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TII Road Emissions Model (REM): Model Development Report

GE-ENV-01107
December 2022

REM
Road Emissions Model
Transport Infrastructure Ireland

GE General

Technical

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TII Publications

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Non-Technical Summary

Introduction

Road transport is a significant contributor to greenhouse gases and air pollution, accounting for just under one fifth of Ireland's greenhouse gas emissions. Promoting cleaner, safer and more sustainable mobility is critical for climate policy. It represents an opportunity to improve health outcomes, boost the quality of lives and contribute to the 'national climate objective' of zero net emissions by 2050.

The Climate Action and Low Carbon (Amendment) Act 2021 commits Ireland to reducing greenhouse gas emissions by 51 per cent by 2030. There is a growing need to improve the modelling of transport-based emissions and for this reason Transport Infrastructure Ireland (TII) has developed the TII Road Emissions Model (REM).

The Need to Develop the Tool

Exhaust emissions from motor vehicles with internal combustion engines contain a variety of pollutants, principally carbon monoxide (CO), carbon dioxide (CO_2) and other greenhouse gas (GHG), oxides of nitrogen (NO_X), nitrogen dioxide (NO_2), volatile organic compounds (VOCs) and very small particulate matter (less than 10 and 2.5 micrometres, known as PM_{10} and $PM_{2.5}$ respectively). It is NO_2 and particulate matter that can be harmful to human health and human respiration, while other pollutants (e.g. NO_X) damage a variety of ecosystems, through changes in biogeochemistry, including changes to the carbon cycle with resultant climate change.

Transport as a sector is seen as a non-point source of air pollution, cumulatively contributing one fifth (20 per cent) of greenhouse gas emissions in Ireland in 2021. Not all emissions and pollutants are the same for different fuel types, vehicle types and weight, nor vehicle engine size. The speed at which a vehicle is travelling, as a proportion of the overall distance travelled per trip, determines the efficiency of fuel use, and therefore levels of emissions per kilometre driven. The rate at which engine catalyst or Diesel Particulate Filter (DPF) failures occur add additional uncertainty to vehicle emissions on a local and national scale. There are differences in emissions from vehicles operating on congested roads adjacent to and through cities and towns compared to those travelling in free-flow conditions in an inter-urban context.

Societies measure what they value, and TII is monitoring, collating, measuring and evaluating the complex effects of road transport on emissions and air pollution. 45% of vehicle-kilometres travelled in Ireland annually are on the National Roads Network, while the emissions resulting from driving on the National Roads Network accounts for in the region of 30% of total transport emissions. TII undertakes research on air quality, primarily through a stakeholder alliance with government departments and agencies, academic institutions and industry partners. Through this process, TII has amassed a considerable evidence base, and continue to develop tools underpinned by data driven analysis.

TII recognised the need to develop a tool that integrates a variety of datasets covering current and possible future road networks, forecasted national vehicle fleets, and emissions rates associated with these fleets. This allows for the development of scenarios and exploration of plausible future outcomes, as people adjust to available emerging technologies in the transition to a low/zero carbon society. The REM will support carbon reduction decision making and the tool provides a robust evidence base to inform future policy.

Policy and Legislative Framework

Development of the TII REM supports TII in aligning its investments and activities with national policy as contained in the National Planning Framework and Project Ireland 2040 (2018); the Climate Action Plan (2021) resulting from the Climate Action and Low Carbon Development (Amendment) Bill (2021) and the National Investment Framework for Transport in Ireland (2021).

The strategic context for transport has changed significantly in recent years, with a focus on addressing emissions and climate change, spatial planning and land use. Project Ireland contains ten National Strategic Outcomes (NSO), a number of which can potentially affect vehicle emissions on the TII road network, including:

- NSO2: Enhanced Regional Accessibility;
- NSO4: Sustainable Mobility; and
- NSO8: Transition to a low Carbon and Climate Resilient Society.

The National Planning Framework sets out National Policy Objectives (NPO) to help deliver the NSOs. The two of most relevance to air quality and carbon emissions from transport are:

- NPO54: Reduce our carbon footprint by integrating climate action into the planning system in support of national targets for climate policy mitigation and adaptation objectives, as well as targets for GHG reductions; and
- NPO 64: Improve air quality and help prevent people being exposed to unacceptable levels of pollution in our urban and rural areas through integrated land use and spatial planning that supports public transport, walking and cycling as more favourable modes of transport to the private car.

The Climate Action Plan sets out actions to reduce Ireland's greenhouse gas emissions across a range of sectors, including transport; with a target of reducing carbon dioxide equivalent emissions from the sector by 51 percent by 2030. Emissions from transport account for 12 million tonnes of carbon dioxide equivalent per annum, or on average 2.5 tonnes per person. The Climate Action and Low Carbon Development Amendment Bill embeds the process of carbon budgeting into law, through the development of five-year carbon budgets. The policy focus has shifted to carbon accounting, requiring a greater and more granular insight into transport emissions from roads and modes of transport.

The TII Sustainability Implementation Plan (2020) outlines key principles for the sustainable development agenda. These are summarised in six key TII Sustainability Principles developed to reflect organisational ambitions of which the REM specifically supports:

- Principle 3, Collaborate for a holistic approach;
- Principle 5, Transition to Net Zero; and
- Principle 6, Create total value for society.

Actions specifically relevant to TII's role in transitioning to a zero net emissions economy specified in the Climate Action Plan (2021) include the following:

- Publish the impact of speed and speed limits on greenhouse gas emissions and pollutants (Action 251).
- Review and, if necessary, develop a regulatory framework for low-emission zones (Action 257).
- Assess the environmental impact of the internationally trading Irish fleet (Action 293).

- Identify opportunities for collaborative research in the area of climate adaptation for the transport sector (Action 296).
- Commission research on adaptation in the transport sector to fill existing knowledge gaps (Action 300).

The key legislation addressing air quality in Ireland is the Air Quality Standards Regulations 2011 (S.I. No. 180 of 2011) and the European Union (National Emission Ceilings) Regulations 2018 (S.I. No. 232/2018). The Air Quality Standards Regulations includes limit values for pollutants in ambient air for the protection of human health and sensitive ecosystems. The European Union National Emissions reduction Commitments (NEC) Directive (2016/2284/EU) requires that emissions of specified pollutants are limited in accordance with the ceilings set out in the Regulations.

The Road Emissions Model

The REM provides a spatial and temporal estimate of carbon dioxide equivalent emissions and the pollutant concentrations resulting from vehicular use on the National Roads Network. The REM integrates:

- Traffic information from the TII National Transport Model which provides validated estimates of the volumes of light and heavy vehicles, and the speed at which they travel, on the National Roads Network.
- A Fleet Mix database developed by researchers in the Energy Policy and Modelling Group at University College Cork for cars based on economic projections, and for other light and heavy vehicles by AECOM. The Fleet Mix database is underpinned by the Central Statistics Office’s goods vehicles registration data (both heavy and light goods vehicles).
- Emission Rate Database derived from the European Environment Agency’s (EEA) COPERT Emissions Tool - the EU industry standard vehicle emissions calculator – published in the EMEP/EEA air pollutant emission inventory guidebook. These data were adjusted further using data published in the UK by DEFRA.
- An Ambient Air Quality Model module, which calculates pollutants (NO_X, NO_2, PM_{10} and $PM_{2.5}$) released from each individual road link, using predictions of atmospheric pollutants concentration and dispersion, scaled up to an annual average concentration.

TII’s REM calculates road transport emissions integrating traffic volumes/speeds for light and heavy vehicles on the Irish National Roads Network with Irish fleet composition information.

This tool, using appropriate traffic data, can be used to help inform policy through testing air quality and emissions impacts arising from interventions on the National Road Network and / or the national fleet. For example the potential impact of modal shift or increased low emission vehicles can be tested on a national or regional basis to help meet climate targets. Alternately, the tool can be used on a local scale to target specific road links to generate benefits (e.g. congestion reduction initiatives). The tool also provides ‘source apportionment’ information to determine the contribution of different vehicle types to emission estimates.

Benefits of the REM

The benefits to TII of developing and using the REM include the ability to:

- Provide a robust and transparent estimation process, which can inform targeted investment in interventions on particular sections of the National Roads Network.

- Calculate emissions between individual road links, rather than the method that was used prior to the development of this tool which averaged carbon dioxide equivalent emissions over long distances.
- Use understanding of optimal / sub-optimal driving conditions to help inform impact of interventions.
- Differentiate effects based on speed travelled and emissions by vehicle type.
- Improve the appraisal of scheme options, with robust and comparable data on carbon and pollution effects
- Support scenario development including futures with differing composition of the vehicle fleet and futures with alternative management and mitigation procedures.
- Help progress the commitments agreed in the TII Sustainability Implementation Plan.

Use of the tool enables Government and Local Authorities to:

- Monitor and manage the risk that Ireland faces air quality exceedances of the EU limit values and ensure new projects do not directly cause EU environmental standards for ambient air quality to be exceeded.
- Contribute to Government's carbon accounting, carbon budgeting in the Climate Action Plan and progress toward emission reduction targets.
- Provide a practical user-friendly decision-support tool for TII project managers and government policy makers.
- Identify communities that may be adversely impacted, contributing to quality of life indicators while also being used to manage health and risk mitigation.
- Consider at a strategic level along individual road links the potential effects of Nitrogen Oxide deposition on designated sensitive ecosystems.
- Highlight corridors or links with highest emissions where interventions such as modal shift may have the greatest benefits.
- Improve consultation with stakeholders and partners in relation to the transition to low to zero emission transport.
- Determine the emissions contribution of different vehicle types on individual links, corridors, or regions; e.g. emissions from HGV on specific roads in rural and urban settings and at different speeds.
- Appraise the emissions change that could be achieved by altering traffic flows or fleet breakdown; e.g. increasing adoption of electric cars.
- Support strategic business case development

The benefits to the general public and wider communities of interest include the ability to:

- Use the output from the model as an education tool, to inform people of the typical carbon impact of their trip-making.
- Encourage the use of a tool that can be used at desktops, without the user requiring data skills such as programming, data management, extraction and analysis and visualisation, leading to considerable efficiencies in and simplification of carbon accounting.
- Be used within research, scientific and academic analyses while it allows for a transparent and standardised, hence consistent and comparable data collecting and emissions reporting procedure.

The tool can work with any transport modelling system used to generate estimates of traffic flows and speeds. It is currently integrated into the TII National Transport Model but can also be used on specific schemes using local transport models.

Overall, the REM was developed out of a need to improve the tools used in decision making. The integrative function of the Tool, which incorporates complex large datasets provides useful policy levers for TII, with many accompanying benefits. These are summarised below.

