Impact of the Belgian 'Net-Zero' Carbon Energy Projections on Air Quality and Climate

Vision on technology for a better world

vito.be

Impact of the Belgian 'Net-Zero' Carbon Energy Projections on Air Quality and Climate

VITO
Boeretang 200
2400 MOL
Belgium
VAT No: BE0244.195.916
vito@vito.be – www.vito.be
IBAN BE34 3751 1173 5490 BBRUBEBB

Stijn Janssen
Project Manager
+32 14 33 67 02 / stijn.janssen@vito.Be

Siemen Timmermans
Air Quality Researcher

AUTORS

Siemen Timmermans, Bart Degraeuwe, Stijn Janssen (VITO)
Andrea Moglianesi, Pieter Lodewijks (VITO - Energyville)

Under the supervision of:

Giuseppe Valastro (Concawe Science Executive)
Thanasis Megaritis (Concawe Science Associate)

At the request of:

Concawe Air Quality Management Group (AQMG)

We thank for their contribution:

Members of AQMG: E. Dalebout, S. Van Gulck

DISTRIBUTION LIST

Limited distribution

SUMMARY

VITO/EnergyVille was commissioned by Concawe to conduct a comprehensive study on the effects of potential ‘Net-Zero’ pathways in Belgium on air pollutant emissions covered under National Emission reduction Commitments (NEC) Directive (i.e., NO_x, SO_x, fine particulate matter,…) and their associated ambient air concentrations governed by the Ambient Air Quality Directive (AAQD).

The impact of the ‘Net-Zero’ pathways on air pollution is known to be a complex interaction between various sectors, technologies and energy carriers. Therefore, an integrated modelling framework is proposed to analyse this complex system through a modelling exercise using Belgium as a case study.

The Belgian energy system model TIMES, developed within the ETSAP (Energy Technology Systems Analysis Program), a long-standing Technology Collaboration Programme of the International Energy Agency (IEA), is utilized to create the various energy scenarios. Subsequently, the study translates the derived energy projections into equivalent air pollutant emissions using a methodology that aligns as much as possible with the standard methods employed by local Belgian authorities. The anticipated emission trends for both existing and emerging technologies have been carefully integrated into the analysis. In a final stage, the emission projections are translated into ambient air concentrations levels via the SHERPA-QUARK dispersion model.

A thorough analysis of the results, alongside benchmarking with existing European and Belgian datasets, highlights significant challenges in developing a fully integrated approach for the energy – emissions - air quality system at Member State level. These challenges primarily involve inconsistency between the energy and air pollutant emission assumptions and detailed data availability at sector level. The latter include e.g., estimated fuel mixes and their evolution at subsector level, evolution of the efficiency of abatement technologies, availability and impact of new emerging technologies.

As an illustrative case study, the methodology was applied to derive 2050 projections for a central scenario and two sensitivity tests. The exercise was used to explore the requirements of an integrated assessment study with respect to data requirements and methodological assumptions. The study primarily aimed to illustrate the difficulties, uncertainties and challenges of linking energy, climate and air quality concepts. While this type of long-term projections are subject to significant uncertainties, it could be demonstrated, assuming a Net-Zero scenario for the Belgian energy system from 2050 onwards, that the NECD targets for Belgian emissions can be met in 2030 and that the AAQD limit values set for NO_2 in 2030 could be reached in most but not all of the Belgian monitoring stations. These conclusions are in line with the general findings of other modelling exercises at European (e.g. GAINS) and Belgian level and demonstrate the level of robustness in the conclusions that still can be obtained in long-term scenario analysis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Europe has set its sights on achieving climate neutrality by 2050, striving for an economy where greenhouse gas emissions are effectively reduced to net-zero. This ambitious goal lies at the core of the European Green Deal, aligning closely with the EU's pledge to contribute to worldwide climate efforts as outlined in the Paris Agreement. Every facet of society and all sectors of the economy are expected to contribute to this endeavour, including the power industry, manufacturing, transportation, infrastructure, agriculture, forestry and the residential sectors. In line with the concerted efforts of many European Member States, Belgium is actively formulating strategic plans to align with European decarbonization targets, exemplified by initiatives such as Fit for 55[1] and the commitment to achieve net-zero emissions by 2050, in the context of the European Green Deal. It is crucial to recognize that the EU objectives extend beyond mitigating greenhouse gas emissions alone, encompassing a broader spectrum that includes, among other things, the related air pollutant emissions and air quality in general. Relevant is the Zero Pollution Ambition which has as an objective "for air, water and soil pollution to be reduced to levels no longer considered harmful to health and natural ecosystems, that respect the boundaries with which our planet can cope, thereby creating a toxic-free environment."[2]

In Europe, air quality regulation is characterized by stringent measures aimed at safeguarding public health and the environment. Emission reduction obligations and concentration thresholds are established for key pollutants such as PM ($PM_{2.5}$ and PM_{10}), SO_x, and NO_x. Belgium sets emission limits according to the revised National Emission reduction Commitments Directive (NECD), formulated as relative reduction with respect to the emissions of base year 2005. In addition to national emission targets, ambient atmospheric pollutant concentrations are regulated by the European Ambient Air Quality Directive (AAQD). The recently renewed AAQD sets annual limit values at 10 µg/m^3 and 20 µg/m^3 for $PM_{2.5}$ and NO_2 respectively. These limit values have to be met everywhere by 2030.

This project seeks to explore the interconnected effects of decarbonization strategies on emissions and air quality in a fully integrated way. It aims to overcome the prevalent 'silo approach' by integrating various domains of expertise. The focus of this study is on understanding the implications of potential 'Net-Zero' trajectories for Belgium on air pollutant emission and the related concentrations in the ambient atmosphere. The goal is to provide a holistic view of the environmental impacts of decarbonization while exploring the strengths, weaknesses, limitations and opportunities of a fully integrated approach of the energy - emissions – atmospheric dispersion system.

The objective of this work is to correlate the two critical dimensions (energy and air quality) by crafting and studying specific decarbonization scenarios tailored explicitly for this project, at the same time aiming to be consistent with the overall Belgian Net-Zero strategy. It should be stressed that it is not the ambition of this work to predict the 2050 situation in Belgium. Afterall, the long-term future cannot be predicted. Over a 25 to 30-year time horizon, it is only feasible to explore and investigate the future via scenario analyses under specific assumptions and conditions. Such an explorative analysis can contribute to the further understanding of the general cross-relations and interlinkages between the energy, climate and air quality domains. By setting up an integrated assessment modelling exercise and apply it for some illustrative case studies, we want to contribute to this challenge.

In a first phase of the study, the energy modelling system and the selected scenarios will be discussed in detail. A future "central" scenario for the energy system in 2050 will be

[1] Fit for 55
[2] https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en

refined with additional sensitivity runs. Subsequently, the study will estimate the effects of the various energy pathways on air quality. This impact analysis will be performed in a two-step approach. First, the energy scenarios are translated into air pollutant emissions. Afterwards these emissions are used in a dispersion model to calculate the effects on air quality.

During the different phases of the modelling chain simulations, the (intermediate) results are benchmarked against existing European or national energy projections, emission projections and air quality plans. This allows for the detailed understanding of the impact of assumptions in each of the model building blocks and helps to identify strengths and weaknesses of the integrated approach.

The approach is designed to provide a comprehensive and nuanced exploration of the interplay between energy-related decarbonization strategies and their implications on air quality. It seeks to demonstrate the added value of a holistic modelling strategy in making prognoses, while also highlighting the existing challenges and limitations related to data availability, foundational assumptions, and (possible) discrepancies between predictions and goals at local, regional and European levels. By benchmarking the results of this study to national Belgian projections or projections from other integrated modelling systems such as GAINS, the robustness as well as the pitfalls of this type of modelling can be illustrated.

2 ENERGY MODELLING

The primary objective of this study is to comprehend the impact on air quality resulting from the implementation of a strategy aimed at achieving Net-Zero carbon status for Belgium by 2050. Therefore, it is imperative to first define an energy scenario conducive to realizing this goal. Subsequently, the model should yield results pertinent to the second phase of the analysis, specifically concerning pollutant emissions and air quality.

This chapter starts with a general discussion of the requirements needed to reach the objective of the study. This section is followed by a description of the energy model that is chosen, its assumptions and a discussion of the results. The chapter concludes with a benchmarking of the results with other data sets available for Belgium.

2.1 Model choice

Numerous families of energy models could be used to draft similar scenario analyses; nevertheless, in this particular instance, the model to be applied must possess the following characteristics:

- It should be capable of providing a sufficient level of sectoral and technical detail in its outcomes, to the extent that they can be translated into greenhouse gas and air pollutant emissions results;
- It must adeptly discern the relationships and potential spill-overs among various energy sectors, both on the production and consumption fronts;
- In order to replicate this exercise for other countries or even on a broader (EU) scale, it should be widely utilized and sustained by an international community, demonstrating robustness and comprehensive documentation.

Given these requirements, the TIMES model framework[3] (a non-comprehensive list of model frameworks can be found in a paper by Plazas-Niño et al., 2022[4]) is very capable and complying with all required characteristics. TIMES is a modelling framework used to model energy systems with the ability of varying the spatial and temporal resolution (e.g., regions, countries, hours, seasons, years) which allows the development of both top-down and bottom-up models. The TIMES model is developed as part of the International Energy Agency - Energy Technology Systems Analysis Program (IEA-ETSAP)'s methodology for energy scenarios to conduct in-depth energy and environmental analyses[5].

When this model framework operates in a bottom-up approach, it exhibits a high level of granularity in describing available technologies. It is proficient in replicating all energy vectors and effectively couples and connects diverse energy sectors, spanning from supply to demand, through the Reference Energy System (RES). Furthermore, TIMES is extensively documented, employed by a community spanning over 20 countries[6], and consistently updated and maintained. TIMES is an optimization model framework, signifying that its sought-after objective is the lowest-cost solution achievable, given the

[3] Manuel Sánchez Diéguez et al., "Modelling of Decarbonisation Transition in National Integrated Energy System with Hourly Operational Resolution," *Advances in Applied Energy* 3 (August 2021): 100043, https://doi.org/10.1016/j.adapen.2021.100043

[4] F.A. Plazas-Niño, N.R. Ortiz-Pimiento, and E.G. Montes-Páez, "National Energy System Optimization Modelling for Decarbonization Pathways Analysis: A Systematic Literature Review," *Renewable and Sustainable Energy Reviews* 162 (July 2022): 112406, https://doi.org/10.1016/j.rser.2022.112406

[5] Richard Loulou et al., "Documentation for the TIMES Model Part I: TIMES Concepts and Theory," *Energy Technology Systems Analysis Programme*, 2005, 151

[6] https://iea-etsap.org/index.php

initial energy system, available investment options, and various constraints (environmental, resource-related, etc.)[7].

Many TIMES models have been built since the framework was developed, with different geographical scales, going from global models[8] to city-level models[9]. However, in order to answer the specific research question of this study, a national model represents the best suited option for the optimal mix of high resolution and still large spatial scale. With this in mind, the TIMES-BE model has been used. It is therefore presented in the next section.

2.2 TIMES-BE energy modelling system

2.2.1 Model structure and setup

TIMES-BE is a TIMES model built by VITO/EnergyVille. It has a high level of technological detail, and its full documentation is available online, in the context of the PATHS2050 Platform[10]. In this subsection some insights on the model characteristics (e.g., structure, main assumptions) will be described.

The model can represent the full energy system from the supply to the demand side, for several energy commodities. In the graph below (Figure 1), a schematic chart of the TIMES model structure is provided. On the supply side, energy can be obtained either by importing it, or through primary energy resources (in Belgium, this is mainly concerning renewable energy sources); the transformation sector is formed by the power sector and fuel manufacturing (refineries, coke plants, etc.); finally, on the end demand side, the main sectors are represented: industry, transport, buildings (residential and commercial) and agriculture.

The model's spatial resolution is mostly national, since the model is composed by one single region; however, a provincial resolution level is provided for some key parameters such as wind and solar energy potential.

Concerning the time resolution, TIMES employs milestone years, aggregating results annually based on the median year within these periods. TIMES-BE operates in 5-year steps periods from 2014, the calibration year. In order to represent the seasonal and intra-day variability, the periods are further split into so-called time-slices (TS) (see Figure 2), which, in the case of TIMES-BE, are 120 TS (10 representative days, with bi-hourly resolution). This choice is made to find an optimal compromise between time resolution and reduced computational expense in running the model. The representative days are chosen by using an optimization algorithm[11] which minimizes the difference for the most important time series (e.g., renewable availability, consumption profiles) between the full, hourly series, and the time-sliced one[12].

[7] S. Jebaraj and S. Iniyan, "A Review of Energy Models," *Renewable and Sustainable Energy Reviews* 10, no. 4 (August 2006): 281–311, https://doi.org/10.1016/j.rser.2004.09.004

[8] Richard Loulou and Maryse Labriet, "ETSAP-TIAM: The TIMES Integrated Assessment Model Part I: Model Structure," *Computational Management Science* 5, no. 1–2 (February 2008): 7–40, https://doi.org/10.1007/s10287-007-0046-z

[9] L.P. Dias et al., "City Energy Modelling - Optimising Local Low Carbon Transitions with Household Budget Constraints," *Energy Strategy Reviews* 26 (November 2019): 100387, https://doi.org/10.1016/j.esr.2019.100387

[10] https://perspective2050.energyville.be/sites/energyoutlook/files/inline-files/Full-Fledged%20Report_1.pdf

[11] https://www.mech.kuleuven.be/en/tme/research/energy_environment/Pdf/wpen201510.pdf

[12] Plazas-Niño, Ortiz-Pimiento, and Montes-Páez, "National Energy System Optimization Modelling for Decarbonization Pathways Analysis."

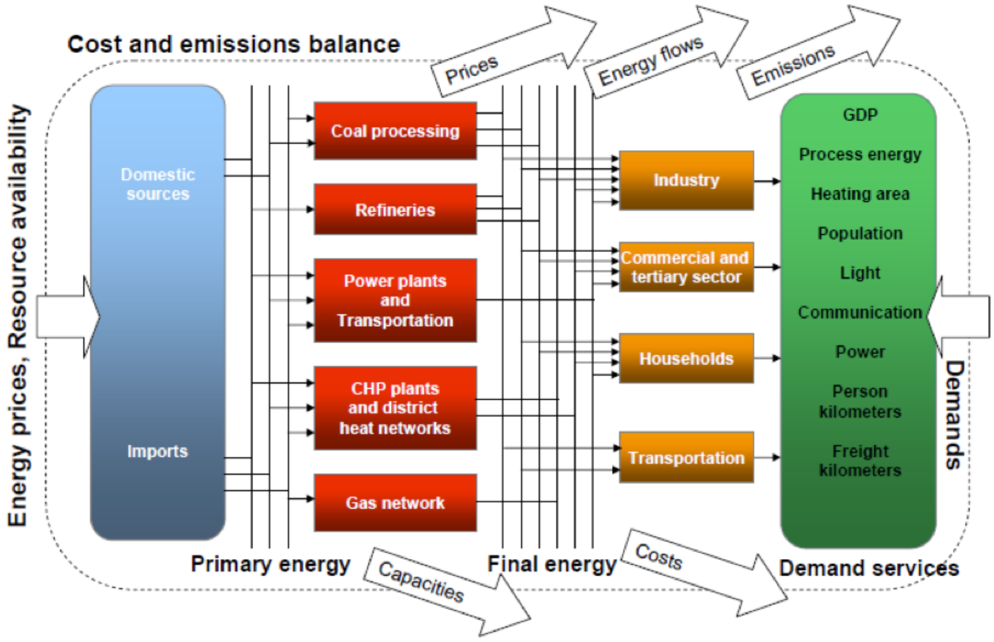


Figure 1: Schematic representation of TIMES model structure (from Loulou et Al., 2008).

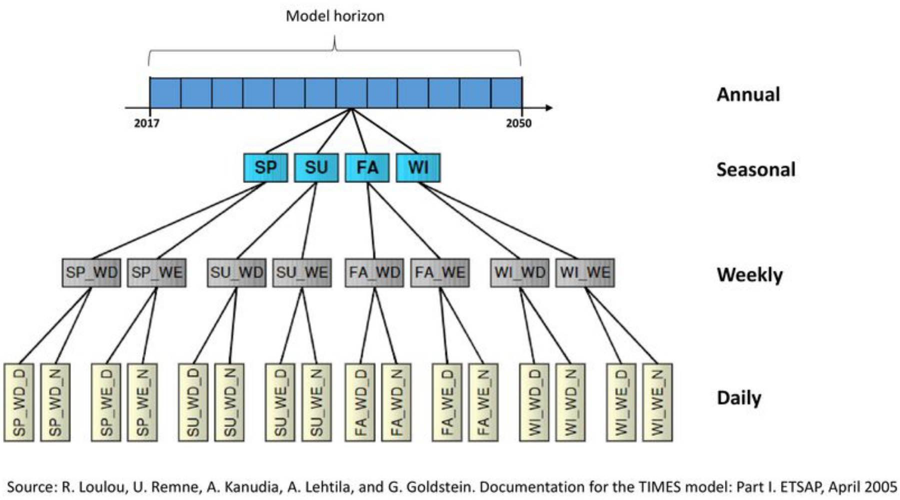


Figure 2: Schematic example of the time-slice structure. In the TIMES-BE model we work with 10 representative days (weekly level, here exemplified with WD – Weekday and WE - Weekend) and with 2-hour time blocks at Daily level (here exemplified with D – Day and N – Night).

2.2.2 Model Assumptions

The model discounts all cost of the energy system to the financial base year (2019), using a user-defined discount rate, which reflects the ‘cost of time’ for the investments across the time horizon. In energy system optimization models, it is possible to either define a technology-specific discount rate to reflect the investor’s perspective (hurdle rate), or a global value, named social discount rate. Even though TIMES offers the possibility to define both, in TIMES-BE only a social discount rate is accounted, which applies to all technologies in all sectors, and it is equal to 3%.

Each sector mentioned in the previous section is further subdivided into subsectors, each of which is defined by specific end-demands. For example, in the transport sector, the subsectors are Road, Rail, Aviation, and Shipping (maritime). Within Road transport, the end-demands are further categorized into Passenger Cars, Bus, Freight, and Motorcycle transport. TIMES provides the capability to utilize macroeconomic parameters as drivers for final demands. This functionality allows the linkage between demands and specific drivers. Projections of such drivers are derived from specialized models or studies, depending on the sector.

For a detailed description of the assumptions or specific modelling decisions within each end-sector, the reader is referred to a comprehensive report prepared for the PATHS2050 platform[13]. This report contains the complete list of end-demands along with their projection assumptions. Additionally, it provides a thorough description of the sectors, including all available technologies for each end-demand. To maintain conciseness, this section does not include this detailed information; the following list however, summarises the most important common assumptions for all scenarios of this study:

- All scenarios are designed to reach net zero CO_2 emissions of the Belgian energy system in 2050. In addition, there is a CO_2 price which increases from 50 EUR/ton CO_2 in 2020 to 350 EUR/ton CO_2 in 2050. This value is in line with the Net-Zero European modelling exercises[14]. The CO_2 price is externally added and needed for techno-economic optimisation models, as otherwise the model only invests in low-carbon technologies at the end of the period (2050).
- In all scenarios, industrial production levels in Belgium are assumed to stay as today (more specifically, to the same production levels as in 2019), where planned new investments are included. It is important to note that this is an external assumption to the model, and the possibility of industrial activities shifting to regions with higher potential for renewables is not included. The planned new investments in the different industrial sectors are derived from bilateral conversations with sector representatives. An exception is the production level of refineries, which is assumed to decrease due to the decreasing international demand for fossil fuels (Crude oil intake is assumed to decrease from 389 TWh in 2014 to 222[15] TWh in 2050).
- Transport demands see an increase (~10/15% in Road and Rail transport, ~30/40% in Aviation and Shipping – see
- *Table* 17), with projections deriving from the TREMOVE model from Transport Mobility Leuven (TML).[16]
- Population growth drives an increase in final demands in buildings (~15% for both Commercial and Residential buildings). Renovation is modelled as an option in the model (residential and commercial sectors), which causes a net decrease in heating demand for buildings. Residential projections are derived from demographic projections from the Federal Planning Bureau (FPB)[17].
- Commercial projections are derived from GDP projections from the FPB[18].
- For agriculture, the energy service demand is assumed to remain constant in Belgium.
- In all scenarios, the lifetime of 2 GW of existing nuclear capacity (Doel 4 and Tihange 3) is extended by 10 years from 2025 until 2035[19-20]. It is assumed that the investments in nuclear lifetime extension will be completed by 2025. In the model, no

[13]https://perspective2050.energyville.be/sites/energyoutlook/files/inline-files/Full-Fledged%20Report_1.pdf
[14]https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2040-climate-target_en
[15]Assumption taken from Concawe's Transition towards Low Carbon Fuels by 2050 (2021) - https://www.concawe.eu/wp-content/uploads/Rpt_21-7.pdf
[16]https://www.tmleuven.be/en/navigation/TREMOVE
[17]https://www.plan.be/sites/default/files/documents/for_pop2070_12389_fr.pdf
[18]https://www.plan.be/uploaded/documents/202102260904210.Rapport_feb2021_12364_N.pdf
[19]https://www.premier.be/fr/declaration-du-premier-ministre-et-de-la-ministre-de-l-energie
[20]https://www.belgium.be/sites/default/files/Accord_de_gouvernement_2020.pdf

new investments in nuclear technologies are allowed (as per latest political agreement).

- Renewables take an important role in the power sector as demand for electrification is expected to increase. In this context, Belgium can invest in renewables up to its technical potential. In the newly developed scenarios, the biomass availability has been updated to bring it in line with the report 'Sustainable biomass availability in the EU, to 2050'[21].

[21] Sustainable biomass availability in the EU, to 2050; Ref: RED II Annex IX A/B; Imperial College London contracted by Concawe; August 2021

- *Appendix 1: Fuels import prices* and renewables availability gives an overview of the mapped technical potential for renewables in Table 16.
- Power interconnection capacity increases from 6.5 GW in 2020 to 13 GW by 2040, in line with Ten-Year Network Development Plan (TYNDP) scenarios. The transmission capacity increase is included as an exogenous assumption for all scenarios without a cost allocation.
- The carbon emissions from international shipping and aviation are not included in the results for Net-Zero Strategies as they are not emitted in Belgium. Also, non-CO_2 GHG emissions, such as methane and N_2O, are not included.
- Electricity distribution grid upgrade costs are taken into account in an aggregated way. In fact, a cost per kW (4320 €/kW) of distribution infrastructure has been taken into account.
- The hydrogen infrastructure costs are taken based on the definition of the Hydrogen Backbone for Belgium[22] and a given investment cost (which depends on the type of line used, whether new or refurbished from the gas one, for a total of 640 km), while for the distribution level, a tariff approach is defined (~3.2€/MWh).
- For CCS grid costs[23], these are taken into account via an estimation of shipping (13.6 €/t_{CO2}) from the main ports (Antwerp and Ghent), and a transport tariff (1.5 €/t_{CO2}). In this way, the last-mile delivery cost of CCS is taken into account for sites not in proximity to the backbone. Access to commercial use of cross-border carbon storage in the North Sea and Norwegian gas fields is not limited.
- Price assumptions on the import of energy commodities can be found in

[22] European Hydrogen Backbone, EHB, 2020. https://ehb.eu/files/downloads/2020_European-Hydrogen-Backbone_Report.pdf
[23] https://www.globalccsinstitute.com/archive/hub/publications/119811/costs-co2-transport-post-demonstration-ccs-eu.pdf

- *Appendix 1: Fuels import prices* and renewables availability, Table 15.

2.3 Energy scenarios

2.3.1 General scenarios setup

The so-called PATHS2050 Central Scenario serves as the reference point in this present work, and its results will be compared to those of the three newly defined scenarios developed for the purposes of this work. These scenarios thus share the same common assumptions as the Central Scenario in PATHS2050, with some updated assumptions, which will be discussed in the next section.

The Central Scenario and all other constructed scenarios aim to depict a comprehensive decarbonization of the country. To achieve this objective, a constraint is imposed on CO_2 emissions in 2050, set at 2 Mt[24] still emitted in Belgium, but intended to be offset by carbon-negative technologies, which are explicitly excluded from the model. Additionally, to foster a more gradual decarbonization process, an escalating carbon price is assumed, commencing at 50 EUR/ton CO_2 in 2020 to 350 EUR/ton CO_2 in 2050.

2.3.2 Specific assumptions for the scenarios of this study

In this study, three scenarios are defined in addition to the PATH2025 Central Scenario: a Central Scenario and two Sensitivity scenarios (Indicated in the results as “Central”, “Sensitivity 1” – or “Sens1”, and “Sensitivity 2” – or “Sens2”). The specific assumptions taken for these three scenarios are presented in this subsection. Updated assumptions mainly impact end-sector assumptions, and specifically the transport sector. The following assumptions were introduced:

- From 2030 onwards, the transport sector must comply with the Renewable Energy Directive (updated to REDIII as of October 2023[25]), mandating a minimum of 29% renewable energy consumption in all transport sectors (by taking into account also a fuel and sector-specific set of multipliers), as well as a minimum of 5.5% of renewable fuels (RFNBOs + biofuels – with traditional ones being bounded to 7%) and a 1% minimum bound on RFNBOs.

[24] This number has been derived from the assumption that, in the absence of carbon-negative technologies, and with the industrial sector running at the same levels, the demand for fossil feedstock remains constant, and its emissions should be captured. Currently, these are more than 15 Mt_{CO2}, which, assuming 10% fugitive emissions of an average CCS technology, would mean >1.5 Mt_{CO2} (rounded to 2 Mt_{CO2}) of remaining, uncaptured emissions.

