections after 2050. The increase will be mainly due to an increase in the number of grazing animals (beef cattle, sheep and goats). The increase in emission projections in the WEM scenario is also visible in the category of applied other organic wastes, namely compost and digestate. The amount of applied matter from cultivated plants to soil will also increase.

The WAM scenario includes two mitigation measures that have a synergistic effect. A measure taken from the Low Carbon Strategy recommends a legislative restriction on the application of urea-based nitrogen fertilisers. The implementation of this measure has an impact on the reduction of ammonia emissions, mainly due to the high volatility of ammonia from urea fertilisers. Limiting urea consumption will also avoid nitrous oxide emissions by reducing the total consumption of inorganic fertilisers in the resulting consumption totals. Detailed information on when the legislative framework would apply was not available, so an expert estimate was used. The urea reduction had a gradual path, which is shown in ***Table 4.5***. Limiting urea also has an effect on $CO_2$ emissions from agriculture and in particular on $NH_3$ emissions.

***Table 4.5:*** *Limiting urea consumption from 2025 – 2050 under the WAM scenario*

| Year of implementation | Percentage reduction in urea consumption |
|---|---|
| **2020 – 2025** | Transition period, time to implement legislation |
| **2026 – 2030** | 10% |
| **2031 – 2035** | 20% |
| **2036 – 2040** | 30% |
| **2041 – 2045** | 50% |
| **2046 – 2050** | 70% |

The second measure, taken from the Farm to Fork strategy, is to reduce the use of pesticides, fertilisers and antibiotics in agriculture. This strategy was developed in synergy with the European Green Deal, which aims to reduce the environmental and climate footprint of the European food system. Under the WAM scenario, the target of reducing nitrogen fertiliser consumption by 20% by 2030 has been implemented. A transition period has been implemented in the emission projections, which is in line with the transition period for urea limitation (2020 – 2025). It is likely that the Slovak Republic will negotiate its own percentage reduction in fertiliser consumption and claim a transitional period, which will be legislatively enshrined at national level. After the legislative process, emission projections will need to be adjusted in line with the future national strategy in force. Even though the planned mitigation measures have been implemented, emission projections are increasing by 2030 and 2050, creating pressure to adopt much more ambitious measures.

## 4.7. Projections of Carbon Dioxide Emissions from Soil Liming and Urea Use (3.H, 3.G)

Carbon dioxide emissions from the application of urea and limestone or dolomite to agricultural soils were estimated based on the IPCC methodology. The only way in which emissions from these sources can be eliminated is by limiting inputs to the soil. Liming is an activity that has a positive effect on the soil (changing the pH on acid soils to neutral), so limiting this activity would not have a positive effect on soil quality and crop yields. Projections of carbon dioxide emissions from soil liming and urea use were prepared in the WEM and WAM scenarios. The impact of implemented policies and measures had the effect of reducing or increasing emissions. The WEM scenario was prepared on the basis of modelling future consumption of dolomite, limestone and urea, which takes into account the previous upward trend in consumption.

The WAM scenario contains one planned measure that could have been implemented in the preparation of the carbon dioxide emission projections. This is to limit the use of urea at the expense of other nitrogen fertilisers. This measure also has a synergistic effect on ammonia and nitrous oxide emissions, as urea has the highest ammonia emission potential of all nitrogen fertilisers. This measure is the same as that used for the projections of $N_2O$ emissions from agricultural soils. Legislatively restricting this activity would have a significant impact on reducing emissions from agriculture.

## 4.8. Projections of Aggregate GHG Emissions in the Agriculture Sector

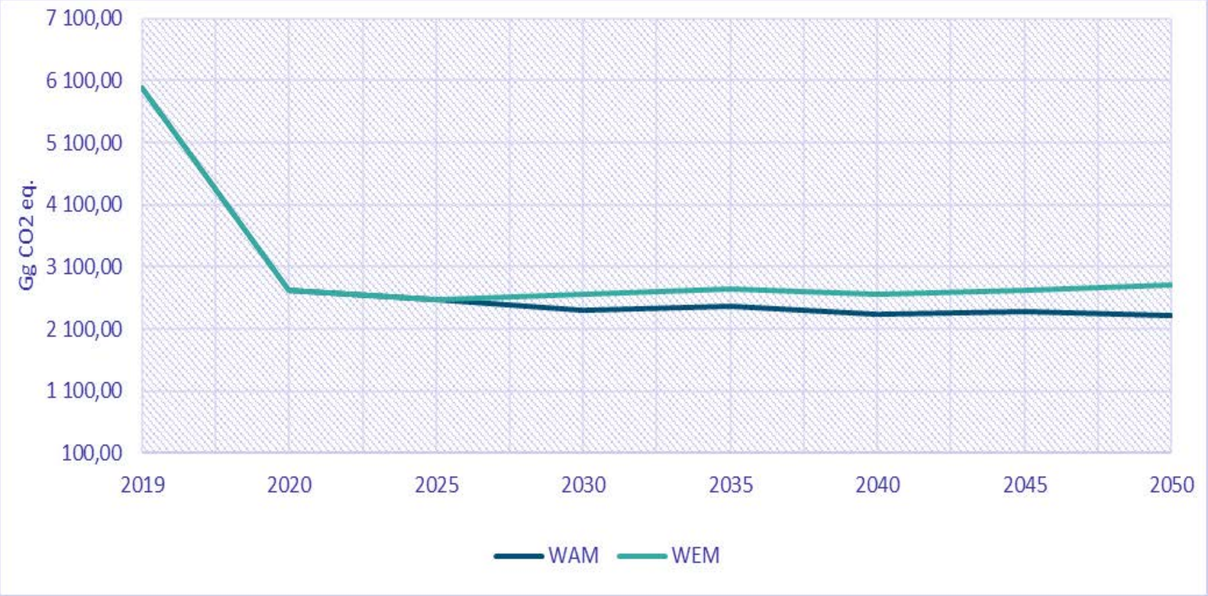
***Table 4.6*** and ***Figure 4.1*** show aggregated data on GHG emission projections in the agriculture sector.

***Table 4.6:*** *GHG emission projections in Gg of $CO_2$ eq. in WEM and WAM scenarios in Agriculture*

| **WEM** | **1990*** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2050** |
|---|---|---|---|---|---|---|---|---|
| 3. Agriculture | 6 076.31 | 2 541.39 | 2 545.04 | 2 628.08 | 2 701.79 | 2 618.01 | 2 686.03 | 2 771.74 |
| 3.A Enteric fermentation | 3 132.29 | 1 085.44 | 1 082.30 | 1 052.47 | 1 070.64 | 1 004.65 | 1 033.23 | 1 070.74 |
| 3.B. Manure management | 892.18 | 255.64 | 230.60 | 238.75 | 235.92 | 224.25 | 227.12 | 226.91 |
| 3.D Agricultural soils | 1 990.82 | 1 132.06 | 1 160.02 | 1 244.18 | 1 294.91 | 1 283.80 | 1 313.45 | 1 356.41 |
| 3.G Limestone and dolomite | 45.73 | 4.71 | 8.45 | 18.95 | 20.97 | 23.70 | 26.12 | 30.44 |
| 3.H Use of urea | 15.29 | 63.54 | 63.67 | 73.73 | 79.36 | 81.61 | 86.11 | 87.23 |
| **WAM** | **1990*** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2050** |
| 3. Agriculture | 6 076.31 | 2 541.39 | 2 545.04 | 2 393.28 | 2 437.93 | 2 313.92 | 2 350.23 | 2 303.81 |
| 3.A Enteric fermentation | 3 132.29 | 1 085.44 | 1 082.30 | 1 002.83 | 1 011.80 | 934.64 | 960.27 | 968.71 |
| 3.B. Manure management | 892.18 | 255.64 | 230.60 | 210.06 | 209.55 | 192.47 | 195.62 | 198.28 |
| 3.D Agricultural soils | 1 990.82 | 1 132.06 | 1 160.02 | 1 087.71 | 1 124.18 | 1 097.83 | 1 107.94 | 1 080.20 |
| 3.G Limestone and dolomite | 45.73 | 4.71 | 8.45 | 18.95 | 20.97 | 23.70 | 26.12 | 30.44 |
| 3.H Use of urea | 15.29 | 63.54 | 63.67 | 73.73 | 71.42 | 65.29 | 60.28 | 26.17 |

***** *Base year 2019; 1990 – 2020 based on the GHG inventory submission 20. 10. 2022*

**Figure 4.1:** *GHG emission projections in the Agriculture sector in WEM and WAM scenarios up to 2050*



# 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.

## 5.1. 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 three scenarios for the development of emissions from 2020 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/capture projections is presented in ***Figure 5.1*** and ***Table 5.1***. In the WEM scenario, the measures adopted and implemented up to 2020 have been implemented, these measures have not prevented a decrease in GHG removals of -78% compared to 1990. The WEM scenario took into account policies and measures from official national strategic documents and programmes valid in Slovakia until 2020, mainly from the National Forestry Programme of the Slovak Republic 2014 – 2020[10], Rural Development Programmes 2007 – 2013, 2014 – 2020[11] 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 2020[1] and the Environmental Policy Strategy of the Slovak Republic 2030. When additional measures were implemented in the WAM scenario, removals decreased by -47% 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 2020 in the WEM scenario, compared to the WAM scenario, is due to a higher decrease in removals in the Forest, Cropland and Permanent Grassland categories and an increase in emissions from the Residential and Other Land categories.

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 2020 indicate that 37 002.71 Gg $CO_2$ eq. The LULUCF sector captured 7 593.17 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 permanent 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,

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

[11] 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

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 $CO_2$ eq. in the LULUCF sector in WEM and WAM scenarios up to 2050

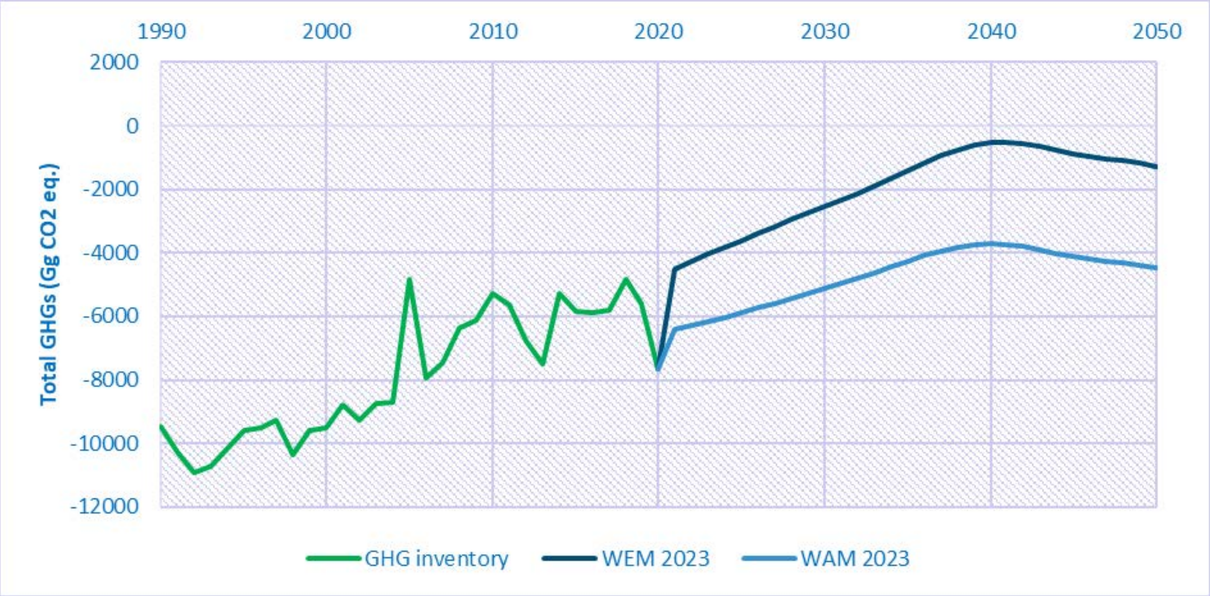

**Table 5.1:** GHG emissions/removals trend and projections in the LULUCF sector in WEM and WAM scenarios up to 2050

| Year | WEM | WAM |
|---|---|---|
| | *Gg $CO_2$ equivalents* | |
| **1990*** | -9 332.80 | -9 332.80 |
| **1995*** | -9 486.95 | -9 486.95 |
| **2000*** | -9 395.36 | -9 395.36 |
| **2005*** | -4 750.02 | -4 750.02 |
| **2010*** | -5 212.74 | -5 212.74 |
| **2015*** | -5 755.83 | -5 755.83 |
| **2019*** | -5 519.27 | -5 519.27 |
| **2020*** | -7 599.64 | -7 599.64 |
| **2025** | -3 551.37 | -5 827.17 |
| **2030** | -2 472.74 | -5 063.98 |
| **2035** | -1 337.39 | -4 196.07 |
| **2040** | -467.89 | -3 661.77 |
| **2045** | -811.01 | -4 055.42 |
| **2050** | -1 203.19 | -4 409.79 |

** Base year 2019; 1990 – 2020 based on the GHG inventory submission 20. 10. 2022*

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 2050.