Complex Large Datasets	Integrative Function of Tool	Output Indicators	Policy Levers	Benefits of Tool
1 - National Transport Model (NTpM). Traffic flows on the Irish National Roads Network 2 - Irish Vehicle Fleet, based on registration data from the Central Statistics Office and the UCC car stock model 3 - Emission Rate Database using emissions profiles published by EEA 4 - Ambient Air Quality Model of air pollutants resultant from the road-source emission rate as a product of dispersion	1 - Light and heavy vehicle speeds and flows for all road sections on the National Roads Network, including average speed on routes 2 - Vehicle Type County by County detailed fleet profile that is applied to the NTpM light and heavy vehicle classes 3 - Rate and Type of Emissions Carbon and non- greenhouse gas emissions, differentiated by speed of vehicles and distance travelled	1 - Total Emissions on the National Road Network Nationally 2 - Emissions by route 3 -Identification of emission hot-spots 4 - Carbon footprint by route	1 - Optimise driver behaviour on the National Road Network from an emissions perspective 2 - Inform future climate action policies 3 -Integrate findings with Information Technology Systems, e.g. to reroute vehicles in congestion 4 - Use indicators in scenario building to explore plausible futures	1 - Practical and user-friendly decision support tool 2 - Granularity and greaterdata insights on transport emissions 3 - Carbon Accounting and Carbon Budgeting 4 - Transparency on carbonfootprint per trip type – enabling drivers to make informed choices 5 - Transparency on carbonfootprint per trip type – enabling drivers to make informed choices

Glossary

Term	Definition
AADT	Annual Average Daily Traffic
BEIS	UK Dept. for Business, Energy and Industrial Strategy
BEV	Battery Electric Vehicle
COPERT	EU standard vehicle emissions calculator published by European Environment Agency (EEA)
CSO	Central Statistics Office
CO_2	Carbon dioxide
CO_2e	Equivalent global warming potential presented as CO_2
CH_4	Methane, greenhouse gas global warming potential
DEFRA	UK Dept. of Environment, Food and Rural Affairs
DPF	Diesel Particulate Filter, exhaust abatement technology to reduce emissions of ultrafine particulates
EFT	Emissions Factors Toolkit published by DEFRA and based on COPERT
EGR	Exhaust Gas Recirculation, exhaust abatement technology to reduce combustion temperatures and increase efficiency
GHG	Greenhouse Gas
HCV	Heavy Commercial Vehicle, including HGV (see below), bus and specialist vehicles
HDV	Heavy Duty Vehicle, >3.5 t
HGV	Heavy Goods Vehicle; e.g. articulated wagon
LAEI	London Atmospheric Emissions Inventory
LDV	Light Duty Vehicle, <3.5 t
LGV	Light Goods Vehicle; e.g. commercial van
N_2O	Nitrous oxide, greenhouse gas global warming potential
NAEI	UK National Atmospheric Emissions Inventory
NEE	Non-exhaust Emissions; i.e. particulate emissions arising from tyre and brake wear and road abrasion
NI	Northern Ireland
NO_X	Oxides of Nitrogen
NO_2	Nitrogen Dioxide
NTpM	National Transport Model
PHEV	Plug-in Hybrid Electric Vehicle
PM_{10}	Fine particulate matter with an aerodynamic diameter of 10 μm
$PM_{2.5}$	Fine particulate matter with an aerodynamic diameter of 2.5 μm
RF	Retrofit, referring to the installation of aftermarket exhaust abatement technology
SCR	Selective Catalytic Reduction, exhaust abatement technology to inject urea (e.g. AdBlue) into exhaust flows
SIMI	Society of the Irish Motor Industry
StatBank	Central Statistics Office Open Data Portal, replaced by PxStat in December 2021.

Term	Definition
TII	Transport Infrastructure Ireland
TUBA	Transport Users Benefit Appraisal software

1. Introduction

AECOM were appointed by Transport Infrastructure Ireland (TII) to create to create an emissions and local air quality modelling tool to carry out strategic scale analysis of greenhouse gases, which are important for climate change, and also non-greenhouse gases that are important for local air quality.

This technical report collates the initial scoping and technical details of the first iteration of the TII Road Emissions Model (REM) developed for strategic scale analysis.

The development of the TII REM was divided into three stages:

- Stage 1: Development of an Emissions Tool capable of calculating Baseline Emissions for the National Road Network in 2018.
- Stage 2: Development of an Emissions Tool capable of calculating projections for the National Road Network up to 2050.
- Stage 3: Development of an Ambient Air Quality Tool capable of calculating local air quality along the National Road Network.

Baseline emission calculations were undertaken for 2018 to help trial the TII REM and also to provide a reference point from which to project changes in future years.

Please note that in order to get access to the REM Tool, prospective users should email climatetools@tii.ie to be set up as an authorised user on the TII Web Application Portal.

1.1 Tool Benefits and Uses

The TII REM differs from contemporary national scale approaches to emission calculations. These typically estimate total national emissions for the existing situation without showing on a local scale where emissions are generated; e.g. based on a simplified fleet and / or average speed across whole journeys. Furthermore, national emissions estimates are also often undertaken separately for greenhouse gases (GHG) and non-greenhouse gases that are pollutants harmful to human health and sensitive designated ecosystems. The TII REM provides additional insight for TII by:

- Focusing on road emissions and, in particular, the National Road Network (NRN) for which TII are responsible (e.g. for annual reporting);
- Identifying NRN route sections with the highest emissions that could be focused on to manage emissions;
- Considering how emissions may change over time on the NRN due to anticipated traffic growth and national policies;
- Analysing how interventions on the NRN (e.g. speed limit changes) will affect emissions;
- Simultaneously calculating GHG and non-GHG emissions will help identify mutually beneficial interventions and avoid unintended adverse outcomes from interventions that could be good for climate change but could negatively impact air quality in general;
- Calculating programme scale emissions before individual scheme development enabling mitigation or enhancements to be developed more cost effectively at an early stage; and
- Using a modular structure that allows for further functionality to be added without needing a completely new tool to be developed.

As the TII REM and the analyses of safety and economics both use traffic flow data from the National Transport Model (NTpM)[1] this facilitates integrated decision making for TII. The legislation and policy relevant to greenhouse gas and local air quality from vehicle emissions is presented in Section 2.

1.2 Tool Description

The TII REM has three main modular tools that are used together with traffic flows to generate emissions and local air quality predictions:

- Emissions Rate Database;
- Fleet Mix Database; and
- Air Quality Algorithm.

The Emissions Rate Database and the Fleet Mix Database are used with Traffic Data to generate vehicle emissions for individual roads (or sections of roads known as links), individual counties, or for total national emissions. The tool does this by multiplying together the classified vehicles in the Fleet Mix Database with the speed-based emission rates in the Emissions Rate Database and traffic flows. Traffic flows are inputted by the tool user through the Traffic Data File, whilst the Fleet Mix Database and Emissions Rate Database are embedded within the tool and linked to user control options.

The last module is the air quality algorithm which takes the link-based emissions and calculates pollutant concentrations. This module incorporates calculations of background pollutant contributions and the conversion of NO_X to NO_2. The modular approach ensures the overall tool is flexible and can input data within the Emission Rate Database and can be updated using the most appropriate sources of data in any future iterations. An overview of the modular TII REM is provided in Figure 1.1.

The following sub-sections describe the different modules and data inputted to the tool to generate emissions (Section 1.3 to 1.5). The module that take the emissions calculated at the link level to calculate pollutant concentrations from emissions are also described (Section 1.6).

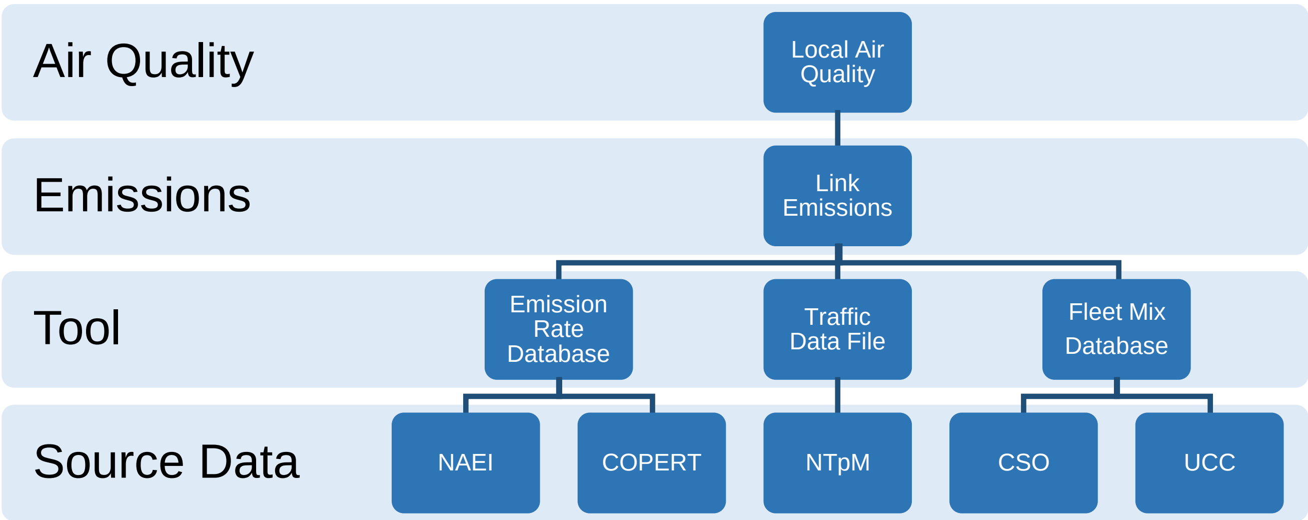

Figure 1.1 Schematic of the TII REM and Source Data

[1] AECOM on behalf of Transport Infrastructure Ireland (2019) NTpM Volumes 1-3 https://www.tii.ie/tii-library/strategic-planning/

1.3 Emission Rate Database

The TII REM utilises available information to create a bespoke emissions rate database which defines a speed-based emission rate for multiple pollutants for each vehicle classification.

The REM is designed to replicate the emissions output by the DEFRA Emissions Factors Toolkit (EFT), which utilises emissions profiles for NO_X and PM_{10} published in COPERT5 by the European Environment Agency (EEA)[2] along with additional scaling for use in the UK.

The EFT was developed on behalf of The Department for Environment, Food and Rural Affairs (DEFRA) in the UK to calculate emission rates for traffic data on discrete road links, which is necessary to inform air quality dispersion models in the prediction of pollutant concentrations around roads.

CO_2 is calculated with reference to emissions rates published by TRL on behalf of the UK Dept. for Transport (DfT)[3].

The REM utilises scenario settings, such as year and region, that refer to fleet composition and age profiles, with further detail incorporated on an individual link basis. This means that each link in a model can be run within a larger model network to determine the total or individual link emission rates.

To create the emissions rate database, emissions were calculated each pollutant at 5kph speeds (up to 140kph for light vehicles and 90 kph for heavy vehicles) and per each vehicle classification, fuel type, engine size or vehicle weight and euro classification. This resulted in an emissions rate database of over 20,000 data points for NO_X, particulate matter (PM_{10}) and CO_2. $PM_{2.5}$ is scaled from PM_{10} outputs, and non-CO_2 greenhouse gas are calculated independently speed (see Section 3.1).

1.4 Fleet Mix Database

The fleet mix is a core aspect of the tool, as this determines what the proportions of the different vehicle classifications (e.g. Euro classification) are to be applied from the classified database to the number of vehicles being modelled.

The proportions of the different vehicle classifications are also expected to change over time. This is because it is expected the fleet will move towards increased adoption of newer and relatively lower emission vehicles in the future, including greater uptake of hybrid (HEV), battery-electric (BEV) and alternative fuelled vehicles.

The fleet mix considers Euro classifications from pre-Euro to Euro 6c for light duty vehicles (<3.5 tonnes), such as cars and Light Goods Vehicles (LGVs), and up to Euro VI for Heavy Duty Vehicles (HDVs) such as Heavy Goods Vehicles (HGVs) and buses. The tool uses a common threshold of gross vehicle weight of 3.5 tonne for air quality and emissions modelling to denote the transition to Heavy Goods Vehicles. This threshold is used as above this weight vehicles tend to use a much larger and / or different category of engine technologies; i.e. vehicles tend to change from vans to light trucks. The Euro nomenclature also changes from numbers (i.e. 1 to 6d) to numerals (i.e. I, II, III, IV, etc) to signify this difference in vehicle class and engine size.