[25] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413

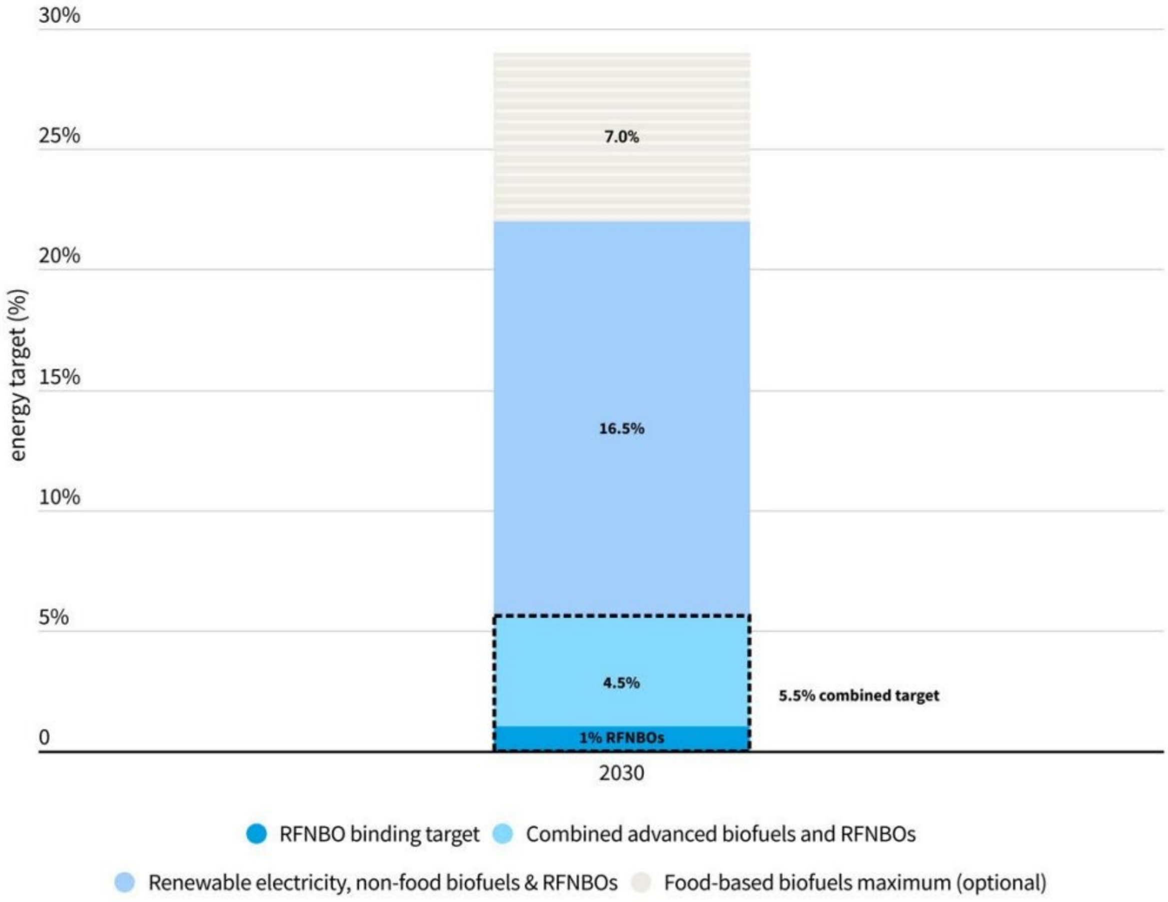
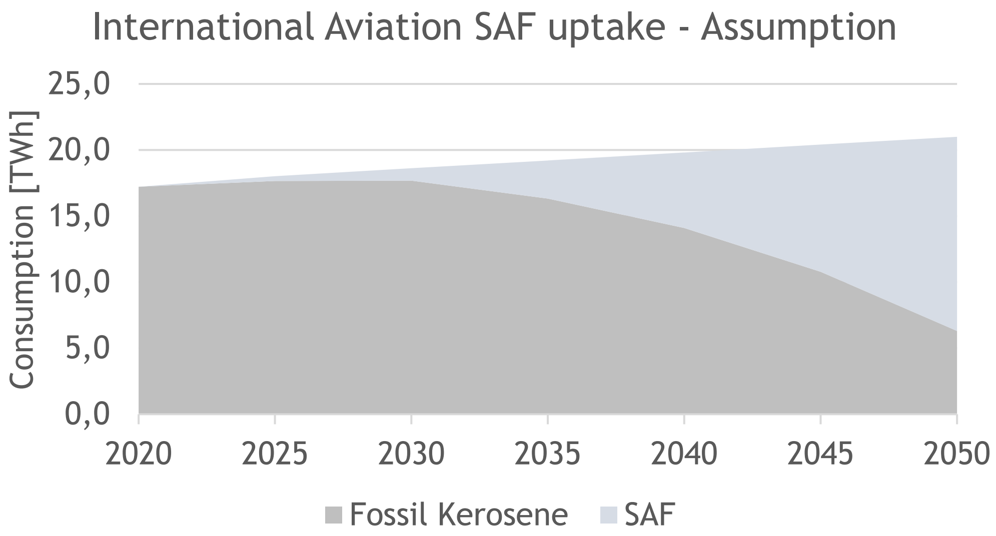


Figure 3: RED 2030 targets in transport (source: Transport & Environment[26]).

- Starting from 2025, in accordance with ReFuelEU Aviation, the aviation sector is required to achieve a minimum consumption of Sustainable Aviation Fuels (SAF). This minimum mandate is projected to reach 70% by 2050. The key assumption in this analysis is that the aviation sector will reach this level of decarbonization. However, the exact origin of the SAF—whether synthetic or of biological origin—depends on multiple external factors not considered here. Additionally, for modelling purposes, it is assumed that 50% of the international SAF used to fuel airplanes in Belgium is also produced domestically.
- Beginning in 2025, in line with FuelEU Maritime, the maritime transport sector must progressively reduce the carbon emission intensity of its fuels, achieving an 80% reduction by 2050.. Given the absence of specific data on the CO_2 emission factor of renewable fuels, it is assumed to be zero. The primary assumption here is that the maritime sector will reach the required decarbonization targets. However, as with aviation, the precise origin of renewable fuels—whether synthetic or biological—is influenced by factors beyond the scope of this analysis. It is also assumed that 50% of the maritime fuels used in Belgium are produced domestically.

[26] T&E Factsheet on RED targets



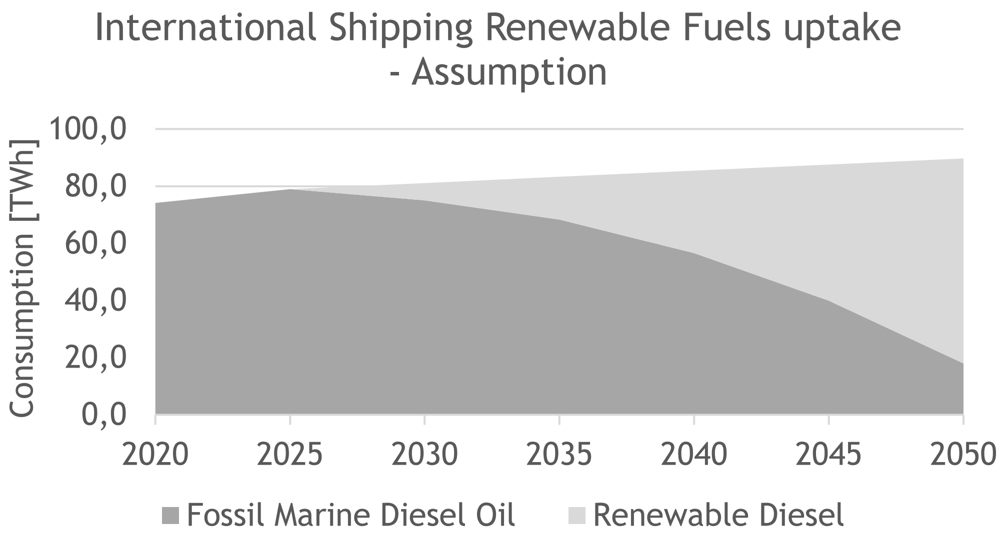


Figure 4: Assumptions on the uptake of e-fuels in international transport[27].

Note that the ReFuelEU Aviation and the FuelEU Maritime regulation are implemented exogenously to the model, as the international transport sector in the TIMES-BE model lacks the optimal degree of detail to implement such policies.

Furthermore, a highly impactful variable for the transportation sector is the uptake of electric vehicles for passenger transport. This is influenced by numerous factors, not solely technological or policy-related; hence, it has been identified as a sensitivity parameter, in terms of an upper-bound constraint on the penetration of EVs on the total passenger cars fleet. The three scenarios to be analysed in the results, including their implications for air quality, are presented here:

- In the Central Scenario, there are no constraints on the uptake of electric passenger vehicles (EVs). This implies that the TIMES-BE model can invest in electric passenger vehicles based on cost efficiency.

- In Sensitivity 1, a progressive constraint is imposed on the maximum EV penetration, aligning with Belgium's stated target in its National Energy and Climate Plan (NECP), where approximately 32% of passenger vehicles would be electric by 2030. Reaching

[27] interpolation between ReFuelEU Aviation targets (2030 – 2050) for the first graph, interpolation between FuelEU Maritime targets (2030 – 2050) for the second graph.

this target would be possible, for instance, by doubling the 2024 EV sales in the next four years (2025-2028).

- In Sensitivity 2 (also referred to as "Conservative"), the constraint on the maximum penetration is even stricter, with a slower growth assumed, i.e., no more than 14% of electric passenger vehicles by 2030. Staying within this this target would mean a reduction by 40% of the 2024 EV sales in the next four years (2025-2028).

It is noteworthy, however, that in both Sensitivity 1 and Sensitivity 2, a maximum possible share of 100% EVs is reached by 2050. This means that the model is free to choose the share of EV penetration in 2050 without any exogenous constraint, and it is intentionally done to leave the model as unconstrained as possible, given the already imposed 100% decarbonization constraint in the same year. Moreover, it is important to highlight that the constraints and assumptions in this analysis apply solely to passenger car EVs and do not extend to Light or Heavy-Duty freight transport, whose decarbonization pathway is determined endogenously through model optimization. The techno-economic parameters characterizing this sector come from the TREMOVE model, and are validated with the Reference Scenarios 2020 by the European Commission[28].

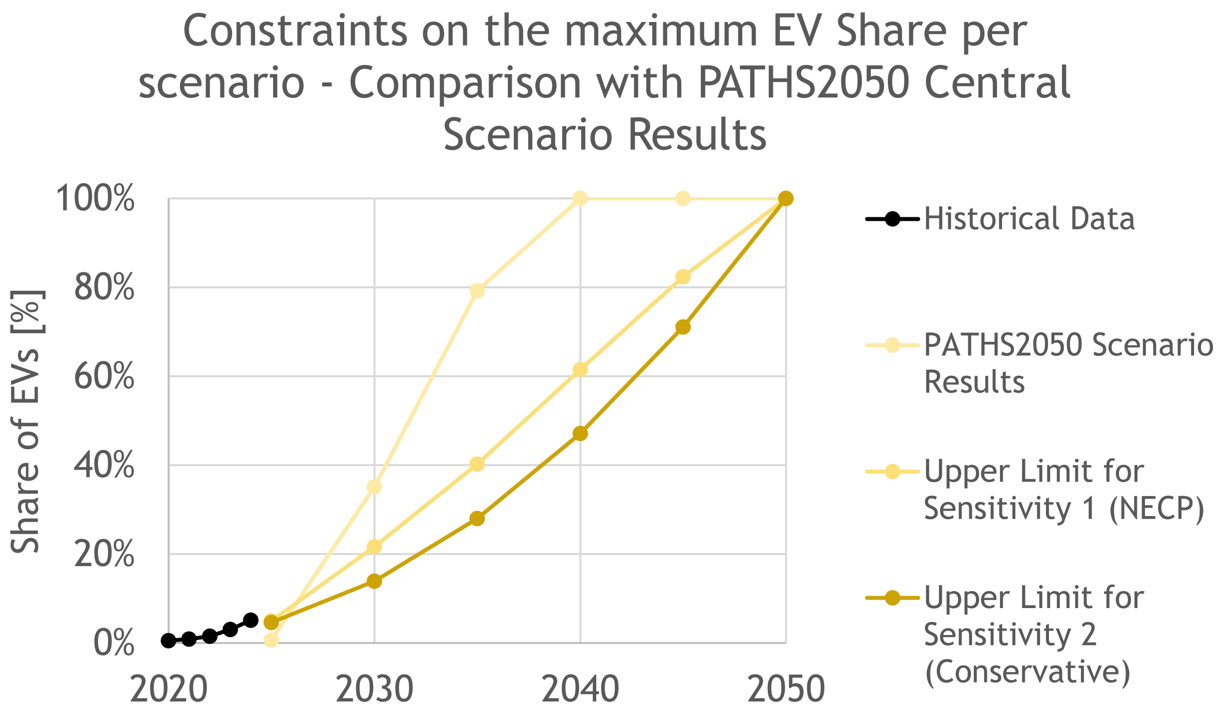


Figure 5: Constraints on the maximum possible EV uptake in the Sensitivity scenarios, compared with the PATHS2050 model results.

2.4 Results

This section will first present the global trends in the three scenarios, namely in terms of energy consumption and carbon emissions. Then, a closer look will be dedicated to the transport sector, to check the impact of the policies on the results. Finally, the fossil fuels supply and use in industry will be object of study, given the pivotal role of these two sectors in driving the air quality in Belgium.

[28]https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

Driven by the increasing carbon price, all three scenarios show a systematic decarbonization of the energy system (see Figure 6). However, despite a Net-Zero constraint in 2050, fossil fuel consumption persists in all scenarios, primarily in industry, where feedstock usage of fossil fuels (indicated as "Non-energy use" in the graph) remains substantial, particularly in processes utilizing carbon capture to mitigate emissions.

Fossil fuels consumption drops from the current levels (350 TWh/y) to nearly 95 TWh/y by 2050. Notable distinctions between the different scenarios arise in 2030 and (mainly) 2040, primarily attributed to constrained electric vehicle fleets, leading to significantly higher fossil fuel consumption in sensitivity 1 and 2 scenarios compared to the Central scenario (by respectively 9 and 30 TWh in 2040).

As electricity increasingly meets final energy demand, total energy consumption declines from 450 TWh in 2020 to approximately 330 TWh in 2050. This reduction is primarily driven by improved end-use efficiency, notably through the adoption of electric vehicles in transport, heat pumps in buildings, and electrified solutions in low-temperature industrial processes.

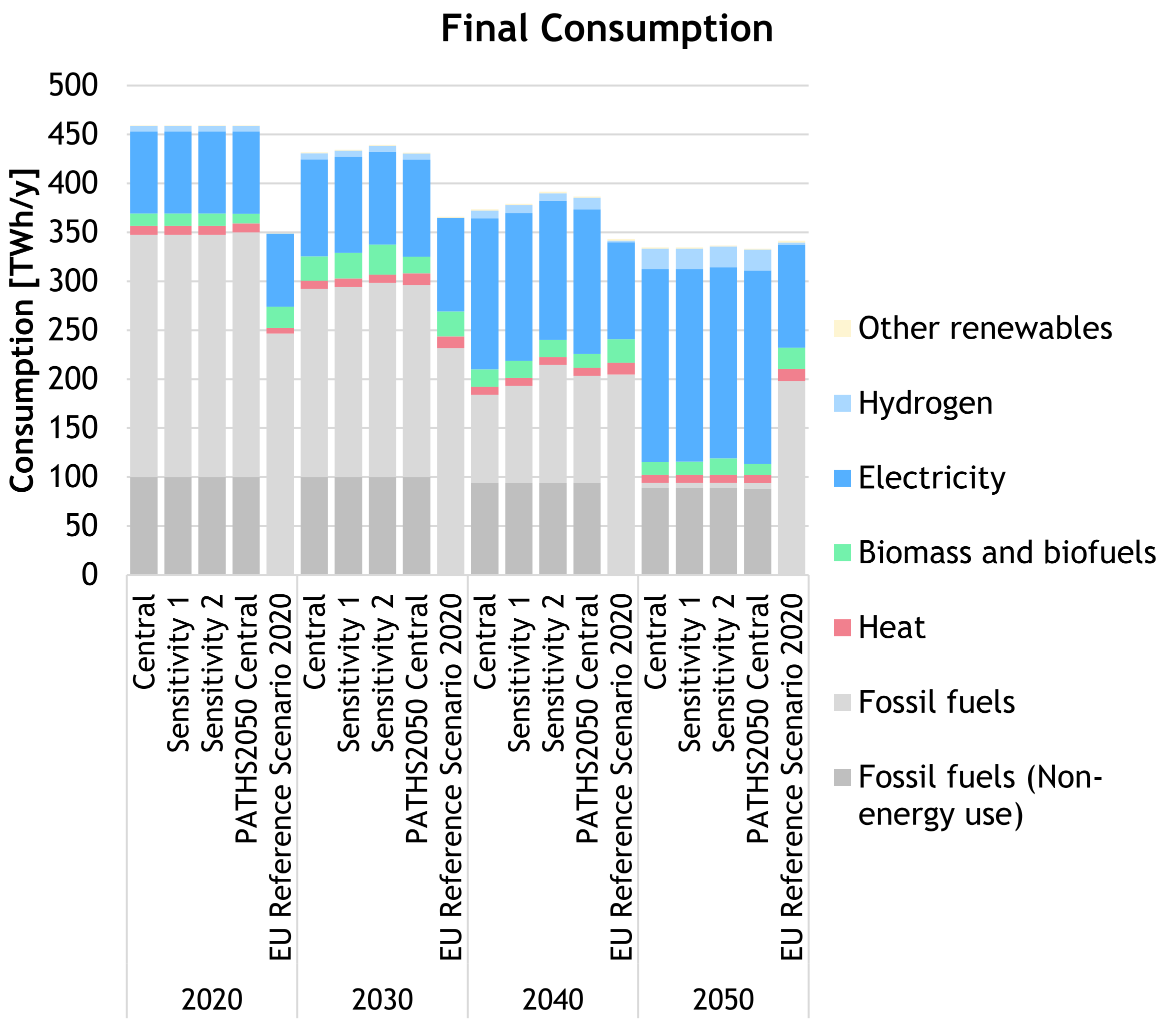


Figure 6: Final Energy Consumption, all sectors combined.

Figure 7 shows that the power sector aligns closely with PATHS2050 outcomes, with an increasing share of renewables up to maximum uptake, to cover the increasing electricity demand shown in the previous graph.

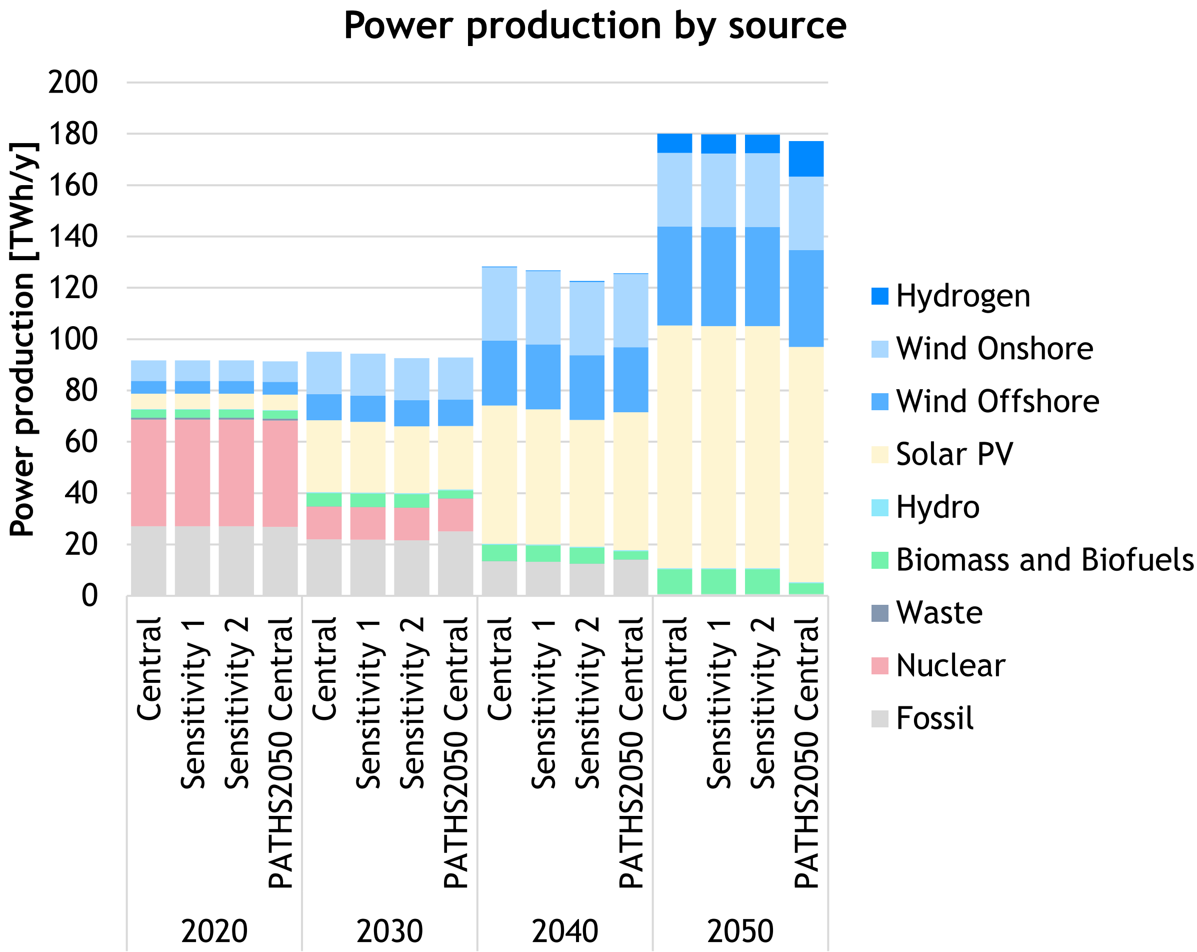


Figure 7: *Power production by source, compared with PATHS2050 results.*

A notable distinction arises in 2050, where, in the new scenarios, the greater biomass availability is exclusively utilized in the power generation sector, yielding an additional 5.5 TWh of renewable electricity. This surplus leads to a reduction in hydrogen-produced electricity (-6 TWh). Biomass is used by the model as a flexible power production source to operate in moments of lacking solar and wind energy. This was also the case for the hydrogen (or derivatives) turbines which produce electricity at higher costs and can now be partially replaced.

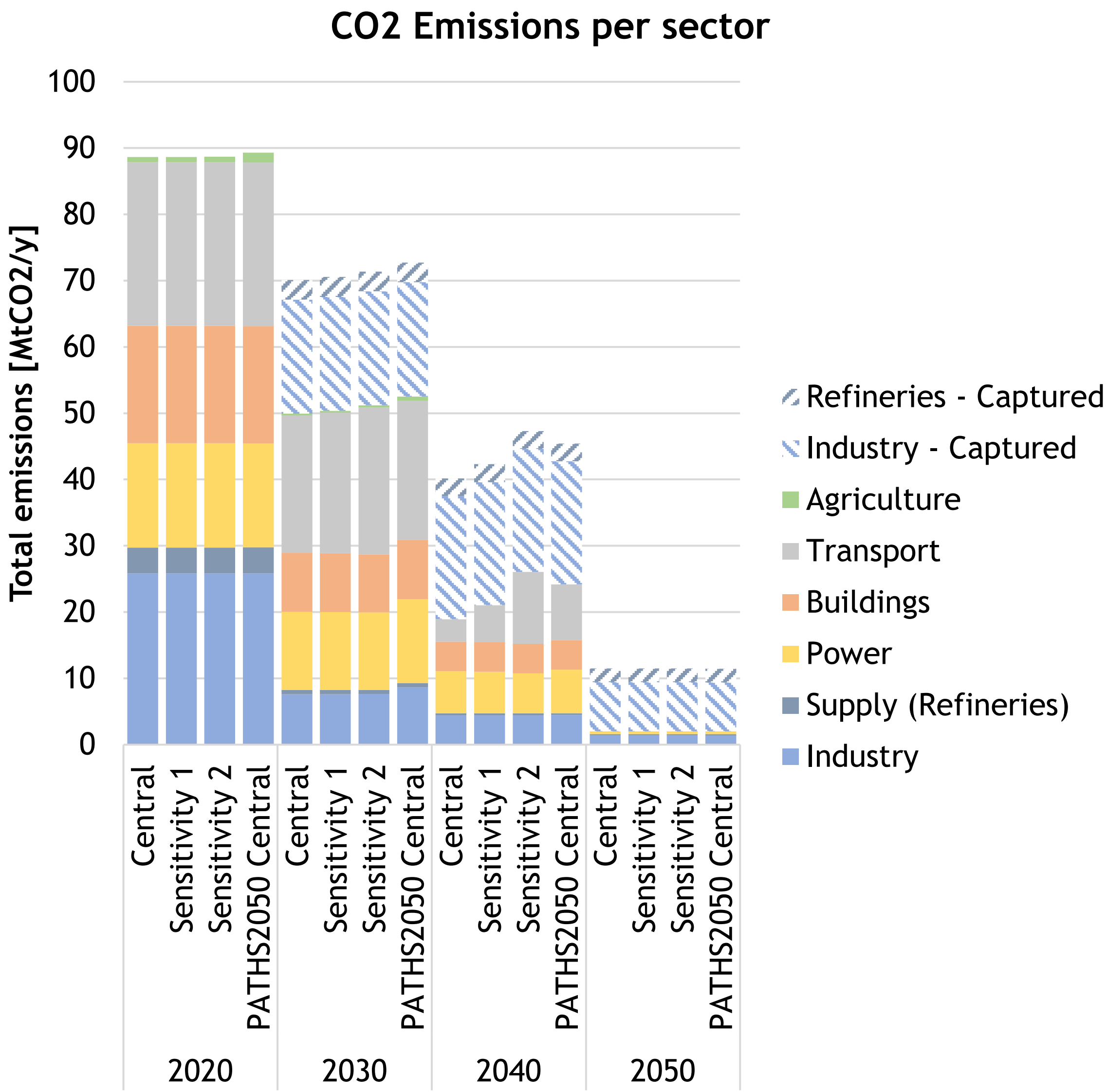


Figure 8: CO2 gross emissions by sector.

Figure 8 shows the carbon emissions per sector for the various scenarios, highlighting with different filling patterns the net emissions (in solid fill) and the captured ones (with a striped pattern). Therefore, the total of the two components represents the gross emissions. Evaluating emissions components reveal the pivotal role of carbon capture in both the industry and refinery sector, where a CO_2 removal of 17.2 and 2.9 Mt respectively, results to be cost-optimal in 2030 in all scenarios. The perfect foresight functionality of the TIMES model shows that, at a carbon price of 150 EUR/ton CO_2 in 2030 and increasing up to 350 EUR/ton by 2050, investments in carbon capture are cost effective.

Variances among scenarios are most pronounced in transport sector emissions, particularly noticeable in 2040, with increases of +2 $MtCO_2$ and +7.5 $MtCO_2$ in the Sensitivity 1 and 2 respectively compared to the Central scenario. These higher CO_2 emissions result from the slower adoption of electric vehicles, which was included as a constraint in the sensitivity scenarios.

When it comes to the transport sector, the results are presented in Figure 9.