Projections of emissions/removals of GHGs in the LULUCF sector were modelled for the 6 main balance land use categories (Forest Land, Cropland, Grassland, Wetlands, Settlements, Other Land) and the 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 1990-2020 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 – 2020, source Statistical Yearbook of the Land Fund of the Slovak Republic, Office of Geodesy Cartography and Cadastre[12]), 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 1970-2020), data available by county, district and cadastral area,
- annual tree growth in $m^3$/ha (1990 – 2020, source Summary Information on the State of Forests (SISL), as part of the Forestry Information System [13](FIS), data available by county,
- annual timber harvest in $m^3$ (1990 – 2020, source FIS), data available for Slovakia by tree species,
- area of individual trees in ha (1990 – 2020, source FIS), data available by county,
- representation of individual tree species in ha (1990-2020, source SFIS), data available by county,
- age structure of forests in ha (2014 – 2020, source FIS),
- area of forest fires in ha (1990 – 2020, 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 – 2020, source FAO database).

## 5.2. 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 – 2019 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 – 2019; Cadastre data available by region, districts and cadastral areas),
- 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),

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[12] 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/

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

- individual tree species composition in ha (NFC data available by regions),
- age structure of forests in ha (2014 – 2019; 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 2020 – 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 fellings) 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 – 2019. 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<br>Detailed data break down<br>Database used is compatible with national data | Incorporate to the model new technologies<br>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)<br>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 2020 – 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). Interannual 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).

### 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 a 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 2020-2050. Forest condition data valid at the end of 2019 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.[14] For category 4.A.1 Remaining forest, 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 (1 996 677 ha in 2020 to 2 024 540 ha in 2040 and 2 035 643 ha in 2050) and dynamically changing tree species composition (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, with the remaining tree species remaining at 2020 levels). 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):

Acreage and tree species composition were projected as static - the average value from historical data 1990-2019 was used (GL/FL - 863 ha, CL/FL - 89 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 1990-2019 was used (FL/GL - 25 ha, FL/CL - 2 ha, FL/S 46 ha, FL/OL - 111 ha. The average hectare stock was modelled as a dynamic variable.

- Category 4.B.1 Cropland:

The acreage of CLA/CLP (annual stands/perennial stands) and CLP/CLA (permanent stands/annual stands) transfers was projected as static and the average value from 1990-2019 historical data was used (CLA/CLP - 6 ha, CLP/CLA - 385 ha). The acreage of each sub-category of permanent grassland (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 (permanent grassland, settlements, other land) were projected as dynamic. The harvested wood products (HWP) 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).

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

- Category 4.A.1 Forest land remaining forest land:

The projections were made as a continuation of forest management in the so-called reference period 2014-2019. In the WAM scenario, the projected development of gains was modelled on the basis of a scenario with dynamically increasing forest area (1 996 754 ha in 2020 to 2 027 654 ha in 2040 and 2 050 106 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):

Acreage 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 1 322 ha in 2020 to 224 ha in 2050, CL/FL - from 65 ha to 122 ha in 2050, OL/FL - 718 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 acreage of CLA/CLP (annual stands/permanent stands) and CLP/CLA (permanent stands/annual stands) 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 acreage of the individual subcategories of permanent crops (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 (permanent 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 by the FCarbon model, with the distribution of harvest volume among the different product categories based on an ideal distribution.[15]

## 5.3. Scenarios, Parameters and PAMs

Projections of the main input parameters - acreage and changes in acreage in each land use category in the LULUCF sector for the period 2021 – 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 – 2020 was

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[15] 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

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).

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

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

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

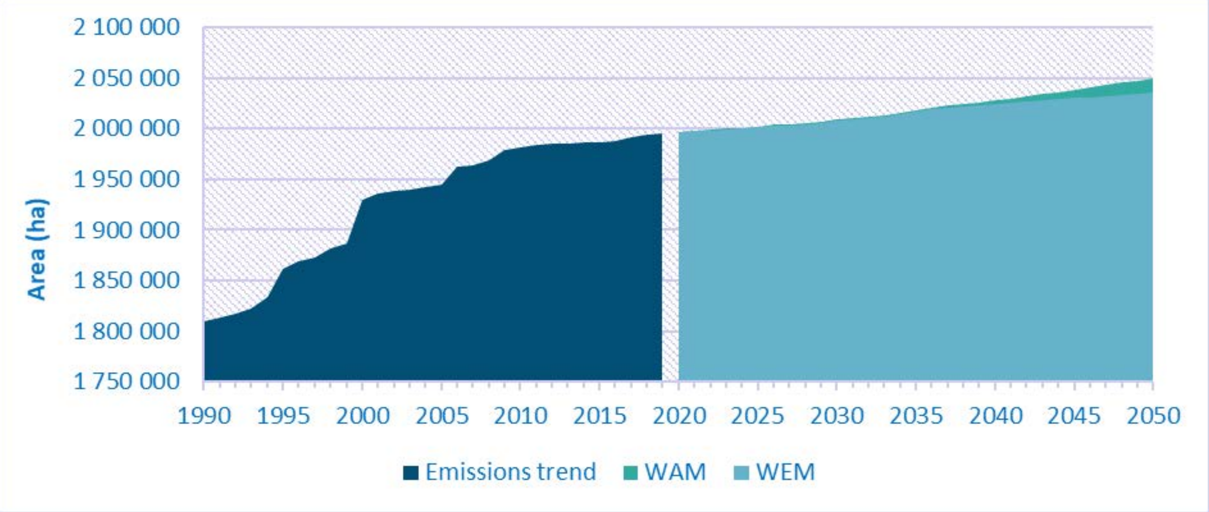
[18] Grassi, G.; Pilli, R. 2017. Projecting forest GHG emissions and removals based on the “continuation of current forest management”: the JRC method. EUR 28623 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2017. doi:10.2760/844243. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC106814/jrc_report_frl.pdf; 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.

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.

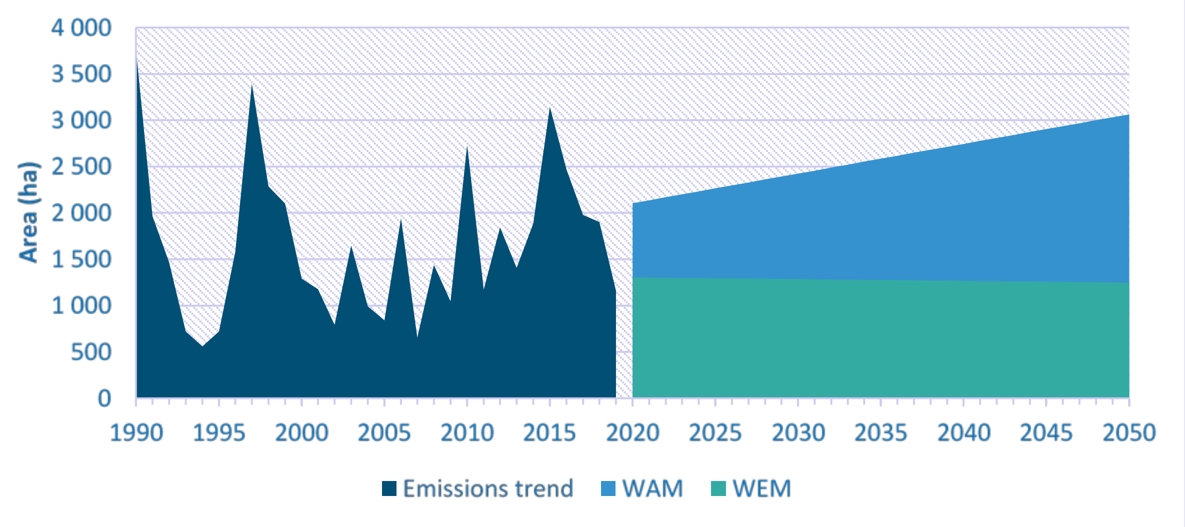
The development of acreage in the category Forest Land remaining Forest Land follows the above mentioned trend of increasing acreage of forests in the Slovak Republic. For this reason, the projection assumes an increase in forest area after 2020, both in the WEM and WAM scenarios (***Figure 5.2***).

***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*



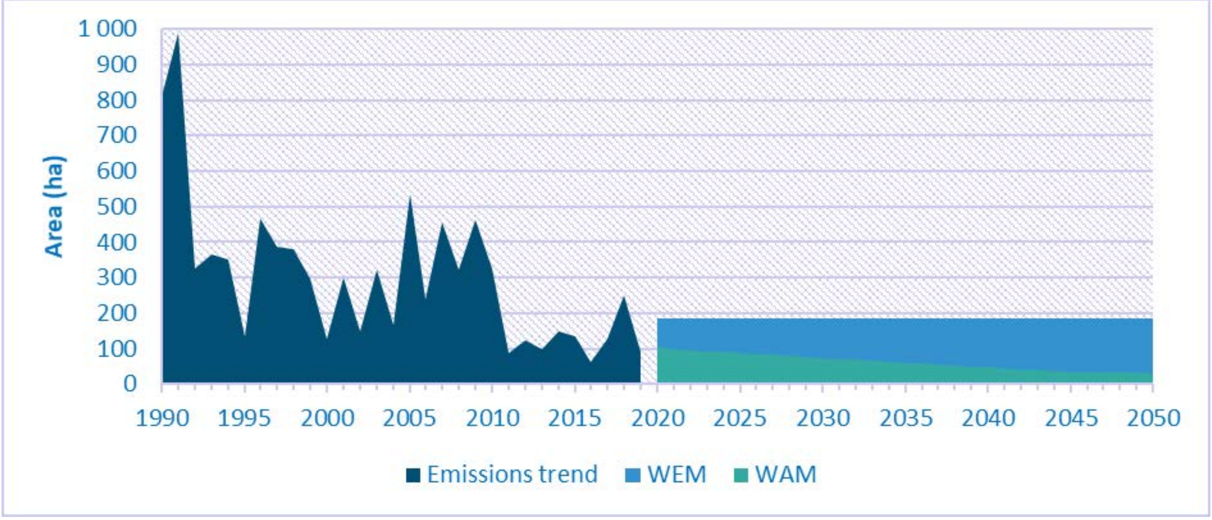
Area of the category Land converted to Forest Land (afforestation) (4.A.2) - historical acreage in this category shows a divergent pattern throughout the 1990 – 2020 period. The highest acreage value was recorded in 1990 at 3 770 ha and the lowest at 559 ha in 1994. The average value was 1 670 ha. The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

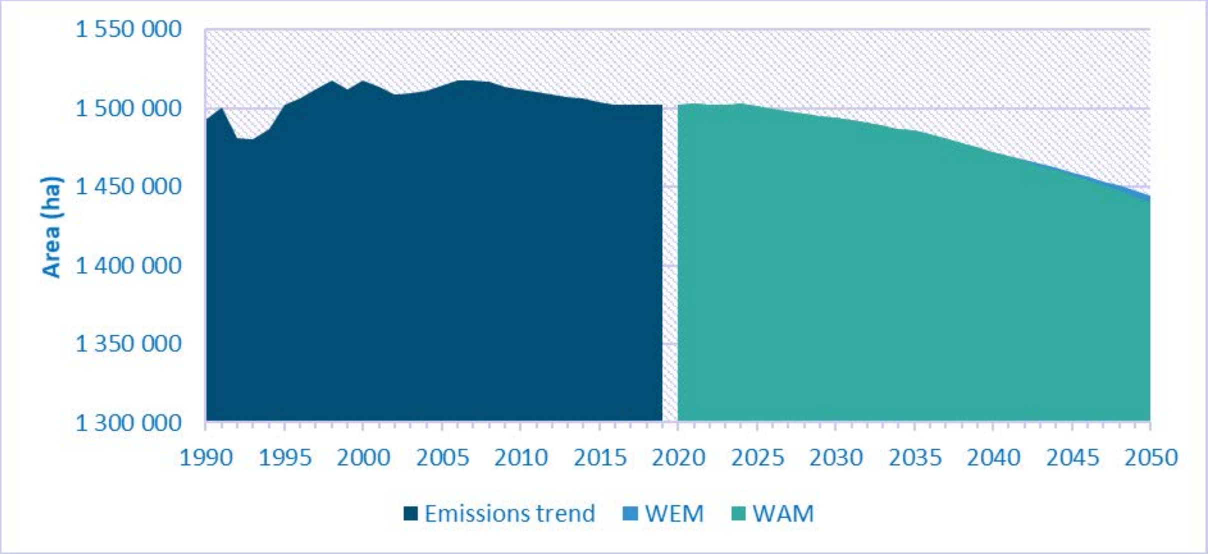
***Figure 5.4:*** *Trend and projections of area in ha in 4.A.2 - Forest Land converted to Land (deforestation) in WEM and WAM scenarios up to 2050*



Area of the category Cropland (4.B) - historical acreage 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.