[2] Appendix 4 to chapter '1.A.3.b.i-iv Road transport', of the EMEP/EEA air pollutant emission inventory guidebook 2019 https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/road-transport-appendix-4-emission/view
[3] DfT (2009) Road vehicle emission factors 2009 https://www.gov.uk/government/publications/road-vehicle-emission-factors-2009

Data from the Central Statistics Office (CSO)[4] data for vehicle registrations for each county for cars and nationally for freight has been used to define the existing fleet mix. A county is assigned to each link in traffic model to determine the fleet breakdown.

For predictions on vehicle emissions in the future, more information is required than in the existing situation to describe how the vehicle fleet mix will change over time. A vehicle stock model (predicting future composition of vehicle fleet) provides this for the TII REM.

The fleet projection figures which underpin the vehicle fleet projections used in REM are derived from CSO registered vehicles[5] and the UCC stock model[6] derived from predecessor research[7, 8, 9]. The UCC car stock model utilises the TIMES Ireland energy systems optimisation model using facto such as technology choices, prices, output, etc, to determine real-world outcomes for given scenario[10]. DfT data[11] has been used to infill data gaps in the fleet model where necessary.

The projected stock models for non-goods vehicles (i.e. cars) are extrapolated from the UCC stock model for:

- Business as Usual (BaU) scenario; i.e. excluding strategic policy interventions for reduction of CO_2, etc, and based on existing trends in vehicle purchasing and turnover of vehicles out of the vehicle fleet.
- Climate Action Plan (CAP) based on achieving increases in EVs including 151,000 passenger car EV and PHEVs by 2025 and 840,000 passenger car EV and PHEVs by 2030.
- An intermediate case calculated by AECOM using linear extrapolation to a central value between BaU and CAP for each vehicle sub-classification.

For goods vehicles (i.e. LGVs and HGVs) there are no stock model projections and so a bespoke projection was created using CSO data for the registered goods vehicle fleet. The annual average mileage was disaggregated by gross weight, wherein it is assumed that all HGV continue to be diesel-fuelled.

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[4] Central Statistics Office data search https://data.cso.ie/#
[5] Central Statistics Office (accessed 2021) https://www.cso.ie/en/databases/
[6] O'Riordan, Vera, Rogan, Fionn, Mulholland, Eamonn, Ó Gallachóir, Brian, & Daly, Hannah. (2021). Irish Car Stock Model V 2.4 (v2.4) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.4651477. These data are open source under a creative commons license, which allows for use for non-commercial purposes.
[7] Hannah Daly, Brian P. Ó Gallachóir (2011), "Modelling private car energy demand using a technological car stock model", Transportation Research Part D: Transport and Environment, Volume 16, Issue 2, 2011, Pages 93-101, ISSN 1361-9209, https://doi.org/10.1016/j.trd.2010.08.009
[8] Hannah E. Daly, Brian P. Ó Gallachóir (2011), Modelling future private car energy demand in Ireland, Energy Policy, Volume 39, Issue 12, 2011, Pages 7815-7824, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2011.09.027
[9] Eamonn Mulholland, Fionn Rogan, Brian P.Ó Gallachóir (2017), Techno-economic data for a multi-model approach to decarbonisation of the Irish private car sector, Data in Brief, Volume 15, 2017, Pages 922-932, ISSN 2352-3409, https://doi.org/10.1016/j.dib.2017.10.006
[10] Gallochoir et. al (2012) Irish TIMES Energy Systems Model https://cora.ucc.ie/handle/10468/7293#:~:text=It%20involved%20building%2C%20developing%2C%20calibrating%2C%20testing%20and%20running,and%20KanORS%20over%20the%20period%20March%202009%E2%80%93November%202011.
[11] Dept. for Transport (2018) Road traffic forecasts 2018 https://www.gov.uk/government/publications/road-traffic-forecasts-2018

1.5 Traffic Data File and Other User Inputs

The users of the tool input Traffic flow data, such as from the National Transport Model[12] (NTpM).

Transport Infrastructure Ireland (TII) has developed and maintained the NTpM over the last decade to support its strategic management of and planning for the national road network. The transport model contains information on the current and future national road networks and the traffic carried on those networks. It contains information on travel demand for a number of trip types between 1,129 zones, including principal ports and airports. It contains information on the volume of light and heavy vehicles, and the speed at which it travels, for all links on the road networks.

The TII National Traffic Model (NTM) is a core module of the TII NTpM focused on highway demand only. The NTM is updated on an annual basis to provide an estimate of traffic demand across the national roads network. To inform this annual update, traffic data from over 300 TII permanent traffic counters[13] are utilised to inform the calibration and validation of these annual updates. For the purposes of the TII REM, the 2018 TII NTM was utilised.

Users input traffic data using a data input template file provided with the tool. The tool user also selects in the tool whether just emissions are required or if pollutant concentrations are required, for which pollutants and the year calculations are required.

A user guidance with frequently asked questions is provided to tool users which is accessible within the tool.

1.6 Air Quality

The air quality tool predicts the atmospheric pollutant concentration resultant from the road-source emission rate as a product of dispersion, which increases with distance, calculating an ambient pollutant concentration. The ambient pollutant concentration is reported as a mass per volume of air as $\mu g/m^3$.

The dispersion algorithm is derived from of the Design Manual for Roads and Bridges (DMRB) screening tool[14]. The results from this algorithm is combined with background contributions; i.e. from non-road sources to determine the overall concentration.

The air quality tool is discussed further in Section 5, and an overview is provided in Figure 1.2.

[12] https://www.tii.ie/tii-library/strategic-planning/
[13] Referred to as TII Traffic Monitoring Units - https://trafficdata.tii.ie/publicmultinodemap.asp
[14] Method for using the output from the Casella Stranger EFT in the Local Air Quality Assessment and Regional Impact Assessment application of DMRB Screening Method Version 1.02

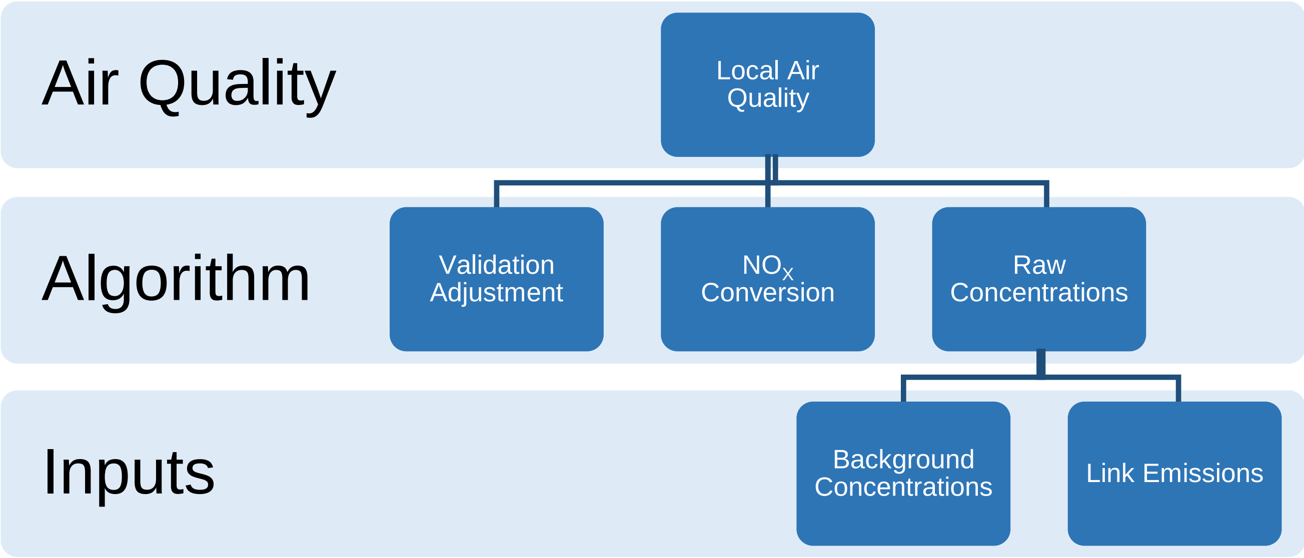

Figure 1.2 Modular Approach Schematic to Air Quality Calculations

1.7 Data Outputs

The tool has three primary types of outputs:

- Total annual emissions in (kg/yr) or tonnes per year (t/yr) for carbon dioxide (CO_2 and CO_2e) for the national scale or for individual counties for all roads or just for the TII National Road Network; or,
- Total annual emissions and emission rates for multiple pollutants for each traffic link, reported as grammes per second (g/s) or g/s per km (g/km/s) that can be used in separate detailed air quality modelling packages, and,
- Local air quality is reported as annual mean pollutant concentrations, as micrograms per cubic metre (µg/m^3).

These data may be tabulated for further analysis and reporting or presented spatially on figures via GIS or graphically (e.g. bar charts or regional totals or projected trends).

1.8 Tool Interface

Emissions and air quality modelling typically incorporate spreadsheets and workbooks in formats compatible with Microsoft Excel, or similar, GIS and databasing.

However, the REM needs to process a significant amount of data resulting in very large file sizes and so spreadsheet-based tools (i.e. Excel) were not considered appropriate. Therefore, the R development language was used for the tool as the R language allows calculations to be undertaken rapidly for large amounts of data.

The tool uses a web-based interface comprising front page, instructions tab, inputs tab, with the classified emissions hidden in a locked tab, and a set of output tabs, as shown in Figure 1.3.

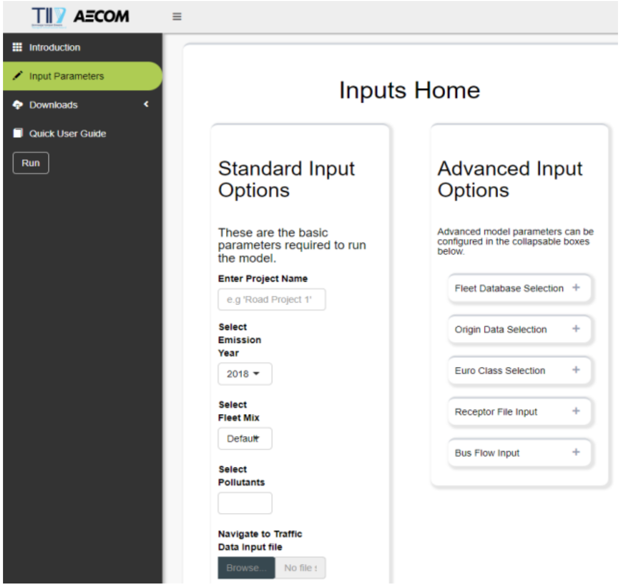

Figure 1.3 Screenshot of TII REM Web Interface

Output data are presented for predicted emissions on a County, National and a link by link basis which may be exported to Geographical Information Systems (GIS).

Where the air quality tool is used, the annual mean roadside pollutant concentration resultant from the emissions are assigned to each individual link and these emissions may be exported to be presented graphically.

1.9 Tool Linkages

In addition to the TII REM there is another TII Emissions Tool; the TII Carbon Tool. The focus of the TII Carbon tool is scheme-based assessments for both road-based projects and light rail projects.