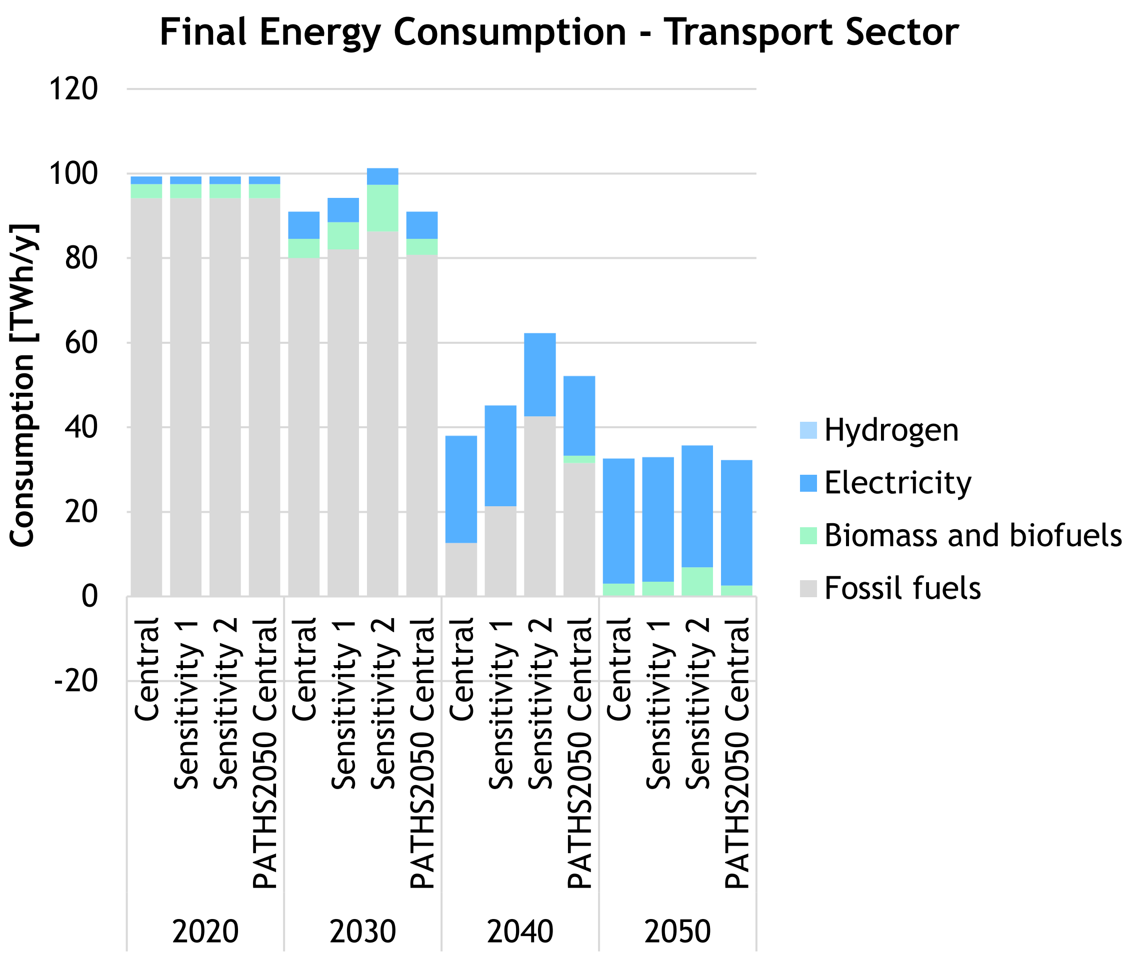


Figure 9: Final Energy Consumption, national transport sector.

These results can be summarized as follows:

- In general, the energy consumption decreases sensibly due to the higher energy efficiency of electrified options (mainly in road transport, which is by far the largest component).
- In 2030, increased biofuel shares are observed in sensitivity scenarios to meet REDIII directive targets; this happens more evidently in these scenarios because in the sensitivity scenarios there is a binding constraint on the uptake of EVs in 2030 (see Figure 5).
- In 2040, limitations on the EV share in the total fleet elevate fossil fuel consumption in sensitivity scenarios, disregarding advanced biofuels due to their high prices.
- Finally, in 2050, the minimal not yet electrified fleet portion shifts to biofuel blending to achieve Net-Zero targets.

Table 1: Achievement of the Renewable Energy Directive targets in the three scenarios (with multipliers) and compared to PATHS2050 Central scenario.

	REDIII Target	Model results - 2030			
		Central	Sensitivity 1	Sensitivity 2	PATHS2050 Central
RFNBOs	1%	1-11.7%	1-11.3%	1-11.1%	0%
Adv. Biofuels		5.7-16.4%	7.9-18.2%	12.1-22.2%	4.2%
Adv. Biofuels + RFNBOs	5.5%	17.4%	19.2%	23.2%	4.2%
Electricity		11.6%	9.8%	5.8%	11.6%
Total Renewables	29%	29%	29%	29%	15.8%

Table 1 explicitly outlines how REDIII targets are met in 2030, including international transport (aviation and maritime). As mentioned at the beginning of this section, various multipliers are considered in target calculations, as suggested in the normative[29]. It is important to note that for the PATHS2050 Central scenario the REDIII directive was not included, so the targets are not met.

As outlined in the assumptions, the origin of renewable fuels used in international transport is not specified. Accordingly, the table presents value ranges for both RFNBOs and advanced biofuels. Regardless of origin, RFNBOs are required to meet the 1% target set by RED III. Combined, RFNBOs and advanced biofuels—subject to a joint target of 5.5%—exceed this threshold in all scenarios, ranging from 17.4% to 23.2%, with higher shares observed in scenarios with lower EV uptake (19.2–23.2%). The remainder needed to achieve the overall 29% target is met through electrification.

2.5 Benchmarking with current Belgian policy ambition

To conclude this section on energy modelling, we compare the results obtained in this study and those of the Central Scenario PATHS2050 with the official projections provided by the Federal Government of Belgium to the European Union. For this comparison, we considered the National Energy and Climate Plan (NECP), the latest version that was released November 2023, and the Long-Term Strategy (LTS), released in March 2020, that includes targets for 2050. However, both documents lack detailed data on specific targets, limiting the extent of our benchmarking. The NECP provides sufficiently detailed projections on carbon emissions and renewable energy penetration in the power sector only for the scenario 'With Additional Measures – WAM' but offers projections only up to 2030 for most metrics. Conversely, the LTS provides projections on carbon emissions up to 2050, excluding those under the ETS1 umbrella.

[29] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413

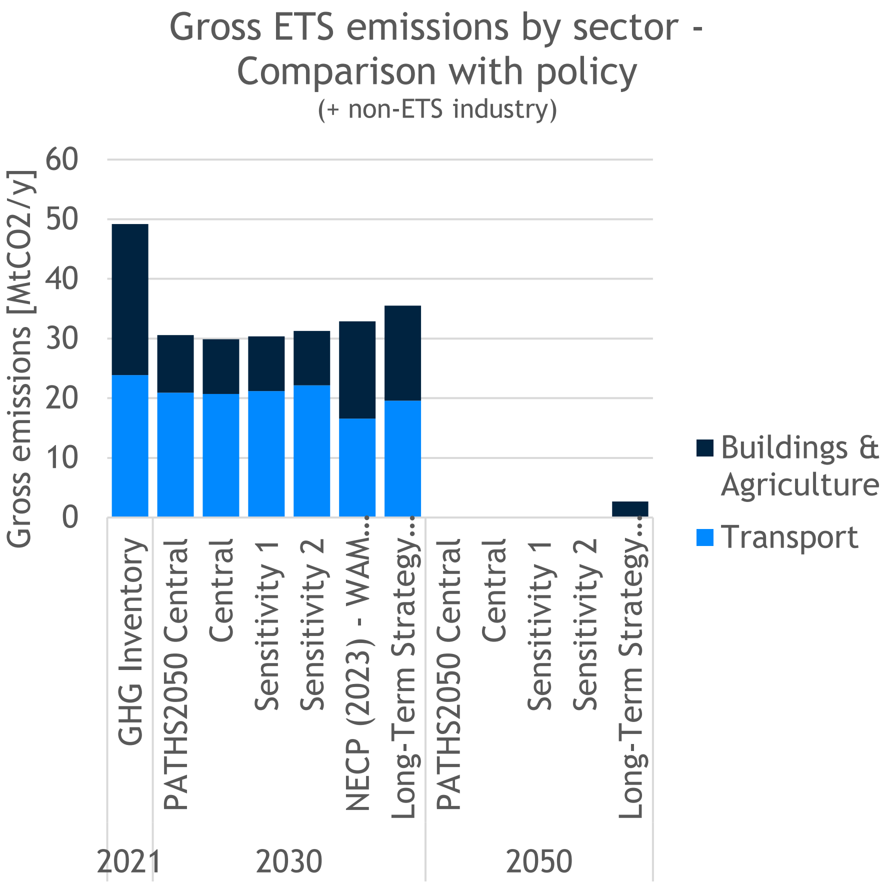


Figure 10: Gross CO2 emissions by ETS sector (+ non-ETS industry) and comparison with policy ambitions.

The CO2 emissions projections are divided into 2 groups; a first group consisting of supply (including refineries), power, and industry sectors (equivalent to the ETS1 sector plus non-ETS1 industry) and a second group consisting of transport[30], and 'other sectors,' which include buildings and agriculture. This latter group represents the total non-ETS1 emissions, except for non-ETS1 industry, which is included in the previous group. For the first group, gross emissions are presented in Figure 10, indicating that the 2030 targets of the NECP-WAM Scenario are less ambitious compared to the results of the TIMES-BE model across all scenarios). There is a discrepancy in the captured emissions component (~20.2 Mt in the studied scenarios vs 5 Mt CO_2 in the NECP-WAM scenario) which makes that the net carbon emissions in the scenarios produced with the TIMES-BE model are ~50% of the NECP-WAM scenario (~19-21 Mt and ~41 Mt CO_2 respectively), while the gross emissions values remain comparable.

[30] Even though emissions from National Aviation and Maritime (from 2024) transport fall under the ETS1, they are not accounted in Figure 13 for the sake of comparability with the NECP, as they were not included in the figure. However, they are included in Figure 14 for the same reason.

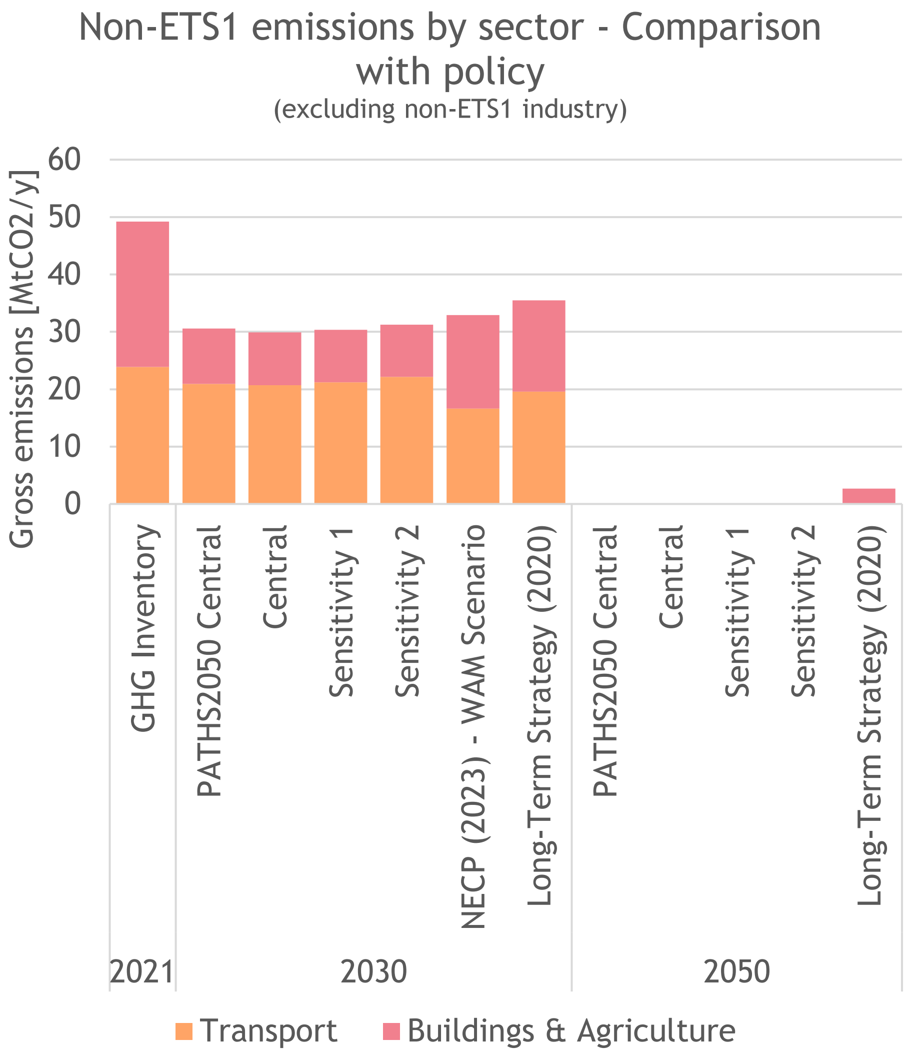


Figure 11: Gross CO2 emissions by non-ETS1 sector (excluding non-ETS1 industry) and comparison with policy ambitions.

Regarding transport and the 'other sectors' (see Figure 11), it is apparent that by 2030, the scenarios produced with the TIMES-BE model demonstrate a greater decarbonization effort for the combined group of transport and 'other sectors' in comparison to the LTS and NECP-WAM scenarios; this is supported by a greater decarbonization effort in the 'other sectors' (~9.0 Mt of CO_2 emissions in all three scenarios vs 15.9 Mt in LTS and 16.3 Mt in NECP-WAM) but is little less ambitious in terms of decarbonizing transport (20.7 – 22.1 Mt of CO_2 emissions in all three scenarios vs 19.6 Mt in LTS and 16.6 Mt in NECP-WAM). Lastly, for 2050, the LTS also anticipates complete decarbonization in the transport sector but still shows residual carbon emissions in the other sectors (2.7 Mt), which are absent in the scenarios produced with TIMES-BE.

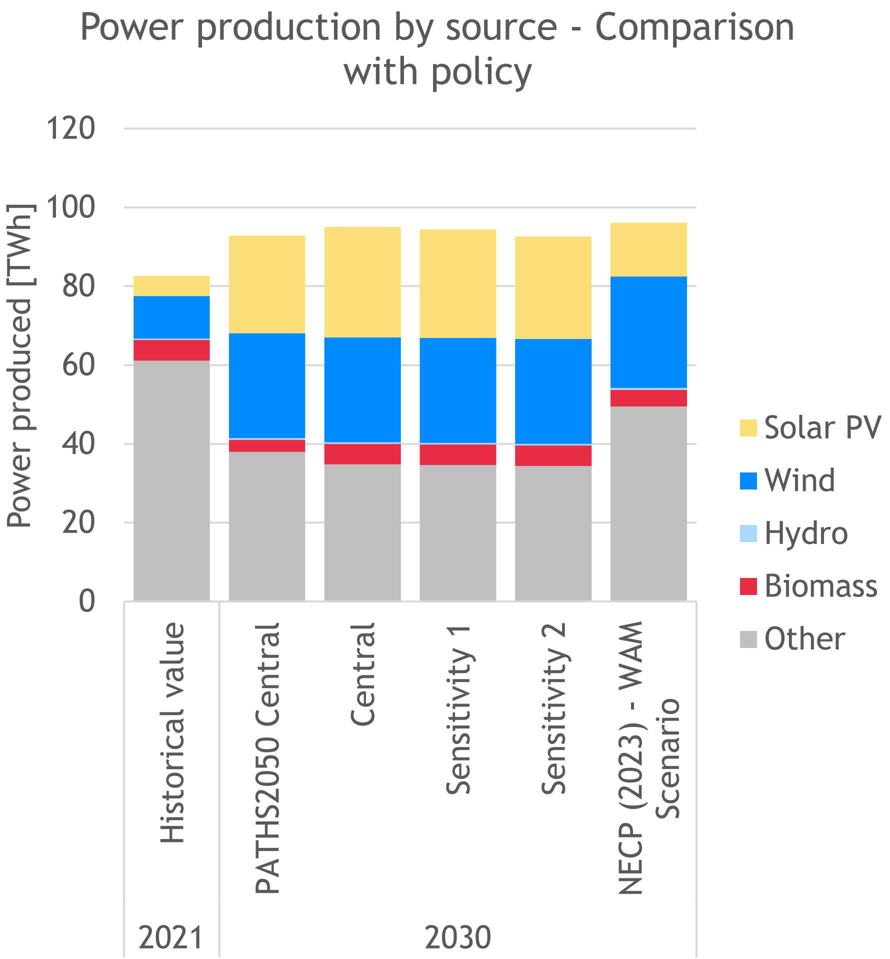


Figure 12: Power production mix - comparison with policy ambitions.

Finally, also a comparison was realized in terms of renewables penetration in the power sector (Figure 12). While the results in all scenarios produced with TIMES-BE align with the NECP-WAM scenario when it comes to power production using wind and biomass, the main difference stands in the solar PV component, expected to be ~25 TWh in the studied TIMES-BE scenarios vs 13.7 TWh in the NECP-WAM scenario. This difference is compensated in the NECP-WAM with other, non-renewable sources (not further specified in the NECP report). An additional comparison has been realized with the EU Reference Scenario 2020 (see Appendix 3: Comparison with EU Reference Scenario 2020); however, this scenario has completely different ambitions in terms of emissions reduction (only -10% in 2050 with respect to current levels); therefore, the comparability of results is very limited.

3 AIR POLLUTANT EMISSIONS

After the description of the energy scenarios, this part of the study translates the scenario results to air pollutant emissions. First the methodology is described to conduct the translation, followed by a discussion of the resulting emission trends.

3.1 Emission modelling Methodology

The objective is to understand how energy and air quality are linked and then to develop an integrated methodology (overcoming the 'silo-approach') to estimate realistic future energy-air quality scenarios. For the air quality modelling part, this is translated to:

- The air pollutant emission model should be aligned with the output of the energy model, both in terms of sectors, technologies and fuels used.

- The methodology should be based on the existing methodologies used to derive the Belgian air pollutant emission projections.

- The emission factors should be in line with the current set of emission factors used by Belgian policy makers.

- Assumptions in the methodology should be aligned and validated with relevant industrial partners and sector federations.

The above requirements set some boundaries to the emission model methodology:

- Given the available input data, a fully integrated methodology for the industrial sectors can only be developed for combustion emissions[31]. Process emissions[32] are not considered. A completely different methodology would be required to estimate these emissions which goes beyond the scope of this study.

- Bottom-up calculations starting from energy prognoses are only available for NO_x, PM10 and SO_x. Only these pollutants are included in the analysis.

- In order to make a meaningful comparison with existing Belgian air and climate plans, compatibility with Long- Range Transboundary Air Pollution (LRTAP) sectors should be ensured.

Figure 13 shows a schematic representation of the general emission modelling methodology. Input consists of TIMES activity data in the form of energy balances for the base year and scenario years combined with LRTAP base year emission data. In short, the base year emissions are linked to the base year energy consumption. This allows to establish 'demonstrated emission factors' (also called 'implied emission factors'). The resulting emission factors are evaluated for future years and combined with the energy data for the scenarios, leading to an LRTAP compatible emission scenario.

The main challenges with the proposed methodology are related to the difference in aggregation level of the reported LRTAP emissions compared to the TIMES activity data. In addition, assumptions are needed to attribute emission factors to current and future

[31] Combustion emissions are the direct byproducts generated when fuel is burned to produce electricity, heat, or pressure in an industrial setting. This process involves the chemical reaction of the fuel with oxygen, resulting in the release of energy and emissions.

[32] Process emissions originate from the conversion of raw materials into intermediate or final products. These emissions are not a result of fuel combustion, but rather, they are released during the various stages of material processing and transformation. This includes all the chemical reactions and physical changes that the raw materials undergo during the production process.

technologies. Especially for the (unknown) future technologies, this remains an important source of uncertainty.

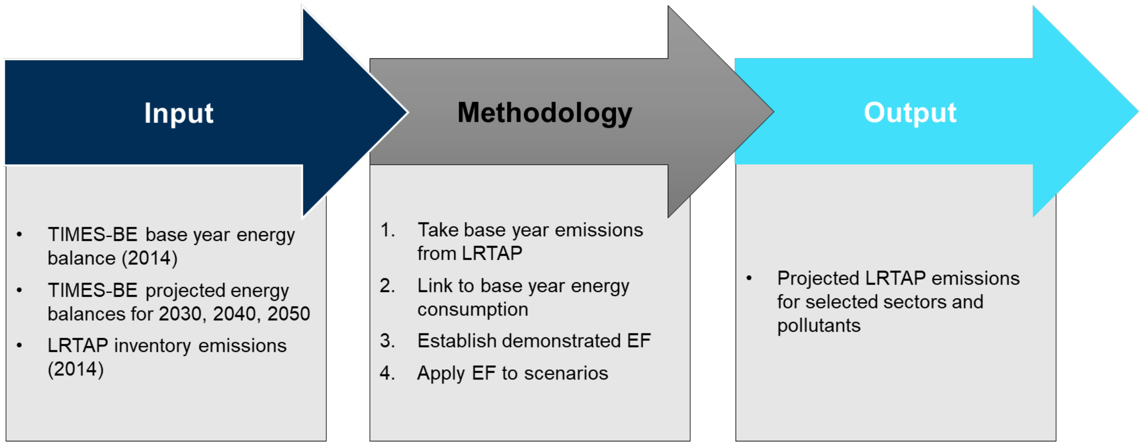


Figure 13: Schematic overview of the general methodology to translate TIMES input data to LRTAP compatible emission scenarios.

3.1.1 LRTAP sector classification

The LRTAP (Long Range Transboundary Air Pollution) reporting format is the reference for reporting air pollutant emissions in Europe. The reporting format works with a predefined and standardized set of (sub)sectors that are commonly used all over Europe, called NFR (Nomenclature For Reporting) sectors. An example of an LRTAP table for the base year 2014 is given in Appendix 2: Assumptions in Transport Sector.

To ensure a seamless fit between the energy and emission modelling, the output of the TIMES model will be translated to an LRTAP compatible format. The LRTAP sectoral classification and fuel disaggregation will be a driving element in any of the methodological choices to be made.

3.1.2 Input data

As a starting point, input data for emission calculations are prepared by connecting process codes and additional meta info to each process of a CRF sector (Common Reporting Format classification) used in TIMES. An example for combustion in the chemical sector is given in Table 2. The preprocessing's goal is to match all the details in the output of the TIME-BE model with LRTAP sector codes. To keep crucial TIMES information for later steps (for example e.g., when adding detailed emission factors to specific installations), we include multiple metadata columns. These include the type of plant (combustion plant, turbine, etc.), details on the installation type, type of fuel used, flow type which matches with Eurostat Energy Balance flow types, whether or not the installation is an auto-producer. The inclusion of metadata makes it easier to identify specific emission factors for different processes in the following stages.

Table 2: Example of the addition of metadata columns to a specific TIMES process.

Sector	CRF code	Plant type	Installation type	Process	Fuel	Flow type	Auto-producer
chemistry	1.A.2.c.	combustion plant	conventional thermal	I-CH-OT-OTHNRG-00	natural gas	final consumption energetic	FALSE

The assignment of metadata to each process relies on expert understanding of the underlying TIMES model, involving some interpretation of process physics. Distinguishing between emissions originating from fuel combustion and process-related emissions can be challenging in certain processes, a crucial distinction for linking activity data to LRTAP emissions (and the corresponding NFR sectors). These assumptions are evaluated in section 4.1, and potential implications are discussed.

The final list of sectors that are retained from TIMES is found in Table 3, linking CRF codes to LRTAP codes. As mentioned before, the list exclusively encompasses combustion emissions, all process emissions activity data is excluded. It also needs to be pointed out that no light duty vehicles (LDV) category exists in TIMES. This category is covered under HDVs. So, the split between HDV and LDV is made manually based on the existing share of trucks and LDV in the base-year, with the assumption that this split remains constant over the years (note that share could be changed in the model if other information were available).

After this preprocessing phase, effortless transfer of TIMES output data to the air quality emissions tool becomes feasible. The uniformization of input data format enables the calculation of new scenarios without additional preprocessing. The necessary columns for input data include the metadata columns mentioned before, expanded to incorporate the fuel type used in each process and the relevant energy consumption data for the specified years in petajoules (PJ).

3.1.3 LRTAP mapping

In a next phase, the mapping to an LRTAP-compatible format (NFR) is accomplished through the utilization of two mapping tables. The sector mapping is straightforward, facilitated by the incorporation of CRF sectors in the activity data (Table 3). However, it must be noted that the different sectoral aggregation in energy and air quality modelling is a point of attention when performing integrated modelling.

Table 3: LRTAP sector mapping.

CRF code	LRTAP_code	LRTAP_long
1.A.1.a.	1A1a	Public electricity and heat production
1.A.1.b.	1A1b	Petroleum refining
1.A.1.c.	1A1c	Manufacture of solid fuels and other energy industries
1.A.2.a.	1A2a	Stationary combustion in manufacturing industries and construction: Iron and steel
1.A.2.b.	1A2b	Stationary combustion in manufacturing industries and construction: Non-ferrous metals
1.A.2.c.	1A2c	Stationary combustion in manufacturing industries and construction: Chemicals
1.A.2.d.	1A2d	Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print
1.A.2.e.	1A2e	Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco

1.A.2.f.	1A2f	Stationary combustion in manufacturing industries and construction: Non-metallic minerals
1.A.2.g.	1A2gviii	Stationary combustion in manufacturing industries and construction: Other
1.A.4.a.	1A4ai	Commercial/Institutional: Stationary
1.A.4.b.	1A4bi	Residential: Stationary
1.A.4.c.	1A4ci	Agriculture/Forestry/Fishing: Stationary
1.A.3.a.i(i)	1A3ai(i)	International aviation LTO (civil)
1.A.3.a.ii(i)	1A3aii(i)	Domestic aviation LTO (civil)
1.A.3.b.i	1A3bi	Road transport: Passenger cars
X	1A3bii	Road transport: Light duty vehicles *(not available in TIMES)*
1.A.3.b.iii	1A3biii	Road transport: Heavy duty vehicles and buses
1.A.3.b.iv	1A3biv	Road transport: Mopeds & motorcycles
1.A.3.c.	1A3c	Railways
1.A.3.d.	1A3dii	National navigation (shipping)
1.A.3.d.i(i)	1A3di(i)	International maritime navigation

Subsequently, an important methodological step involves the determination of the level of detail for fuel types in the emission calculations. The TIMES output comes with a high detail of fuels used in the energy systems. The LRTAP reporting provides only one emission value per sector and pollutant, leading to a loss of the existing detail present in TIMES. Although adhering fully to the TIMES aggregation level is not feasible due to the absence of emission factor information at the highest level of detail, we have opted for a compromise. The option chosen is to align with the conventional LRTAP fuel types, striking a balance between accuracy and the availability of data. This approach results in a mapping table given in Table 4.

Table 4: Fuel type mapping table linking fuels used in TIMES with fuels used in the LRTAP data set.