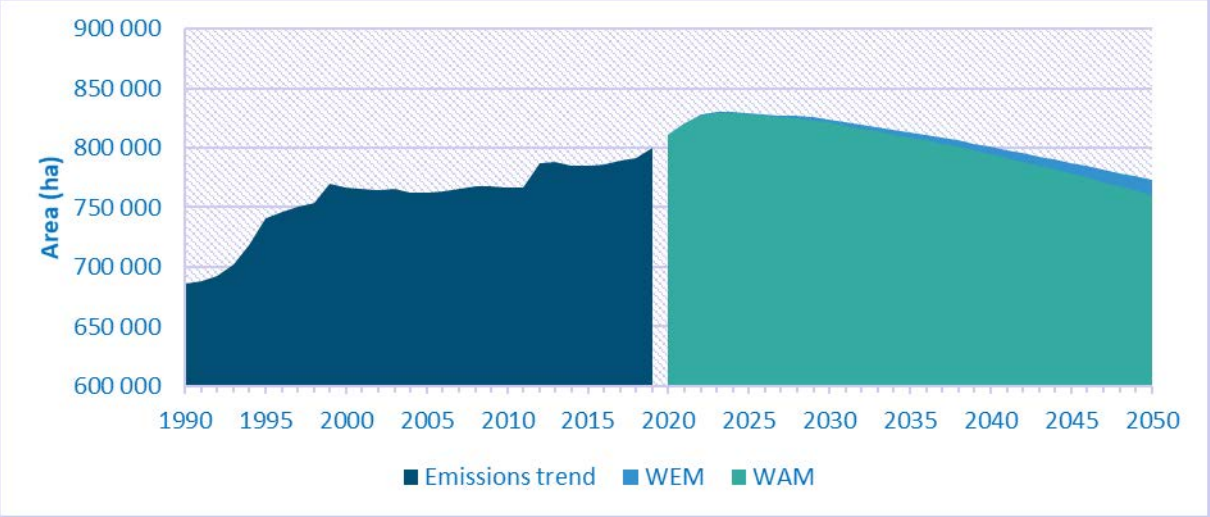
On the basis of the above, it is possible to assume a stabilisation of the acreage in this category, or a very slight decrease. As regards the internal structure, an increase in the area of individual permanent crops is expected, particularly orchards, vineyards and, it would be appropriate, hop-growing, 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*



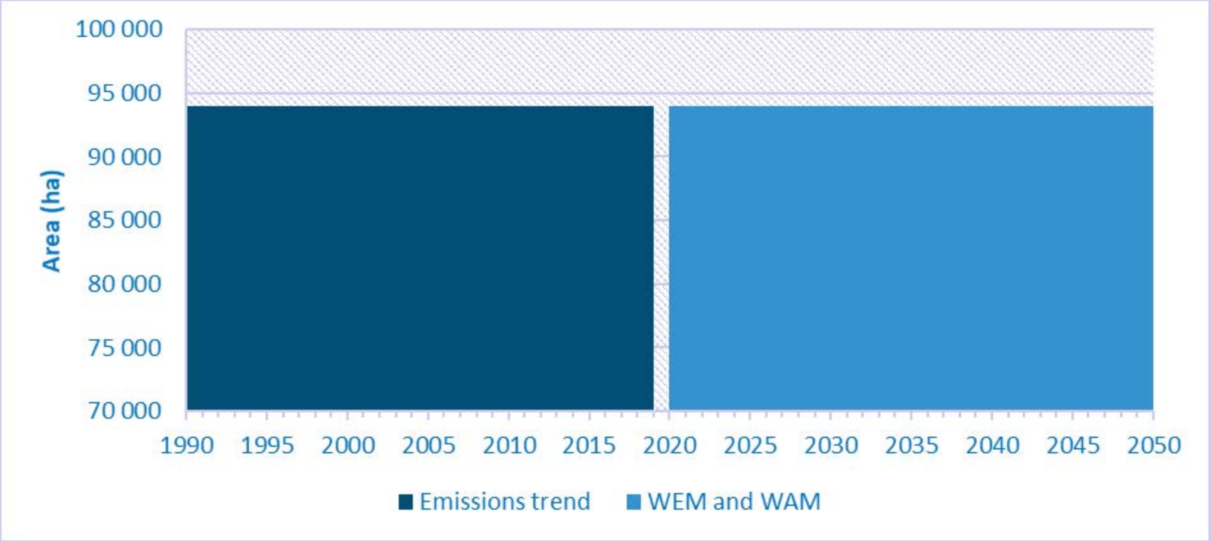
Area of the category Grassland (4.C) - the set trend gives an outlook that most probably the gradual reduction of the area of permanent grasslands will continue, mainly due to the transfer of unused and abandoned grasslands to the forest fund, ecological and water protection restrictions, the introduction 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*



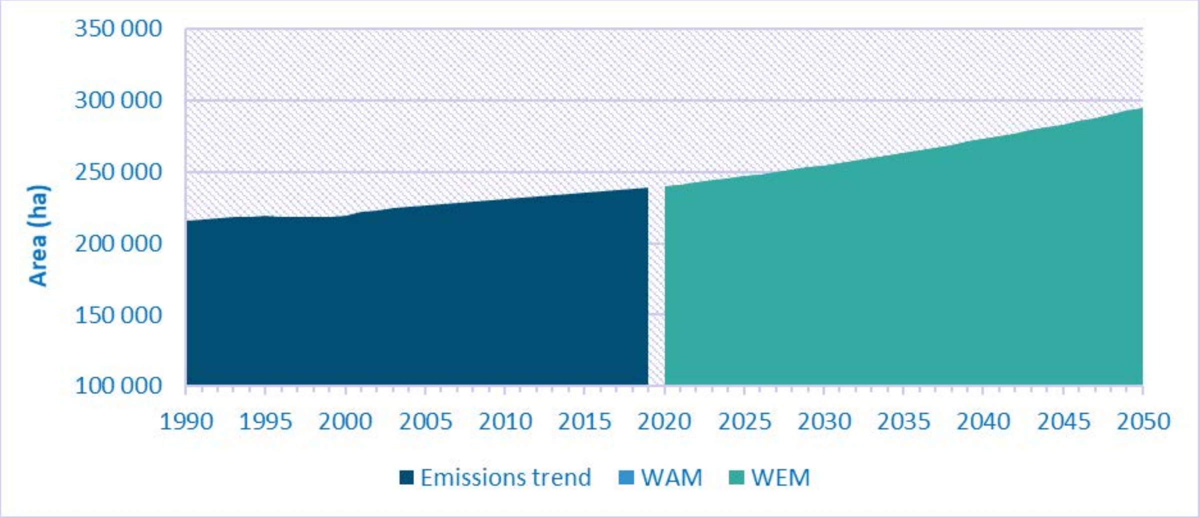
Area of the category Wetlands (4.D) - Slovakia shows no change in this category in the long term. It is realistic to assume that this will remain the case in the future, which is why the acreages for the WEM and WAM scenarios are identical (***Figure 5.7***).

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



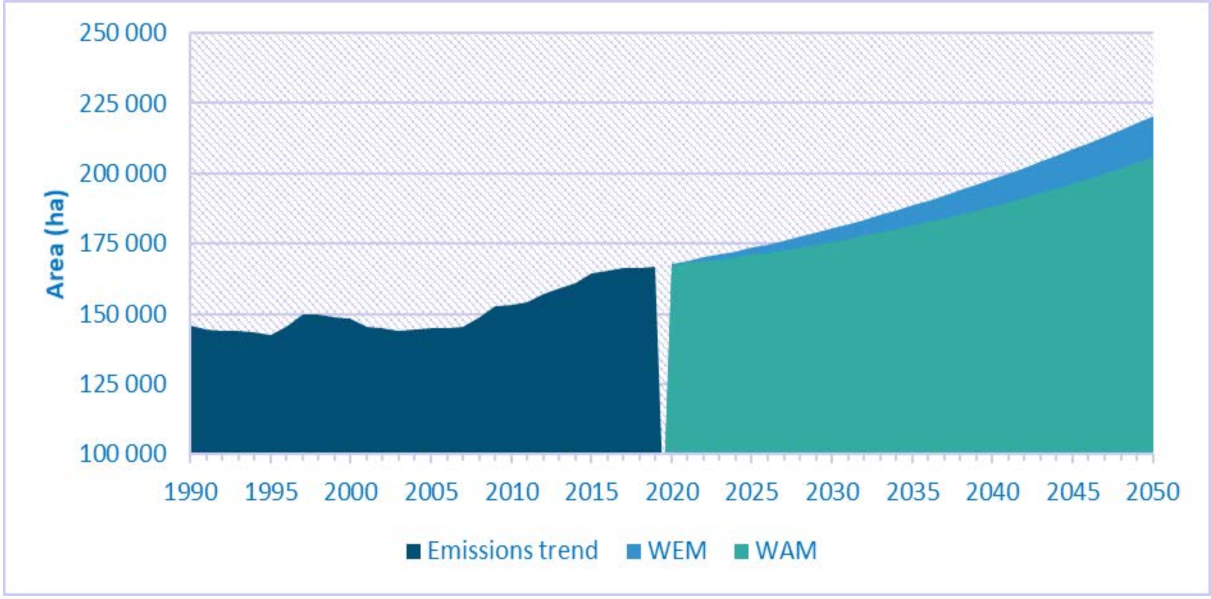
Area of the category Settlements (4.E) - the acreage of this land use category has shown a steadily increasing trend throughout the period. This situation is mostly due to the development of transport infrastructure, industrial areas, the development of towns and villages, the increase in the area of 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*



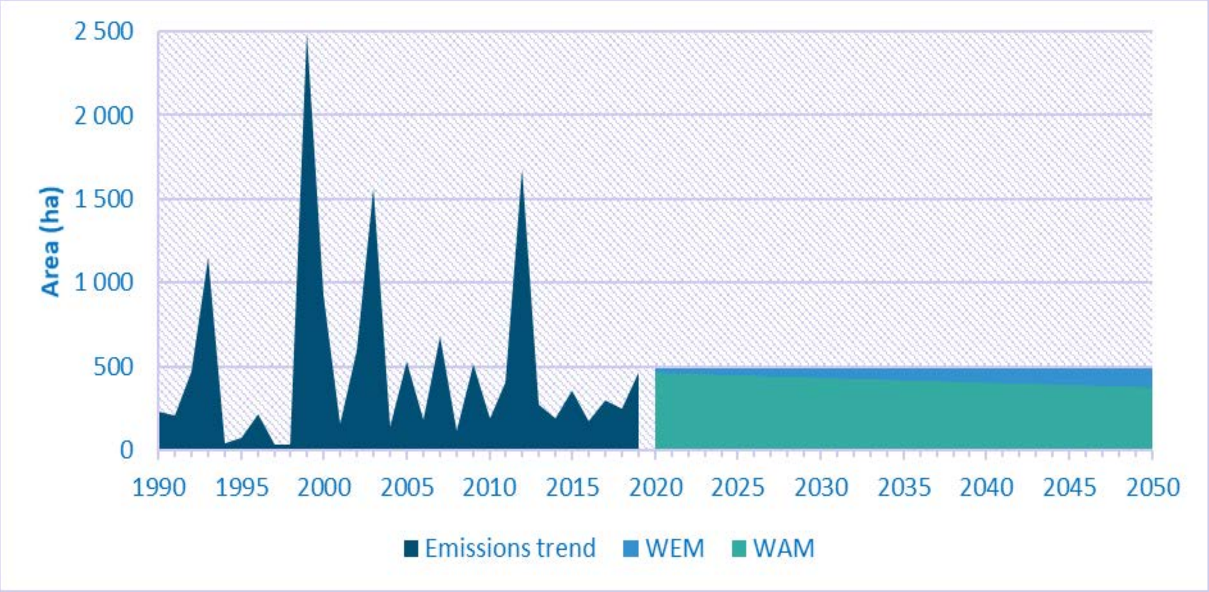
Area of the category Other Land (4.F) - the acreage of this land use category has shown a steadily increasing trend throughout the period. This situation is mostly due to the degradation of cropland, but also due to leaving the territory of Slovakia without active management. Future developments show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