The TII Carbon tool considers a wide range of Carbon sources and different stages including before scheme opening (pre-construction, embodied carbon, construction activities and waste), in service (e.g. maintenance emissions and vehicles emissions) and decommissioning.

Vehicle emissions that are associated with schemes are typically inputted by the user into the TII Carbon tool from transport users benefit appraisal (TUBA) traffic model[15] outputs. These are inputted in to one tab of the TII Carbon tool entitled 'Emissions Associated with Vehicles Using the Infrastructure Data Entry'.

The Carbon emissions data calculated from the TII emissions and air quality model are output using common nomenclature (i.e. tCO_2e), and so ensures compatibility with associated industry tools and the TII Carbon Tool.

The TII REM has clear advantages over current alternative tools, such as TUBA, as it is intended to be scalable, and enable differentiation of discrete geospatial areas, road types, vehicle classifications, etc, to match the resolution of the traffic model. The TII REM differs significantly from TUBA which provides emissions calculated over longer journeys compared to individual link emissions calculations.

[15] Dept. of Transport (2020) Transport users benefit appraisal: software and user manuals, https://www.gov.uk/government/publications/tuba-downloads-and-user-manuals

This link-based emission calculation approach avoids smoothing out of emissions that can occur in TUBA. Also, as the TII REM uses detailed fleet predictions for age, fuel technology, engine size and weight it also enables the user to gain additional insights to inform on possible interventions for different scenarios.

1.10 Data Sources

The available data sources that have been considered below:

- Navteq data for the island of Ireland[16]
- Central Statistics Office (CSO) CSO Road Traffic Volumes
- Irish Bulletin of Driver Statistics 2019
- Statistics of the Irish Motor Industry
- National Transport Model Update – Travel Demand Forecasting Report[17]
- EU COPERT
- UK (DEFRA) Emissions Factors Toolkit
- EPA Air Quality in Ireland annual reporting[18]
- EPA Urban Environmental Indicators Annual Report[19]
- CERC -Urban air quality modelling of Dublin 2019

The key information identified from the above available data sources is summarised in the following sections of the report and a detailed breakdown of the information is also provided in Appendix A.

[16] https://www.here.com/navteq
[17] https://www.tii.ie/tii-library/strategic-planning/national-transport-model/NTpM-Vol3-Travel-Demand-Forcasting-Report.pdf
[18] https://www.epa.ie/our-services/monitoring--assessment/air/
[19] https://www.epa.ie/publications/monitoring--assessment/air/Urban_Environmental_Indicators_2019.pdf

2. Legislation and Policy

This section of the scoping report describes relevant legislation and policy used to inform upon the key indicators and questions the TII REM may be required to address.

2.1 European Legislation and Policy

European Union (EU) air quality legislation is provided within The Ambient Air Quality and Cleaner Air for Europe Directive 2008/50/EC[20], which is transcribed into Irish legislation by the Air Quality Standards Regulations 2011[21]. The Air Quality Limit Values (AQLVs) are legally binding for Ireland and have been set with the aim of avoiding, preventing, or reducing harmful effects on human health and on the environment.

The European Commission set down the principles to this approach in 1996 with its Air Quality Framework Directive. Four "daughter" directives lay down limits for specific pollutants:

- 1st Daughter Directive: Sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead[22];
- 2nd Daughter Directive: Carbon monoxide and benzene[23];
- 3rd Daughter Directive: Ozone[24]; and
- 4th Daughter Directive: Polyaromatic hydrocarbons, arsenic, nickel, cadmium and mercury in ambient air[25].

CAFE replaced the Framework Directive and the first, second and third Daughter Directives. The fourth Daughter Directive (2004/107/EC) will be included in CAFE at a later stage.

2.1.1 Air Quality Zones

Under the Clean Air for Europe Directive, EU member states must designate "Zones" for the purpose of managing air quality. For Ireland, four zones were defined in the Air Quality Standards Regulations (2011)[26]. The zones were amended on 1 January 2013 to take account of population counts from the 2011 CSO Census and to align with the coal restricted areas in the 2012 Regulations (S.I. No. 326 of 2012). The main areas defined in each zone are presented in Table 2.1.

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[20] Ambient Air Quality and Cleaner Air for Europe Directive 2008/50/EC
[21] Air Quality Standards Regulations 2011 - S.I. No. 180/2011
[22] Air quality 1st Daughter Directive 1999/30/EC
[23] Air quality 2nd Daughter Directive 2000/69/EC
[24] Air quality 3rd Daughter Directive 2002/3/EC
[25] Air quality 4th Daughter Directive 2004/107/EC
[26] Air Quality Standards Regulations 2011 - S.I. No. 180/2011

Table 2.1 Air Quality Zones in Ireland

Zone	Areas within zones
A	Dublin
B	Cork
C	Other cities and large towns comprising Limerick, Galway, Waterford, Drogheda, Dundalk, Bray, Navan, Ennis, Tralee, Kilkenny, Carlow, Naas, Sligo, Newbridge, Mullingar, Wexford, Letterkenny, Athlone, Celbridge, Clonmel, Balbriggan, Greystones, Leixlip and Portlaoise.
D	Rural Ireland, i.e. the remainder of the State excluding Zones A, B and C.
Source: Environmental Protection Agency - Air Quality Zones27	

The Air Quality Standards (AQS) of relevance to this assessment are outlined in Table 2.2 and apply at locations outlined in Table 2.3. Standards are expressed in one of two ways: as annual mean concentrations which are not to be exceeded without exception, due to their chronic effects; or as shorter term (24-hour or 1-hour) mean concentrations for which only a specified number of exceedances are permitted within a specified time frame, due to their acute effects.

Table 2.2 Irish National Air Quality Standards

Pollutant	Averaging Period	Value	Max Permitted Exceedances
Nitrogen Dioxide (NO_2)	Annual Mean	40 µg/m^3	None
	Hourly Mean	200 µg/m^3	18 times per year
Particulate Matter (PM_{10})	Annual Mean	40 µg/m^3	None
	24-hour	50 µg/m^3	35 times per year
Fine Particulate Matter ($PM_{2.5}$)	Annual Mean	25 µg/m^3	None
Nitrogen Oxides (NO_X)	Annual Mean	30 µg/m^3	None
Source: Environmental Protection Agency – Air Quality Standards[28]			

[27] Environmental Protection Agency - Air Quality Zones. Available online at: https://www.epa.ie/air/quality/zones/, Accessed on: July 2020
[28] Environmental Protection Agency – Air Quality Standards. Available online at: https://www.epa.ie/air/quality/standards/, Accessed on: July 2020

Table 2.3 Examples Where Air Quality Standards Apply

Averaging Period	Objectives Should Apply At	Objectives Should Not Apply At
Annual mean	All locations where members of the public might be regularly exposed. Building façades of residential properties, schools, hospitals, care homes etc.	Building façades of offices or other places of work where members of the public do not have regular access. Hotels, unless people live there as their permanent residence. Gardens of residential properties. Kerbside sites (as opposed to locations at the building façade), or any other location where public exposure is expected to be short term.
24-hour mean	All locations where the annual mean objective would apply, together with hotels. Gardens of residential properties.	Kerbside sites (as opposed to locations at the building façade), or any other location where public exposure is expected to be short term.
1-hour mean	All locations where the annual mean and 24-hour mean objectives apply. Kerbside sites (for example, pavements of busy shopping streets). Those parts of car parks, bus stations and railway stations etc. which are not fully enclosed, where members of the public might reasonably be expected to spend one hour or more. Any outdoor locations where members of the public might reasonably be expected to spend one hour or longer.	Kerbside sites where the public would not be expected to have regular access.
Source: Local Air Quality Management, Technical Guidance (LAQM.TG (16))[29]		

2.1.2 Emissions Legislation

The National Emission Ceilings (NEC) Directive[30] defines national emission reduction commitments for EU Member States, including Ireland, for nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2), ammonia (NH_3) and fine particulate matter ($PM_{2.5}$).

Ireland has consulted on the statutory National Air Pollution Control Programme, which includes:

- An overview of sectors and national policy frameworks;
- An overview of the current outlook for compliance with NEC targets;
- Projections of relevant pollutant emissions to 2030; and

[29] Local Air Quality Management Technical Guidance (TG16) (Department for Environment, Food and Rural Affairs, 2018)
[30] National Emissions Ceiling Directive 2016/2284/EU

- Policy options, measures, and actions across sectors; particularly in the residential, transport agricultural and energy sectors.

2.2 National Policy

2.2.1 Project Ireland 2040

Project Ireland 2040[31] was launched in February 2018 and comprises the National Planning Framework (NPF)[32] and the National Development Plan 2018 – 2027 (NDP)[33]. Project 2040 is a long-term overarching strategy which aligns investment decisions with a clearly defined development strategy and ten National Strategic Outcomes (NSO).

A number of these NSOs have the potential to affect vehicle emissions on the TII road network including:

- Enhanced Regional Accessibility (NSO2);
- Sustainable Mobility (NSO4);
- Transition to a low Carbon and Climate Resilient Society (NSO8); and
- Sustainable Management of Water, Waste and other Environmental Resources (NSO9).

2.2.2 National Planning Framework

The National Planning Framework (NPF) will guide development and exchequer investment up to 2040. The Strategy provides each region with a set of objectives and key principles from which detailed plans are to be developed. The NPF also sets out national policy objectives (NPO) to help deliver the NSOs. The two policies of greatest relevance to air quality and greenhouse gases are set out below:

- NPO54: Reduce our carbon footprint by integrating climate action into the planning system in support of national targets for climate policy mitigation and adaptation objectives, as well as targets for greenhouse gas emissions reductions.
- NPO64: Improve air quality and help prevent people being exposed to unacceptable levels of pollution in our urban and rural areas through integrated land use and spatial planning that supports public transport, walking and cycling as more favourable modes of transport to the private car, the promotion of energy efficient buildings and homes, heating systems with zero local emissions, green infrastructure planning and innovative design solutions.

The proposals in the NPF for NSO2 include a range of actions for Inter-urban roads. The actions include traffic management and infrastructure upgrades. NSO4 actions describe plans to expand public transport as an alternative to car transport with a focus on urban areas.

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[31] Project Ireland 2040. Available Online at: https://www.gov.ie/en/policy/project-ireland-2040-policy/, Accessed on: July 2020
[32] Project Ireland 2040: National Planning Framework. Available online at: https://www.housing.gov.ie/sites/default/files/publications/files/project_ireland_2040_npf_7mb.pdf, Accessed on: July 2020
[33] Project Ireland 2040: National Development Plan 2018 – 2027. Available online at: https://www.gov.ie/pdf/?file=https://assets.gov.ie/37937/12baa8fe0dcb43a78122fb316dc51277.pdf#page=null, Accessed on: July 2020

The specific actions relating to NSO8 do not include actions related to road traffic with actions focused on electricity generation and distribution. Similarly, NSO9 does not include actions relating to road traffic.

2.2.3 National Development Plan 2018 - 2027

Project Ireland 2040s National Development Plan 2018 – 2027 (NDP) is the most recent infrastructure investment plan adopted by the government.

The NDP supports the delivery of Project Ireland 2040 through public capital investment over the next ten years and guides national, regional, and local planning and investment decisions in Ireland over the next two decades.

The Plan caters for an increase in the population of over 1 million people by 2040. It identifies €116 billion for investment in capital projects targeted at enhancing regional development and driving economic growth.