TIMES_fuel	LRTAP_fuel
Biofuels solid	Biomass
Biogas	Gaseous fuels
Blast furnace gas	Gaseous fuels
Coal	Solid fuels
Coke oven coke	Solid fuels
Coke oven gas	Gaseous fuels
Crude oil and intermediate products	Liquid fuels

Diesel	Liquid fuels
Heavy fuel oil	Liquid fuels
Hydrogen gas	NA
Kerosene-type jet fuel (excluding biofuel portion)	Liquid fuels
LPG	Liquid fuels
Motor gasoline (excluding biofuel portion)	Liquid fuels
Naphtha	Liquid fuels
Natural gas	Gaseous fuels
Other oil products	Other fuels
Pure biodiesels	Liquid fuels
Pure biogasoline	Liquid fuels
Refinery gas	Gaseous fuels
Industrial waste	Solid fuels
Renewable municipal waste	Biomass
Synthetic kerosene-type jet fuel (excluding biofuel portion)	Liquid fuels
Synthetic diesel	Liquid fuels

3.1.4 Emission factors

3.1.4.1 Base-year 2014

In Belgium existing methodologies for estimating future industrial emissions rely on base-year emission reports for large combustion plants (LCPs) in conjunction with individual installation emission limit values and their expected evolution over time. However, this approach is unsuitable for our current project due to the absence of explicit installations in the TIMES model. Alternative sets of base-year emission factors, while available from literature, yield sectoral emissions inconsistent with LRTAP reports, hindering meaningful comparisons with air and climate plans. Therefore, 'demonstrated emission factors' were chosen.

To calculate the base-year demonstrated emission factor (also called 'implied emission factor'), the total base-year emission is divided by the base-year activity data. Given the constraints outlined earlier, this division is performed at the LRTAP sector and fuel type level.

Given the absence of base-year emissions at the highest aggregation level, a method is required to attribute the share of LRTAP emissions per sector originating from a specific fuel type. For this attribution, the method is aligned with the established Flemish methodology for (sub-) sectors where this information is available, while for other sectors, there is a need to rely on internal expertise. Assumptions about fuel split per sector are listed below:

- 1A4ai and 1A4bi, stationary combustion in commercial/institutional and Residential sectors: it is assumed that the fuel share will correspond to the share in sector 1A4ci, stationary combustion in agriculture/forestry/fishing (only the share of emissions coming from a specific fuel type in the base year).

- 1A3ai(i) and 1A3aii(i), aviation: only liquid fuels are included in TIMES so the share is set to 100% from liquid fuels.

- 1A3bi, 1A3bii, 1A3biii and 1A3biv, road transport: the base year fleet emission factors from the Belgian emission inventory are used to obtain the relative share related to each fuel type. There are only liquid and gaseous fuel types in the mix. The resulting emission factor is a weighted emission factor based on the underlying fleet composition (see note 3.1.4.3) for liquid fuels on the one hand and gaseous fuels on the other hand.

- 1A3c, railways: only liquid fuels are included in TIMES so the share is set to 100% from liquid fuels. Electricity for railways is included in sector 1A1a - electricity production and has no direct emissions in sector 1A3c.

- 1A3dii and 1A3di(i), shipping: only liquid fuels are included in TIMES; consequently, the share is set to 100% from liquid fuels. Discussions with relevant entities indicate a non-zero share of gaseous fuels in the shipping sector. This could be included but has no effect considering the TIMES activity data (set to 100% liquid). This discrepancy can be one of the reasons for differences observed in the results between the national air quality plans and the current study.

Table 5 below gives the share of emissions per fuel type per sector. It is important that shares are present for all sectors and fuel types, to avoid errors in the calculations.

Table 5: Share of emissions per different fuel type per subsector. Share is given per subsector and per pollutant for the base-year 2014.

NFR	LRTAP_fuel	NO_x	SO_2	PM10
1A1a	Liquid Fuels	17.35%	10.76%	32.05%
	Solid Fuels	24.67%	56.33%	27.56%
	Gaseous Fuels	6.58%	2.22%	3.21%
	Biomass	34.95%	28.48%	33.97%
	Other Fuels	16.45%	2.22%	3.21%
1A1b	Liquid Fuels	16.97%	18.46%	47.15%
	Solid Fuels	25.92%	40.25%	21.71%
	Gaseous Fuels	9.19%	3.80%	4.71%
	Biomass	28.37%	33.69%	21.72%
	Other Fuels	19.56%	3.80%	4.71%
1A1c	Liquid Fuels	17.35%	10.76%	32.05%
	Solid Fuels	24.67%	56.33%	27.56%
	Gaseous Fuels	6.58%	2.22%	3.21%
	Biomass	34.95%	28.48%	33.97%
	Other Fuels	16.45%	2.22%	3.21%
1A2a	Liquid Fuels	16.97%	18.45%	47.13%
	Solid Fuels	25.91%	40.27%	21.71%
	Gaseous Fuels	9.19%	3.80%	4.71%
	Biomass	28.38%	33.68%	21.73%
	Other Fuels	19.55%	3.80%	4.71%
1A2b	Liquid Fuels	17.04%	16.65%	43.99%
	Solid Fuels	25.70%	44.04%	22.93%

	Gaseous Fuels	8.73%	3.43%	4.40%
	Biomass	29.53%	32.46%	24.28%
	Other Fuels	19.01%	3.43%	4.40%
1A2c	Liquid Fuels	16.99%	17.90%	46.19%
	Solid Fuels	25.85%	41.42%	22.08%
	Gaseous Fuels	9.06%	3.69%	4.62%
	Biomass	28.71%	33.31%	22.49%
	Other Fuels	19.40%	3.69%	4.62%
1A2d	Liquid Fuels	17.05%	16.40%	43.55%
	Solid Fuels	25.66%	44.55%	23.10%
	Gaseous Fuels	8.66%	3.38%	4.35%
	Biomass	29.70%	32.29%	24.64%
	Other Fuels	18.93%	3.38%	4.35%
1A2e	Liquid Fuels	17.22%	12.89%	36.71%
	Solid Fuels	25.11%	51.88%	25.76%
	Gaseous Fuels	7.51%	2.65%	3.67%
	Biomass	32.61%	29.92%	30.19%
	Other Fuels	17.55%	2.65%	3.67%
1A2f	Liquid Fuels	17.06%	16.17%	43.12%
	Solid Fuels	25.63%	45.04%	23.27%
	Gaseous Fuels	8.60%	3.33%	4.31%
	Biomass	29.87%	32.13%	24.99%
	Other Fuels	18.85%	3.33%	4.31%
1A2gviii	Liquid Fuels	17.27%	12.06%	34.93%
	Solid Fuels	24.95%	53.62%	26.45%
	Gaseous Fuels	7.17%	2.48%	3.49%
	Biomass	33.46%	29.36%	31.63%
	Other Fuels	17.15%	2.48%	3.49%
1A3ai(i)	Liquid Fuels	100%	100%	100%
	Solid Fuels	0%	0%	0%
	Gaseous Fuels	0%	0%	0%
	Biomass	0%	0%	0%
	Other Fuels	0%	0%	0%
1A3aii(i)	Liquid Fuels	100%	100%	100%
	Solid Fuels	0%	0%	0%
	Gaseous Fuels	0%	0%	0%
	Biomass	0%	0%	0%
	Other Fuels	0%	0%	0%
1A3bi	Liquid Fuels	98.00%	98.00%	98.00%
	Solid Fuels	0%	0%	0%
	Gaseous Fuels	2.00%	2.00%	2.00%
	Biomass	0%	0%	0%
	Other Fuels	0%	0%	0%
1A3bii	Liquid Fuels	98.00%	98.00%	98.00%
	Solid Fuels	0%	0%	0%
	Gaseous Fuels	2.00%	2.00%	2.00%
	Biomass	0%	0%	0%

	Other Fuels	0%	0%	0%
1A3biii	Liquid Fuels	98.00%	98.00%	98.00%
	Solid Fuels	0%	0%	0%
	Gaseous Fuels	2.00%	2.00%	2.00%
	Biomass	0%	0%	0%
	Other Fuels	0%	0%	0%
1A3biv	Liquid Fuels	98.00%	98.00%	98.00%
	Solid Fuels	0%	0%	0%
	Gaseous Fuels	2.00%	2.00%	2.00%
	Biomass	0%	0%	0%
	Other Fuels	0%	0%	0%
1A3c	Liquid Fuels	100%	100%	100%
	Solid Fuels	0%	0%	0%
	Gaseous Fuels	0%	0%	0%
	Biomass	0%	0%	0%
	Other Fuels	0%	0%	0%
1A3dii	Liquid Fuels	100%	100%	100%
	Solid Fuels	0%	0%	0%
	Gaseous Fuels	0%	0%	0%
	Biomass	0%	0%	0%
	Other Fuels	0%	0%	0%
1A3di(i)	Liquid Fuels	100%	100%	100%
	Solid Fuels	0%	0%	0%
	Gaseous Fuels	0%	0%	0%
	Biomass	0%	0%	0%
	Other Fuels	0%	0%	0%
1A4ai	Liquid Fuels	17.35%	10.78%	32.10%
	Solid Fuels	24.68%	56.29%	27.55%
	Gaseous Fuels	6.59%	2.22%	3.21%
	Biomass	34.93%	28.49%	33.94%
	Other Fuels	16.46%	2.22%	3.21%
1A4bi	Liquid Fuels	17.35%	10.78%	32.10%
	Solid Fuels	24.68%	56.29%	27.55%
	Gaseous Fuels	6.59%	2.22%	3.21%
	Biomass	34.93%	28.49%	33.94%
	Other Fuels	16.46%	2.22%	3.21%
1A4ci	Liquid Fuels	17.35%	10.78%	32.10%
	Solid Fuels	24.68%	56.29%	27.55%
	Gaseous Fuels	6.59%	2.22%	3.21%
	Biomass	34.93%	28.49%	33.94%
	Other Fuels	16.46%	2.22%	3.21%

The proportion of emissions attributed to distinct LRTAP fuel types, as explained earlier, must be translated into a disaggregated emission factor per NFR sector and LRTAP fuel type. This translation is achieved through the application of a mathematical formula. The formula considers both total emissions and activity data at the same aggregation level, allowing the derivation of a disaggregated emission factor:

$$EF_{ij} = \frac{Sh_{ij}}{\sum_{j=1}^{n} Sh_{ij} * A_{ij}} * \overline{EF_i} * A_i$$

with:

i the NFR sector;

j the different LRTAP fuels;

Sh_{ij} the share per fuel type j;

A_i the total activity level of NFR sector i;

A_{ij} the activity level of NFR sector i and fuel type j;

$\overline{EF}_i$ the average emission factor of NFR sector i, independent of fuel type.

EF_{ij} the average emission factor of NFR sector i and fuel type j

This calculation gives the final base year demonstrated emission factor EF_{ij}. An example of this methodology is given for the NO_x emission factor for the sector 1A1a (public electricity and heat production sector):

First the average demonstrated NO_x EF for the sector is calculated by dividing the total base-year NO_x emissions (9.12 kt) by the total energy consumption of the sector (165.82 PJ): $\overline{EF} = 0.055\ kton/PJ$.

Next, the sectoral fuel split is taken from the table above:

NFR	*LRTAP_fuel*	NO_x*_share*
1A1a	*Liquid Fuels*	*17.35%*
	Solid Fuels	*24.67%*
	Gaseous Fuels	*6.58%*
	Biomass	*34.95%*
	Other Fuels	*16.45%*

Via the above formula, a disaggregated emission factor can now be calculated:

NFR	*LRTAP_fuel*	NO_x*_EF (kt/PJ)*
1A1a	*Liquid Fuels*	0.049
	Solid Fuels	0.070
	Gaseous Fuels	0.019
	Biomass	0.099
	Other Fuels	0.047

From these demonstrated emission factors for the public electricity and heat production sector (1A1a) it can be deduced that higher emissions are expected from biomass and solid fuels than from gaseous fuels.

3.1.4.2 Future projections

To estimate the air pollutant emissions for future scenario years, the projected activity data coming from the TIMES simulations is multiplied by a future emission factor. Hereby it is assumed that over time processes will undergo changes, becoming more efficient, and new processes will emerge. Both aspects must be considered when determining emission factors for the scenario calculations.

First, to account for the improvement of existing processes, a percentage evolution of the emission factor is applied. The expectation is that the emission factor for most sectors will decrease over the years, considering technological evolution. The specific evolution adopted in this study is consistent with the Flemish model for industrial prognosis. The corresponding values are provided in

Appendix 5: Emission factor evolution, for the sectors covered by this Flemish data set. The evolution is given with respect to a base-year 2018 (current base-year of the Flemish model for industrial prognosis). A recalibration to base-year 2014 (TIMES base-year) was performed using the LRTAP inventory data for 2014 and 2018 which includes emission data and fuel use numbers for 2014 and 2018, respectively.

For the sectors not included in the aforementioned methodology, expert estimations are made in

Appendix 5: Emission factor evolution). The underlying assumptions are as follows:

- 1A4ai and 1A4bi, stationary combustion in commercial/institutional and residential sectors: it is assumed that the evolution equals the evolution in sector 1A4ci, stationary combustion in agriculture/forestry/fishing.

- 1A3ai(i) and 1A3aii(i), aviation: evolution is compiled based on an extensive airplane engine database for Brussels Airport with projections up to 2032. Different phases in the flight are distinguished with strongly varying emission factors. An average emission factor for the LTO-cycle per pollutant is used for 2018 and 2030 and a linear interpolation is chosen. After 2030, the uncertainty is very large which made us decide to use a constant emission factor up to 2050.

- 1A3bi, 1A3bii, 1A3biii and 1A3biv, road transport: the fleet emission prognoses from an existing (Flemish) WEM[33] scenario are used to define the evolution of the emission factor due to technological improvements. The resulting percentages are compiled based on the underlying fleet composition (see note 3.1.4.3) for liquid fuels on the one hand and gaseous fuels on the other hand.

- 1A3c, railways: the evolutionary effect is expected to be negligible, and the emission factors are kept constant.

- 1A3dii and 1A3di(i), shipping: for inland shipping, the evolution in emission factors is compiled based on a Flemish Business As Usual (BAU) scenario for the sector. For maritime shipping, the sulphur content of marine fossil fuels is assumed to remain equal to the current sulphur content. Biofuels do not contain sulphur and therefore reduce the sulphur content of the fuel blend. The SO_2-emission factor can be adapted to reflect blending biofuel in marine fuel. For PM_{10}, the emission factor is also assumed to remain at the level of 2014. PM_{10} emissions are largely dependent on the sulphur level of the fuel (due to the formation of sulfate particles), but this relation is not linear to the fuel blend. For NO_x, the emission factors are expected to decline due to the introduction of NECA in the North Sea, as from 2021. We assume a reduction of 75%

[33] WEM: with existing measures. A business as usual scenario.

for a Tier III-engine compared to a Tier II- engine (worst case approach). The adopted shares of Tier III engines in the fleet are set to 30% in 2030, 40% in 2040 and 45% in 2050 (also conservative estimation).

It should be noted that the emission model provides users with the flexibility to modify the emission factor evolution and override default values mentioned above, particularly for sectors where more accurate information is available. This feature enables the model to be updated over time as new data becomes available.

Secondly, the emergence of new processes is accounted for through TIMES. Each new process, whether involving a new fuel or other emission factors, is represented as a distinct line in the TIMES output. This allows for the utilization of an adjusted emission factor.

Additionally, the model incorporates an option for users to employ a custom emission factor, following the input format outlined in Table 6. To enable this functionality, users need to select a specific existing process and specify the starting date for the new emission factor. From that designated date onward, the new emission factor is applied in the scenario calculations.

Table 6: User defined emission factors.

Process	Process description	Starting_Year	EF
T-RO-CAR-M-CO-LD-GAS-N01	Gasoline driven passenger cars	2028	0.5

3.1.4.3 Note on fleet composition

The emission factor calculations for road transport are based on the Flemish methodology for road transport emissions. Flemish emission calculations are based on detailed fleet predictions in a COPERT[34]-like format but complemented with 'new' future fuel technologies (EV, PHEV,…). The expected future fleet composition is calculated with the Fleet-Model tool[35] from Transport & Mobility Leuven.

The fleet predictions start from the most recent historic fleet (this is 2023), as composed for the inventory statistics. In addition, the fleet predictions require a forecast of the yearly activity (vehicle kilometers) and assumptions on the market shares of fuel technologies for each year in the predictions. These assumptions differ for each scenario.

The fleet predictions are built up stepwise, i.e. for each year Y+1, the tool starts from the (historic or calculated) fleet of year Y to calculate the fleet of year Y+1. For each year, the following steps are applied:

1. For the fleet of year Y, the tool determines how many of the vehicles remain present in the fleet of year Y+1 based on survival curves.

2. This 'surviving' fleet is linked to mileages to calculate its activity in year Y+1.

3. This activity of the surviving fleet is compared to required activity in year Y+1 (= input). The difference in activity level will be filled by the new vehicle fleet, taking the assumed market shares for year Y+1 (= input) and mileages per fuel technology into account.

4. The surviving fleet together with the new fleet for year Y+1 constitute the fleet for year Y+1 and will form the basis for the predictions for year Y+2.

[34] https://copert.emisia.com/
[35] https://www.tmleuven.be/en/navigation/Fleet-Model#!#collapseOne

3.1.4.4 Note on uncertainty

There is a large uncertainty related to the quantitative values of the future emission factors. For new technologies foreseen by TIMES on the one hand, it is generally accepted that the emission factors are merely a first estimate based on currently known state of the art and existing legislation defining emission limit values.

On the other hand, there are also emerging technologies that are currently unknown. It goes without saying that these technologies are not included in the current analysis. This should be considered when interpreting the results and all conclusions should mainly be focused on looking at evolutions and relative changes, rather than absolute values.

3.1.5 Output

Finally, the results of the emission model are collected in a table resembling the LRTAP format (see section Emission results).

3.2 Emission results

This section presents the results of the emission modelling. As an example of the modelling output, a single table is included in this chapter for one pollutant and one scenario (Table 7). The results for other pollutants and scenarios are included in Appendix 6: Results.

3.2.1 Emission results: Central scenario

Table 7: Emission model output for NOx for the Central scenario.

LRTAP Code	GNFR Code	2020 NOx [kton]	2030 NOx [kton]	2040 NOx [kton]	2050 NOx [kton]
1A1a	A_PublicPower	6.03	3.07	3.46	5.00
1A1b	B_Industry	2.63	2.24	1.67	1.26
1A1c	B_Industry	1.94	1.94	1.94	0.03
1A2a	B_Industry	1.21	1.28	1.14	0.02
1A2b	B_Industry	0.28	0.26	0.17	0.00
1A2c	B_Industry	1.78	3.80	3.31	0.37
1A2d	B_Industry	1.51	1.14	0.81	0.78
1A2e	B_Industry	2.10	0.47	0.22	0.20
1A2f	B_Industry	0.85	0.58	0.48	0.26
1A2gviii	B_Industry	2.44	1.68	0.74	0.69
1A3ai(i)	H_Aviation	1.92	2.22	2.36	2.51
1A3aii(i)	H_Aviation	0.02	0.03	0.00	0.00
1A3bi	F_RoadTransport	32.61	6.14	0.00	0.00
1A3bii	F_RoadTransport	13.57	4.87	0.63	0.00
1A3biii	F_RoadTransport	12.11	3.19	0.63	0.04
1A3biv	F_RoadTransport[36]	0.23	0.00	0.00	0.00
1A3c	I_Offroad	0.73	0.34	0.00	0.00
1A3di(i)	G_Shipping	19.87	22.82	19.45	19.23
1A3dii	G_Shipping	4.69	4.61	4.32	4.53

[36] Non-engine related PM emissions are attributed to a separate NFR sector which is not included in this study.

1A4ai	**C_OtherStationaryComb**	**2.48**	**1.55**	**0.72**	**0.00**
1A4bi	**C_OtherStationaryComb**	**5.15**	**1.65**	**0.93**	**0.08**
1A4ci	**C_OtherStationaryComb**	**3.57**	**4.80**	**2.77**	**1.82**

3.2.2 Scenario comparison

As a first evaluation of the emission data, the total NO_x, SO_x, and PM_{10} emissions of the 3 scenarios are compared for the 4 projection years. The results are given in Figure 14 to Figure 16. It must be noted that these totals cannot be compared directly to the nationally reported emission totals as only a subset of the sectors is taken into account in this study.

The comparison shows very little variation between the 3 scenarios: the Central scenario and the two sensitivity runs. In general, a steep decline is observed for NO_x and PM_{10}, between 2020 and 2030 with a more gentil decline afterwards. On the contrary, for SO_x a much more stable evolution is observed in the same period, but emissions are expected to decline afterwards toward 2050.

A more thorough analysis of the evolution of emissions and its correlation with the TIMES energy scenarios is performed in the next chapter.

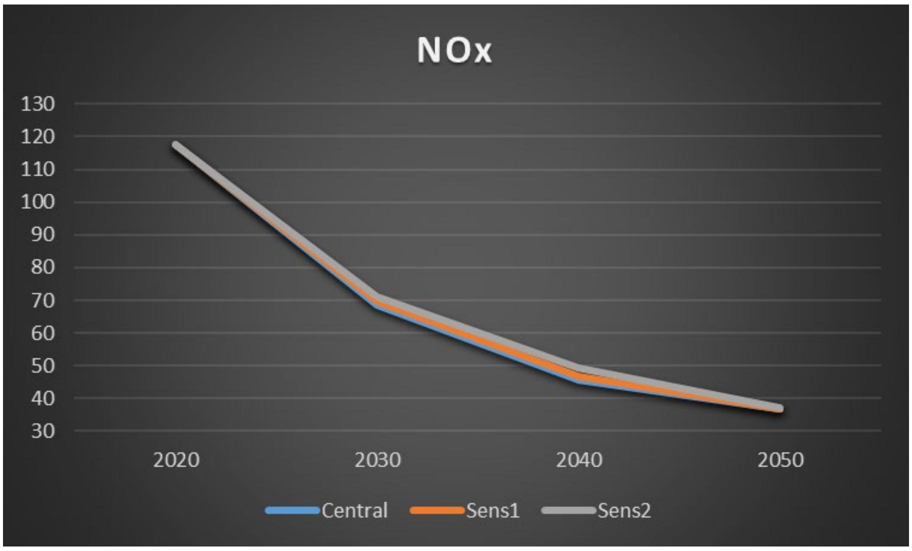


Figure 14: Total NO_x emissions in kTon in Belgium for the sectors in Table 7.

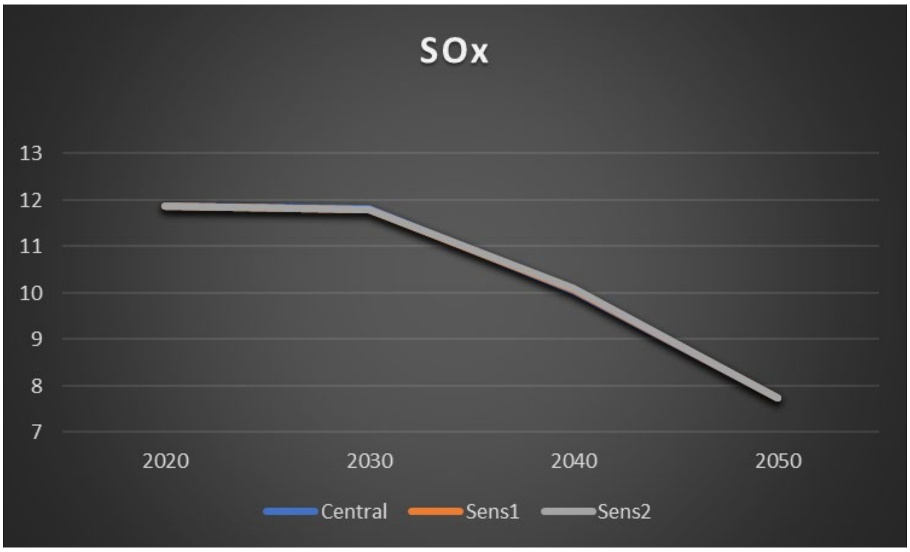


Figure 15: Total SO_x emissions in kTon in Belgium for the sectors in Table 7.

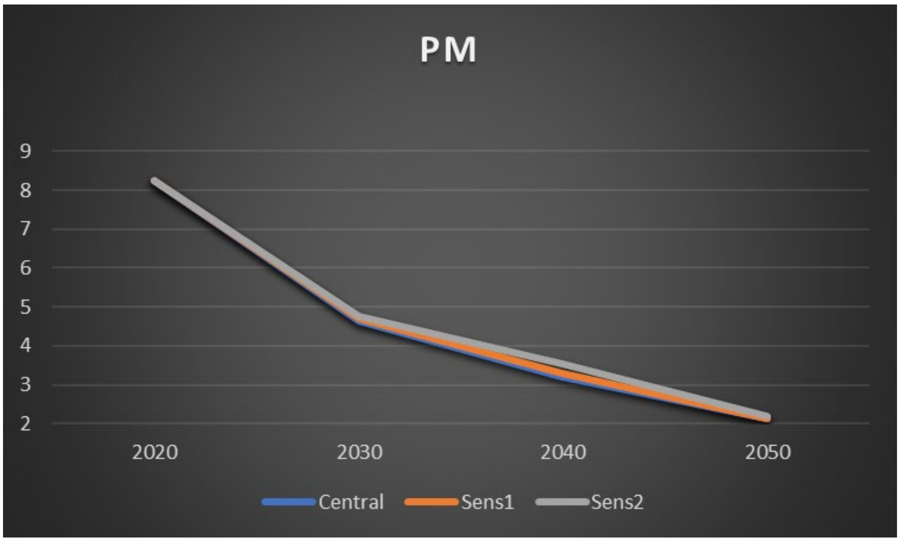


Figure 16: Total PM_{10} emissions in kTon in Belgium for the sectors in Table 7.

4 METHODOLOGY EVALUATION: COMPARATIVE EMISSION ANALYSIS

This chapter provides a detailed analysis of the emission results. In section 4.1, the findings from the current exercise are compared with those from a similar modeling study conducted with the GAINS modelling system in a European context. Although useful as a benchmark, it should be stressed that the GAINS approach comes with different underlying assumptions and modeling workflows. This comparison illustrates how integrated model design and workflow influence quantitative emission outcomes. It also highlights the inherent challenges of integrated modeling, particularly in sectors with significant uncertainties regarding future trajectories. Furthermore, the analysis demonstrates that incorporating a high level of technological detail —such as in the TIMES model— can enhance the reliability of emission estimates, leading to recommendations for future modeling exercises.

To reinforce the strength of our approach, this section concludes with two use cases: one comparing the calculated emissions with NECD limit values (section 4.2) and another with available Belgian projections (section 4.3). These examples suggest that the integrated approach could serve as a valuable tool for supporting future projections.

4.1 Detailed model analysis

This section provides a comparative analysis of sectoral emissions. The analysis focuses on the current model results comparted to the GAINS emission projections extending to 2050. This dataset is selected due to the availability in the required sectoral breakdown and its broad acceptance within the scientific community (cfr. Task Force on Integrated Assessment Modelling under the LRAP convention[37]). GAINS projections used in this work are based on baseline activity assumptions from the Second Clean Air Outlook, which relies on the 'EUCO 32 32.5' PRIMES scenario calibrated with national statistics up to 2015.

Delving into the comparison results shows the crucial role of methodological choices in shaping emission estimates. Each model is built on distinct assumptions regarding activity projections, technological developments, and policy impacts, which must be considered when interpreting the results. The current section focuses on two key aspects: (1) sectors and pollutants where strong alignment exists across the 2 models, and (2) cases where significant discrepancies arise, examining the underlying reasons for these differences. By structuring the analysis in this manner, we avoid going into a discussion on which prediction is the most reliable, rather we identify key factors that contribute to the consistency between models, and we provide critical insights into why discrepancies occur. This will support a more informed interpretation of emission modeling results and implications for future integrated modelling assessments.