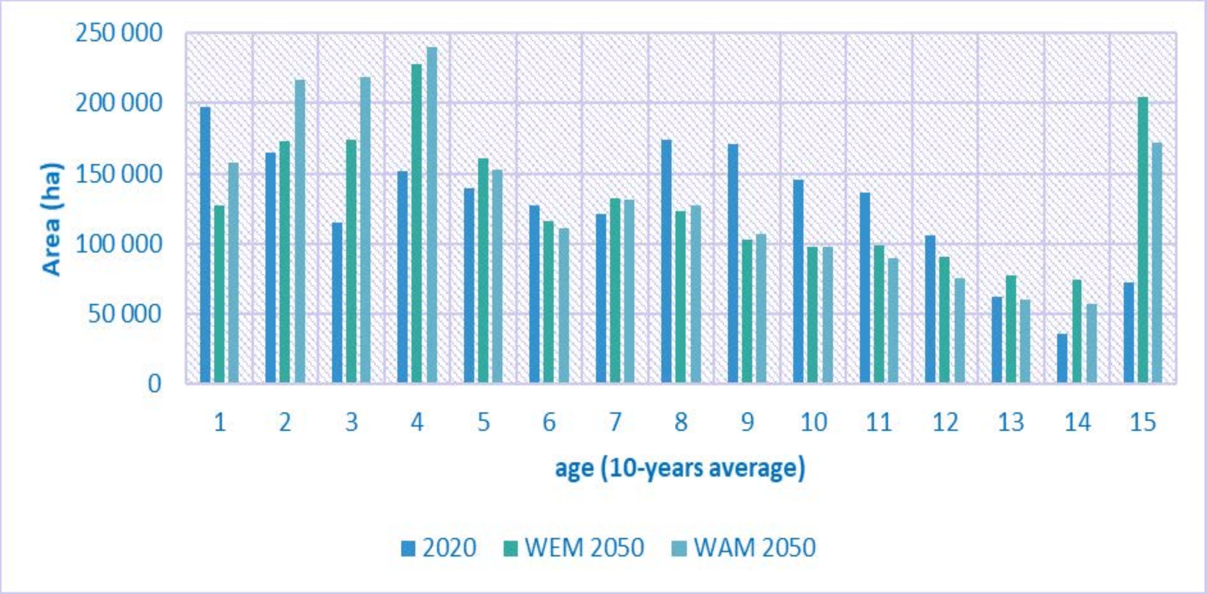
Area of the category Forest Fires - historical forest fire acreage shows a discontinuous pattern throughout the period. The highest acreage value was recorded in 1999 at 2 496 ha and the lowest at 32 ha in 1998. The average value was 488 ha. The future development shows a steady trend (WEM) and a slightly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



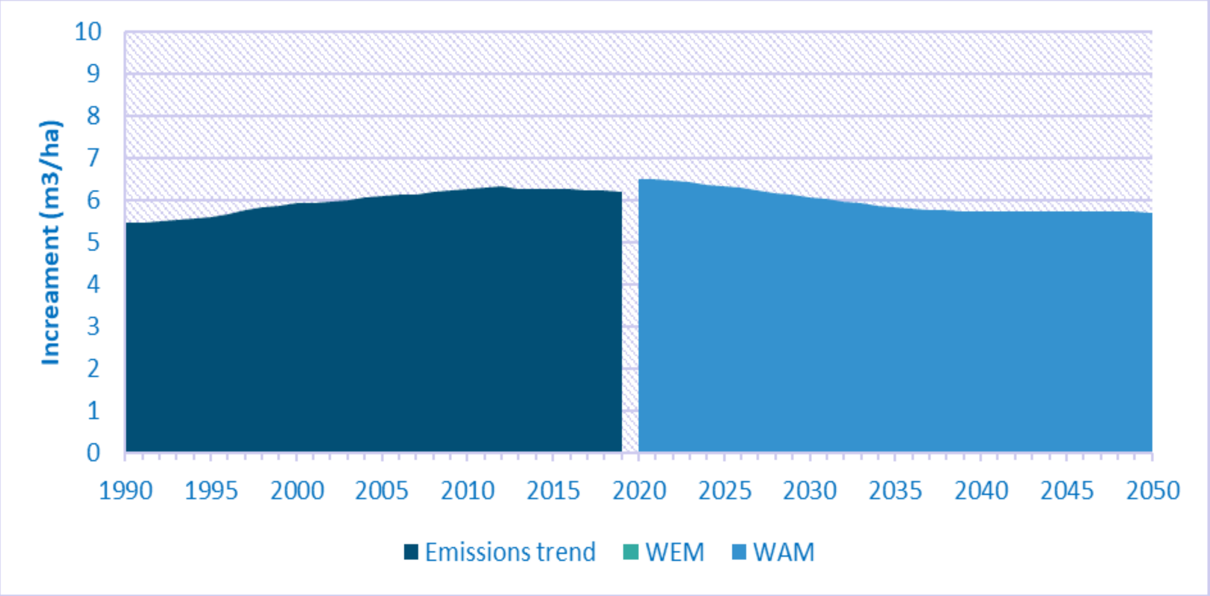
Trend of age structure, increments and timber harvests - future forest development was simulated using the FCarbon model for the period 2020 – 2050. Input data on forest condition were based on the summarised stand characteristics of individual tree species (age structure, stock (m$^3$), area (ha) and suitability) for the year 2019. Harvesting percentages (percentage of annual coarse harvest of total stock) were derived from data for the period 2013 – 2018, 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*



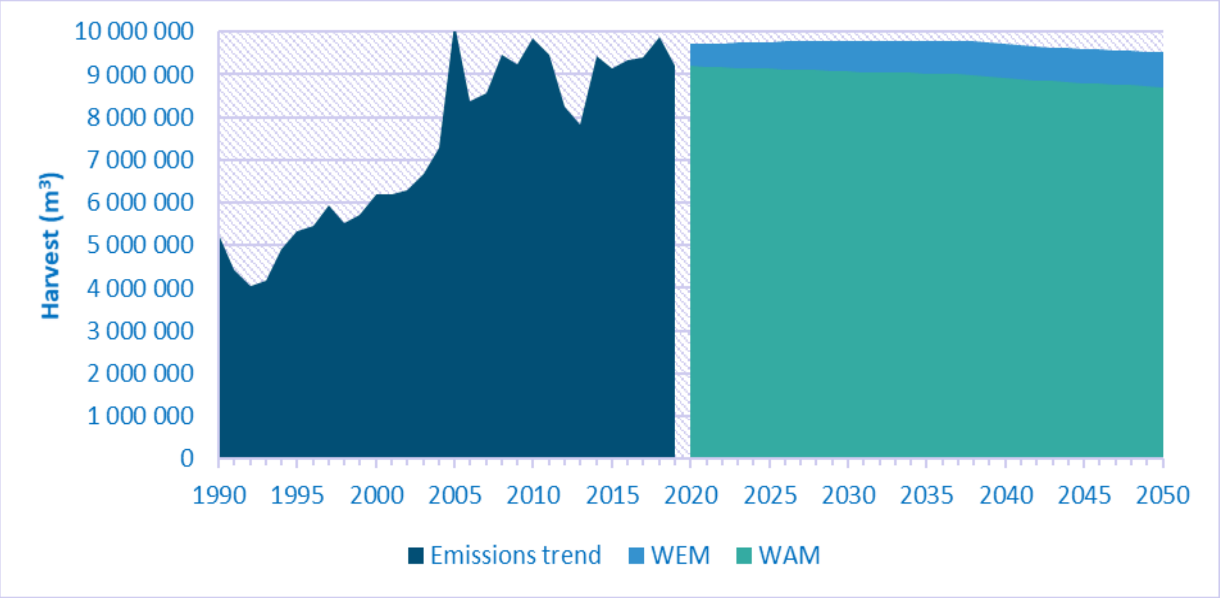
Based on these inputs, the FCarbon model calculated, at each time step (1 year) during the simulation, the trend of the age structure of the forest (by increasing the age, by transferring harvested areas to the youngest categories; (***Figure 5.11***), stock changes using current annual increments (***Figure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

***Figure 5.12:*** *Trend and projections of wood increments (in m$^3$ 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 m$^3$) in WEM and WAM scenarios up to 2050*



## Policies and measures in scenarios

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) 2018/841 by individual Member States should also contribute to achieving this 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) 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 2020 and their effect on LULUCF emissions/removals from 2020 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 2020. 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 will follow 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 will also 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 new National Forestry Programme of the Slovak Republic for the period 2022-2030 will include 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), it was not until November 2020 that the trilogies with the European Parliament and the EU Commission on the preparation of the Common Agricultural Policy (CAP) Strategic Plan were launched. The legislative process continues in 2021 and 2022. A two-year transition period (2021 and 2022) has been agreed. The Slovak agri-ministry is working intensively on the CAP for the next programming period, which will last until 2027.

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<br>RDP<br>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<br>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<br>Adaptation strategy[20] | WAM | $CO_2$ / forest land | Promote measures to increase carbon sinks as part of sustainable forest management.<br>Adjust tree species composition to increase the resilience of stands to drought and reduce vulnerability to biotic and abiotic agents. | Synergic |
| Low carbon strategy<br>Envirostrategy | WAM | $CO_2$ / forest land | Increasing forest cover through afforestation of agriculturally unused land while maintaining the diversity of non-forest habitats<br>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 | synergic |

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[20] 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

| PAM | Scenario | Gas/Category | Measure | Effect of Measure |
|---|---|---|---|---|
| | | | measures aimed at forest adaptation (support for the use of alternative management models to adjust tree species composition, use of suitable provenances). | |
| 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 |

## 5.4. GHG Emission/Removal Projections in the LULUCF Sector

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 6 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 ~ -4 000 Gg $CO_2$ to ~ -2 000 by 2040 and a subsequent slight increase to ~ -2 800 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 ~ -200 Gg $CO_2$, followed by a slight increase to ~ -1 000 Gg $CO_2$ in 2050. Changes in the tree species composition of forests have a more pronounced effect on $CO_2$ 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 2050*

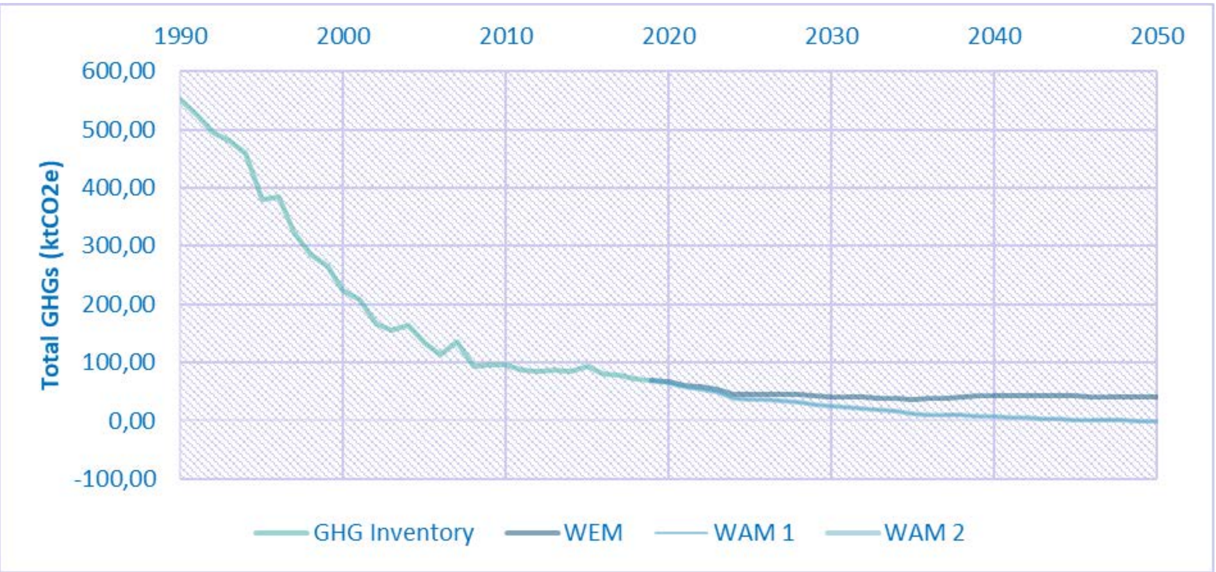
Projections of emissions/removals in Land Converted to Forest Land - in this category, projections of emissions and removals of $CO_2$, $CH_4$, $N_2O$ (Gg $CO_2$ eq.) were calculated for the WEM and WAM scenarios (***Figure 5.15***). When land is converted to forest (afforestation), significant carbon 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 2050*