The NDP includes a range of investment proposals relating to NSO2 including the TII National Roads Programme 2018 - 2027 supporting both inter-urban road improvements and accessibility to the North-West. Whilst for NSO4 a range of bus, tram and rail proposals are identified. For NSO8 there are a wide range of proposals including 7 relating to transport:

- At least 500,000 electric vehicles on the road by 2030 with additional charging infrastructure to cater for planned growth;
- No new non-zero emission vehicles to be sold in Ireland post 2030;
- Transition to low emission, including electric buses, for the urban public bus fleet with no diesel only buses purchased from 1 July 2019;
- Bus Connects Programme;
- No NCT Cert will be issued for non-zero emission cars post 2045;
- Sustainable travel measures, including comprehensive Cycling and Walking Network for metropolitan areas of Ireland’s cities, and expanded Greenways; and
- Comprehensive integrated public transport network for Ireland’s cities connecting more people to more places (see NSO4).

2.2.4 Strategic Investment Framework for Land Transport (SIFLT)

The Department of Transport, Tourism and Sport's (DTTaS) Strategic Investment Framework for Land Transport (2015)[34] lays out the role of transport in the future development of the Irish economy.

The Framework highlights Ireland's obligations regarding the reduction of carbon emissions. It identifies the need for radical transformation within the transport sector if the targeted reduction in carbon emissions of 80% by 2050 is to be achieved.

The need for investment now is also established by illustrating that the existing land transport systems cannot cater for the projected increases in population and a 35% increase in commuting trips by 2040.

[34] Strategic Investment Framework for Land Transport (SIFLT) 2015. Available online at: https://igees.gov.ie/wp-content/uploads/2014/09/consultation-sfilt-investing-our-transport-future-steering-group-report.pdf, Accessed on: July 2020

The framework priorities outlined below echo the Project Ireland 2040 National Strategic Outcomes and guide investment decisions for transport schemes:

- **Address Urban Congestion:** The need to address urban congestion is prioritised within the Framework to improve the efficiency and sustainability of the urban transport system. Specifically, there is a need to remove bottlenecks in the system which hinder growth. This is to be achieved by improving and expanding public transport capacity, the expansion of walking and cycling infrastructure and the broader use of technology within transport systems.
- **Maximise the contribution of Land Transport to National Development:** Transport systems should enhance the efficiency of the existing network, improve connections to key ports and airports and support national and regional spatial planning priorities.
- **Maintain existing assets:** The Framework states that the foremost priority for land transport funding should be the maintenance and renewal of identified strategically important elements of the current land transport system, to protect earlier investment and maintain essential functioning.

2.2.5 National Investment Framework for Transport in Ireland (NIFTI)

Following the publication of Project Ireland 2040, DTTaS commenced the National Investment Framework for Transport in Ireland (NIFTI)[35] initiative to update the SIFLT. The review to date has identified several priorities for incorporation into the planning framework. Within NIFTI, there is continued focus on the need to address climate change through the delivery of lower emissions in transport networks supported by technological initiatives. NIFTI has established priorities for transport projects up to 2040 which include:

- A land transport network which delivers a high level of service for the population of Ireland;
- Enabling the delivery of the NPF objectives regarding where people live and work;
- Maximising the contribution of the sector to Ireland's economic competitiveness; and
- Realising a low carbon sustainable transport system.

2.2.6 Climate Action Plan

The government published the Climate Action Plan in June 2021[36]. The Action Plan sets out actions to reduce Irelands greenhouse gas emission across a range of sectors, including transport, to combat climate change.

The realisation of the Action Plan will have positive impacts on the environment, society, and economy of the country. The Action Plan states that transport accounted for 19.6% of Ireland's greenhouse gases in 2018. The impact of emissions contributes to poor local air quality which reduces people's quality of life and harms their health.

The Action Plan sets out specific timeframes and targets to meet the required level of emissions by 2030 for the transport sector, including:

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[35] National Investment Framework for Transport in Ireland (NIFTI), Department of Transport, Tourism and Sport. Available online at: https://igees.gov.ie/wp-content/uploads/2018/07/Planning-Land-Use-and-Transport-%E2%80%93-Outlook-2040-by-Alan-Scarlett-and-Tom%C3%A1s-Campbell.pdf, Accessed on: July 2020
[36] Climate Action Plan 2021. Available online at: https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/ Accessed on: July 2021.

- Reduce CO_2e emissions from the sector by 45–50% relative to 2030 pre-NDP projections';
- Provide for an additional 500,000 daily public transport and active travel journeys;
- Increase the number of EVs to 945,000, comprised of:
  - 845,000 passenger EVs;
  - 95,000 electric vans;
  - 3,500 low emitting trucks; and,
  - 1,500 electric buses.
- Raise the blend proportion of biofuels to B20 in diesel and E10 in petrol;
- Reduce ICE kilometres by ~10 compared to present day levels; and
- Undertake a programme of work which will review progress and further refine measures that will seek to deliver the additional ~0.9 $MtCO_2$ reduction by 2030 in a fair and equitable manner.

A key policy to drive mode shift is the delivery of compact development and greater integration of policies for land use and transport planning. Combined, these policies will reduce the demand for commuter travel and support more efficient patterns of development and travel.

The Action Plan identifies actions (actions 231-302) for the transport sector to reduce the impact of emissions and meet the overall targets of the Climate Action Plan.

A key focus is of the plan is supporting the transition away from combustion engine vehicles with a wide range of actions in this area. There are also actions concerning alternative fuels, taxation plans to encourage cleaner vehicles, low emission zone actions, actions on cleaning up public transport vehicles and modal shift, including park and ride and active travel actions to encourage cycling etc.

2.2.7 National Mitigation Plan

The National Mitigation Plan published by the Department of Communications, Climate Action and Environment in 2017[37] outlines a series of medium to long term measures to facilitate the transition to a low carbon, climate-resilient and environmentally sustainable economy by 2050. The Plan includes over 100 individual actions across numerous government departments and public bodies within the electricity, built environment and transport sectors.

The Plan responds to targets laid out previously in the Paris Climate Agreement (COP21) in 2015 which mandated member states to move towards decarbonised economies by 2050 and sets a target of an 80% reduction in emissions across the electricity, built environment and transport sectors by 2050.

[37] National Mitigation Plan 2017. Available online at: https://static.rasset.ie/documents/news/national-mitigation-plan-2017.pdf, Accessed on: July 2020

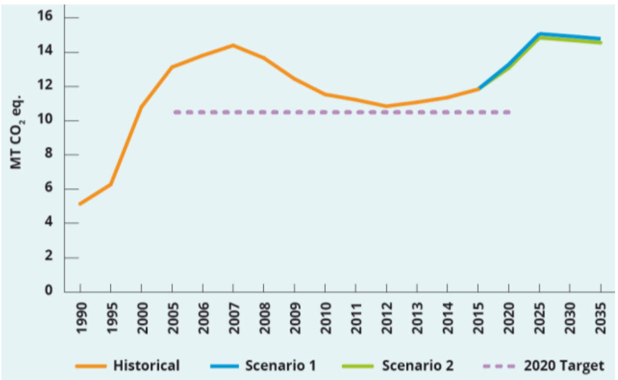

Figure 2.1 Projections of Greenhouse Gas Emissions from the Transport Sector[38]

Recognising transport as one of the largest contributors of greenhouse gas emissions and that emissions within the sector have increased in recent years, the plan identifies specific measures to develop and invest in public transport and encourage a modal shift away from private cars.

2.2.8 Transport Infrastructure Ireland Statement of Strategy 2019 - 2023

The TII Statement of Strategy sets out the strategic objectives and actions for TII in the period 2019 to 2023[39]. One of the strategic objectives set out is Sustainability;

"Apply sustainability principles in developing and operating road and light rail systems".

This objective is further broken down in a series of ten strategic actions. Those of particular relevance are set out below:

- Implement measures outlined in M50 Demand Management study;
- Plan and deliver energy efficiency measures;
- Expand and enhance deployment and operation of intelligent transport systems;
- Develop standards to promote innovation and collaboration based on best international practice; and
- Develop a vision for the national road network to 2040 to align with Project 2040.

The strategy also includes a new infrastructure objective to "*Lead the cost efficient and effective delivery of national road, light rail and metro elements of the National Development Plan."*

There are an associated 7 strategic actions for this objective. These include actions relating to the development of scheme pipelines, appraisals, and approvals for schemes:

- Achieve planning approval for Capital Investment Plan projects including: N6 Galway City Bypass and N28 Cork to Ringaskiddy;
- Develop a pipeline of major projects for future capital investment plans;
- The development of a pipeline of major road projects within the overall national roads programme and available funding will be prioritised; and

[38] Environmental Protection Agency (2019) – Air Quality in Ireland 2018
[39] TII Statement of Policy 2019 – 2023. Available online at: https://www.tii.ie/tii-library/statements-of-strategy/statement-of-strategy-2019-2023/TII-Statement-of-Strategy_Approved_May_2019.pdf Accessed July 2020

- Undertake appraisal, planning and design of Luas network expansion to Bray, Lucan, Finglas and Poolbeg in accordance the NDP and the Transport Strategy for the Greater Dublin Area.

2.2.9 Transport Infrastructure Ireland's Environmental Strategy

The TII Environmental Strategy[40] sets out how TII will minimise and enhance the environment, where possible, whilst delivering national road, light rail, and metro services. Key aspects of the Environmental Strategy of relevance to this scoping study include:

- The TII four stage Environmental Integration Model (EIM) and particularly stage 1;
- The TII Environmental Vision for the Future; and
- The TII focus areas for the future, both over the short and medium term.

The EIM considers Stage 1 of Project Planning where there is the first opportunity to consider the risk of significant environmental effects from schemes, consider alternatives and potential mitigation.

Air quality is highlighted in this section of the EIM as a typical issue for projects and setting out TIIs commitment to air quality:

> *"The key focus is to ensure that air quality for communities adjoining national road, light rail and metro projects is not significantly impacted. TII continues to work with stakeholders and partners to explore opportunities to manage the operation of major roads and to provide a road network that will allow a more flexible approach to the adoption of Ultra Low Emission Vehicles and new emerging vehicle technologies."*

In the Future Transport Trends, 11 trends are highlighted. These include themes of particular relevance including:

- Smarter Infrastructure;
- Decarbonisation;
- Congestion Costs;
- Regional Connectivity, Land-Use Patterns; and
- Ecosystem Services.

In the TII areas of particular focus in the short term the decarbonisation agenda is highlighted as a key area, along with monitoring for air quality both along the M50 and more broadly. Further real time air quality monitoring using sensor technology is also identified as a medium-term area of focus.

2.2.10 TII Sustainability Implementation Plan

As a United Nations (UN) Member State, Ireland has adopted the 2030 Agenda for Sustainable Development[41]. TII is tasked with improving Ireland's quality of life and national economic competitiveness by developing, maintaining and operating the national road and light rail network in a safe, cost effective and sustainable way.

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[40] Transport Infrastructure Ireland 2019. Available online at: https://www.tii.ie/technical-services/environment/strategy/TII-Environmental-Strategy.pdf, Accessed July 2020
[41] United Nations (2022) Transforming Our World:
The 2030 Agenda tor
Sustainable Development
https://www.un.org/ohrlls/sites/www.un.org.ohrlls/files/2030_agenda_for_sustainable_development_web.pdf

In 2020 TII published its Sustainability Implementation Plan[42] which sets the direction for TII, aligns objectives, brings together different workstreams and harnesses the opportunity each Division/Section has to contribute to sustainability. The plan is guided by the following six key principles:

- Provide effective, efficient and equitable mobility;
- Enable safe and resilient networks and services;
- Collaborate for a holistic approach;
- Deliver end-to-end improvements;
- Transition to net zero; and
- Create total value for society.