The fact that there are historic data available for 2020, which is a scenario year in both our model and the GAINS model, puts us in a unique position to see how inventory emissions relate to emission projections. An LRTAP datapoint for 2020 is therefore included in the figures. Due to the inherent nature of projected emissions, discrepancies with inventory emissions are inevitable, and perfect correlation should not be expected. To support this exploration, a separate paragraph has been included to discuss the comparison with LRTAP emissions.

It is important to mention that the above datasets are not intended to serve as absolute benchmarks for emissions comparisons. Rather, their inclusion facilitates

[37] https://iiasa.ac.at/policy/applications/task-force-on-integrated-assessment-modelling-tfiam-under-lrtap-convention

an analysis that underscores the significant impact of model-specific assumptions on emission estimates in prognoses. The aim is to highlight the variations arising from differing methodologies and assumptions, not to achieve direct numerical alignment. In this context, it is important to point out that the PRIMES scenario is not a net-zero scenario, so the underlying goal of the scenario differs substantially which the one adopted in this study, will also be visible in the numerical results.

The same color code is used in the different graphs. The Central scenario developed in this study is shown in blue, the LRTAP data point is orange, and the GAINS scenario is shown with the grey line.

4.1.1 Causes for good correlation between emission results

This section explores the sectors and pollutants where the models exhibit strong agreement, highlighting the key drivers behind this consistency.

A notable example is the road transport sector, particularly passenger cars. There is a broad consensus regarding the future trajectory of this sector, which reduces uncertainty in projections and limits variation in the initial assumptions used across models. Furthermore, the availability and quality of datasets linking emission factors to the Belgian vehicle fleet are high, especially for NO_x emissions, which have been extensively studied and validated. This alignment is clearly illustrated in the figure below.

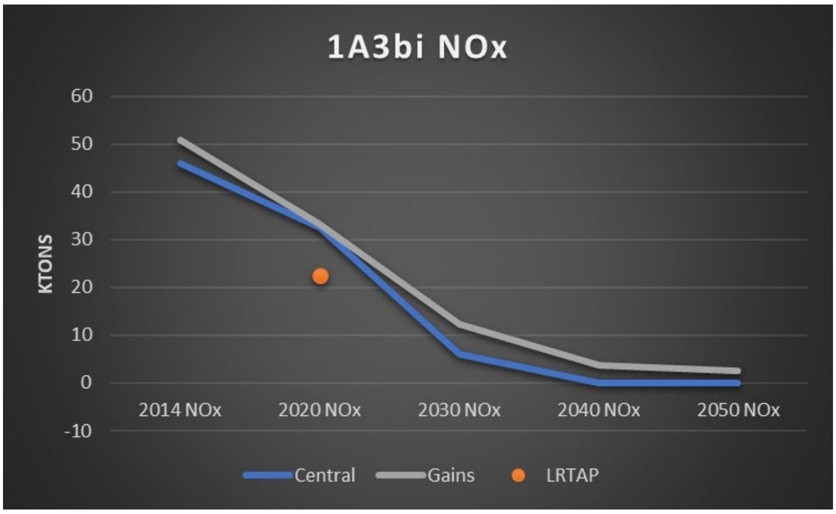


Figure 17: Comparison between the emission results in this study and the GAINS results, demonstrating good correlation for the road transport sector – passenger cars.

Another sector showing a reasonable degree of agreement is stationary combustion, particularly with respect to SO_x emissions, as shown in the accompanying figure. While the general trend toward cleaner fuels (gas instead of liquid and solid fuels) and increased electrification is consistent across models, the timing of this transition remains more uncertain. This illustrates how differences in model assumptions can translate directly into emissions outcomes.

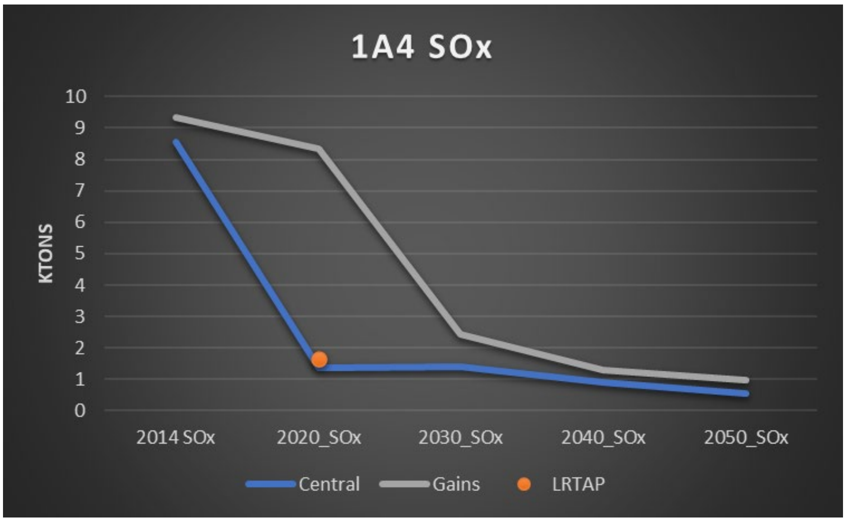


Figure 18: Comparison between the emission results in this study and the GAINS results, demonstrating fair correlation for the sector of stationary combustion.

4.1.2 Causes for bigger discrepancies between emission results

The analysis also reveals (sub)sectors where the modelling results diverge significantly. In this section a few examples are given and some of the reasons for these discrepancies are further explored.

Discrepancies between emission results from different models or studies can arise from several factors. Significant differences are often attributable to how total energy consumption is allocated across technologies and fuel types. A notable example is presented for the energy sector. Energy system models, such as TIMES, determine the most cost-effective technology mix for each scenario year, which can result in substantial year-to-year shifts in technology utilization or even the commissioning of new capacity within the energy sector. Since emission factors are typically differentiated by fuel type (e.g., gaseous, solid, biomass), changes in the fuel mix can strongly influence overall emission estimates. These methodological nuances, especially when projecting future scenarios, contribute to the observed divergence in Figure 19. In this context, the analysis indicates that incorporating a high level of technological detail —as done in the TIMES model— can play a valuable role in capturing such dynamics, thereby improving the robustness of emission projections.

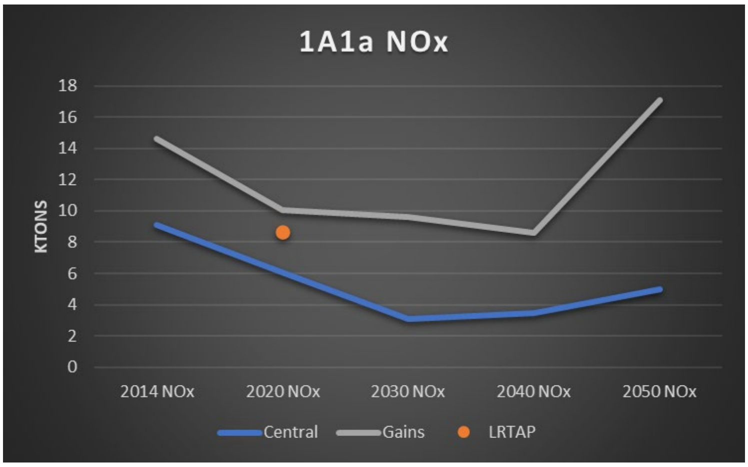


Figure 19: Comparison between the emission results in this study and the GAINS results for the energy sector.

The discrepancies observed in the refining sector cannot be explained by differences in the allocation of total energy consumption. Instead, a likely source of variation lies in the emission factor values applied. This is reflected in the differences shown in Figure 20. Given that Flanders hosts some of the most advanced refineries in Europe, the emission factors derived from inventory data (i.e., implied emission factors) tend to be lower than those used in the GAINS model, which are based on average European conditions. This regional specificity highlights the importance of context-sensitive emission factor selection in accurately estimating sectoral emissions.

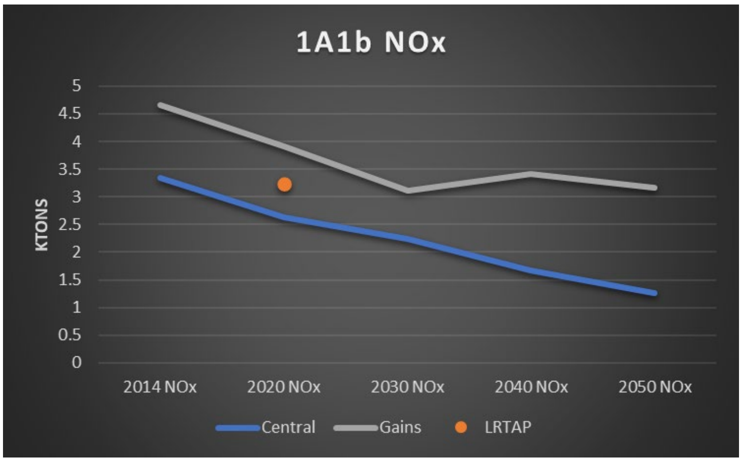


Figure 20: Comparison between the emission results in this study and the GAINS results, demonstrating the differences related to differing emission factor assumptions for the refining sector.

However, comparison of emission factors for technologies with a moderate level of abatement for the base-year (2014) gives quite good resemblance in the 1A2 sector (1A2: Stationary combustion in selected manufacturing industries[38]) and therefore does not account for the significant differences observed between the GAINS results and this study, as illustrated in the figure below. In this case, the discrepancies can be attributed to a combination of factors that vary across the different subsectors. This further highlights the importance of incorporating a high level of technological detail —at the subsectoral level— to adequately reflect the underlying dynamics and improve the accuracy of emission estimates.

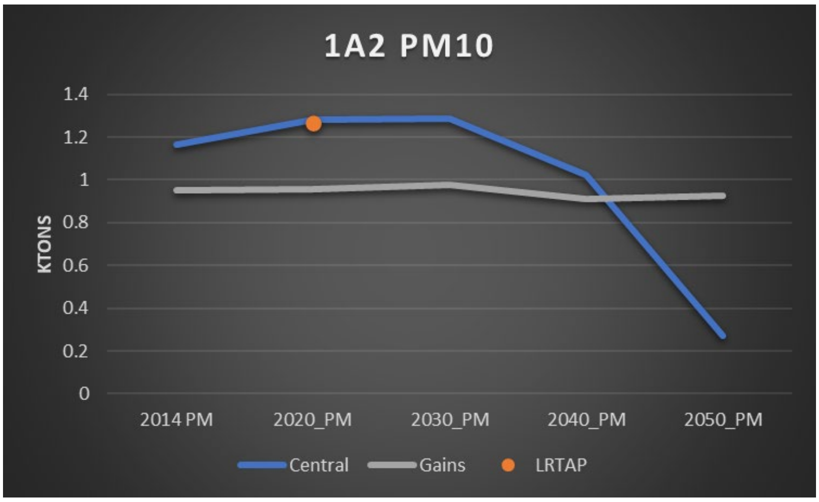


Figure 21: Comparison between the emission results in this study and the GAINS results for stationary combustion in the manufacturing industries.

[38] 1A2 is an aggregation of 1A2a=Iron and steel, 1A2b=Non-ferrous metals, 1A2c=Chemicals, 1A2d=Pulp, Paper and Print, 1A2e=Food processing, 1A2f=Non-metallic minerals, 1A2gviii=Other

4.1.3 LRTAP comparison

In most sectors, there is a non-negligible difference between model projections and LRTAP emissions in 2020. As the inventory emissions (LRTAP) are the best possible estimate of the actual emissions, this highlights the uncertainty which is inherent to making prognoses. A clear example of this uncertainty is the covid pandemic. 2020 is a covid year which is something that could not be estimated in 2014 and has huge effects on the actual emissions in 2020. This is nicely shown in Figure 17.

Nevertheless, often the trend from 2014 towards 2020 and the general order of magnitude in emissions are well-estimated. This means, when used correctly, integrated models can also be a valuable tool to develop scenario's and quantify integrated impacts.

When using the LRTAP emissions as an absolute benchmark, the proposed methodology —based on energy modelling and LRTAP emission factors— generally yields a better correlation for 2020 emissions than the GAINS estimates. This demonstrates the robustness of the proposed approach. However, the additional calibration step introduced in this study (see section 3.1 - Emission modelling Methodology) currently offers limited benefit across most sectors. This limited impact appears to stem from the siloed nature of climate and air inventory teams. It is likely that methodological discrepancies at the inventory level, where coordination between climate and air pollutant reporting remains limited, contribute to inconsistencies that reduce the effectiveness of the calibration process.

4.1.4 Conclusions

In the previous Chapter we developed a methodology that helps to "translate" energy modelling outputs to air pollutants emissions. In Chapter 4.1, we performed a methodological evaluation to benchmark the current methodology with GAINS and analysed general alignment of the projected trends. The outcome of this analysis reveals a large variation among the sectors. This is reflecting the complexity in some of these sectors and the associated parameters driving the projections towards 2050. It is clear that a robust assessment requires for a comprehensive understanding of all relevant factors such as: energy and fuel usage at sector levels, attribution of technologies to specific sectors, combustion/process emission distribution, operations of individual installations, pollution control methods, and the technology used in these installations. Comparing different models is challenging because they use different assumptions for different pollutants, leading to varied results, even within the same sector. It does not necessarily mean that one model is better than the other, but -as has been demonstrated- it is merely a reflection of the inputs and methods used.

Specifically, the GAINS model estimates activity data based on certain timeframes, policy perspectives, and defined priorities. It is based on the PRIMES activity data which is a partial equilibrium model. This makes it difficult to compare with rational optimization models like TIMES, which focus solely on costs without considering social acceptance or support. When comparing these models, historical data validation (like e.g. comparison with the LRTAP reporting) provides crucial insights, revealing significant differences from the outset of modelling exercises.

Important aspects that can explain the differences in modelling outcomes and might need further investigations, are:

- Alignment between TIMES least cost scenarios and effectively implemented policies;
- Disaggregation level of demonstrated base-year emission factors;

- Validity of the methodology using demonstrated emission factors which might decrease for longer time horizons;
- Consistency between different years in the LRTAP fuel use data used for emission factor calibration;
- Emission factor evolution due to autonomic improvement of technologies might be too optimistic.

Also, it makes sense to learn from sectors/pollutants where there is much less difference (f.e. transport sector).

Detailed information on individual installations, like energy use, age, technology type, fuel use or pollution control methods, is not always readily available which partially explains the large differences observed when comparing with GAINS results. It underscores the importance of local models like TIMES-BE. The current analysis also confirms that such integrated approaches should start with collaborative efforts between energy system and emission modelling experts to consider all relevant factors from the start and to keep this high level of detail throughout the modelling exercise.

4.2 NECD comparison

The National Emission Ceilings reduction Commitments Directive (NECD) sets targets for national totals of specific air pollutant emissions. Each EU Member State is assigned specific emission reduction targets for a range of pollutants namely fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOCs), and ammonia (NH_3). Member States are responsible for implementing measures to ensure that their total emissions of these pollutants do not exceed the prescribed emission targets.

The Belgian NECD reductions are given in Table 8. These correspond with an absolute emission limit for $PM_{2.5}$, SO_x, and NO_x of 27.8 kt, 81 kt, and 179.1 kt respectively for 2020 and 21.2 kt, 48.3 kt, and 124.4 kt respectively for 2030.

Table 8: Belgian NECD Emission reduction commitment as a reduction percentage compared to 2005 (taken from IRCELINE[39]).

Ceiling	NO_x	NMVOC	SO_x	NH_3	PM2.5
2020 – 2029	-41%	-21%	-43%	-2%	-20%
> 2030	-59%	-35%	-66%	-13%	-39%

The emission targets are set for specific years, and they apply to the overall emissions from a country, rather than for individual sectors. Assumptions are therefore required to compare the emission estimates of the present study with Belgium's NECD targets as the complete set of all emission sources is not modeled in this study.

A potential assumption could be that the proportion of emissions modeled in the current study, compared to the national total for Belgium, remains constant. However, it's important to acknowledge that this assumption comes with its own set of limitations. There may be sector-specific regulations, policies, and measures aimed at reducing emissions from particular sources such as industry, transport, agriculture, and residential heating. These sector-specific measures contribute to the overall goal of meeting the NECD targets and may change the relative contribution of the emissions modelled in this study. It is however the best assumption that can be made to arrive at an objective NECD comparison.

[39] Belgian Interregional Environment Agency

The relative contribution of the sectoral emissions modelled in the current study[40] to the national emission total for base year 2014 is given in Table 9 below and ranges between 50 and 75%. These proportions per pollutant are kept constant.

Table 9: Relative sectoral contribution of emissions included in the current study to the total Belgian emission for the year 2014.

Pollutant	NO_x	SO_x	PM10
Relative contribution	75%	55%	50%

When extrapolating the indicated proportion to the results of the Central scenario for year 2030, it can be concluded that all NECD targets are met for Belgium (see Table 10, notice that we only calculated PM_{10} while targets are only available for $PM_{2.5}$). This is in line with the official Belgian prognosis (corresponding to the WaM Belgium column). The same conclusions arise from the other 2 Sensitivity scenarios. It is essential to underscore that – as with all modelling exercises - the results reflect the input provided during the modelling exercise. A comprehensive understanding of the models and their assumptions is necessary to interpret the conclusions.

Table 10: Comparison of the Central scenario with Belgian NECD targets 2030 and With additional Measures (WaM) projections.

	NECD 2030 targets [kt]	Central [kt]	WaM Belgium [kt]
NO_x	124.4	91.11	106.46
SO_x	48.3	21.29	25.11
PM10	21.2	9.27	14.93

4.3 Comparison with official Belgian projections

The emission projections provided by Belgium on the IRCELINE website[41] offer a comprehensive insight into the levels of air pollutants that are expected to be emitted within the country over the next years. These projections are crucial for policymakers, environmental agencies, and stakeholders to understand the potential impacts of various factors such as economic activities, technological advancements, and regulatory measures on air quality.

In this section a comparison is made between the Central Scenario emission projections for 2030 and the official Belgian WaM (with additional measures) projections. The results are presented in Table 11. Sectors are grouped based on the level of detail provided by IRCELINE in the Belgian future estimates. A colour scaling is used to indicate the relative deviation between the official numbers: a green background indicates lower emissions in the Central scenario, a red(dish) background indicates higher emissions in the Central scenario. Based on these findings, a few remarks can be made:

- In general, there is a fair agreement between the estimated emissions of the selected sectors.
- For NO_x, the Central scenario seems to be predicting lower emissions compared to the BE-WaM scenario, except for emissions of passenger cars and light-duty vehicles.

[40] Sectors modelled in the current study can be found in *Table 3*
[41] https://www.irceline.be/en/emissions, consulted on 30/05/24

- The emissions of road transport (NO_x, SO_x and PM_{10}) for passenger cars and light duty vehicles are consistently higher in the Central scenario, than in the official Belgian projections.
- The SO_x emissions generally seem to be higher in the Central scenario.
- There is a strong underestimation of the PM_{10} emissions from residential heating (part of NFR sector 1A4) in the Central scenario. This is most likely caused by the emission factor evolution assumptions (taken over from 1A4ci, stationary combustion in agriculture/forestry/fishing) which might be too optimistic compared to local assumptions.

Table 11: Comparison of emissions from the Central scenario with Belgian WAM projections for 2030

NFR sector	NOx [kt]		SOx [kt]		PM10 [kt]	
	Central	BE-WAM	Central	BE-WAM	Central	BE-WAM
1A1	7.25	13.49	2.89	3.08	0.13	0.34
1A2	9.21	11.39	2.68	1.70	1.29	0.89
1A3a,c,d,e	7.20	8.18	0.13	0.23	0.27	0.44
1A3bi	6.14	3.96	0.05	0.01	0.44	0.36
1A3bii	4.87	2.79	0.01	0.00	0.17	0.07
1A3biii	3.19	4.23	0.03	0.02	0.24	0.25
1A4	7.99	15.26	1.39	1.22	0.92	5.96

5 AIR QUALITY

As a final step in this study, the emission projections derived in the previous phase can be translated into air pollution concentrations to assess the impact on air quality. The emission datasets developed based on the energy scenarios will be used as input to the SHERPA-QUARK atmospheric dispersion model. NO_2 is used as an example to illustrate this part of the methodology.

The SHERPA-QUARK model has already been applied for Concawe to develop the NO_2 Source Apportionment web application[42.] The model accounts for long-distance impacts of pollutant emissions by making use of the SHERPA source-receptor coefficients. To assess the local impact at high-resolution, the QUARK kernel method is applied.

To translate the emission projections into air pollutant concentrations, the following steps will be followed:

1. Sector pre-processing: For dispersion calculations emissions from all relevant sources are required. However, not all sectors are (entirely) covered by the energy scenarios. Therefore, a blend will be made between the emissions of the Central scenario and those of the 2nd Clean Air Outlook (CAO2) baseline scenario. Emissions of GNFR and NFR[43] sectors that are not available in the Central scenario will be taken from the CAO2 baseline.

   As presented in the previous chapters, the Central scenario only provides emissions for a selection of sectors in Belgium. For the air pollution dispersion modelling also emissions outside Belgium are needed. As for the missing Belgian NFR sectors, these are taken from the CAO2 baseline.

2. Spatial pre-processing: Spatially distributed emissions are needed for air pollution dispersion modelling. However, the emissions of the Central scenario do not provide spatial information, they only consist of national totals. Spatial information is available at the level of the GNFR sectors and can be taken from the CAMS[44] emission inventory of 2018[45]. For some sectors, the derived emissions of the Central scenario are available at the level of NFR sectors. At this NFR level though spatial distributions are not available. Therefore, the spatial distribution of the GNFR sector to which the NFR sector belongs will be used to spread the emission totals spatially.

3. Dispersion modelling: With this complete set of spatially distributed emissions the SHERPA model is run on each sector for each scenario-year combination. The results are air quality maps at a 0.1-by-0.1-degree resolution over Belgium with a contribution of each sector to the total NO2-concentration. For the traffic sector a high-resolution NO2-layer is added with the QUARK model to arrive at high-resolution NO2 maps revealing the high spatial gradients expected in the vicinity of major roads and highways.

Each of these steps will be further described in the following subsections.

[42] https://no2contribtool.concawe.eu/login
[43] (G)NFR: (General) Nomenclature For Reporting
[44] CAMS: Copernicus Atmosphere Monitoring Service, https://atmosphere.copernicus.eu/
[45] https://ads.atmosphere.copernicus.eu/cdsapp#!/search?type=dataset

5.1 Sectoral pre-processing

As described above, the emission projections for the Central energy scenario must be merged with the CAO2 emissions to arrive at a complete emissions data set covering all relevant sources. Table 12 gives an overview of how the emissions of the CAO2 baseline and the Central scenario are merged. If emissions of an NFR sector are available in the Central scenario, they are used; otherwise, the CAO2 emissions are used. The used information is marked in green in Table 12. The sectors Public Power, Aviation, Road Transport, Shipping and Other Stationary Combustion are provided entirely by the Central scenarios. The Industrial and Offroad sector (GNFR_B) are a mix of both sources. The shipping sector is a special case. The Central scenario provide inland and international shipping separately. However, no separate proxies for both shipping sectors are available in CAMS, only the combined sector. Therefore, the sum of inland and international shipping was distributed with the CAMS proxy. The agricultural sectors (GNFR_K, livestock and GNFR_L other) are included at GNFR level because they are not the focus of this study.

Table 12: Overview table of the merge between NFR sector emissions from the 2nd Clean Air Outlook baseline scenario and the current scenarios. The green fields mark the emissions used for air quality modelling.

NFR Sector	NFR CAO2	NFR Current study	GNFR
Public electricity and heat production	1A1a	1A1a	A_PublicPower
Petroleum refining	1A1b	1A1b	B_Industry
Manufacture of solid fuels and other energy industries		1A1c	B_Industry
Stationary combustion in industry Iron and steel	1A2a	1A2a	B_Industry
Stationary combustion in industry: Non-ferrous metals	1A2b	1A2b	B_Industry
Stationary combustion in industry: Chemicals	1A2c	1A2c	B_Industry
Stationary combustion in industry: Pulp, Paper and Print	1A2d	1A2d	B_Industry
Stationary combustion in industry: Food processing	1A2eg	1A2e	B_Industry
Stationary combustion in industry: Non-metallic minerals	1A2f	1A2f	B_Industry
Mobile combustion in manufacturing industries and construction	1A2gvii		I_Offroad
Stationary combustion in manufacturing industries and construction: Other		1A2gviii	B_Industry
Civil aviation LTO (international)	1A3a	1A3ai(i)	H_Aviation
Civil aviation LTO (domestic)		1A3aii(i)	H_Aviation
Road transport: Passenger cars	1A3bi	1A3bi	F_RoadTransport
Road transport: Light duty vehicles	1A3bii	1A3bii	F_RoadTransport
Road transport: Heavy duty vehicles and buses	1A3biii	1A3biii	F_RoadTransport
Road transport: Mopeds and motorcycles	1A3biv	1A3biv	F_RoadTransport
Railways	1A3c	1A3c	I_Offroad
International maritime navigation	1A3dii(+)	1A3di(i)	G_Shipping
National navigation (shipping)		1A3dii	G_Shipping
Commercial / institutional: Stationary	1A4ai	1A4ai	C_OtherStationaryComb
Residential: Stationary	1A4bi	1A4bi	C_OtherStationaryComb
Household and gardening (mobile)	1A4bii		I_Offroad
Agriculture/Forestry/Fishing: Stationary	1A4ci	1A4ci	C_OtherStationaryComb

Agriculture/Forestry/Fishing: Off-road vehicles and other machinery	1A4cii		I_Offroad
Other / mobile (including military / land based and recreational boats)	1A5b		I_Offroad
Oil: Refining / storage	1B2aiv		B_Industry
Nitric acid production	2B2		B_Industry
Iron and steel production	2C1		B_Industry
Pulp and paper industry	2H1		B_Industry
Dairy cattle Manure management	3B1a		K_Lifestock
Non-dairy cattle_Manure management	3B1b		K_Lifestock
Sheep Manure management	3B2		K_Lifestock
Swine Manure management	3B3		K_Lifestock
Horses Manure management	3B4e		K_Lifestock
Laying hens Manure management	3B4gi		K_Lifestock
Other poultry Manure management	3B4giv		K_Lifestock
Other animals Manure management	3B4h		K_Lifestock
Managed soils Direct and indirect emissions	3Dab		L_OtherAgriculture
Field burning of agricultural residues	3F		L_OtherAgriculture
Biological treatment of waste, Solid waste disposal on land	5A		L_OtherAgriculture
Other (included in national total)	6A		L_OtherAgriculture

5.2 Spatial pre-processing

In the previous section it is explained in detail how the total emission inventory, encompassing all relevant sources, is compiled based on the best available information in the context of this study. However, for practical reasons it has been deemed appropriate to further combine some sectors and reduce the total number of sectors in the analysis. Further, all the emission data must be translated into spatially explicit gridded layers. As mentioned before, the gridded patterns of the related GNFR sectors from CAMS are used for this purpose.