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 2050*

***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 2050*

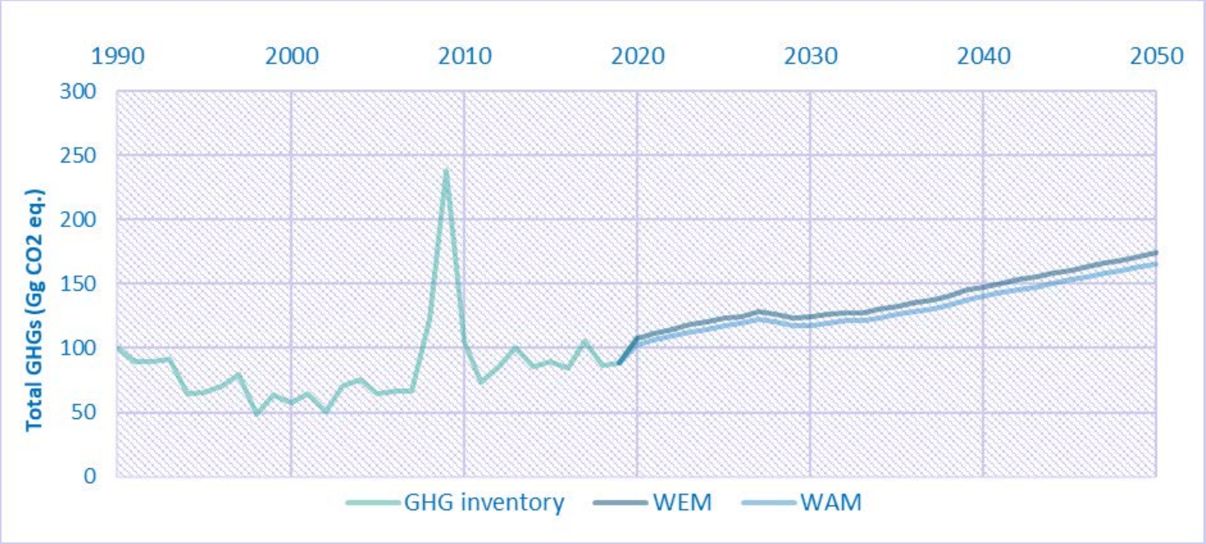


Projections of emissions/removals in Grassland - in this category, projections of $CO_2$ emissions and sinks (Gg) were determined for all scenarios, with the scenarios (***Figure 5.18***). Both scenarios show $CO_2$ sinks by 2050, but a significant decrease in sinks can be expected compared to historical 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 2050*

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 2050*



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 2050*

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 2050*

# 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 amount 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 accounted for 4.6% of total greenhouse gas emissions in 2020. Methane emissions have increased by more than 100% since 1990 due to the use of cumulative methodology in the solid waste landfilling category. A similar trend, although not as pronounced, is expected in the coming years.

The volume of emissions from landfills is also strongly dependent on the implementation of landfill gas capture and utilisation.

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 91% of the sector's GHG emissions, followed by $N_2O$ with almost 9%. Most emissions come from landfilling, followed by wastewater.

## 6.1. Methodologies and Key Assumptions/Trends

Emissions projections are based on the assumption of demographic development of the Slovak population according to the EU Reference Scenario 2020 (EU REF 2020), according to EUROPOP2019 projections (***Table 6.1***).

***Table 6.1:*** *Projections of demographic development in Slovakia up to 2050*

| Year | Source | Scenario | 2020 | 2025 | 2030 | 2035 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Total (median state) | EÚ REF 2020 | WEM | 5 460 136 | 5 467 891 | 5 440 730 | 5 384 612 | 5 312 439 | 5 147 215 |

Municipal solid waste (MSW) production per capita/year in kg - for the purpose of calculating the specific municipal solid waste production, the standard OECD model of annual municipal waste increment (0.69% of GDP) was used. The MSW metrics for the projections are shown in ***Table 6.2***.

***Table 6.2:*** *Specific production of MSW in Slovakia by 2050*

| Year | *Unit* | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Unit production MSW | *kg/capita* | 446 | 484 | 547 | 608 |

Share of landfilled municipal solid waste in total MSW production - Slovakia is gradually reducing the share of landfilled MSW in total municipal waste production by introducing waste management policies. According to the targets set by the EU Landfill Directive, a maximum of 10% of MSW produced in Slovakia should be landfilled in 2035 (***Table 6.3***).

***Table 6.3:*** *Projections of the development of the MSW landfill fraction in Slovakia until 2050*

| Year | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Proportion of landfilling from MSW | 48.4% | 22.4% | 10% | 10% |

MSW composition and degradable organic carbon (DOC) content of landfilled waste - on the basis of the available data on the representation of these components in MSW in Slovakia as well as the trend of increasing separate collection and thus the diversion of some components (kitchen waste, textiles), the expected DOC values for the next period were determined. The calculated DOC values are presented in ***Table 6.4***.

***Table 6.4:*** *Projections of the development of the MSW landfill fraction in Slovakia until 2050*

| Year | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| DOC value | 0.120 | 0.103 | 0.094 | 0.088 |

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 in Slovakia will develop in 2022 – 2025 – 2030 in the context of the current energy crisis or the change in the structure of the economy (automotive industry), as well as the consequences of some climate measures. According to the European Commission's DG Economic and Finance (ECFIN) GDP growth for 2021-2023 was estimated at between 3.03% and 5.13%. The National Bank of Slovakia recently revised its estimate for this period to only 0.5-1.9%. The ECFIN forecast for 2030 to 2050 estimates a gradual slowdown in annual GDP growth from 1.65% to just 0.95%. It is clear from these figures that the economic boom of 2015-2019, with GDP growth of +5%, is certainly not foreseen in the near term. Thus, the recession is likely to dampen the growth of industrial waste production, although on the other hand, the shift away from landfill to recovery is likely to slow down.

On the basis of these facts, we assume that ISW production in Slovakia will be stable or slightly increasing in the coming years. From the current approx. 10.2 million tonnes, we expect an increase to 11.0 million tonnes by 2030 and to approx. 12.5 million tonnes by 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. In Slovakia, the share of landfilled ISW has been significantly reduced from 31-46% in 2005-2015 to less than 20% today. In terms of weight, this represents a decrease in landfilled ISW from the original 2.5 to 4.3 million tonnes to around 1.8 million tonnes today:

- Exactly half (50% = 901 628 t) of the landfilled ISW is EWC 10, i.e. waste from thermal processes (slag), and this waste group also has the lowest recovery rate (up to 85% of the waste generated still ends up in landfills) and we do not foresee a significant change in the total production or the proportion of landfilling for the time being. However, this group has a DOC < 0 and is therefore neutral in terms of the methane balance.
- One third of the landfilled ISW (33% = 620 000 t) is EWC 17, i.e. construction waste. This represents 13% of the total volume of construction waste generated, so the potential to reduce the landfilled amount to at least 10% (and optimally less than 5%) is still relatively significant. Achieving these levels of recovery of construction waste would reduce landfill by around 200-450 000 t/y.
- Less than 10% (167 320 t) is waste from EWC 19, i.e. waste from waste treatment, and only this group is expected to show a significant increase in total production in the near future. With the ban on landfilling of untreated mixed municipal waste from 1.1.2023 (which constitutes the majority of landfilled municipal waste = MSW), a gradual shift of this waste away from landfilling to mechanical-biological treatment plants (MBTs) can be expected over time. According to the availability of new MBU capacities, about 1.0 million tonnes of mixed municipal waste will thus end up in these facilities over time. In Germany, in 2010 (5 years after the MSW landfilling ban), 61 MBU facilities were in operation, treating 4.47 million t of residual waste per year, with 22% eventually ending up in landfills as the remainder of the process. In Poland, for 20 MBT plants, an average residue of up to 46% is reported to be destined for landfill. Depending on the technological level of individual plants in Slovakia, we can therefore expect about 25-45% of waste of category 19 EWC at the outlet. If no energy recovery or (co)incineration facilities are built in Slovakia, this output waste from MBTs will end up only in landfills. This will lead to a significant increase in landfilling of waste from Sc. 19 EWC from the current approx. 170 000 t by a further 250 to 450 000 t per year (∑420-620 000 t) in the 2025-2030 timeframe.
- The other three groups of industrial waste: en. 02 + 03 + 15 EWC each contribute only about ± 1.0% to the total amount of ISW landfilled, which is only about 10-30 000 t/year by weight. Given that for each of these groups the share of landfilled waste is less than 10% of the total production

in the group (even only 1.2% for 02 EWC), we are probably approaching the technological limit of recovery for these wastes. More significant reductions in landfilling are likely to come only at the cost of greater financial investment, which is likely to be difficult to enforce and implement in the coming recession.

These six groups of industrial waste (10 + 17 + 19 + 02 + 03 + 15 EWC) together account for up to 96.5% of the total amount of landfilled ISW in Slovakia. Therefore, the other 13 groups of ISW, which have only a minimal contribution to landfilling (and methane production), are not further included in the preparation of the emission projections. In summary, the amount of landfilled industrial waste (ISW->SWDS) is steadily decreasing. In Slovakia, landfilling is "decoupling", i.e. despite relatively high economic growth in recent years, the production of ISW has increased only slightly and the share of landfilling of these wastes has declined significantly. However, due to the dominant share of landfilling of ISW in the 10 EWCs, a significant decrease in landfilling of ISW is not expected. Unless a suitable recovery method for waste from 10 EWCs (waste from thermal processes) is found, the share of landfilling of ISW in the total industrial waste production in that year is also expected to be around 15% by 2050 (approx. 1.5-1.8 million t/y). However, these wastes are neutral in terms of the methane emission balance and the EWC groups 17 and 19 are particularly important. Landfilling of EWC 17 is expected to decrease in the coming years (due to new policies and the increase in the landfill tax for construction waste). Conversely, landfilling of sc. 19 EWC is expected to increase (as output from new MBT facilities).

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 3.6% 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. 100-120 000 t/y. In terms of the weight of the different components according to the IPCC classification, mixed construction waste (50-60%) and mixed packaging (25-33%) have the largest share, followed by paper and sludge, and food, textiles and wood have the smallest share.

The different components of industrial waste (wood, paper, textiles, sludge, etc.) each contribute their individual share to the total methane emissions based on their content of organically degradable carbon (DOC) and decomposition rate constant (k). Therefore, the contribution of methane emissions from each component is different and the amount of landfilled waste in tonnes may not then correspond to the amount of emissions produced. The components wood, textiles and food do not represent a major source of emissions due to their share of landfilling (about 1-2%) and their contribution to the 2025-2050 emissions balance will remain minor.