2.3 Summary of Policy

The review of policy has identified that there is a wide range of transport related policy that is expected to change traffic flows across the TII road network. The development of the TII REM will enable TII to understand many of the anticipated changes that will be required to achieve strategic objectives such as:

- Enhanced Regional Accessibility (NSO2) - through infrastructure development;
- Sustainable Mobility (NSO4) – through modal shift reducing car use; and
- Transition to a low Carbon and Climate Resilient Society (NSO8) – through increased EV use and reductions in combustion engines.

In relation to specific TII areas of focus relating to the TII Statement of Strategy the following benefits from the TII REM are anticipated be:

- The potential to show changes in air quality and carbon emissions over large scales across the road network due to demand or intelligent traffic management systems.
- The ability to demonstrate how air quality and carbon emissions would be affected across the road network as the vision for the national road network to 2040 is developed.

Whilst for the TII Environmental Strategy the anticipated benefits of the REM are set out below:

- The crucial Stage 1 step of the EIM could be enhanced by allowing an earlier view of the entire TII National Roads Programme 2018 - 2027, by modelling schemes in the NTpM at a high level and then calculating the associated emissions and air quality using the proposed tool. This will enable TII to understand potential air quality and carbon vehicle emissions at a far earlier stage. This stage of assessment for programmes of schemes or individual schemes could become a discrete earlier stage in the EIM process (e.g. Stage 0).
- The focus on decarbonisation and the use of the TII Carbon Tool will be bolstered by the development of the REM, providing a network wide scale of carbon vehicle emissions. This could be combined with an expanded TII Carbon tool that considers network scale embodied carbon etc. to provide whole network carbon emission estimates.

[42] TII (2020) Sustainability Implementation Plan https://www.tii.ie/tii-library/sustainability/TII-Sustainability-Implementation-Plan_Our-Future_EXTERNAL.pdf

For the short and medium-term air quality monitoring areas of focus the proposed TII REM will enable monitoring to be focused on the locations of greatest potential concern along the TII road network.

3. Methodology

The REM uses the structure outlined in Figure 1.1 to combine the Emission Rate Database and Fleet Mix Database with the Traffic Data File.

3.1 Emissions

The REM is designed to replicate the emissions output by the DEFRA Emissions Factors Toolkit (EFT)[43], which utilises emissions profiles for NO_X and PM_{10} published in COPERT5 by the European Environment Agency (EEA)[44]. These data are the same as those used in the UK National Atmospheric Emissions Inventory (NAEI)[45].

The EFT was developed on behalf of The Department for Environment, Food and Rural Affairs (DEFRA) in the UK to calculate emission rates for traffic data on discrete road links, which is necessary to inform air quality dispersion models in the prediction of pollutant concentrations around roads.

Emissions for alternative technology vehicles, e.g. hybrid-petrol, are derived from NAEI guidance on emission factors for alternative vehicle technologies[46] that apply speed-based scaling or different road types to comparable ICE vehicle emissions.

Further adjustments to emissions rates were made to account for fuel scaling[47] and engine degradation[48, 49] as well as catalyst or DPF fails, which are modelled based on a fraction of the LDV fleet reassigned as pre-Euro or Euro 4 respectively[50].

CO_2 is calculated with reference to emissions rates published by TRL on behalf of the Dept. for Transport (DfT)[51].

Non-CO_2 GHG, predominantly nitrous oxide (N_2O) and methane (CH_4), are presented as CO_2 equivalent (CO_2e) and scaled for global warming potential.

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43 DEFRA (2021) Emissions Factors Toolkit https://laqm.defra.gov.uk/air-quality/air-quality-assessment/emissions-factors-toolkit/
44 Appendix 4 to chapter '1.A.3.b.i-iv Road transport', of the EMEP/EEA air pollutant emission inventory guidebook 2019 https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/road-transport-appendix-4-emission/view
45 NAEI Emission factors for transport https://naei.beis.gov.uk/data/ef-transport
46 NAEI (2013) Emission Factors for Alternative Vehicle Technologies https://naei.beis.gov.uk/resources/NAEI_Emisison_factors_for_alternative_vehicle_technologies_Final_Feb_13.pdf
47 TRL (2009) Emission Factors - scaling factors for mileage and improvements in fuel quality https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fassets.publishing.service.gov.uk%2Fgovernment%2Fuploads%2Fsystem%2Fuploads%2Fattachment_data%2Ffile%2F4255%2Ffuelscaling.xls&wdOrigin=BROWSELINK
48 EMEP/EEA air pollutant emission inventory guidebook 2016 Chapter 1-a-3-b-i. https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i
49 DEFRA (2017) Method for Applying Emission Degradation Correction Factors to the COPERT 5 NO_X Emission Factors For
Petrol Cars and LGVs
50 NAEI (2019) rtp_fleet_projection_NAEI_2017_Base 2019r_v1.1 https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fnaei.beis.gov.uk%2Fresources%2Frtp_fleet_projection_TfL_London_data.xlsx&wdOrigin=BROWSELINK
51 DfT (2009) Road vehicle emission factors 2009 https://www.gov.uk/government/publications/road-vehicle-emission-factors-2009

The UK Department for Business, Energy & Industrial Strategy (BEIS) publish data tables of emission rates for CO_2, CH_4 and N_2O as CO_2e as g/km[52], which were used to calculate CO_2e. A comparison of the primary tools for calculating and reporting Carbon Dioxide (CO_2) and CO_2-equivalient (CO_2e) vehicle emissions are provided in Appendix E.

The fraction of $PM_{2.5}$ from exhaust is assumed to be equal to PM_{10} in accordance with current best-practice guidance[53].

Non-exhaust Emissions (NEE) are calculated with reference to emissions rates published by the DEFRA Air Quality Experts Group[54] and Ricardo-AEA[55]. These values are the same as a more recent report, also published by Ricardo-AEA[56].

3.2 Traffic Flow Data

The traffic flow data used in the emissions model is from the NTpM, which is a strategic link-based transport model.

The extents of the NTpM and NRN are shown in Figure 3.1 and Figure 3.2, respectively.

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52 https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020
53 DEFRA (2021) Emissions Factors Toolkit v11.0 User Guide
54 DEFRA (2019) Air Quality Expert Group: Non-Exhaust Emissions from Road Traffic https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1907101151_20190709_Non_Exhaust_Emissions_typeset_Final.pdf
55 Ricardo-AEA (2013). UK Informative Inventory Report (1980 to 2011). https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1303261254_UK_IIR_2013_Final.pdf
56 Ricardo-AEA (2014) Production of Updated Emission Curves for Use in the National Transport Model https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/662795/updated-emission-curves-ntm.pdf