In Table 13 an overview is given of all 37 sectoral spatially explicit emission layers that are used in NO2 dispersion modelling. Notice that for each GNFR sector (except sectors K and L) there is also a layer with the emissions outside Belgium (nonBE). Depending on the modelling setup, these layers can also be used in a source apportionment analysis.

Table 13: 37 spatial emission layers used for NO2 dispersion modelling.

GNFR	NFR/nonBE	GNFR	NFR/nonBE
A_PublicPower	1A1a	F_RoadTransport	1A3bi
A_PublicPower	nonBE	F_RoadTransport	1A3bii
B_Industry	1A1b	F_RoadTransport	1A3biii
B_Industry	1A1c	F_RoadTransport	1A3biv
B_Industry	1A2a	F_RoadTransport	nonBE
B_Industry	1A2b	G_Shipping	BE
B_Industry	1A2c	G_Shipping	nonBE
B_Industry	1A2d	H_Aviation	1A3ai(i)
B_Industry	1A2e	H_Aviation	1A3aii(i)
B_Industry	1A2f	H_Aviation	nonBE
B_Industry	1A2gviii	I_Offroad	1A3c
B_Industry	1B2aiv	I_Offroad	1A4bii
B_Industry	2B2	I_Offroad	1A4cii
B_Industry	2C1	I_Offroad	1A5b
B_Industry	2H1	I_Offroad	nonBE
B_Industry	nonBE	K_AgriLivestock	all

C_OtherStationaryComb	1A4ai	L_AgriOther	all
C_OtherStationaryComb	1A4bi		
C_OtherStationaryComb	1A4ci		
C_OtherStationaryComb	nonBE		

5.3 Dispersion modelling

As a final step in this analysis, the emission data set is used as input for a SHERPA-QUARK dispersion modelling system to derive high-resolution NO_2 maps. A detailed description of this modelling chain can be found in Degraeuwe et al.[46] In short, the methodology is based on the following steps:

Step 1: Emissions at 0.1-by-0.1 degree for all scenario years

As explained above the NO_x emissions of each NFR sector are gridded at a resolution of 0.1-by-0.1 degree (the resolution of the SHERPA source-receptor model). For sectors not available in the Central, Sens1 and Sens2 scenarios, the emissions from the 2nd Clean Air Outlook (CAO2) baseline scenario are used. An emission data set is produced for each scenario-year combination.

Step 2: Calibration to the CAMS 2020 ensemble

The SHERPA model is applied to produce an NO_2 map for the year 2020. However, as for every air quality modelling result, it can be expected that some bias occurs in the result. The CAMS 2020 ensemble can be considered as the best available historical European NO_2 map, given the data assimilation procedures that are used to increase the quality of the map. Therefore, this CAMS data set is used for calibration of the SHERPA results. A calibration factor is derived for each grid cell by comparing the SHERPA output to the CAMS NO_2 ensemble for 2020. A map of these calibration factors (NO2_CAMS/NO2_SHERPA) is given in Figure 22. On average calibration factors range between 1.2 and 0.8 in most parts of the country. In some distinct areas calibration factors larger than 1.5 or smaller than 0.5 occur, indicating locations where SHERPA underpredicts or overpredicts the CAMS results, respectively. Figure 23 shows the histogram of the calibration factors for all cells in Belgium. The average calibration factor is 0.97 which means that on average SHERPA predicts the concentration well. The standard deviation is 0.2.

These calibration factors are derived for the year 2020 and will further on be applied to all the SHERPA results for all scenarios (Central, Sens1 and Sens2) and all years (2020, 2030, 2040, 2050) covered in this study. It is assumed that the calibration factors remain constant over time, but this is clearly an assumption.

[46] Bart Degraeuwe, Hans Hooyberghs, Stijn Janssen, Wouter Lefebvre, Bino Maiheu, Athanasios Megaritis, Marlies Vanhulsel, A source apportionment and air quality planning methodology for NO2 pollution from traffic and other sources, Environmental Modelling & Software, Volume 176, 2024, https://doi.org/10.1016/j.envsoft.2024.106032

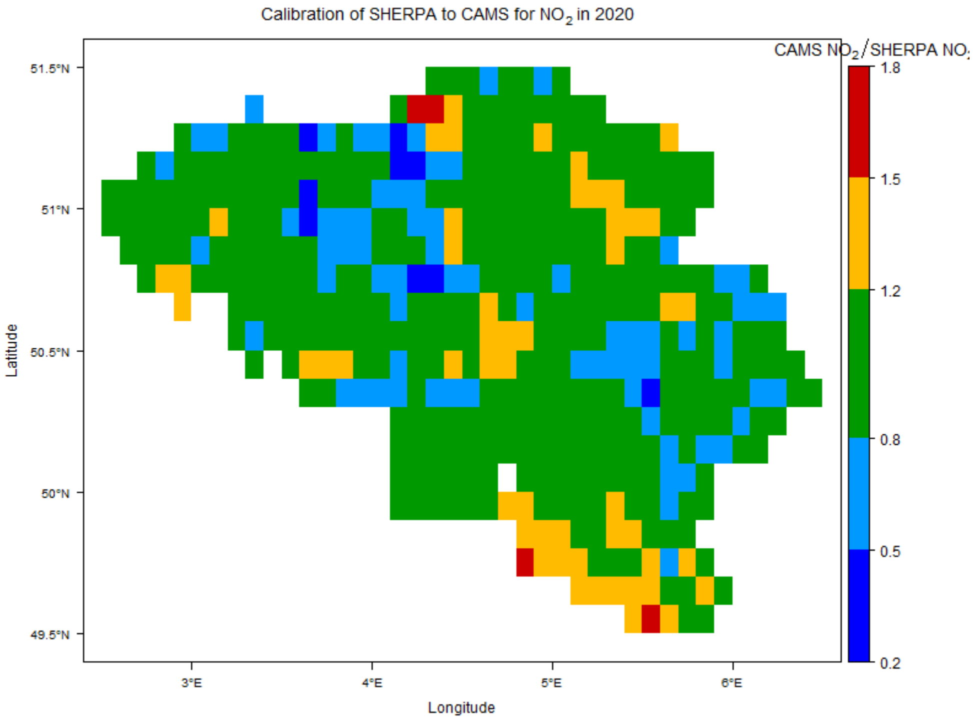


Figure 22: Spatially explicit calibration factors between SHERPA and the CAMS ensemble for 2020 (CAMS_NO2/SHERA_NO2).

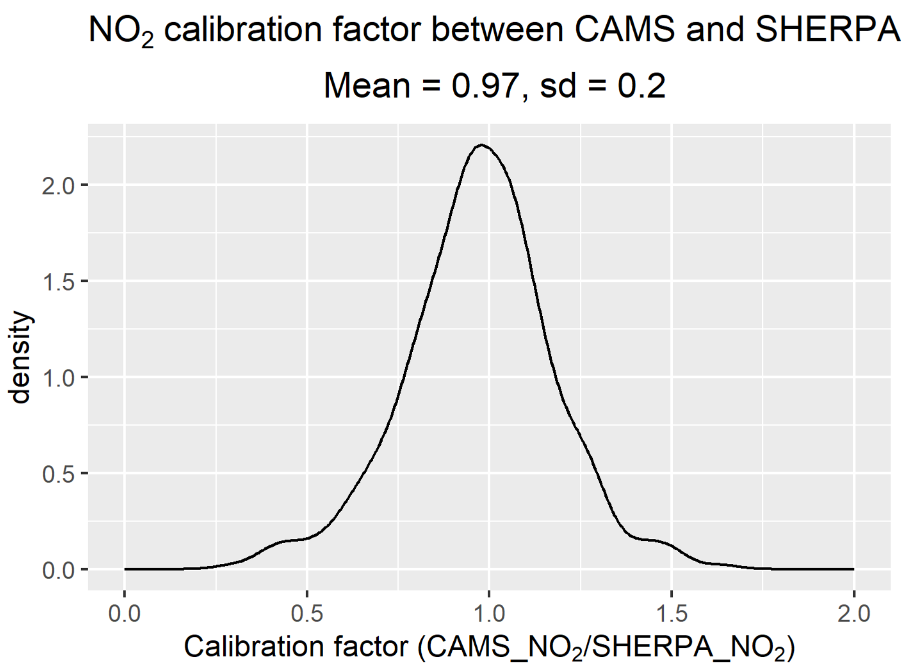


Figure 23: Histogram of the calibration factors between SHERPA and the CAMS ensemble for 2020. A calibration factor for each cell in Belgium is derived.

Step 3: Calibrated SHERPA runs for all scenario-year combinations.

The SHERPA model is applied to the emissions of each scenario-year combination. The result is an NO_2 concentration map at a resolution of 0.1-by-0.1 degree. This map is multiplied cell-by-cell with the calibration factor derived in the previous step. The output of this procedure for the central scenario for the year 2030 is given in Figure 24.

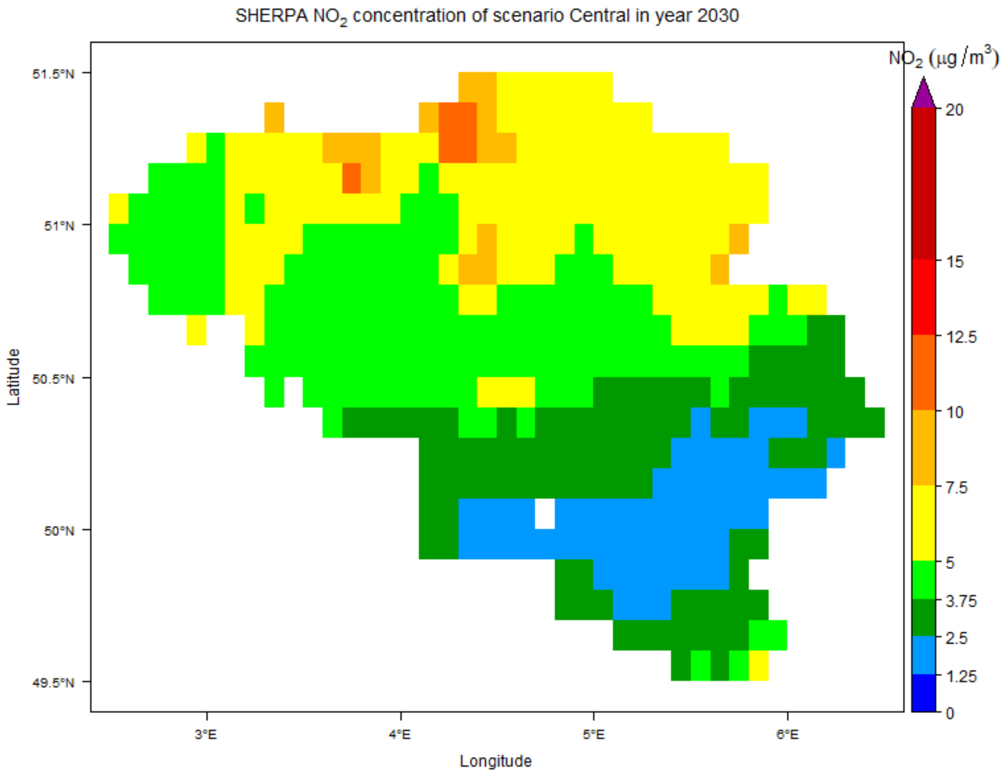


Figure 24: SHERPA NO_2 map for the Central scenario in 2030

.

Step 4: Addition of the high-resolution road transport NO_x

It is well known that NO_2 concentrations in the vicinity of major roads vary significantly. To account for these high spatial gradients, the contribution of the road transport sector is calculated at high spatial resolution (0.001-by-0.002 degree) with the QUARK kernel method giving rise to a high-resolution NO_x concentration map. Because the traffic sector is already considered at low resolution in the SHERPA model a double counting correction has to be applied before the two modelling results can be merged. From the high-resolution map a moving average of the size of the kernel (4-by-4 km) is subtracted so that the net addition is zero. This avoids double counting of the traffic contribution.

The high-resolution NO_x map can then be added to the calibrated low-resolution NO_2 map from SHERPA. Therefore, the NO_2 map from SHERPA is converted to NO_x with the inverse Bächlin correlation. The Bächlin correlation is an empirical relation between annual average NO_2 and NO_x concentrations. After addition of the high-resolution component, the result is converted back to NO_2 with the regular Bächlin correlation. The final result is given in Figure 25 and can be compared to the low-resolution counterpart in Figure 24. A complete explanation of this procedure can be found in Degraeuwe et al. (2024)[47].

[47] Degraeuwe, B., Hooyberghs, H., Janssen, S., Lefebvre, W., Maiheu, B., Megaritis, A., & Vanhulsel, M. (2024). A source apportionment and air quality planning methodology for NO2 pollution from traffic and other sources. Environmental Modelling and Software, 176. https://doi.org/10.1016/j.envsoft.2024.106032

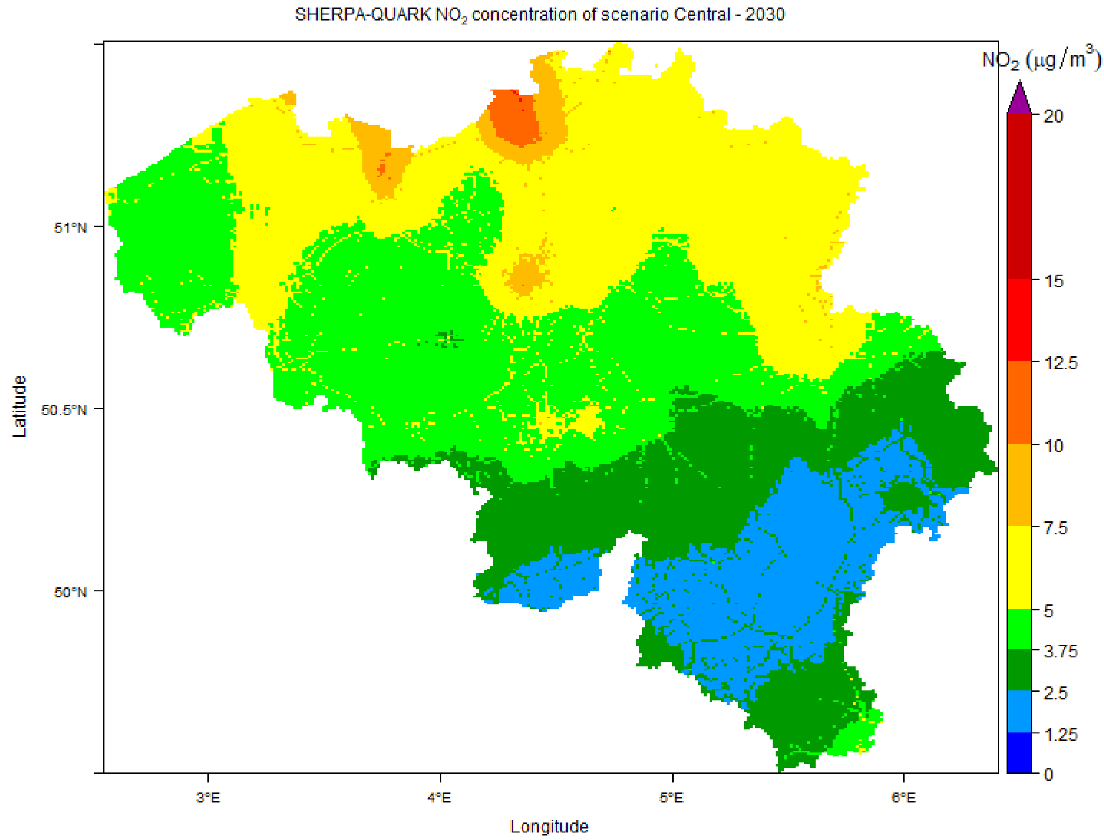


Figure 25: SHERPA-QUARK NO_2 concentration map for the Central scenario in 2030.

5.4 Analysis and benchmarking

In this final section, the output of the SHERPA-QUARK modelling system is further analysed and benchmarked with legal targets and other data sets.

A first analysis is given in Figure 26 which contains the high-resolution air quality maps for the three scenarios developed in this study. It can be observed that the differences in terms of NO_2 concentration are small. This is in line with earlier findings based on emission data.

A similar but more detailed analysis is given in Figure 27. This graph shows the source apportionment of the population averaged NO_2 concentration over Belgium for the three scenarios from 2020 to 2050. For this purpose, the total NO_2 concentration in each cell is multiplied by the share of the Belgian population living in the cell. This gives rise to an NO_2 exposure indicator. To produce a source apportionment analysis, this procedure is repeated for each of the sectors retained in the SHERPA analysis as mentioned in section 5.2. Based on this source apportionment exposure graph, it can be concluded that the main driver for the anticipated reduction in population NO_2 exposure is the road transport sector. The contribution of this sector is expected to be reduced significantly between 2020 and 2030. The contributions from the power sector slightly decrease towards 2050 whereas the industrial sectors remain constant, and shipping and aviation even increase over this period.

Over the 2020–2050 time horizon the difference between the Central, Sens1 and Sens2 scenarios is small.

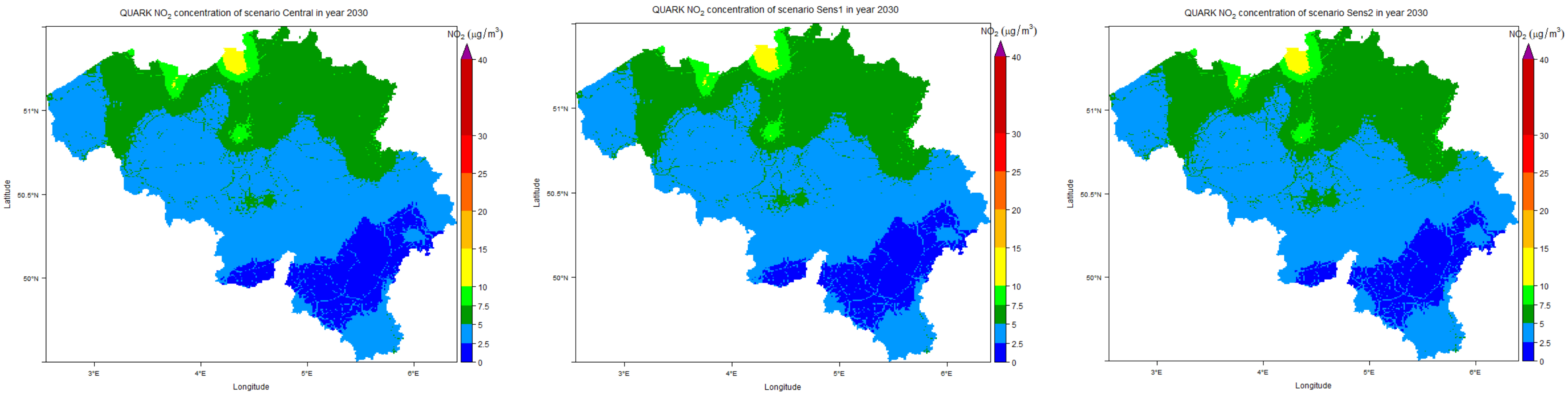


Figure 26: SHERPA-QUARK NO2 map (in µg/m³) for the Central scenario (left), Sens1 scenario (middle) and Sens2 scenario (right) in 2030.

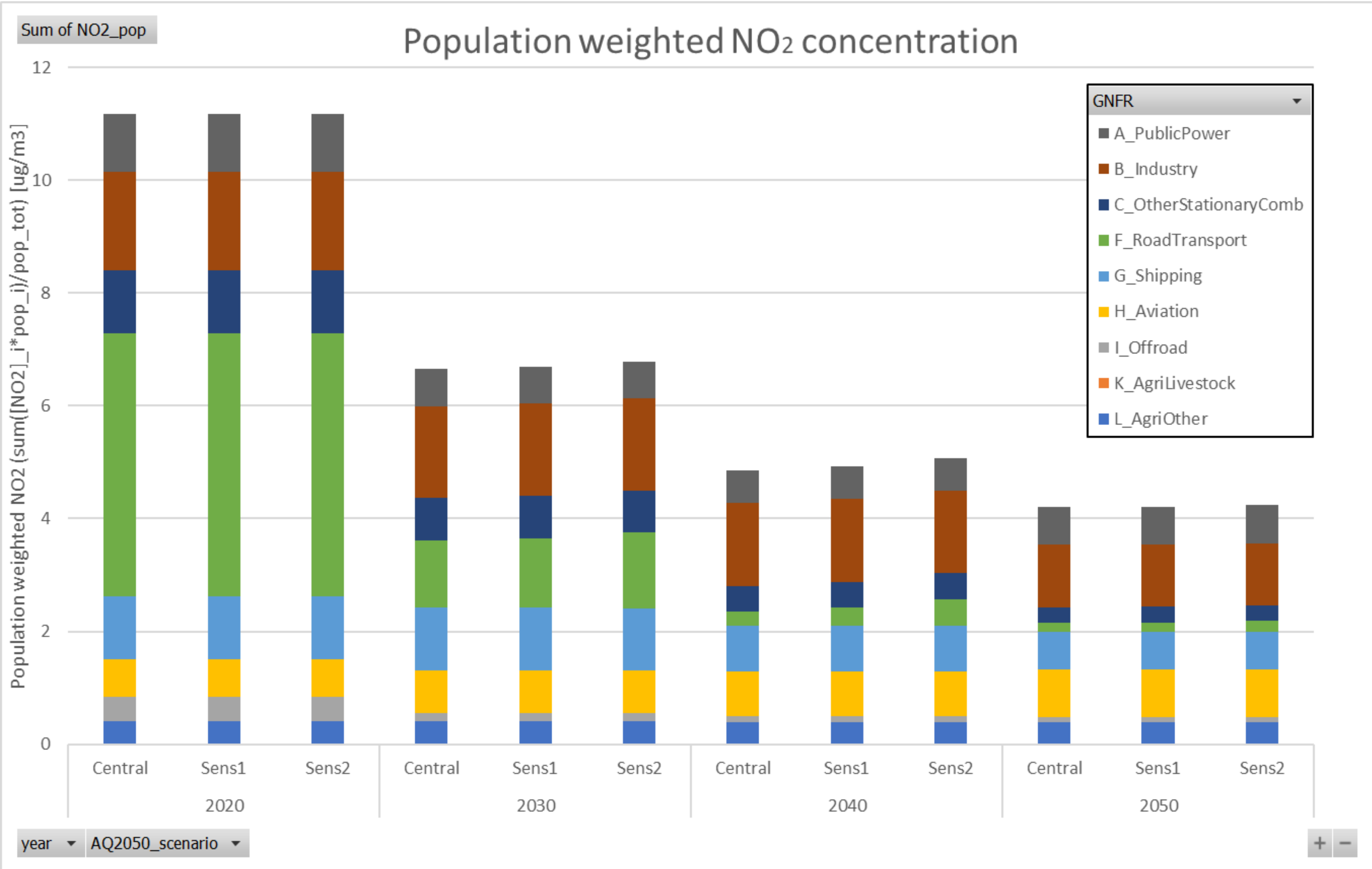


Figure 27: Source apportionment of the population weighted NO_2 concentrations over Belgium for the 3 current scenarios from 2020 to 2050.

In addition to an intercomparison of the scenarios developed within this study, the results can also be benchmarked with European air quality data sets. Therefore, a comparison can be made with the CAO2 baseline air quality map. For this purpose, the CAO2 map is derived with the same SHERPA-QUARK modelling systems as described above. Use is made of the original CAO2 baseline emission data set which was already processed to complement the missing emissions in section 5.1 and section 5.2.

The comparison between the central scenario and the CAO2 baseline scenario for the year 2050 is given in Figure 28. Overall, it can be concluded that the CAO2 NO_2 concentrations are higher than the projections of this study. This is in line with earlier findings based on the emission data sets. More in particular, it can be observed that in 2050 the road transport contribution almost vanishes in the scenario(s) because road transport emissions almost drop to zero. In the CAO2 baseline a traffic contribution is still visible around major roads because the road transport emissions remain around 10 kton in 2040 and 2050. This is made clear in

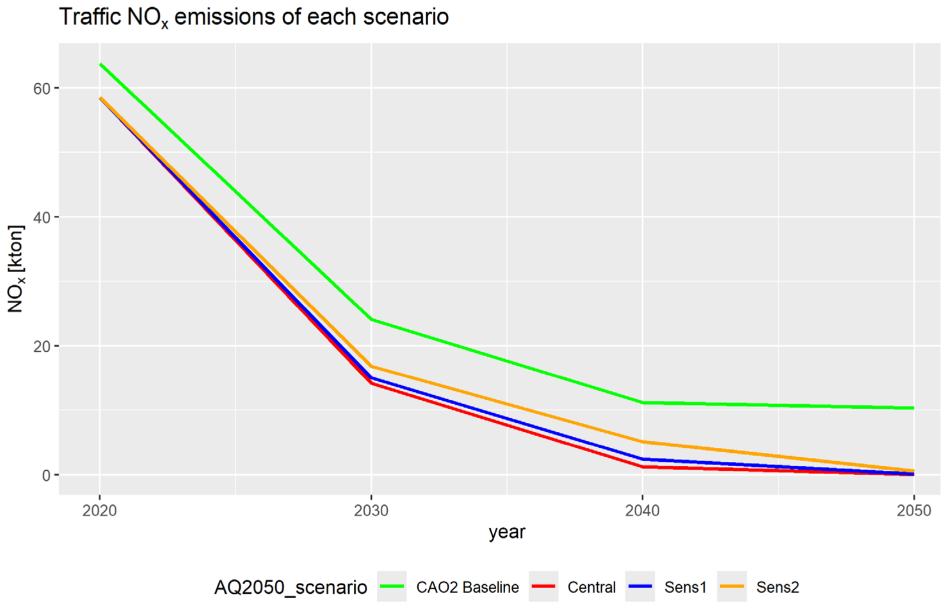


Figure 29: Traffic NO_x emissions in Belgium for the 2nd Clean Air Outlook baseline and the three current scenarios (Central, Sens1 and Sens2).

Figure 29 which presents an evolution of the NO_X traffic emission for this study and the CAO2 baseline scenarios between 2020 and 2050. Other sectors (Industry, Shipping and Aviation) become more important in relative terms as is illustrated by Figure 27.