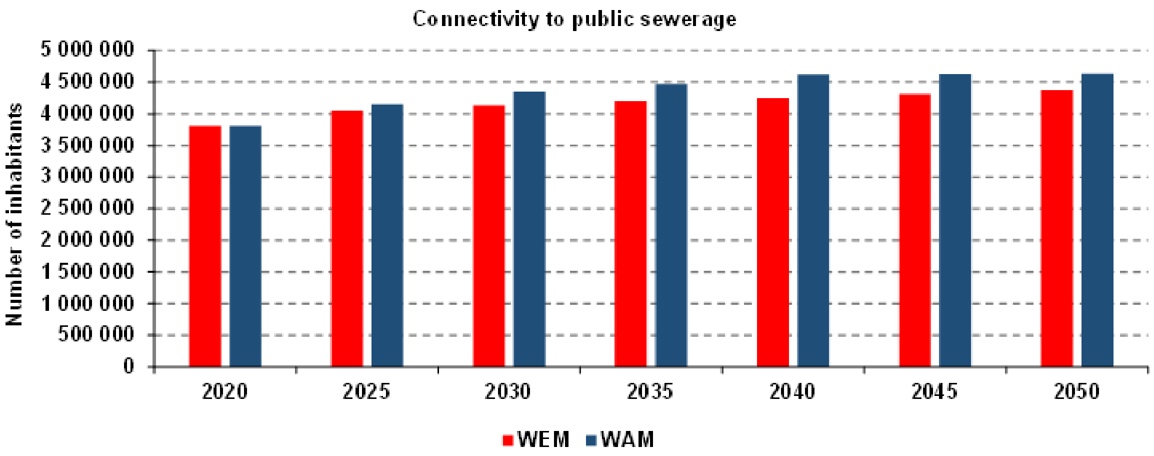
Sludge production has fluctuated in previous years, but here again a long-term slight decline is expected rather than a significant increase in landfilling. The Mix_Pack component could decrease slightly due to beverage container backup, although it is not known what proportion of mixed plastics these containers account for. However, the first results of the backup have not yet confirmed this assumption and the volume of plastics recycled is not yet decreasing. By 2050, we foresee a decrease in landfilling of this component by approx. 1/3 from the current 35 000 t/y to approx. 20 000 t/y, due to the intensification of separate collection as well as to the re-sorting of separated plastics. Similarly, for mixed construction waste, we foresee a decrease of up to 1/2 (from 70 000 t/y to 30 000 t/y) due to the increase in landfill charges. Only for the paper component (which also includes waste from EWC 19 12 12) do we foresee a significant increase in landfill from less than 10 000 t today to up to 60 000 t/year by 2050. The total amount of landfilled ISW with DOC > 0 stabilises at around 110 to 120 000 t/y 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 (***Table 6.5***). These estimates under the two scenarios are shown in ***Figure 6.1***.

*__Table 6.5:__ 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 2020 | Water Research Institute/Blue Report, expert estimates | | | | | |
| **WEM Real version** | | | | | | | |
| **2020** | 5 460 136.00 | 3 805 330.00 | 3 782 220.00 | 23 110.00 | 1 538 834.20 | 109 937.87 | 6 033.93 |
| **2025** | 5 467 891.00 | 4 046 239.34 | 4 018 899.89 | 27 339.46 | 1 298 624.11 | 117 559.66 | 5 467.89 |
| **2030** | 5 440 730.00 | 4 134 954.80 | 4 118 632.61 | 16 322.19 | 1 164 316.22 | 136 018.25 | 5 440.73 |
| **2035** | 5 384 612.00 | 4 199 997.36 | 4 186 535.83 | 13 461.53 | 1 032 230.12 | 148 076.83 | 4 307.69 |
| **2040** | 5 312 439.00 | 4 249 951.20 | 4 236 670.10 | 13 281.10 | 899 395.92 | 159 373.17 | 3 718.71 |
| **2050** | 5 147 215.00 | 4 375 132.75 | 4 362 264.71 | 12 868.04 | 589 356.12 | 180 152.53 | 2 573.61 |
| **WAM Optimistic version** | | | | | | | |
| **2020** | 5 460 136.00 | 3 805 330.00 | 3 782 220.00 | 23 110.00 | 1 538 834.20 | 109 937.87 | 6 033.93 |
| **2025** | 5 467 891.00 | 4 155 597.16 | 4 133 725.60 | 21 871.56 | 1 183 798.40 | 123 027.55 | 5 467.89 |
| **2030** | 5 440 730.00 | 4 352 584.00 | 4 336 261.81 | 16 322.19 | 933 085.20 | 149 620.08 | 5 440.73 |
| **2035** | 5 384 612.00 | 4 469 227.96 | 4 455 766.43 | 13 461.53 | 751 153.37 | 161 538.36 | 2 692.31 |
| **2040** | 5 312 439.00 | 4 621 821.93 | 4 611 197.05 | 10 624.88 | 502 556.73 | 185 935.37 | 2 124.98 |
| **2050** | 5 147 215.00 | 4 632 493.50 | 4 622 199.07 | 10 294.43 | 255 816.59 | 257 360.75 | 1 544.16 |

*__Figure 6.1:__ Trend of the number of connections to public sewerage in WEM and WAM scenarios up to 2050*



## 6.2. Model Description

Projections of emissions were prepared in accordance with the methodology of the Intergovernmental Panel on Climate Change from the year of IPCC 2006 Guidelines, 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. Calculations of emissions projections of individual gases were carried out according to 2006 IPCC Guidelines for National Greenhouse Gas Inventories – Chapter 3 Solid Waste Disposal".

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, or at least specifying the specific national parameters that enter the calculations (ideally up to tier 3 level). We are currently working partly at the level of tier 1 (IPCC default parameters 10-15 years old) and partly already at the level of tier 2 (national data on production and waste management), as we lack the necessary statistical data specific to Slovakia.

Improving the quality and timely availability of input data as well as further improvements in the preparation of emissions projections from the waste sector should enable the entire calculation process to be automated, which should bring a reduction in 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 separated collection 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 6.6:*** *SWOT analysis of the Waste-model*

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

## 6.3. Scenarios, Parameters and PAMs

Current policies of the MŽP SR (collection of biodegradable waste, advance packaging system, collection of kitchen waste, collection of textiles):

- Each of these policies will have an impact on some of the parameters affecting the calculation of emissions from landfilling in Slovakia. Separate collection of kitchen waste will reduce the share of the "FOOD" component in mixed municipal waste. A decrease of -40% is foreseen in the projections. Similarly, separate collection of textiles could reduce the share of this component in landfilled MSW by 50%. Continued separate collection will result in a decrease in the paper and garden waste components of around 20%. The deposit system for returnable packaging may also result in a reduction in the production of mixed packaging, which accounts for a significant proportion of landfilled waste. This could lead to a reduction in DOC of around 30% by 2050, which also represents an adequate reduction in landfilled bio-degradable carbon and ultimately a reduction in methane emissions from landfills**.**

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.

WEM scenario - the business-as-usual (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. GDP growth will be accompanied by growth in waste production, but this will gradually slow down. Conversely, in line with the "Environmental Kuznets Curve" (EKC) theory, the environmental behaviour of the population and firms will increase, leading to more sophisticated waste management practices - less landfilling, more recovery and, ultimately, waste prevention.

Municipal waste production (5.A.1) - the WEM scenario presents a projections 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 WEM scenario assumes that the landfilling target of a maximum of 10% of MSW is achieved in 2035 with a gradual diversion of about 1.0 million tonnes of MSW to new MBT facilities.

**Table 6.7:** *Trend projections of parameters and methane emissions from MSW in WEM scenario up to 2050*

| Year | Unit | 2019* | 2020* | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| MSW | *kilo tonnes* | 2 369.73 | 2 434.04 | 2 631.14 | 2 906.55 | 3 127.04 |
| MSW->MBT | *tonnes* | 0 | 0 | 330 000 | 660 000 | 1 000 000 |
| MSW-> SWDS | *kilo tonnes* | 1 198.25 | 1 307.21 | 590.25 | 290.66 | 300.00 |
| $CH_4$ Emissions | *Gg* | 39.74 | 39.57 | 30.884 | 18.522 | 13.257 |

** Base year 2019; 1990 – 2020 based on the GHG inventory submission 20. 10. 2022*

Production of industrial waste (5.A.2) - the WEM scenario represents a projections 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 115 000 t/year. Methane emissions from landfilling of industrial waste are shown in ***Table 6.8*** below.

**Table 6.8:** *Trend and projections of methane parameters and emissions from ISW in WEM scenario up to 2050*

| Year | Unit | 2019* | 2020* | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| ISW -> SWDS | *kilo tonnes* | 98.809 | 129.265 | 115.862 | 115.722 | 119.547 |
| $CH_4$ emissions | *Gg* | 5.441 | 5.285 | 5.029 | 5.100 | 5.236 |

** Base year 2019; 1990 – 2020 based on the GHG inventory submission 20. 10. 2022*

Municipal waste production (5.A.1) - the WAM scenario presents a projections of the future development of methane emissions from landfilling in Slovakia with the introduction and application of new policies in waste management without taking into account more significant external influences (economic crisis, impact of pandemics, etc.). This scenario assumes a significant decrease in the amount of landfilled municipal waste, i.e. diversion of mixed MSW, to new MBTs (gradually 330 000 t to 1.0 million t in 2050). In terms of the EC targets for waste management by 2035 (D1<10% MSW and R>60% MSW) and maintaining the current level of energy recovery of MSW (approx. 195 000 t/y), there is still approx. 850 000 t of MSW for which additional facilities or technological procedures are needed to divert MSW from landfilling and reduce emissions. Other policies and measures that, based on knowledge from abroad, can lead to significant changes in the parameters affecting the calculation of landfill emissions include:

- Construction and operation of new WtE (waste-to-energy plants = WEEE). All original EU countries ("old EU15") that have achieved a reduction of landfill emissions of about 60-80% in the past show a minimum share of MSW energy recovery above 40% (Slovakia shows only about 8% i.e. about 200 000 t/y).
- Increased use of LFG for energy production or combustion or oxidation of methane on biofilters. Slovakia is at the very bottom of the ranking according to the European National Greenhouse Gas Inventory Report 2022 (5%21) in the share of LFG use for energy production or "recovery methane" (EU28 average = 39%). Despite the relatively high similarity of landfilling in the V4 countries (landfill capacity, collection area, MSW composition), Slovakia shows only about one third (CR) to one half (PL) of the recovered methane per tonne of landfilled MSW. Alternatively, additional policies for LFG for electricity generation, flaring or oxidation on biofilters, (or active landfill aeration under the "2019 Refinement IPCC GL") have the potential to significantly increase this amount and thus further reduce final methane emissions.

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[21] European Union National Inventory Report EU27+UK, page 789, Figure 7.9

**Table 6.9:** *Trend and projections of parameters and methane emissions from MSW in WAM scenario up to 2050*

| Year | *Unit* | 2019* | 2020* | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| MSW | *kilo tonnes* | 2 369.73 | 2 434.04 | 2 631.14 | 2 906.55 | 3 127.04 |
| $CH_4$ Emissions | *Gg* | 39.74 | 39.57 | 21.0 | 11.0 | 8.0 |

Production of industrial waste (5.A.2) - the WAM scenario presents projections of the future development of methane emissions from landfilling of industrial waste in Slovakia under the introduction and application of new policies in waste management. Taking into account the development and experience with other EU countries, we foresee a significant strengthening of energy recovery of waste (R01) combined also with incineration (D10) for those industrial wastes that are incinerated (or calorific value exceeds 6 MJ/kg).

**Table 6.10:** *Trend and projections of methane parameters and emissions from ISW in WAM scenario up to 2050*

| Year | *Unit* | 2019* | 2020* | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Σ ISW | *kilo tonnes* | 98.809 | 129.265 | 115.862 | 115.722 | 119.547 |
| Σ ISW > 6 MJ/kg | *kilo tonnes* | 50.125 | 55.508 | 66.131 | 75.298 | 86.675 |
| ISW -> R01+D10 | *%* | 0% | 0% | 20% | 50% | 75% |
| ISW -> SWDS | *kilo tonnes* | 98.809 | 129.265 | 102.636 | 78.073 | 54.540 |
| $CH_4$ Emissions | *Gg* | 5.441 | 5.285 | 4.454 | 3.388 | 2.367 |

Wastewater treatment (5.D) - the business-as-usual (realistic) scenario, 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[22], as well as with the recently adopted document "Concept of water policy of the Slovak Republic until 2030 with a view to 2050"[23]. 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 the current 30% to 11.45% in 2050) due to the expansion of the sewerage network from the current 70% to 85% and also by increasing the number of domestic wastewater treatment plants from the current 2% to 3.5%.

WAM scenario is based on the expectation that developments in the waste management sector will continue with increased financial support from the Slovak government as well as EU support under the Recovery Plan for Europe. At the same time, some new knowledge and trends from other EU countries, which have led to a shift away from landfilling as well as a reduction in emissions from landfills, will be implemented in the Slovak waste management sector.