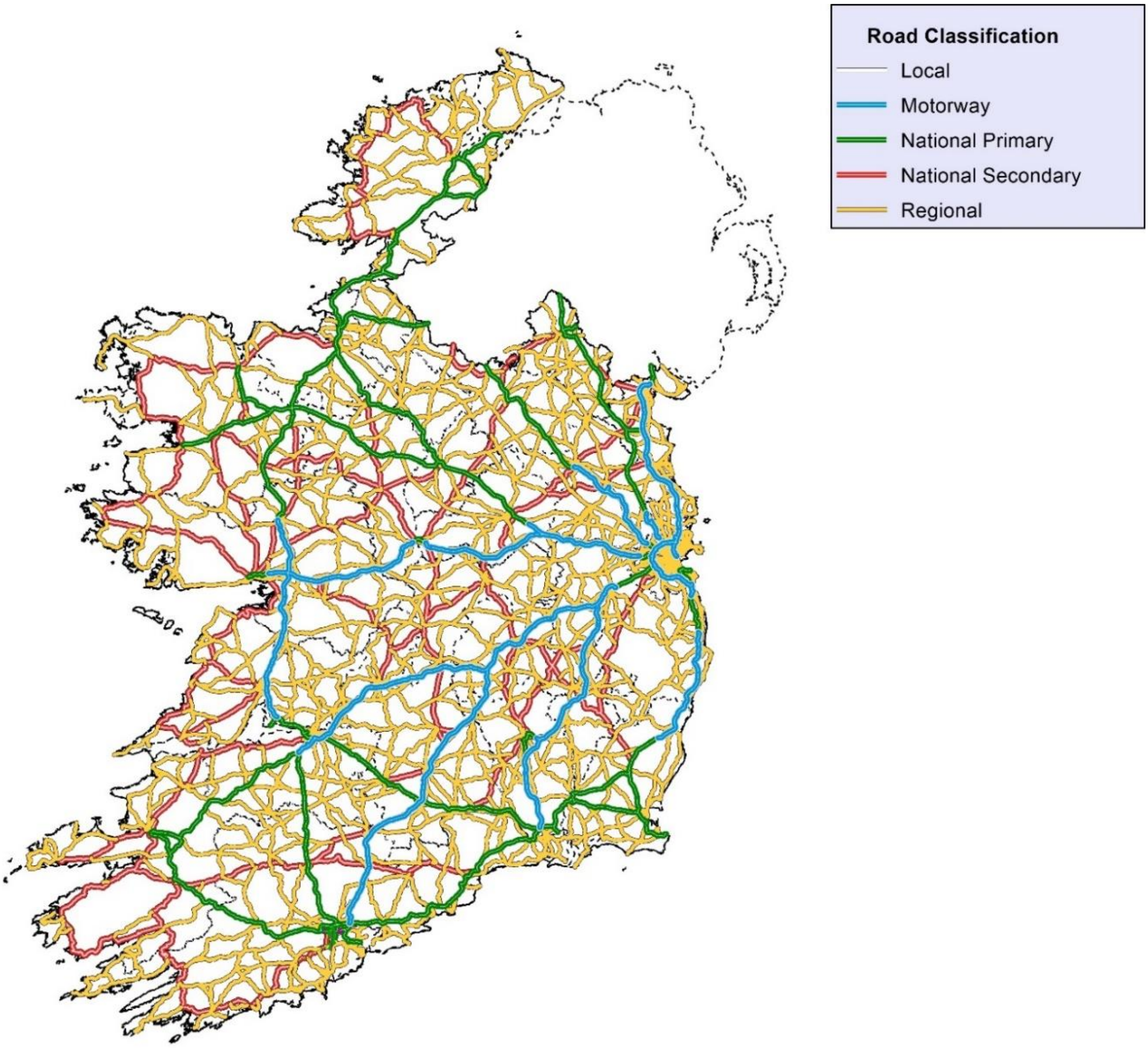

Figure 3.1 NTpM Network Extent

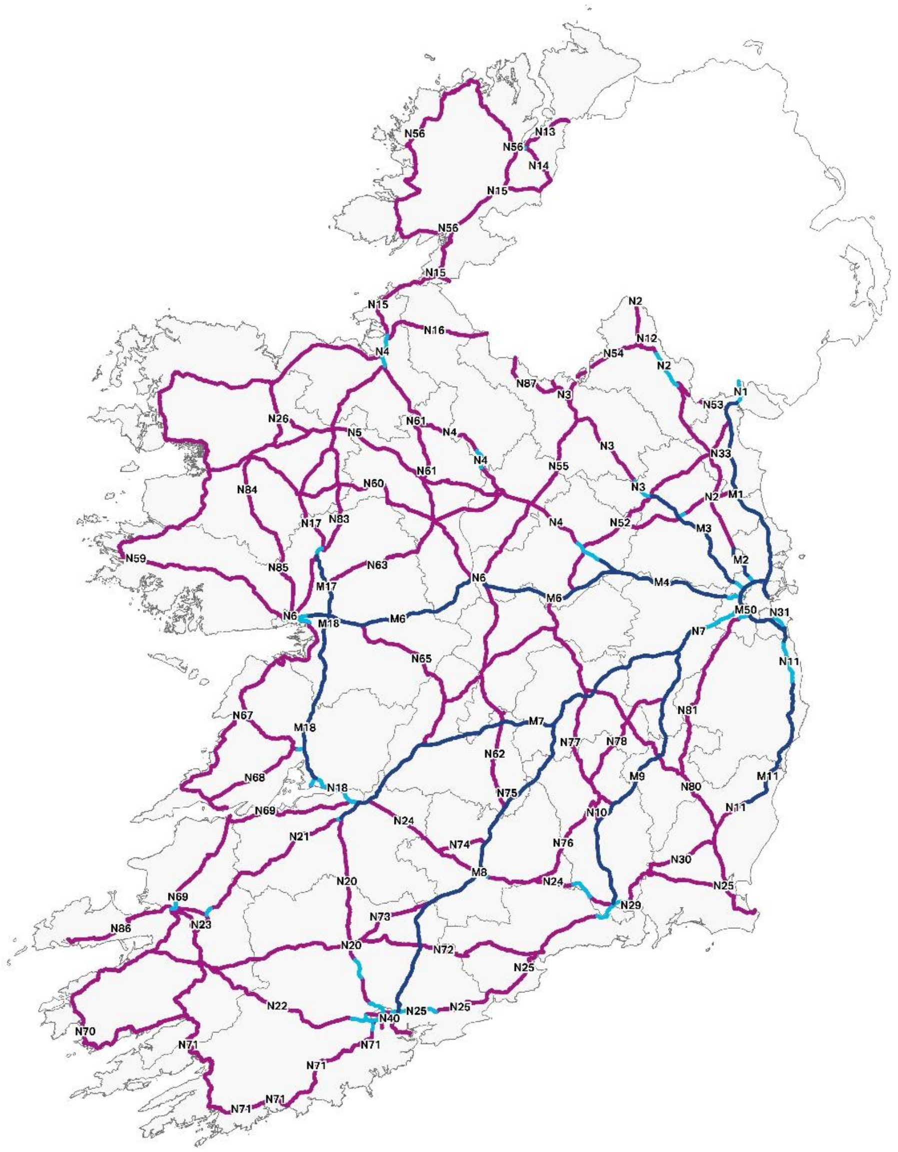

Figure 3.2 National Road Network Extent

The NTpM provides traffic flow data as Annual Average Daily Traffic (AADT) for light-duty vehicles (LDV, <3.5t) comprising cars and vans (i.e. Light Goods Vehicles; LGV) and heavy-duty vehicles (HDV, >3.5t) comprising trucks (i.e. Heavy Goods Vehicles; HGV).

The NTpM also provides congested and free-flow average speeds to each link. The emissions applied to the data presented in this report are based on the free-flow, steady speeds.

A separate technical review has been undertaken of congested traffic conditions and the use of average, binned, and individual count speeds to calculate corresponding emissions rates. This is reported in Appendix H, wherein the key findings were:

- The difference in Particulate Matter emissions using the different data resolutions is not considered significant.
- The emissions of NO_X and CO_2e are significantly affected by congested conditions, whereby the model tends to under-predict emission from congestion.

- The speed histogram for congested count locations has a distinct low-speed feature that correlates with a scattered relationship of hourly flows vs speeds in high-flow conditions and may represent an indication of traffic conditions where the model under-predicts.

A comparison of modelled speeds with the monitored count speeds indicated the emissions on the model were slightly lower, although within the context of the test they were consistent with the confidence range of the traffic model validation.

3.3 Flow Composition

The heavy and light fractions from the NTpM are split into the following core vehicle types or car, LGV and HGV.

Buses / coaches and motorcycles / mopeds are excluded from this model iteration as there was limited, or no, data available and are generally not considered to be significant emission sources on strategic roads.

The core vehicle types are classified by fuel type; e.g. petrol, diesel, plug-in hybrid electric vehicle (PHEV), etc.

Within each fuel type a further classification is applied for light vehicle engine size and heavy vehicle weight (see Section 3.5).

The size and weight classifications are then scaled for age and assigned a Euro rating.

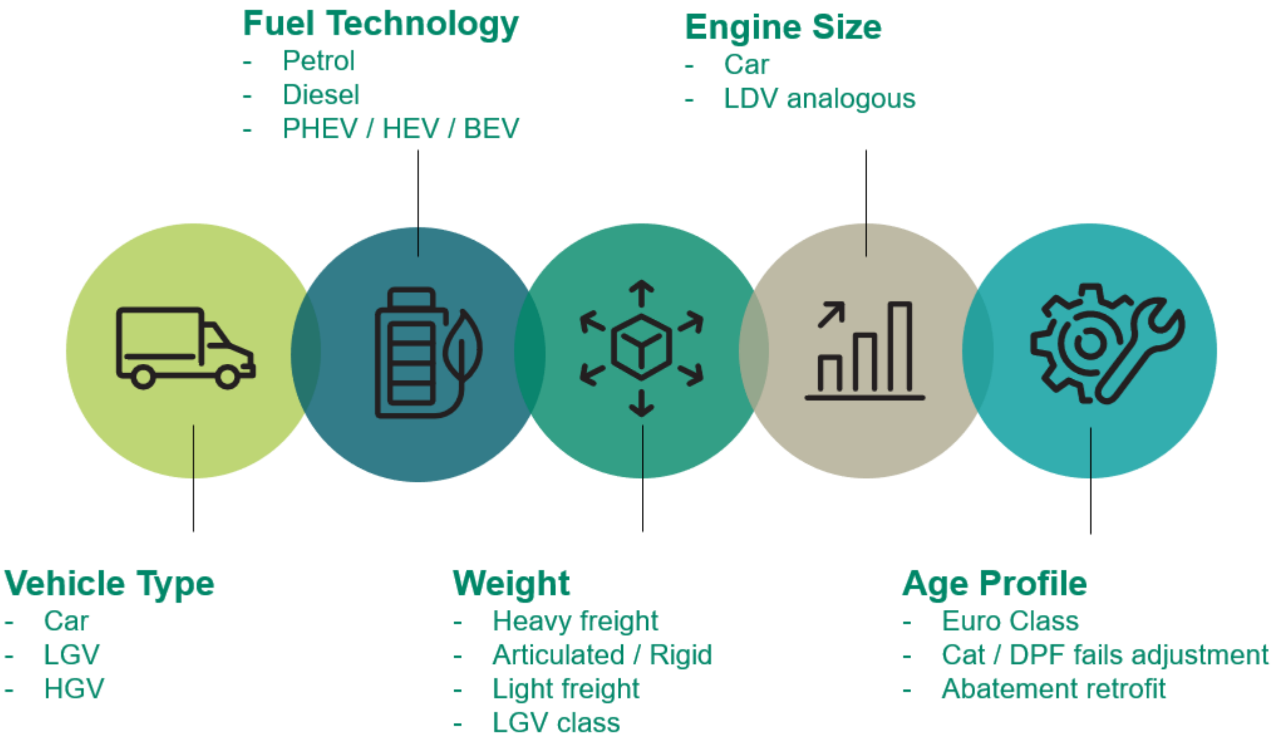

Figure 3.3 Schematic of Fleet Model Inputs

These data are extracted from CSO data based on the average annual mileage for each vehicle sub-category registered in each County in 2018.

For cars, these data are published for fuel type as petrol, diesel or other fuel-types.

For good vehicles (LGV and HGV), these data are published based on weight, as discussed below in Section 3.5.

Light duty vehicles are split into cars and LGV based on the total number of registered vehicle types, whereby goods vehicles <3.5t were assigned as LGV.

3.4 Fuel Profiles

The CSO provides fuel-type split into petrol, diesel and alternative technology (i.e. BEV, PHEV, etc) for cars in the 2018 baseline validation year.

No local data is available for fuel type for goods vehicles, or for the detailed breakdown of alternative fuels. It was therefore assumed that all HGV are diesel-fuelled, with no component of biofuel (B100) or alternative technology. This was considered to be a cautious approach based on the available data.

UK DfT publish a nominal profile for fuel type within each vehicle classification, which changes year-on-year; e.g. adoption of BEV is predicted to increase in the future. The additional detail based on UK DfT / NAEI data[57] for rural, urban and motorway road types.

The data in Table 3.1 to Table 3.3 are the national fuel profiles for 2018, where the car breakdown was scaled for each County based on CSO data.

Table 3.1 Alternative-fuel Cars Profile, 2018

Car, 2018	% Full Hybrid Petrol Cars	% Plug-In Hybrid Petrol Cars	% Full Hybrid Diesel Cars	% Battery EV Cars
National, scaled to county	70.1%	7.3%	11.7%	10.8%

Table 3.2 LGV Fuel Profile, 2018

LGV, 2018	Petrol	Diesel	Other
All Roads	1.6%	98.2%	0.2%

Table 3.3 HGV Type Profile, 2018

HGV, 2018	Rigid	Artic
All Roads	64.4%	35.6%

[57] Dept for Transport (2018) Road Traffic Forecasts

3.5 Freight Weight / Size Profiles

Cars are classified by engine size and goods vehicles by weight. CSO publishes goods vehicle (i.e. van and HGV) weight distribution for multiple weigh categories:

- <2t;
- 2-5t;
- 5- 7.5t;
- 7.5-10t;
- 10-12.5t; and
- >12.5t.

To extract the LGV proportions (i.e. <3.5t) used in the emissions profile the number of vehicles in the range 2-5t was split 50/50; i.e. 2-3.5t assigned to heavier LGVs, and 3.5-5t assigned to lighter HGVs.

Vehicles >12t and the proportion of articulated and rigid HGVs were assigned based on the fuel-type profile published by NAEI for Northern Ireland (see Section 3.4).

The nominal proportion of LDV assigned as LGV was derived from the 2018 CSO national freight fleet veh-km data for vehicles <3.5t compared to the total national fleet, as shown in Table 3.4. This is used only where a detailed traffic flow input is not available.

Table 3.4 Vehicle Type Breakdown, 2018

	Car	LGV	HGV
All Classes	80.4%	13.1%	6.5%
LDV Only	86.0%	14.0%	-

3.6 Euro Profiles

The age profile for all vehicle types were extracted from CSO data based on the registration year for each vehicle type.

The registration year was used to assign a Euro classification based on the proportional time period of each classification being enforced.

It was assumed the year of first registration related to the country of origin; e.g. a car first registered in the UK in 2016 would be assigned to this year, rather than a later year of registration in the Irish fleet.

3.7 Speed Emissions Profiles

Emissions are indirectly proportional to speed, with lighter engines tending to be most efficient (i.e. lowest emissions) at speeds in the range of approximately 40-50 km/hr, whilst heavy engines demonstrate decreasing emissions up to the maximum modelled speed of 140 km/hr. In all cases the highest emissions are at the lowest speeds.

Average emissions models tend towards uncertainty at low speeds, where transient, very short-period events related to congestion and queuing are highly complex to predict. Therefore, the emissions profile has a minimum speed of 5 km/hr.