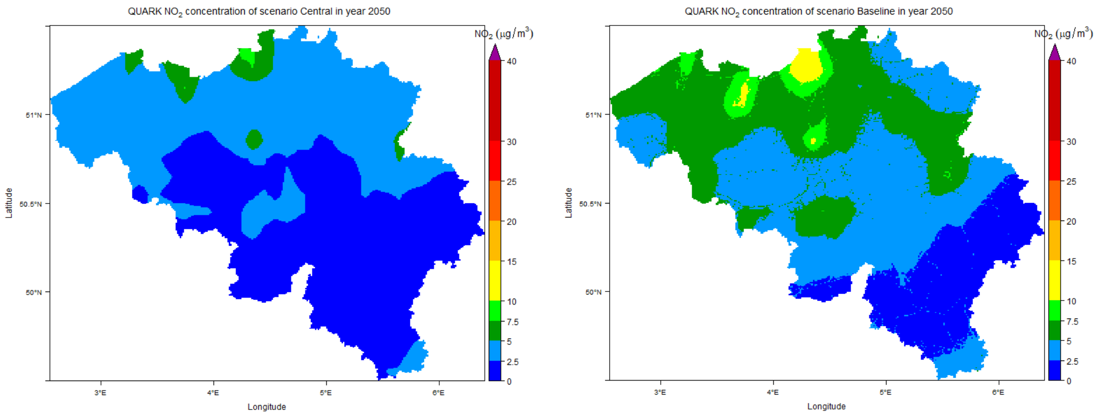


Figure 28: SHERPA-QUARK NO_2 map for the Central scenario (left) and the 2nd Clean Air Outlook baseline scenario in 2050.

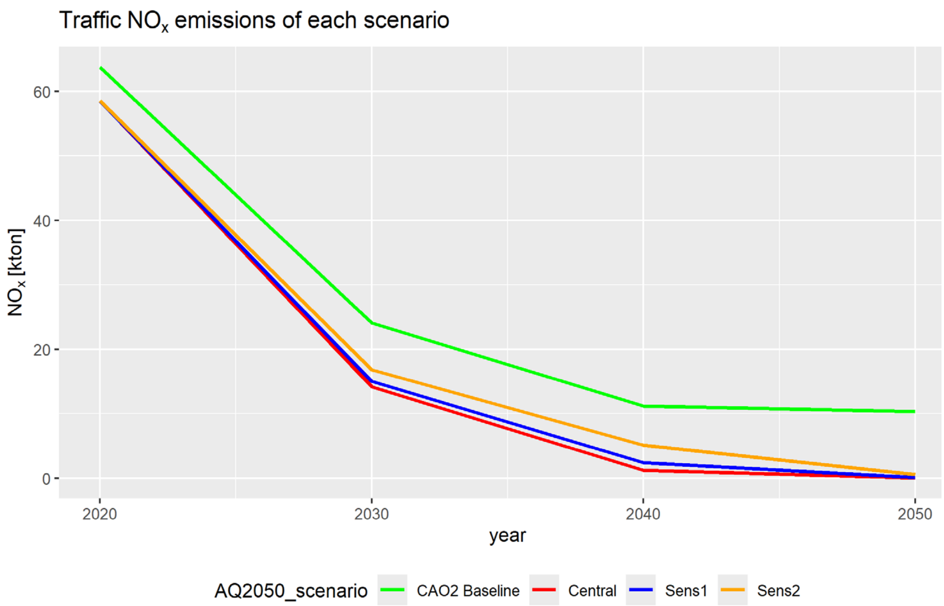


Figure 29: Traffic NO_x emissions in Belgium for the 2nd Clean Air Outlook baseline and the three current scenarios (Central, Sens1 and Sens2).

As a final benchmark, the results of the SHERPA-QUARK dispersion modelling are compared to the European standards set by the AAQD. Figure 30 and Table 14 show the NO_2 concentration distribution in 114 measurement stations in Belgium for the time horizon 2020 - 2050. The number and share of stations with a concentration within 10 µg/m^3 bins is shown. The NO_2 concentrations at station locations are obtained by interpolation in the high-resolution SHERPA-QUARK maps, corrected with the relative bias between measurements and observations in 2018. The average correction factor is 1.12, 1.19 and 1.73 in background, industrial and traffic stations, respectively. Especially in traffic stations the correction factor is higher because the SHERPA-QUARK model does not consider street canyons.

As observed before, NO_2 concentrations of the CAO2 baseline scenario are higher than our projections. This can be partly explained by the higher NO_X emissions of the transport sector, as explained in **Error! Reference source not found.**. In general, there is little difference between the Central, Sens1 and Sens2 scenarios.

From 2030 onwards, the European revised AAQD is setting an annual mean limit value for NO_2 at 20 µg/m³. Based on the model simulations it is expected that this target will not be met in 2030 in all Belgian monitoring stations. All scenarios estimate a few stations above this limit value: 20 % in the CAO2 Baseline, 5 % in the Central and Sens1, and 6% in the Sens2 (see Figure 30 and Table 14). No exceedances are predicted by 2040 under current projections.

The WHO has set a guideline value for annual mean NO_2 at 10 µg/m³. This guideline value is more ambitious than the European AAQD limit value and is developed based on health impact studies. In none of the model simulation and related scenarios the objective of this WHO guideline is fully attained. Up to 2050, it is expected that NO_2 concentrations will exceed the 10 µg/m³ guideline value in several stations, irrespective of the modelling system (GAINS/SHEPRA-QUARK) or the future scenario (CAO2/current study). Under the CAO2 Baseline scenario, it is expected that 60% of the monitoring stations will not be compliant by 2050, versus 8% under current projections.

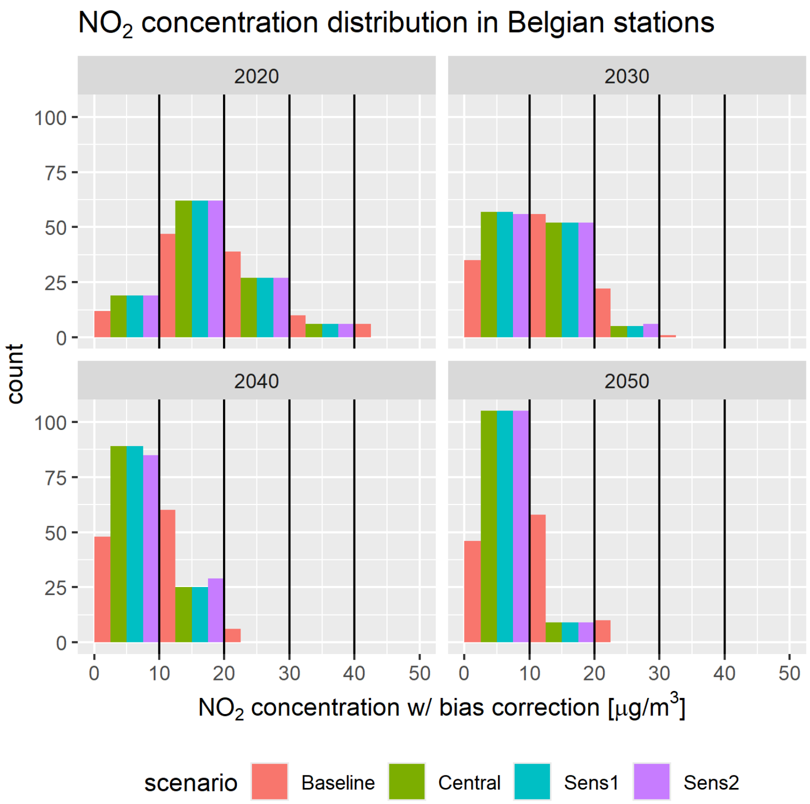


Figure 30: NO_2 concentration distribution in 114 air quality measurement stations in Belgium for the CAO2 baseline scenario and the three current scenarios.

Table 14: NO_2 concentration distribution in 114 air quality measurement stations in Belgium for the CAO2 baseline scenario and the three current scenarios

	NO_2 concentration interval				
2020	**[0,10)**	**[10,20)**	**[20,30)**	**[30,40)**	**[40,50)**
Baseline	12 (11%)	47 (41%)	39 (34%)	10 (9%)	6 (5%)
Central	19 (17%)	62 (54%)	27 (24%)	6 (5%)	
Sens1	19 (17%)	62 (54%)	27 (24%)	6 (5%)	
Sens2	19 (17%)	62 (54%)	27 (24%)	6 (5%)	
2030					

Baseline	35 (31%)	56 (49%)	22 (19%)	1 (1%)	
Central	57 (50%)	52 (46%)	5 (4%)		
Sens1	57 (50%)	52 (46%)	5 (4%)		
Sens2	56 (49%)	52 (46%)	6 (5%)		
2040					
Baseline	48 (42%)	60 (53%)	6 (5%)		
Central	89 (78%)	25 (22%)			
Sens1	89 (78%)	25 (22%)			
Sens2	85 (75%)	29 (25%)			
2050					
Baseline	46 (40%)	58 (51%)	10 (9%)		
Central	105 (92%)	9 (8%)			
Sens1	105 (92%)	9 (8%)			
Sens2	105 (92%)	9 (8%)			

6 KEY CONCLUSIONS

The objective of this study was to analyse the effect of 2050 Net-Zero pathways in the Belgian energy system on the emissions and concentrations of a set of relevant air pollutants. The underlying ambition of the exercise was to perform the analysis in a fully integrated way and to analyse the strengths and weaknesses of such an approach, to better understand the data requirements in terms sector granularity, technology details, fuel split, process and activity data, etc. By benchmarking the results of illustrative modelling cases to existing data sets in the energy, emission, or air pollution domain some lessons learnt could be formulated. Further, Belgium was selected as a test case since various detailed policy data sets are available for each of the intermediate phases, although there was no guarantee that each of the policy data sets was obtained in an integrated and holistic way.

To tackle the objective of the study, an integrated modelling system is set up. The TIMES energy model is combined with a specifically designed emission model and the SHERPA-QUARK dispersion model. The modelling chain was used to make detailed projections for various policy options in the energy system and translate the output into the relevant emission data and related air pollutant concentrations in the atmosphere. The modelling chain was capable to make projections between the base year 2014 and 2050.

The basic assumptions for the energy modelling are the result of an interactive discussion between Concawe and VITO resulting in a final set of 3 net-zero scenarios that were agreed upon in the early project phases. In line with the Concawe ambitions, the TIMES central scenario for Belgium is adapted to include the following elements:

- Starting from 2030, the transport sector is required to adhere to the updated Renewable Energy Directive (issued in October 2023). This mandates a minimum of 29% renewable energy consumption across all transport sectors. This calculation also considers a set of multipliers specific to each fuel and sector.
- From 2025 onwards, the aviation sector, in line with ReFuelEU Aviation, is required to consume a minimum amount of Sustainable Aviation Fuels (SAF). The goal is to reach a minimum SAF mandate of 70% by 2050.
- Beginning in 2030, in accordance with FuelEU Maritime, the maritime transport sector is required to gradually reduce the carbon emission intensity of its fuels, aiming for an 80% reduction by 2050.

To link the output of the energy system modelling to emissions, a specific emission model was setup during this study. During the development of this emission model, some key features were considered:

- The emission model should be aligned as much as possible to the output of the energy model, both in terms of sectors, technologies and fuels used.
- The methodology should be based as much as possible on the existing methodologies used to derive the Belgian air pollutant emission projections.
- The emission factors should be in line with the current set of emission factors used by Belgian policy makers.
- Assumptions in the methodology should be aligned and validated as much as possible with relevant industrial partners and sector federations.

For the final step in the analysis, the well validated SHERPA-QUARK dispersion model was selected that is capable to translate (future) emissions into atmospheric concentrations for the whole Belgian territory. By its setup the modelling chain is able to resolve the fine scale gradients that occur in the vicinity of major emission sources such as industry or major roads.

The integrated modelling systems is used to derive a central scenario accompanied by two sensitivity scenarios. These projections are used as illustrative test cases for a potential 2050 future situation. A benchmark with existing Belgian and European data sets at all available stages was performed. For some sectors, there is a strong alignment between the various projections. This demonstrates the solid understanding of the particular sector and its expected evaluation towards 2050. For other sectors, discrepancies were observed between the illustrative cases developed in this study and e.g. the results of the GAINS system. In most cases, these differences could be explained and traced back to underlying deviations in assumptions or data sets used. Factors contributing to these differences include:

- Alignment between TIMES energy scenarios and actual European policies embedded in PRIMES/GAINS
- Disaggregation level of the base-year emission factors
- Validity of the methodology to develop future emission factors
- Consistency of LRTAP fuel use data
- Over-optimistic assumptions about technological improvements

The analysis emphasizes the need for detailed, regional-scale data on installations, covering energy use, technology, fuel, and pollution controls. The lack of such data in generic European modelling systems partly explains the differences seen with GAINS results, highlighting the importance of local models like TIMES-BE. It also stresses the need for collaboration between energy system and emissions modelling experts, maintaining detailed consideration throughout the process.

The illustrative projections of the integrated modelling system were benchmarked with the NetZero, NECD and AAQD ambitions set at Belgian and European level for 2030 and 2050. While these types of long-term projections are subject to significant uncertainties, it could be demonstrated, assuming a Net-Zero scenario for the Belgian energy system from 2050 onwards, that the NECD targets for Belgian emissions can be met in 2030 and that the AAQD limit values set for NO_2 in 2030 could be reached in most but not all the monitoring stations. The WHO guideline value of 10 µg/m³ for NO_2 can currently not be realised in Belgium.

Little variation is observed between the Central scenarios and the two sensitivity tests developed in the context of this project. Main reason is the focus of the sensitivity scenarios on the road transport sector. The contribution of this sector to the air pollution is expected to become very limited in the time frame 2030 – 2050.

From a methodological perspective, the current project in essence seeks to explore and enhance the consistency and alignment between the energy and air quality modelling methodologies and assumptions. The broad spectrum of results obtained in this modelling exercise highlights the importance of integrated approaches. This should commence with joint efforts between energy system, emission and air quality modelling to identify, consider and agree on the relevant factors in the entire chain from the initial stages. The analysis further shows the impact of the level of information detail on the results and underscores the necessity for granular information on individual (or cluster of) installations, covering their energy use, age, type of technology, fuel, and pollution control methods, for both current and future projections. Such data is often not readily accessible. This has hampered the development of a fully integrated approach and the alignment of a robust interface between the energy and emission modelling system.

Our findings also emphasize the importance of local information, as exemplified by the TIMES-BE model, which integrates detailed local data effectively. In contrast, while the GAINS model performs well at the EU level, its applicability to the Belgian context reveals significant differences, most likely due to the lack of detailed local information. Addressing these gaps is crucial for achieving more accurate and reliable air quality projections at local level. Furthermore, it is essential that all detailed local information is retained throughout the entire modelling chain (for instance, as metadata) to ensure its availability for use in the final stages of air quality modelling.

In a follow up study, the energy – emission interface could be further refined taking into account even more detailed and granular information from individual sectors and (clusters of) installations to refine the expected fuel mixes, the potential abatement technologies and the penetration and environmental impact of completely new technologies. Such an approach would give further insights in the potential of specific industries and sectors to reduce their environmental impact during the energy transition. Additionally, the air quality analysis could be extended to PM_{10} and SO_2 concentrations.

7 GLOSSARY

Abbreviation	*Full Meaning*
AAQD	Ambient Air Quality Directive
AQ	Air Quality
BEV	Battery Electric Vehicle
CAMS	Copernicus Atmosphere Monitoring Service
CAO	Clean Air Outlook
CRF	Common Reporting Format
EF	Emission Factor
ETSAP	Energy Technology Systems Analysis Program
GHG	Greenhouse Gas
GNFR	Gridded Nomenclature For Reporting
GAINS	Greenhouse gas - Air pollution Interactions and Synergies
IEA	International Energy Agency
ICE	Internal Combustion Engine
LCP	Large Combustion Plant
LDV	Light Duty Vehicle
LRTAP	Long-Range Transboundary Air Pollution
LTO	Landing and Take Off
LTS	Long-Term Strategy
NA	Not Available
NECD	National Emission reduction Commitments Directive
NECP	National Energy and Climate Plan
NFR	Nomenclature For Reporting

PJ	Petajoule
RED	Renewable Energy Directive
RFNBO	Renewable Fuels of Non-Biological Origin
TIMES	The Integrated MARKAL-EFOM Model
TML	Transport & Mobility Leuven
TWh	Terawatt Hour
TYNDP	Ten-Year Network Development Plan
VOC	Volatile Organic Compound
WAM	With Additional Measures

8 APPENDIX 1: FUELS IMPORT PRICES AND RENEWABLES AVAILABILITY

Table 15: Energy commodity price projections in TIMES-BE (for imports and exports).

Commodity	Unit	2018	2025	2030	2040	2050	Source
Natural Gas	€/MWh	27.16	72.15	38.52	34.99	34.99	World Energy Outlook 2022[48]
Coal	€/MWh	13.61	23.05	11.20	11.20	11.52	World Energy Outlook 2022
Crude Oil	€/MWh	35.76	31.32	31.68	30.24	28.80	World Energy Outlook 2022
LPG	€/MWh	73.56	43.81	44.32	42.30	40.28	Historical + driver: Crude Oil
Gasoline	€/MWh	43.24	38.38	38.81	37.04	35.28	Historical + driver: Crude Oil
Kerosene	€/MWh	78.96	51.98	52.56	50.18	47.81	Historical + driver: Crude Oil
Naphtha	€/MWh	25.88	33.84	34.24	32.65	31.10	Historical + driver: Crude Oil
Diesel	€/MWh	43.78	40.61	41.08	39.24	37.37	Historical + driver: Crude Oil
Fuel oil	€/MWh	25.88	22.86	23.15	22.07	21.02	Historical + driver: Crude Oil
Oven coke	€/MWh	30.00	30.00	30.00	30.00	30.00	Historical + constant
Biomass	€/MWh	16.20	16.92	16.92	18.00	18.00	IEA Bioenergy
Biodiesel	€/MWh	77.80	96.60	-	-	-	Fixed spread with fossil eq.[49]
Renewable diesel	€/MWh	-	-	117.4	115.6	113.8	Fixed spread with fossil eq.[50]
Bioethanol	€/MWh	128.5	117.3	-	-	-	Fixed spread with fossil equivalent
Ren. gasoline	€/MWh	-	-	149.3	147.6	145.8	Fixed spread with fossil equivalent
Electricity	€/MWh	61.9	89.1	102.2	104.7	91.6	TYNDP2020 + I-E methodology[51]

[48] Takes into account the current energy prices after the Russia-Ukraine conflict, inflation and post-COVID economic impact.
[49] The spread between biofuel and fossil equivalent is fixed until 2025 (this is valid for both biodiesel and bioethanol).
[50] From 2030, the assumption is that primarily advanced biofuels will be used, due to the entering into force of REDIII; because of this, the spread is increased by an additional 40% (this is valid for both renewable diesel and gasoline).
[51] For the import and export electricity prices, an external dispatch model has been used, with inputs coming from ENTSO-E's TYNDP2020. From there, import-export price-quantity curves have been derived. Therefore, what is shown above is only a yearly average. See https://perspective2050.energyville.be/sites/energyoutlook/files/inline-files/Full-Fledged%20Report_1.pdf for more information.

Hydrogen	€/MWh	176.4	123.4	96.91	87.84	78.77	H2 Import Coalition (green H_2)[52]

Table 16: Maximum availability of selected resources in TIMES-BE.

Commodity	Unit	2020	2025	2030	2040	2050	Source
Biomass	PJ/y	60.06	73.99	87.92	92.95	97.97	Concawe, Imperial College[53]
MSW (Municipal Solid Waste)	PJ/y	13.20	13.20	13.20	13.20	13.20	Eurostat average
District Heating	PJ/y	4.34	18.73	33.12	64.34	86.06	EnergyVille
Residential PV	GW	49.71	49.71	49.71	49.71	49.71	BREGILAB study by EnergyVille
Commercial /Industrial PV	GW	49.73	49.73	49.73	49.73	49.73	BREGILAB study by EnergyVille
Onshore wind	GW	18.27	18.27	18.27	18.27	18.27	BREGILAB study by EnergyVille
Offshore wind	GW	2.26	2.26	4.60	8.00	8.00	Belgian Offshore Platform[54]

[52] 2018 data are calculated as extrapolation of H2IC results and current electrolyzer investment cost and electricity prices.
[53] Sustainable biomass availability in the EU, to 2050, Concawe and Imperial College (2021)
[54] https://www.belgianoffshoreplatform.be/en/

9 APPENDIX 2: ASSUMPTIONS IN TRANSPORT SECTOR

Table 17: Transport demand projections - source: TREMOVE model (Transport Mobility Leuven)

	Category	Unit	2020	2030	2040	2050
Aviation	International Aviation	TWh	17.23	18.61	19.81	21.00
	Domestic Aviation	TWh	0.05	0.05	0.06	0.06
Navigation	International Bunkers	TWh	74.17	81.11	85.40	89.69
	Inland Shipping	TWh	2.13	2.33	2.45	2.58
Road	Bus – Intercity	Pkm*109	3.71	3.87	3.97	4.06
	Bus – Urban	Pkm*109	14.80	15.34	15.64	15.94
	Car – Commuting – Long Distance	Pkm*109	52.01	53.85	55.06	55.67
	Car – Commuting – Short Distance	Pkm*109	13.00	13.46	13.76	13.92
	Car – Non-Commuting – Long Distance	Pkm*109	40.87	42.31	43.26	43.74
	Car – Non-Commuting – Short Distance	Pkm*109	10.22	10.58	10.82	10.94
	Motorcycles	Pkm*109	1.41	1.67	1.97	2.27
	Freight	Tkm*109	33.47	36.07	38.51	40.94
Rail	Passenger - Light	Pkm*109	1.13	1.22	1.28	1.34
	Passenger – Heavy	Pkm*109	10.75	11.13	11.47	11.81
	Freight	Tkm*109	8.89	10.77	12.38	13.99

10 APPENDIX 3: COMPARISON WITH EU REFERENCE SCENARIO 2020

Table 18: Final Energy Consumption - Comparison with EU Reference Scenario 2020

Fuel Type	Unit	Historical[55]	Central			PATHS2050 Central			EU Reference Scenario 2020[56]		
		2023	2030	2040	2050	2030	2040	2050	2030	2040	2050
Solid fossil fuels	TWh	6.6	9.3	9.0	1.6	9.6	9.0	1.6	9.9	4.0	1.9
Petroleum products	TWh	138.5	84.5	14.7	1.3	86.2	33.6	1.3	97.5	69.6	58.9
Natural and manufactured gases	TWh	96.3	74.2	44.7	2.7	76.3	44.9	2.7	124.2	131.1	137.0
Electricity	TWh	73.9	99.1	154.2	197.0	98.8	147.8	197.6	95.4	99.2	105.2
Heat	TWh	4.0	8.7	8.3	8.2	12.2	8.3	8.1	12.1	12.1	12.4
Biomass and biofuels	TWh	25.6	24.7	17.5	12.9	17.1	14.0	11.5	25.6	23.9	21.9
Other renewables	TWh	0.3	1.1	1.5	1.2	1.0	1.4	1.2	1.1	1.9	2.1
Ambient Heat	TWh	3.3	23.8	33.7	48.1	23.9	33.8	48.5	2.0	2.0	2.0
Hydrogen	TWh		6.2	7.9	21.1	6.1	11.7	21.1	0.1	1.5	2.2

55 https://ec.europa.eu/eurostat/databrowser/view/nrg_bal_c/default/table?lang=en
56 https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

11 APPENDIX 4: EXAMPLE OF LRTAP EMISSION REPORTING

Table 19: LRTAP emission reporting example for the year 2014.

BE: 12.02.2021: 2014	**NFR sectors to be reported**			**Main Pollutants** (from 1990)				**Particulate Matter** (from 2000)			
				NOx (as NO_2)	NMVOC	SOx (as SO_2)	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC
NFR Aggregation for Gridding and LPS (GNFR)	**NFR Code**	**Long name**	**Notes**	**kt**	**kt**	**kt**	**kt**	**kt**	**kt**	**kt**	**kt**
A_PublicPower	1A1a	Public electricity and heat production		9.11941478	0.41049166	1.69242968	0.18415823	0.28303715	0.31929319	0.34846443	0.03098099
B_Industry	1A1b	Petroleum refining		3.33547900	0.37303061	7.03721700	0.00164000	0.01481440	0.01510640	0.01569040	0.00110973
B_Industry	1A1c	Manufacture of solid fuels and other energy industries		1.74854280	0.07060000	0.28200501	0.00530900	0.01410000	0.01450000	0.06837700	0.00001200
B_Industry	1A2a	Stationary combustion in manufacturing industries and construction: Iron and steel		1.42888447	0.11493392	0.14286601	0.00925865	0.06760762	0.08798166	0.10337983	0.00444162
B_Industry	1A2b	Stationary combustion in manufacturing industries and construction: Non-ferrous metals		0.16632312	0.01353930	0.00777661	0.00042941	0.04604867	0.05126408	0.05739707	0.00506574
B_Industry	1A2c	Stationary combustion in manufacturing industries and construction: Chemicals		3.07827069	0.39376931	0.30484021	0.02475262	0.23929433	0.28966342	0.35951694	0.05425732
B_Industry	1A2d	Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print		1.58999038	0.15882734	0.22112614	0.01340080	0.12130310	0.13308972	0.15648657	0.04862771
B_Industry	1A2e	Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco		2.56311892	0.31778161	0.60642671	0.06319187	0.16665922	0.17748732	0.19405610	0.03950677
B_Industry	1A2f	Stationary combustion in manufacturing industries and construction: Non-metallic minerals		1.44064132	0.06458806	1.46151983	0.00156731	0.10102475	0.11398197	0.13313270	0.01617192
I_Offroad	1A2gvii	Mobile combustion in manufacturing industries and construction (please specify in the IIR)		2.52523360	1.06594579	0.03863848	0.00115911	0.16846808	0.26597411	1.07177408	0.11176643
B_Industry	1A2gviii	Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)		2.43616356	0.16389429	0.46857130	0.01196262	0.29577842	0.30880461	0.33221607	0.03744974

12 APPENDIX 5: EMISSION FACTOR EVOLUTION

Table 20: Emission factor evolution. LRTAP codes can be found in Table 3

NFR	LRTAP_fuel	Pollutant	2018	2020	2025	2030	2035	2040	2045	2050
1A1a	Biomass	NO_x	100%	99%	95%	90%	87%	85%	83%	83%
1A1a	Biomass	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A1a	Biomass	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A1a	Gaseous Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A1a	Gaseous Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A1a	Gaseous Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A1a	Liquid Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A1a	Liquid Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A1a	Liquid Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A1a	Solid Fuels	NO_x	100%	99%	97%	94%	92%	89%	87%	85%
1A1a	Solid Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A1a	Solid Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A1b	Gaseous Fuels	NO_x	100%	98%	94%	87%	82%	76%	75%	75%
1A1b	Gaseous Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A1b	Gaseous Fuels	SO2	100%	25%	25%	25%	25%	25%	25%	25%
1A1b	Liquid Fuels	NO_x	100%	99%	95%	91%	87%	82%	78%	78%
1A1b	Liquid Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A1b	Liquid Fuels	SO2	100%	59%	53%	47%	41%	34%	24%	24%
1A1b	Solid Fuels	NO_x	100%	86%	66%	54%	43%	35%	27%	24%
1A1b	Solid Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A1b	Solid Fuels	SO2	100%	53%	44%	35%	26%	17%	12%	11%
1A2a	Gaseous Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A2a	Gaseous Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%