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

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

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

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 30% today to 5% in 2050) as a result of the intensive expansion of sewerage from 70% today to 90% and the construction of decentralised domestic wastewater treatment plants from 2% today to 5%. 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 waste water treatment. These measures are expected to contribute to a reduction of methane emissions in the municipal sector by almost 86% and in the industrial sector by 69% in 2050 compared to 2005.

## 6.4. GHG Emission Projections in the Waste Sector

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. Methane from category 5.A - SWDS has an increasing trend year on year due to the cumulative approach to its calculation.

Total greenhouse gas emissions from landfills in the WEM scenario reach a reduction of 1.5% in 2030 compared to 2005 and 49.3% in 2050 compared to 2005 (***Table 6.11***).

***Table 6.11:*** *Trend and projections of methane emissions from category 5.A - SWDS in WEM scenario up to 2050*

| **WEM Scenario** | **UNIT** | **2019*** | **2020*** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|
| Emissions from MSW | *Gg* | 39.737 | 39.572 | 30.884 | 18.522 | 13.257 |
| Emissions from ISW | *Gg* | 5.441 | 5.285 | 5.029 | 5.100 | 5.236 |
| Emissions $\Sigma CH_4$ | *Gg* | 45.178 | 44.857 | 35.913 | 23.622 | 18.493 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

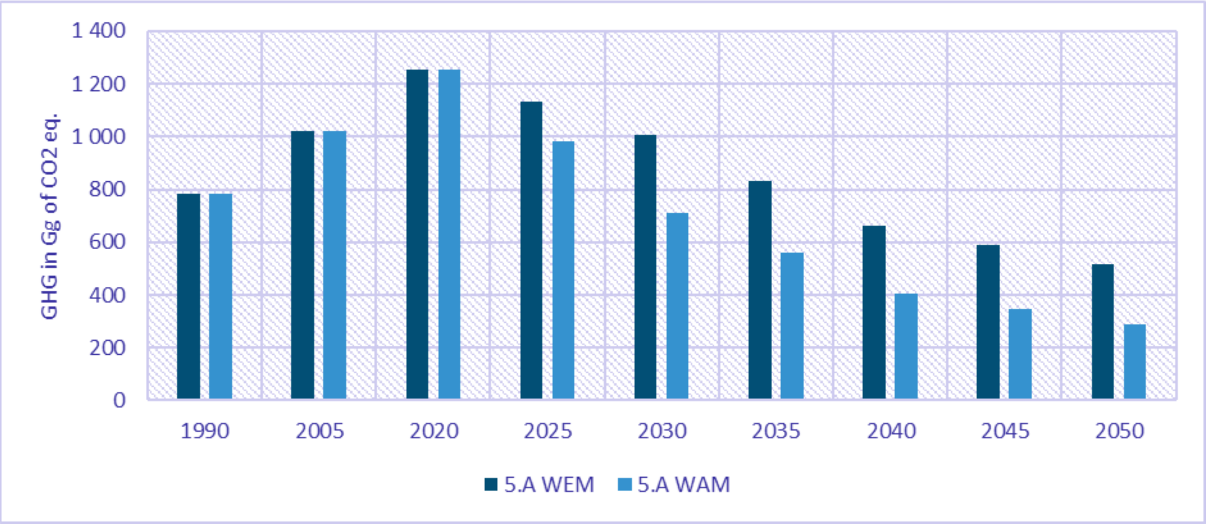
Total greenhouse gas emissions from landfills in the WAM scenario reach a reduction of 30% in 2030 compared to 2005 and 72% in 2050 compared to 2005 (***Table 6.12***).

***Table 6.12:*** *Trend and projections of methane emissions from category 5.A - SWDS in WAM scenario up to 2050*

| **WAM Scenario** | ***Unit*** | **2019*** | **2020*** | **2030** | **2040** | **2050** |
|---|---|---|---|---|---|---|
| Emissions from MSW | *Gg* | 39.737 | 39.572 | 21.000 | 11.000 | 8.000 |
| Emissions from ISW | *Gg* | 5.441 | 5.285 | 4.454 | 3.388 | 2.367 |
| Emissions $\Sigma CH_4$ | *Gg* | 45.178 | 44.857 | 25.454 | 14.388 | 10.367 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

**Figure 6.2:** *Trend and projections of GHG emissions in 5.A - SWDS in WEM and WAM scenarios up to 2050*



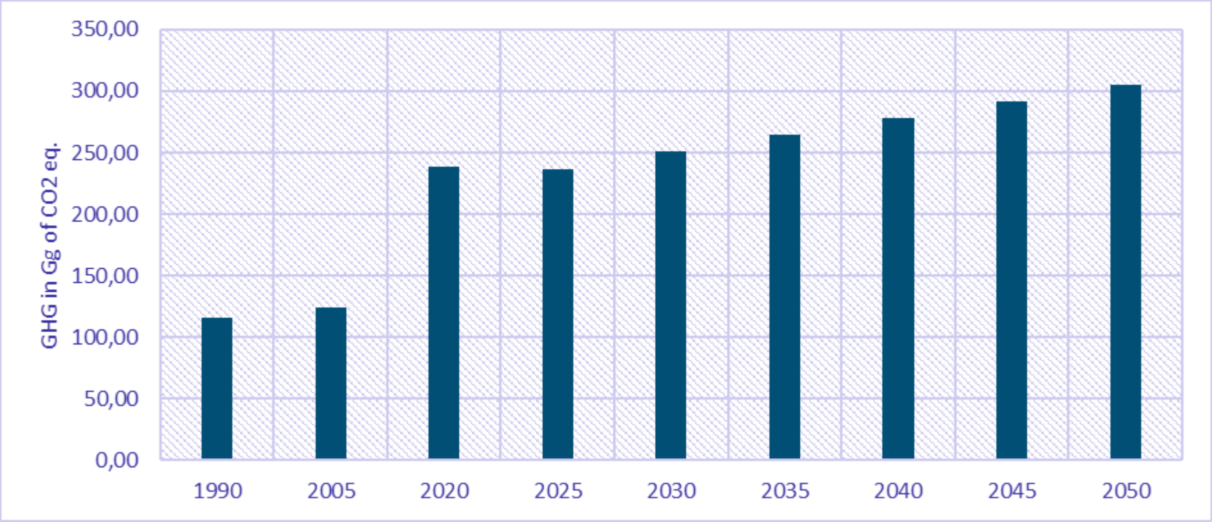
Total GHG emissions in the WEM=WAM scenario reach an increase of 50.43% in 2030 compared to 2005 and an increase of 59.35% in 2050 compared to 2005 (***Table 6.13***, ***Figure 6.3***). Compared to the 1990 base year, they will increase by 54.52% in 2030 and 62.70% in 2050.

**Table 6.13:** *Trend and projections of GHG emissions in 5.B - Waste Composting in WEM=WAM scenario up to 2050*

| 5.B – Waste Composting | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5.B | **1990*** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| | *Gg $CO_2$ equivalents* | | | | | | | | |
| | 113.96 | 206.77 | 238.42 | 236.84 | 250.58 | 264.33 | 278.07 | 291.81 | 305.56 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

**Figure 6.3:** *Trend and projections of GHG emissions in 5.B - Waste Composting in WEM=WAM scenario up to 2050*



The WEM=WAM scenario will increase non-biogenic GHG emissions from waste incineration without energy recovery, with an expected increase of 22.14% in 2050 and 24.47% in 2050 after 2030 compared to 2005. However, similar to the composting category, the benefit to the entire waste management sector exceeds the increase in emissions in this category (***Table 6.14***, ***Figure 6.4***).

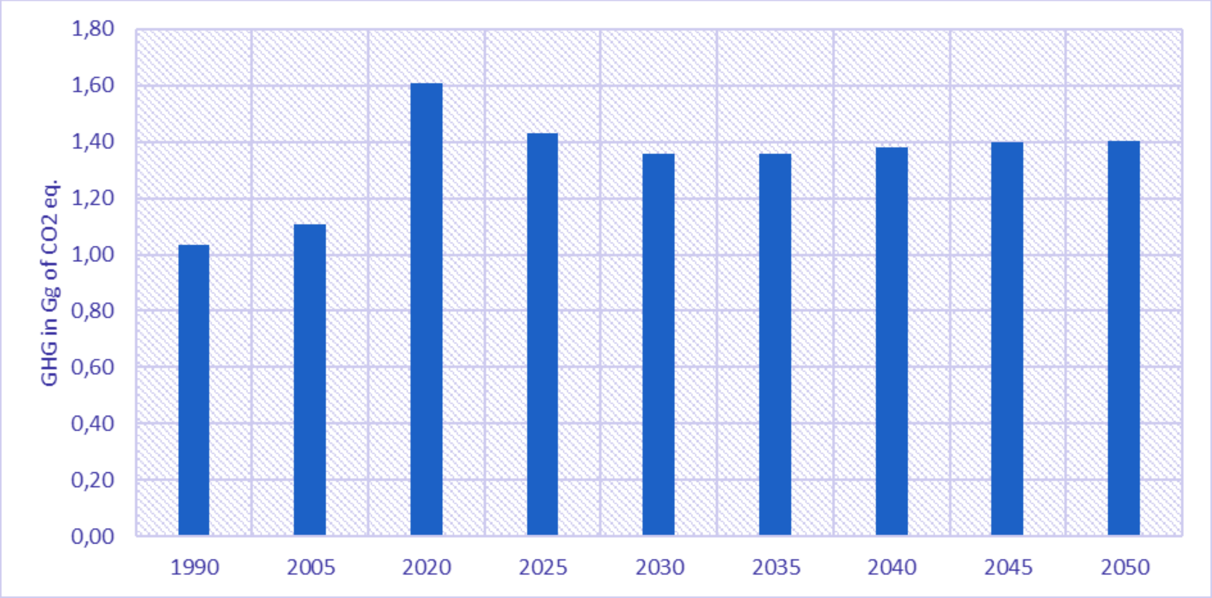
Total GHG emissions in the WEM=WAM scenario increase by 2.17% in 2030 compared to 1990 and by 5.10% in 2050.

***Table 6.14:*** *Trend and projections of GHG emissions in 5.C – Incineration of Non-biogenic Waste without energy recovery in WEM=WAM scenario up to 2050*

| 5.C - Incineration of waste without energy recovery non-biogenic emissions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5.C | **1990*** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| | *Gg $CO_2$ equivalents* | | | | | | | | |
| | 1.38 | 1.49 | 1.61 | 1.43 | 1.36 | 1.36 | 1.38 | 1.40 | 1.40 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Figure 6.4:*** *Trend and projections of GHG emissions in 5.C – Incineration of Non-biogenic Waste without energy recovery in WEM=WAM scenario up to 2050*



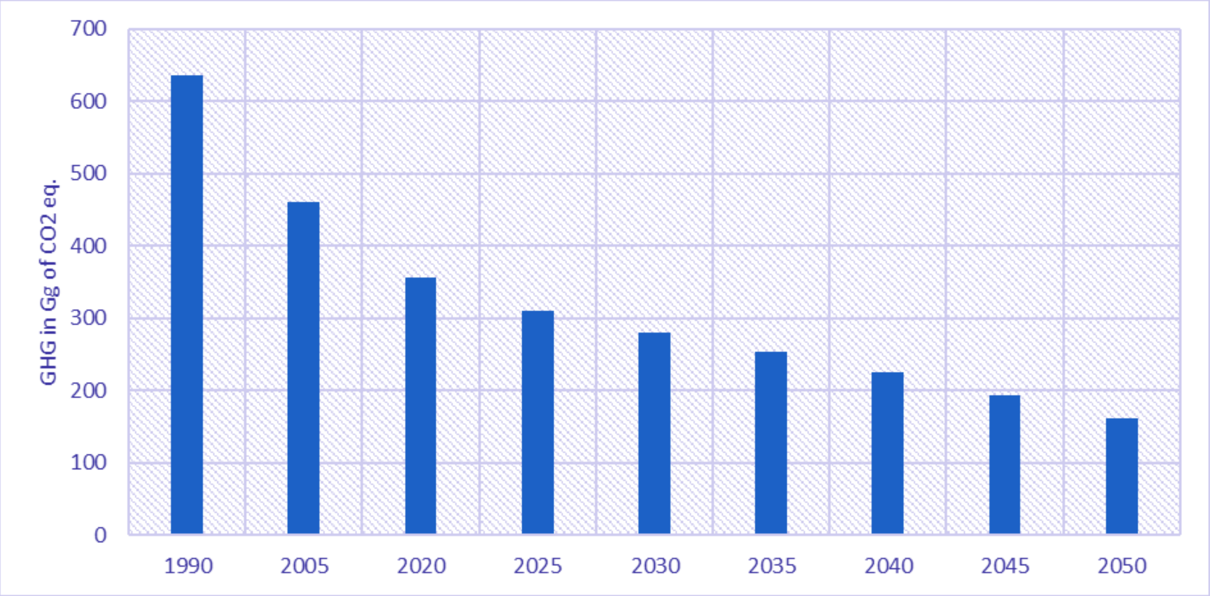
The WEM scenario reduces methane emissions from municipal wastewater (CRF category 5.D.1) by 40.5% in 2030 compared to 2005 and by about 69% in 2050 compared to 2005. Methane emissions from industrial wastewater (CRF category 5.D.2) are currently significantly lower than methane emissions from municipal wastewater, yet we expect further reductions in methane emissions in 2030 of around 63% compared to 2005 and in 2050 of around 68% compared to 2005, mainly due to wastewater recycling and reduced production of organic pollution in industrial production. $N_2O$ emissions from both the domestic and industrial wastewater sectors are relatively low, but here too we expect emissions to decrease by 22% in 2030 and by around 32% in 2050 compared to 2005.