1A2a	Gaseous Fuels	SO_2	100%	100%	100%	100%	100%	100%	100%	100%
1A2a	Liquid Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A2a	Liquid Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A2a	Liquid Fuels	SO_2	100%	100%	100%	100%	100%	100%	100%	100%
1A2a	Solid Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A2a	Solid Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A2a	Solid Fuels	SO_2	100%	100%	100%	100%	100%	100%	100%	100%
1A2b	Gaseous Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A2b	Gaseous Fuels	PM10	100%	67%	42%	42%	42%	42%	42%	42%
1A2b	Gaseous Fuels	SO_2	100%	100%	100%	100%	100%	100%	100%	100%
1A2b	Liquid Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A2b	Liquid Fuels	PM10	100%	24%	17%	14%	11%	8%	6%	5%
1A2b	Liquid Fuels	SO_2	100%	100%	100%	100%	100%	100%	100%	100%
1A2b	Solid Fuels	NO_x	100%	98%	92%	85%	79%	73%	67%	64%
1A2b	Solid Fuels	PM10	100%	77%	55%	44%	34%	24%	17%	15%
1A2b	Solid Fuels	SO_2	100%	100%	100%	100%	100%	100%	100%	100%
1A2c	Biomass	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A2c	Biomass	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A2c	Biomass	SO_2	100%	100%	100%	100%	100%	100%	100%	100%
1A2c	Gaseous Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A2c	Gaseous Fuels	PM10	100%	89%	94%	99%	100%	100%	100%	100%
1A2c	Gaseous Fuels	SO_2	100%	87%	92%	97%	100%	100%	100%	100%
1A2c	Liquid Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A2c	Liquid Fuels	PM10	100%	83%	69%	67%	66%	64%	62%	61%
1A2c	Liquid Fuels	SO_2	100%	89%	89%	89%	89%	89%	89%	89%
1A2c	Solid Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A2c	Solid Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A2c	Solid Fuels	SO_2	100%	100%	100%	100%	100%	100%	100%	100%
1A2d	Biomass	NO_x	100%	98%	94%	89%	82%	76%	76%	76%

1A2d	Biomass	PM10	100%	97%	90%	83%	76%	68%	60%	57%
1A2d	Biomass	SO2	100%	94%	94%	94%	94%	94%	94%	94%
1A2d	Gaseous Fuels	NO_x	100%	100%	99%	99%	98%	98%	97%	97%
1A2d	Gaseous Fuels	PM10	100%	69%	58%	64%	71%	77%	81%	81%
1A2d	Gaseous Fuels	SO2	100%	69%	75%	81%	87%	94%	99%	100%
1A2d	Liquid Fuels	NO_x	100%	99%	96%	94%	91%	89%	85%	85%
1A2d	Liquid Fuels	PM10	100%	55%	39%	32%	25%	17%	10%	8%
1A2d	Liquid Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A2d	Solid Fuels	NO_x	100%	98%	94%	90%	86%	82%	78%	76%
1A2d	Solid Fuels	PM10	100%	96%	87%	78%	69%	60%	49%	45%
1A2d	Solid Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A2e	Biomass	NO_x	100%	68%	60%	55%	50%	45%	42%	42%
1A2e	Biomass	PM10	100%	98%	94%	90%	86%	81%	77%	75%
1A2e	Biomass	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A2e	Gaseous Fuels	NO_x	100%	99%	95%	91%	87%	83%	79%	78%
1A2e	Gaseous Fuels	PM10	100%	71%	79%	87%	93%	98%	100%	100%
1A2e	Gaseous Fuels	SO2	100%	69%	77%	85%	93%	97%	100%	100%
1A2e	Liquid Fuels	NO_x	100%	87%	81%	77%	70%	66%	63%	62%
1A2e	Liquid Fuels	PM10	100%	66%	55%	48%	40%	32%	25%	20%
1A2e	Liquid Fuels	SO2	100%	71%	71%	71%	71%	71%	71%	71%
1A2e	Solid Fuels	NO_x	100%	97%	88%	79%	71%	62%	53%	48%
1A2e	Solid Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A2e	Solid Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A2f	Biomass	NO_x	100%	69%	61%	54%	49%	43%	40%	39%
1A2f	Biomass	PM10	100%	95%	84%	70%	55%	40%	30%	29%
1A2f	Biomass	SO2	100%	40%	38%	36%	35%	33%	32%	32%
1A2f	Gaseous Fuels	NO_x	100%	93%	77%	64%	54%	45%	40%	39%
1A2f	Gaseous Fuels	PM10	100%	50%	40%	47%	54%	61%	69%	71%
1A2f	Gaseous Fuels	SO2	100%	23%	24%	25%	26%	27%	28%	29%

1A2f	Liquid Fuels	NO_x	100%	76%	68%	63%	59%	56%	55%	55%
1A2f	Liquid Fuels	PM10	100%	34%	24%	20%	16%	12%	8%	7%
1A2f	Liquid Fuels	SO2	100%	34%	31%	29%	26%	24%	20%	20%
1A2f	Solid Fuels	NO_x	100%	54%	41%	33%	26%	21%	17%	15%
1A2f	Solid Fuels	PM10	100%	82%	58%	47%	37%	26%	18%	16%
1A2f	Solid Fuels	SO2	100%	64%	54%	43%	33%	23%	16%	15%
1A2gviii	Biomass	NO_x	100%	84%	74%	67%	61%	56%	53%	52%
1A2gviii	Biomass	PM10	100%	91%	80%	70%	59%	45%	36%	36%
1A2gviii	Biomass	SO2	100%	96%	96%	96%	96%	96%	96%	96%
1A2gviii	Gaseous Fuels	NO_x	100%	98%	93%	87%	82%	74%	69%	68%
1A2gviii	Gaseous Fuels	PM10	100%	58%	45%	51%	58%	64%	70%	72%
1A2gviii	Gaseous Fuels	SO2	100%	65%	72%	78%	85%	91%	98%	100%
1A2gviii	Liquid Fuels	NO_x	100%	91%	85%	81%	77%	73%	69%	69%
1A2gviii	Liquid Fuels	PM10	100%	48%	35%	28%	22%	15%	10%	8%
1A2gviii	Liquid Fuels	SO2	100%	64%	64%	64%	64%	64%	64%	64%
1A2gviii	Solid Fuels	NO_x	100%	95%	71%	58%	45%	37%	28%	25%
1A2gviii	Solid Fuels	PM10	100%	95%	75%	61%	47%	34%	23%	21%
1A2gviii	Solid Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A4ai	Biomass	NO_x	100%	99%	96%	94%	87%	85%	84%	84%
1A4ai	Biomass	PM10	100%	100%	99%	95%	95%	95%	95%	95%
1A4ai	Biomass	SO2	100%	89%	89%	89%	89%	89%	89%	89%
1A4ai	Gaseous Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A4ai	Gaseous Fuels	PM10	100%	65%	75%	85%	92%	99%	100%	100%
1A4ai	Gaseous Fuels	SO2	100%	48%	59%	69%	80%	90%	99%	100%
1A4ai	Liquid Fuels	NO_x	100%	89%	82%	73%	65%	58%	54%	53%
1A4ai	Liquid Fuels	PM10	100%	77%	64%	53%	43%	32%	20%	16%
1A4ai	Liquid Fuels	SO2	100%	78%	78%	78%	79%	79%	79%	79%
1A4ai	Solid Fuels	NO_x	100%	58%	42%	34%	26%	22%	17%	15%
1A4ai	Solid Fuels	PM10	100%	95%	84%	72%	60%	48%	33%	30%

1A4ai	Solid Fuels	SO2	100%	97%	90%	84%	77%	70%	63%	59%
1A4bi	Biomass	NO_x	100%	99%	96%	94%	87%	85%	84%	84%
1A4bi	Biomass	PM10	100%	100%	99%	95%	95%	95%	95%	95%
1A4bi	Biomass	SO2	100%	89%	89%	89%	89%	89%	89%	89%
1A4bi	Gaseous Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A4bi	Gaseous Fuels	PM10	100%	65%	75%	85%	92%	99%	100%	100%
1A4bi	Gaseous Fuels	SO2	100%	48%	59%	69%	80%	90%	99%	100%
1A4bi	Liquid Fuels	NO_x	100%	89%	82%	73%	65%	58%	54%	53%
1A4bi	Liquid Fuels	PM10	100%	77%	64%	53%	43%	32%	20%	16%
1A4bi	Liquid Fuels	SO2	100%	78%	78%	78%	79%	79%	79%	79%
1A4bi	Solid Fuels	NO_x	100%	58%	42%	34%	26%	22%	17%	15%
1A4bi	Solid Fuels	PM10	100%	95%	84%	72%	60%	48%	33%	30%
1A4bi	Solid Fuels	SO2	100%	97%	90%	84%	77%	70%	63%	59%
1A4ci	Biomass	NO_x	100%	99%	96%	94%	87%	85%	84%	84%
1A4ci	Biomass	PM10	100%	100%	99%	95%	95%	95%	95%	95%
1A4ci	Biomass	SO2	100%	89%	89%	89%	89%	89%	89%	89%
1A4ci	Gaseous Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A4ci	Gaseous Fuels	PM10	100%	65%	75%	85%	92%	99%	100%	100%
1A4ci	Gaseous Fuels	SO2	100%	48%	59%	69%	80%	90%	99%	100%
1A4ci	Liquid Fuels	NO_x	100%	89%	82%	73%	65%	58%	54%	53%
1A4ci	Liquid Fuels	PM10	100%	77%	64%	53%	43%	32%	20%	16%
1A4ci	Liquid Fuels	SO2	100%	78%	78%	78%	79%	79%	79%	79%
1A4ci	Solid Fuels	NO_x	100%	58%	42%	34%	26%	22%	17%	15%
1A4ci	Solid Fuels	PM10	100%	95%	84%	72%	60%	48%	33%	30%
1A4ci	Solid Fuels	SO2	100%	97%	90%	84%	77%	70%	63%	59%
1A3bi	Gaseous Fuels	NO_x	100%	101%	104%	110%	113%	114%	114%	114%
1A3bi	Gaseous Fuels	PM10	100%	100%	104%	109%	112%	113%	113%	113%
1A3bi	Gaseous Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A3bi	Liquid Fuels	NO_x	100%	82%	45%	27%	20%	18%	18%	18%

1A3bi	Liquid Fuels	PM10	100%	91%	82%	82%	85%	87%	87%	87%
1A3bi	Liquid Fuels	SO2	100%	101%	101%	101%	100%	100%	100%	100%
1A3bii	Liquid Fuels	NO_x	100%	95%	57%	34%	23%	18%	18%	18%
1A3bii	Liquid Fuels	PM10	100%	87%	73%	71%	73%	74%	74%	74%
1A3bii	Liquid Fuels	SO2	100%	100%	101%	101%	101%	101%	101%	101%
1A3biii	Liquid Fuels	NO_x	100%	65%	27%	17%	14%	14%	14%	14%
1A3biii	Liquid Fuels	PM10	100%	93%	89%	92%	96%	98%	98%	98%
1A3biii	Liquid Fuels	SO2	100%	100%	98%	94%	92%	91%	91%	91%
1A3biv	Liquid Fuels	NO_x	100%	71%	53%	38%	27%	22%	22%	22%
1A3biv	Liquid Fuels	PM10	100%	75%	69%	65%	63%	62%	62%	62%
1A3biv	Liquid Fuels	SO2	100%	101%	101%	101%	101%	101%	101%	101%
1A3ai(i)	Liquid Fuels	NO_x	100%	103%	107%	110%	110%	110%	110%	110%
1A3ai(i)	Liquid Fuels	PM10	100%	97%	93%	90%	90%	90%	90%	90%
1A3ai(i)	Liquid Fuels	SO2	100%	102%	103%	104%	104%	104%	104%	104%
1A3aii(i)	Liquid Fuels	NO_x	100%	103%	107%	110%	110%	110%	110%	110%
1A3aii(i)	Liquid Fuels	PM10	100%	97%	93%	90%	90%	90%	90%	90%
1A3aii(i)	Liquid Fuels	SO2	100%	102%	103%	104%	104%	104%	104%	104%
1A3c	Liquid Fuels	NO_x	100%	100%	100%	100%	100%	100%	100%	100%
1A3c	Liquid Fuels	PM10	100%	100%	100%	100%	100%	100%	100%	100%
1A3c	Liquid Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A3dii	Liquid Fuels	NO_x	100%	100%	95%	90%	85%	80%	80%	80%
1A3dii	Liquid Fuels	PM10	100%	90%	75%	60%	50%	40%	40%	40%
1A3dii	Liquid Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%
1A3di(i)	Liquid Fuels	NO_x	100%	100%	120%	105%	90%	85%	80%	80%
1A3di(i)	Liquid Fuels	PM10	100%	100%	140%	140%	140%	140%	140%	140%
1A3di(i)	Liquid Fuels	SO2	100%	100%	100%	100%	100%	100%	100%	100%

13 APPENDIX 6: RESULTS

13.1 Central scenario

Table 21: Modelling result - Central scenario, SOx. LRTAP codes are available in Table 3

LRTAP_code	GNFR code	2020 SO_x [kton]	2030 SO_x [kton]	2040 SO_x [kton]	2050 SO_x [kton]
1A1a	A_PublicPower	0.27	0.13	0.19	0.36
1A1b	B_Industry	3.66	2.64	1.60	0.89
1A1c	B_Industry	0.12	0.12	0.12	0.00
1A2a	B_Industry	0.09	0.09	0.08	0.00
1A2b	B_Industry	0.01	0.01	0.01	0.00
1A2c	B_Industry	0.32	1.38	1.41	0.10
1A2d	B_Industry	0.24	0.20	0.17	0.16
1A2e	B_Industry	0.21	0.08	0.06	0.06
1A2f	B_Industry	0.63	0.49	0.33	0.17
1A2gviii	B_Industry	0.50	0.44	0.19	0.19
1A3ai(i)	H_Aviation	0.11	0.12	0.13	0.14
1A3aii(i)	H_Aviation	0.00	0.00	0.00	0.00
1A3bi	F_RoadTransport	0.07	0.05	0.00	0.00
1A3bii	F_RoadTransport	0.01	0.01	0.00	0.00
1A3biii	F_RoadTransport	0.03	0.03	0.01	0.00
1A3biv	F_RoadTransport	0.00	0.00	0.00	0.00
1A3c	I_Offroad	0.00	0.00	0.00	0.00
1A3di(i)	G_Shipping	4.22	4.62	4.86	5.11
1A3dii	G_Shipping	0.00	0.01	0.01	0.01
1A4ai	C_OtherStationaryComb	0.08	0.04	0.02	0.00
1A4bi	C_OtherStationaryComb	0.43	0.09	0.06	0.02
1A4ci	C_OtherStationaryComb	0.85	1.26	0.81	0.54

Table 22: Modelling result - Central scenario, PM10.

LRTAP_code	GNFR code	2020 PM10 [kton]	2030 PM10 [kton]	2040 PM10 [kton]	2050 PM10 [kton]
1A1a	A_PublicPower	0.23	0.11	0.16	0.30
1A1b	B_Industry	0.01	0.01	0.01	0.00
1A1c	B_Industry	0.01	0.01	0.01	0.00
1A2a	B_Industry	0.06	0.06	0.05	0.00
1A2b	B_Industry	0.08	0.05	0.02	0.00
1A2c	B_Industry	0.27	0.73	0.69	0.09
1A2d	B_Industry	0.19	0.14	0.09	0.08
1A2e	B_Industry	0.22	0.05	0.03	0.03
1A2f	B_Industry	0.13	0.09	0.06	0.03
1A2gviii	B_Industry	0.32	0.17	0.06	0.05
1A3ai(i)	H_Aviation	0.02	0.02	0.02	0.02
1A3aii(i)	H_Aviation	0.00	0.00	0.00	0.00
1A3bi	F_RoadTransport	0.65	0.44	0.00	0.00
1A3bii	F_RoadTransport	0.20	0.17	0.04	0.00
1A3biii	F_RoadTransport	0.24	0.24	0.06	0.00
1A3biv	F_RoadTransport	0.02	0.00	0.00	0.00
1A3c	I_Offroad	0.35	0.17	0.00	0.00
1A3di(i)	G_Shipping	0.77	1.18	1.24	1.30
1A3dii	G_Shipping	0.12	0.09	0.06	0.06
1A4ai	C_OtherStationaryComb	0.07	0.02	0.01	0.00
1A4bi	C_OtherStationaryComb	3.99	0.56	0.34	0.04
1A4ci	C_OtherStationaryComb	0.26	0.33	0.21	0.14

13.2 Sensitivity 1 scenario

Table 23: Modelling result - Sensitivity 1 scenario, NO_x.

LRTAP_code	GNFR code	2020 NOx [kton]	2030 NOx [kton]	2040 NOx [kton]	2050 NOx [kton]
1A1a	A_PublicPower	6.03	3.11	3.45	5.00
1A1b	B_Industry	2.63	2.24	1.67	1.26
1A1c	B_Industry	1.94	1.94	1.94	0.03
1A2a	B_Industry	1.21	1.28	1.14	0.02
1A2b	B_Industry	0.28	0.26	0.17	0.00
1A2c	B_Industry	1.78	3.80	3.31	0.37
1A2d	B_Industry	1.51	1.14	0.81	0.78
1A2e	B_Industry	2.10	0.47	0.22	0.20
1A2f	B_Industry	0.85	0.58	0.48	0.26
1A2gviii	B_Industry	2.44	1.68	0.74	0.69
1A3ai(i)	H_Aviation	1.92	2.22	2.36	2.51
1A3aii(i)	H_Aviation	0.02	0.03	0.00	0.00
1A3bi	F_RoadTransport	32.61	6.94	1.20	0.06
1A3bii	F_RoadTransport	13.57	4.87	0.63	0.00
1A3biii	F_RoadTransport	12.11	3.19	0.63	0.04
1A3biv	F_RoadTransport	0.23	0.00	0.00	0.00
1A3c	I_Offroad	0.73	0.34	0.00	0.00
1A3di(i)	G_Shipping	19.87	22.82	19.45	19.23
1A3dii	G_Shipping	4.69	4.61	4.32	4.53
1A4ai	C_OtherStationaryComb	2.48	1.53	0.70	0.00
1A4bi	C_OtherStationaryComb	5.15	1.64	0.93	0.08
1A4ci	C_OtherStationaryComb	3.57	4.76	2.79	1.82

Table 24: Modelling result - Sensitivity 1 scenario, SOx.

LRTAP_code	GNFR code	2020 SO_x [kton]	2030 SO_x [kton]	2040 SO_x [kton]	2050 SO_x [kton]
1A1a	A_PublicPower	0.27	0.13	0.19	0.36
1A1b	B_Industry	3.66	2.64	1.60	0.89
1A1c	B_Industry	0.12	0.12	0.12	0.00
1A2a	B_Industry	0.09	0.09	0.08	0.00
1A2b	B_Industry	0.01	0.01	0.01	0.00
1A2c	B_Industry	0.32	1.38	1.41	0.10
1A2d	B_Industry	0.24	0.20	0.17	0.16
1A2e	B_Industry	0.21	0.08	0.06	0.06
1A2f	B_Industry	0.63	0.49	0.33	0.17
1A2gviii	B_Industry	0.50	0.44	0.19	0.19
1A3ai(i)	H_Aviation	0.11	0.12	0.13	0.14
1A3aii(i)	H_Aviation	0.00	0.00	0.00	0.00
1A3bi	F_RoadTransport	0.07	0.06	0.01	0.00
1A3bii	F_RoadTransport	0.01	0.01	0.00	0.00
1A3biii	F_RoadTransport	0.03	0.03	0.01	0.00
1A3biv	F_RoadTransport	0.00	0.00	0.00	0.00
1A3c	I_Offroad	0.00	0.00	0.00	0.00
1A3di(i)	G_Shipping	4.22	4.62	4.86	5.11
1A3dii	G_Shipping	0.00	0.01	0.01	0.01
1A4ai	C_OtherStationaryComb	0.08	0.04	0.02	0.00
1A4bi	C_OtherStationaryComb	0.43	0.09	0.06	0.02
1A4ci	C_OtherStationaryComb	0.85	1.25	0.81	0.54

Table 25: Modelling result - Sensitivity 1 scenario, PM10.

LRTAP_code	GNFR code	2020 PM10 [kton]	2030 PM10 [kton]	2040 PM10 [kton]	2050 PM10 [kton]
1A1a	A_PublicPower	0.23	0.11	0.16	0.30
1A1b	B_Industry	0.01	0.01	0.01	0.00
1A1c	B_Industry	0.01	0.01	0.01	0.00
1A2a	B_Industry	0.06	0.06	0.05	0.00
1A2b	B_Industry	0.08	0.05	0.02	0.00
1A2c	B_Industry	0.27	0.73	0.69	0.09
1A2d	B_Industry	0.19	0.14	0.09	0.08
1A2e	B_Industry	0.22	0.05	0.03	0.03
1A2f	B_Industry	0.13	0.09	0.06	0.03
1A2gviii	B_Industry	0.32	0.17	0.06	0.05
1A3ai(i)	H_Aviation	0.02	0.02	0.02	0.02
1A3aii(i)	H_Aviation	0.00	0.00	0.00	0.00
1A3bi	F_RoadTransport	0.65	0.49	0.10	0.00
1A3bii	F_RoadTransport	0.20	0.17	0.04	0.00
1A3biii	F_RoadTransport	0.24	0.24	0.06	0.00
1A3biv	F_RoadTransport	0.02	0.00	0.00	0.00
1A3c	I_Offroad	0.35	0.17	0.00	0.00
1A3di(i)	G_Shipping	0.77	1.18	1.24	1.30
1A3dii	G_Shipping	0.12	0.09	0.06	0.06
1A4ai	C_OtherStationaryComb	0.07	0.02	0.01	0.00
1A4bi	C_OtherStationaryComb	3.99	0.56	0.34	0.03
1A4ci	C_OtherStationaryComb	0.26	0.33	0.21	0.14

13.3 Sensitivity 2 scenario

Table 26: Modelling result - Sensitivity 2 scenario, NO_x.

LRTAP_code	GNFR code	2020 NO_x [kton]	2030 NO_x [kton]	2040 NO_x [kton]	2050 NO_x [kton]
1A1a	A_PublicPower	6.03	3.13	3.39	5.00
1A1b	B_Industry	2.63	2.24	1.67	1.26
1A1c	B_Industry	1.94	1.94	1.94	0.03
1A2a	B_Industry	1.21	1.28	1.14	0.02
1A2b	B_Industry	0.28	0.26	0.17	0.00
1A2c	B_Industry	1.78	3.80	3.31	0.37
1A2d	B_Industry	1.51	1.14	0.81	0.78
1A2e	B_Industry	2.10	0.47	0.22	0.20
1A2f	B_Industry	0.85	0.58	0.48	0.26
1A2gviii	B_Industry	2.44	1.68	0.74	0.69
1A3ai(i)	H_Aviation	1.92	2.22	2.36	2.51
1A3aii(i)	H_Aviation	0.02	0.03	0.00	0.00
1A3bi	F_RoadTransport	32.61	8.75	3.84	0.52
1A3bii	F_RoadTransport	13.57	4.87	0.63	0.00
1A3biii	F_RoadTransport	12.11	3.19	0.63	0.04
1A3biv	F_RoadTransport	0.23	0.00	0.00	0.00
1A3c	I_Offroad	0.73	0.34	0.00	0.00
1A3di(i)	G_Shipping	19.87	22.82	19.45	19.23
1A3dii	G_Shipping	4.69	4.61	4.32	4.53
1A4ai	C_OtherStationaryComb	2.48	1.52	0.69	0.00
1A4bi	C_OtherStationaryComb	5.15	1.61	0.93	0.08
1A4ci	C_OtherStationaryComb	3.57	4.71	2.78	1.82

Table 27: Modelling result - Sensitivity 2 scenario, SO_x.

LRTAP_code	GNFR code	2020 SO_x [kton]	2030 SO_x [kton]	2040 SO_x [kton]	2050 SO_x [kton]
1A1a	A_PublicPower	0.27	0.13	0.18	0.36
1A1b	B_Industry	3.66	2.64	1.60	0.89
1A1c	B_Industry	0.12	0.12	0.12	0.00
1A2a	B_Industry	0.09	0.09	0.08	0.00
1A2b	B_Industry	0.01	0.01	0.01	0.00
1A2c	B_Industry	0.32	1.38	1.41	0.10
1A2d	B_Industry	0.24	0.20	0.17	0.16
1A2e	B_Industry	0.21	0.08	0.06	0.06
1A2f	B_Industry	0.63	0.49	0.33	0.17
1A2gviii	B_Industry	0.50	0.44	0.19	0.19
1A3ai(i)	H_Aviation	0.11	0.12	0.13	0.14
1A3aii(i)	H_Aviation	0.00	0.00	0.00	0.00
1A3bi	F_RoadTransport	0.07	0.07	0.04	0.00
1A3bii	F_RoadTransport	0.01	0.01	0.00	0.00
1A3biii	F_RoadTransport	0.03	0.03	0.01	0.00
1A3biv	F_RoadTransport	0.00	0.00	0.00	0.00
1A3c	I_Offroad	0.00	0.00	0.00	0.00
1A3di(i)	G_Shipping	4.22	4.62	4.86	5.11
1A3dii	G_Shipping	0.00	0.01	0.01	0.01
1A4ai	C_OtherStationaryComb	0.08	0.04	0.02	0.00
1A4bi	C_OtherStationaryComb	0.43	0.09	0.06	0.02
1A4ci	C_OtherStationaryComb	0.85	1.23	0.81	0.54

Table 28: Modelling result - Sensitivity 2 scenario, PM_{10}.

LRTAP_code	GNFR code	2020 PM10 [kton]	2030 PM10 [kton]	2040 PM10 [kton]	2050 PM10 [kton]
1A1a	A_PublicPower	0.23	0.12	0.16	0.30
1A1b	B_Industry	0.01	0.01	0.01	0.00
1A1c	B_Industry	0.01	0.01	0.01	0.00
1A2a	B_Industry	0.06	0.06	0.05	0.00
1A2b	B_Industry	0.08	0.05	0.02	0.00
1A2c	B_Industry	0.27	0.73	0.69	0.09
1A2d	B_Industry	0.19	0.14	0.09	0.08
1A2e	B_Industry	0.22	0.05	0.03	0.03
1A2f	B_Industry	0.13	0.09	0.06	0.03
1A2gviii	B_Industry	0.32	0.17	0.06	0.05
1A3ai(i)	H_Aviation	0.02	0.02	0.02	0.02
1A3aii(i)	H_Aviation	0.00	0.00	0.00	0.00
1A3bi	F_RoadTransport	0.65	0.58	0.35	0.05
1A3bii	F_RoadTransport	0.20	0.17	0.04	0.00
1A3biii	F_RoadTransport	0.24	0.24	0.06	0.00
1A3biv	F_RoadTransport	0.02	0.00	0.00	0.00
1A3c	I_Offroad	0.35	0.17	0.00	0.00
1A3di(i)	G_Shipping	0.77	1.18	1.24	1.30
1A3dii	G_Shipping	0.12	0.09	0.06	0.06
1A4ai	C_OtherStationaryComb	0.07	0.02	0.01	0.00
1A4bi	C_OtherStationaryComb	3.99	0.55	0.34	0.03
1A4ci	C_OtherStationaryComb	0.26	0.33	0.21	0.14

vision on technology
for a better world

vito