***Table 6.15:*** *Trend and GHG emission projections in 5.D - Wastewater in WEM scenario up to 2050*

| 5.D - Wastewater Treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5.D | **1990*** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| | *Gg $CO_2$ equivalents* | | | | | | | | |
| | 637.18 | 362.90 | 356.54 | 309.97 | 280.93 | 253.61 | 225.43 | 192.43 | 161.73 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Figure 6.5:*** *Trend and projections of GHG emissions from 5.D - Wastewater in WEM scenario up to 2050*



The WAM scenario will reduce GHG emissions from wastewater, and after 2020 we expect emissions to decrease by -48.20% in 2030 and by -77.37% in 2050 compared to 2005. Similar to the landfill category, the benefit for the entire waste management sector is the second highest as it is a significant source of emissions (***Table 6.16***, ***Figure 6.6***). Total GHG emissions in the WAM scenario achieve a 63.18% reduction in 2030 compared to 1990 and an 83.91% reduction in 2050.

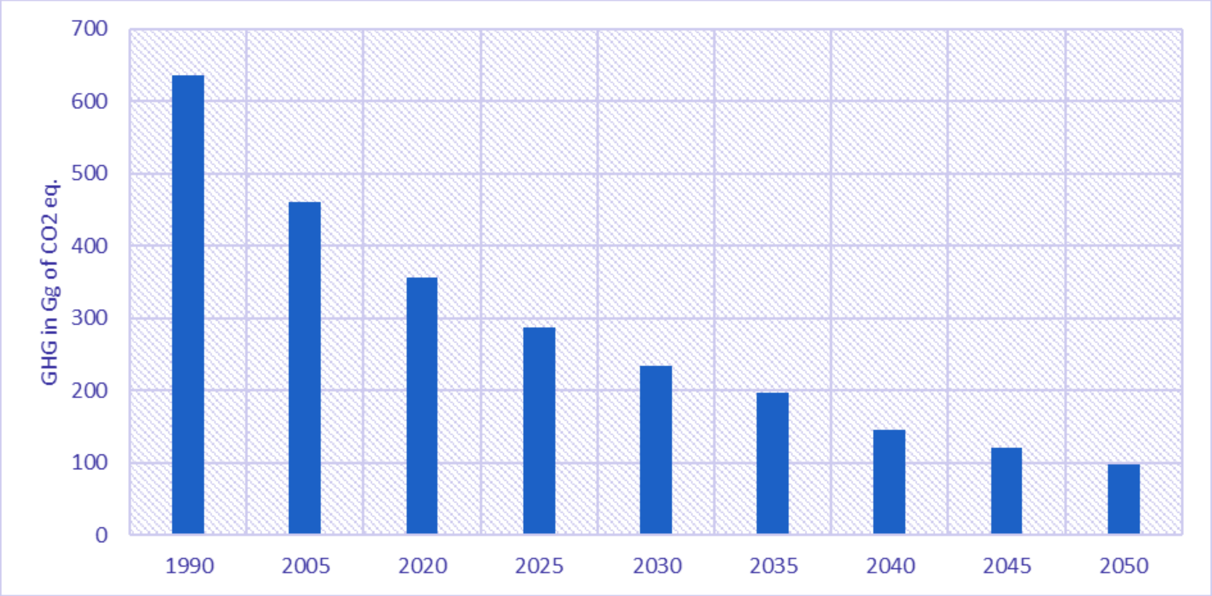
This scenario (WAM) will reduce methane emissions from municipal wastewater (CRF category 5.D.1) by 52% in 2030 compared to 2005 and by about 86% in 2050 compared to 2005. Methane emissions from industrial wastewater (CRF category 5.D.2) ) are currently significantly lower than methane emissions from municipal wastewater, yet we expect further reductions in methane emissions in 2030 of around 64% compared to 2005 and in 2050 of around 69% compared to 2005. $N_2O$ emissions from both the municipal and industrial wastewater sectors are relatively low, but we also expect reductions of around 24% in 2030 and around 36% in 2050 compared to 2005.

***Table 6.16:*** *Trend and projections of GHG emissions from 5.D - Wastewater in WAM scenario up to 2050*

| **5.D - Wastewater Treatment** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5.D | **1990*** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| | *Gg $CO_2$ equivalents* | | | | | | | | |
| | 637.18 | 362.90 | 356.54 | 286.47 | 234.82 | 197.33 | 145.71 | 121.23 | 97.44 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Figure 6.6:*** *Trend and projections of GHG emissions in 5.D - Wastewater in WAM scenario up to 2050*



The Waste sector accounted for 4% of total greenhouse gas emissions in 2020. Methane emissions have increased by more than 100% since 1990 due to the use of cumulative methodology in the solid waste landfilling category. A similar trend, although not as pronounced, is expected in the coming years. The volume of emissions from landfills is also strongly dependent on the implementation of landfill gas capture and utilisation. According to the prepared WEM and WAM scenarios for each category, it can be concluded that after recalculating all four main waste treatment categories, there will be a 24.41% reduction in GHG emissions by 2030 compared to 2005 and a 21.65% reduction compared to 1990. The reductions by 2050 will be even more significant, with a 53.43% reduction in emissions from the waste sector compared to 1990 (***Table 6.17***, ***Figures 6.7*** and ***6.8***).

***Table 6.17:*** *Trend and projections of GHG emissions in 5 - Waste sector in WEM and WAM scenarios up to 2050*

| Sector 5 - Waste | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| WEM | **1990*** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| | *Gg $CO_2$ equivalents* | | | | | | | | |
| | 1 534.317 | 1 836.131 | 1 852.550 | 1 679.019 | 1 538.429 | 1 352.789 | 1 166.297 | 1 075.250 | 986.491 |

| Sector 5 - Waste | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| WAM | **1990*** | **2019*** | **2020*** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| | *Gg $CO_2$ equivalents* | | | | | | | | |
| | 1 534.317 | 1 836.131 | 1 852.550 | 1 509.092 | 1 199.468 | 1 020.798 | 828.021 | 761.01 | 694.678 |

**Base year 2019; 2019-2020 based on the GHG inventory submission 20. 10. 2022*

***Figure 6.7:*** *Trend and projections of GHG emissions in 5 - Waste sector by categories in WEM scenario up to 2050*

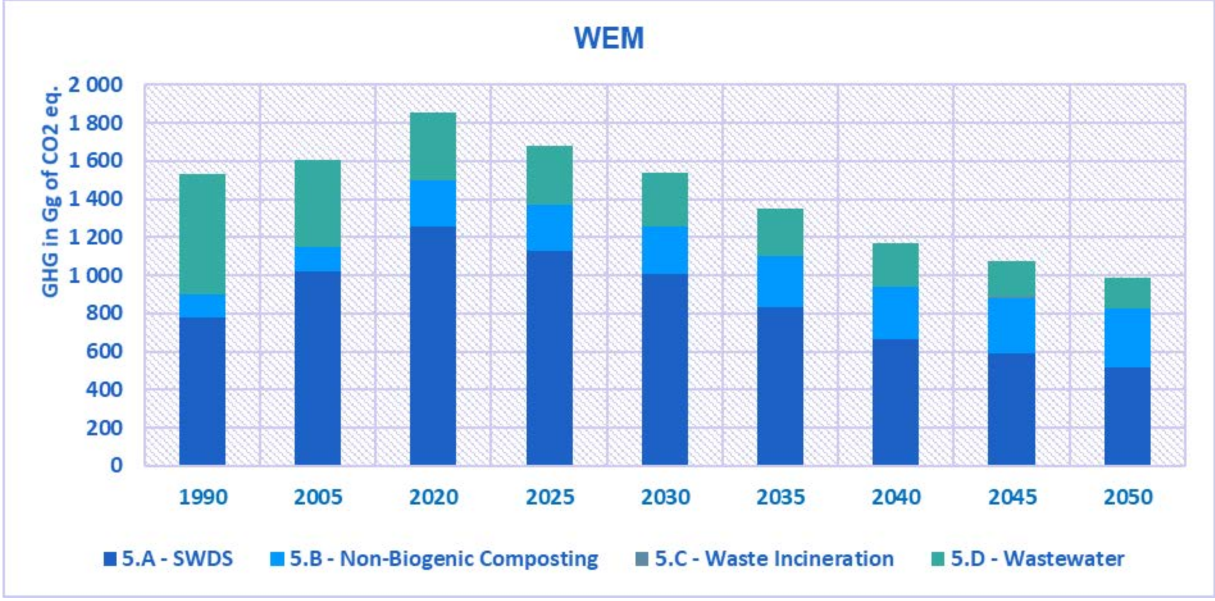
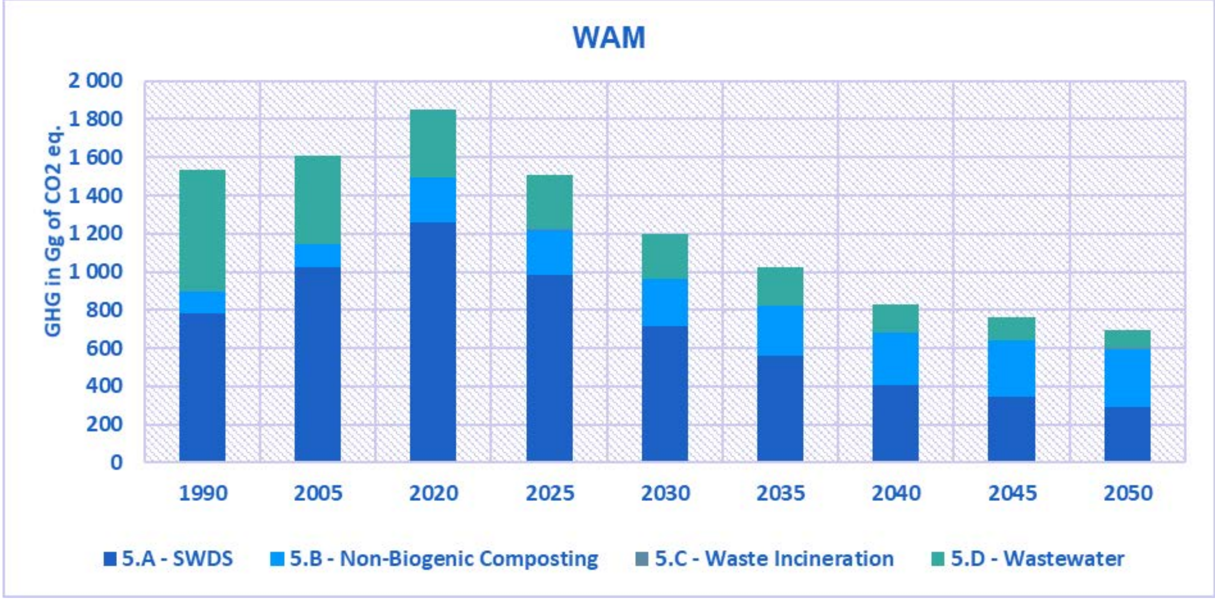


***Figure 6.8:*** *Trend and projections of GHG emissions in 5 - Waste sector by categories in WAM scenario up to 2050*



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