An example of a NO_X emissions profile is presented in Figure 3.4, showing how emission rates vary with speed for a medium sized petrol car for the various Euro classes.

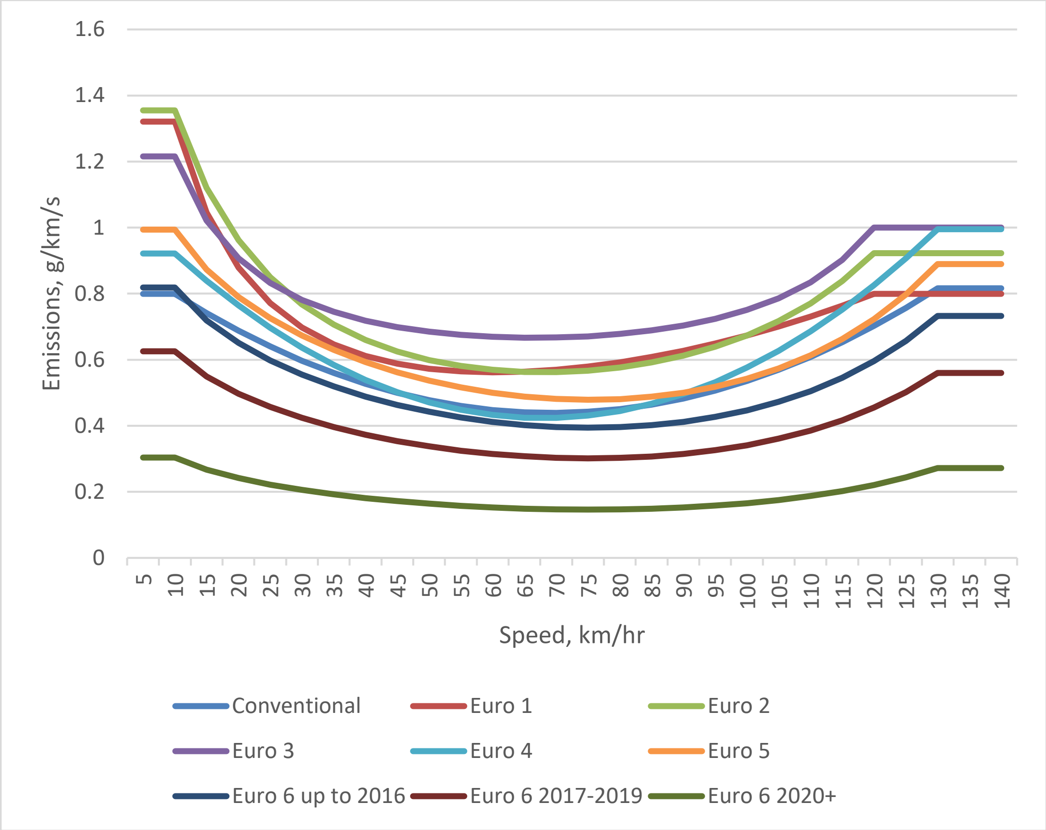

Figure 3.4 Example Emissions Profile, Medium Petrol Car

It should be noted by users that some fleet projections include a significant fraction of HEV and PHEV cars, where the emissions model implements a switch between ICE and EV operation at approximately 50 km/hr. This can, therefore, affect the outcomes of models where speed changes occur in this range.

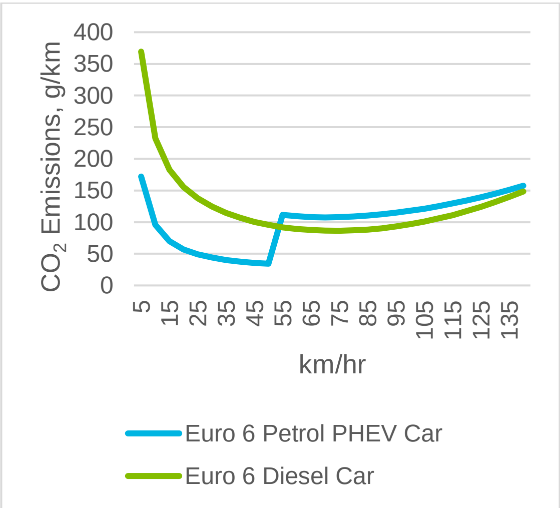

Figure 3.5 Comparison of Hybrid Emissions

3.8 Catalyst / DPF Fails

The emission rates applied to the model include scaling for ‘failed’ exhaust abatement; catalysts or DPF, which may deteriorate with age or be actively removed by the owner, whereby catalyst or DPF fails reassign a fraction of the LDV fleet as pre-Euro or Euro 4 respectively[58].

A nominal factor is applied to vehicles fitted with this technology to represent a failed fraction, whereby petrol vehicles with failed catalysts are reassigned pre-Euro equivalent emission rates[59], and Euro 5/6 diesel vehicles with DPF are reassigned as equivalent Euro 4 (i.e. before DPF were introduced).

Further discussion of this subject is presented in Appendix G.

[58] NAEI (2019) rtp_fleet_projection_NAEI_2017_Base 2019r_v1.1 https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fnaei.beis.gov.uk%2Fresources%2Frtp_fleet_projection_TfL_London_data.xlsx&wdOrigin=BROWSELINK

[59] DEFRA (2017) Method for Applying Emission Degradation Correction Factors to The COPERT 5 NO_X Emission Factors for Petrol Cars and LGVs, NAEI reference ED62553001

4. Stock Model and Fleet Projections

Traffic flow data is extracted from the TII National Transport Model (NTpM) for all years from 2018 to 2050, disaggregated as total flow of light (LDV) and heavy (HDV) vehicles. To predict vehicle emissions more information than the number of vehicles is needed, including fuel type, engine size (for LDV), gross weight (for HDV) and Euro classification (i.e. age). A stock model of the vehicle fleet provides this information assigning proportional splits of fuel type, engine size (for LDV), gross weight (for HDV) and Euro classification (i.e. age).

The fleet projection figures which underpin the vehicle fleet projections used in REM are derived from CSO registered vehicles[60] and the UCC stock model[61] derived from predecessor research[62, 63, 64]. DfT data[65] has been used to infill data gaps in the fleet model where necessary.

The UCC car stock model uses *'an optimization model of the Irish energy system (Irish TIMES), a simulation model of the Irish private transport sector (CarSTOCK), and a market share algorithm used to provide a behaviour rich representation into the multi-modelling process'*[64]. This effectively determines outcomes based on overall economic cost, taking into account factors such as the cost of adoption of new technology and propensity of users to pay within the constraints of policy outcomes, such as the CAP scenario.

The 2018 baseline goods vehicle fleet (i.e. vans and trucks) was defined using data published by the CSO using reported registered vehicles and annual mileage for each county. Further information about the domestic national fleet was supplied by the DoT in a review of Ireland's HGV Fleet and Compressed Natural Gas (CNG) Infrastructure.

Discussion with the Sustainable Energy Authority Ireland (SEAI), Environmental Protection Agency (EPA) and DoT indicate that no projected stock model explicitly outlining the age and fuel profile is available for goods vehicles, either Light Goods Vehicles (LGV; i.e. vans) or Heavy Goods Vehicles (HGV; i.e. rigid or articulated trucks). Therefore, a bespoke goods vehicle projection was created and the approach to this is outlined in this document.

4.1 Car Stock

The UCC car stock model includes several scenario projections for fleet changes between 2018-2050 (see Section 1.4).

This included data for:

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[60] Central Statistics Office (accessed 2021) https://www.cso.ie/en/databases/
[61] O'Riordan, Vera, Rogan, Fionn, Mulholland, Eamonn, Ó Gallachóir, Brian, & Daly, Hannah. (2021). Irish Car Stock Model V 2.4 (v2.4) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.4651477. These data are open source under a creative commons license, which allows for use for non-commercial purposes.
[62] Hannah Daly, Brian P. Ó Gallachóir (2011), "Modelling private car energy demand using a technological car stock model", Transportation Research Part D: Transport and Environment, Volume 16, Issue 2, 2011, Pages 93-101, ISSN 1361-9209, https://doi.org/10.1016/j.trd.2010.08.009
[63] Hannah E. Daly, Brian P. Ó Gallachóir (2011), Modelling future private car energy demand in Ireland, Energy Policy, Volume 39, Issue 12, 2011, Pages 7815-7824, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2011.09.027
[64] Eamonn Mulholland, Fionn Rogan, Brian P.Ó Gallachóir (2017), Techno-economic data for a multi-model approach to decarbonisation of the Irish private car sector, Data in Brief, Volume 15, 2017, Pages 922-932, ISSN 2352-3409, https://doi.org/10.1016/j.dib.2017.10.006
[65] Dept. for Transport (2018) Road traffic forecasts 2018 https://www.gov.uk/government/publications/road-traffic-forecasts-2018

- Petrol;
- Diesel;
- HEV;
- PHEV; and
- BEV.

The core statistics extracted from the model were:

- Annual distance travelled (km) per vehicle registration year, for each engine size; and
- Number of vehicles per registration year, for each engine size.

The annual vehicle-km for each registration year, fuel type and engine size were calculated. The ratio of change between each year and the proportion of new registration year vehicles and period of retention (i.e. age of vehicles in the fleet) was calculated for each county.

Examples of projected age profiles for a national fleet are provided in Appendix B.

4.2 Goods Vehicles Stock

The CSO publish data for the registered goods vehicle fleet and annual average mileage is disaggregated by gross weight, wherein it is assumed that all vehicles are diesel-fuelled. This is consistent with the DoT HGV and compressed natural gas (CNG) infrastructure review of the existing situation, which states 99.8% of HGVs are diesel for road freight.

For the purpose of emissions modelling vehicles are split into HGV comprising rigid and articulated trucks weighing >3.5t and LGV weighing <3.5t. This classification is consistent with the European COPERT and UK EFT models and the DMRB LA105 guidance[66].

Within the CSO weight disaggregation, the heavier classified good vehicles in the range 2-5t are proportionally reassigned to the LGV and lighter HGV categories that align to the emissions tool. This assumption represents a potential limitation in the stock model but does ensure the greatest resolution of weight categories for the available data.

The CSO data include fleet stock data, as described above, for the years 2015 to 2019, encompasses the number of vehicles for each year of registration from 2000 to 2019. These data were used to calculate an average fraction of goods vehicles retained within each age category up to 15-years old, also incorporating the effects of used vehicles joining the fleet.

It was recognised that the number of new vehicles assigned to the fleet each year was less than the subsequent year (i.e. vehicles 1-year old), whereby new vehicles registered part-way through the year may not be counted until the following year and so cause a peak of 2-year old vehicles.

The DoT HGV and CNG infrastructure review indicates that an average 8.4% of HGVs were retired from the fleet annually between 2006 and 2017, which corresponds well with the annual retention rates for the year 2015 to 2019 extracted from CSO data in the range 0.86-0.91 across different weight categories.

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[66] Highways England (2019) Design Manual for Roads and Bridges, LA105, https://www.standardsforhighways.co.uk/dmrb/search/10191621-07df-44a3-892e-c1d5c7a28d90

In terms of long-term trends, the CSO data since 2015 indicates effectively flat growth for vehicles >5 tonnes, but with 2% annual increased growth for goods vehicles 2-5 tonnes and corresponding decrease in the <2 tonnes category representing strong growth in favour of larger LGVs; a shift towards larger vans.

The fraction of retained vehicles was applied to the 2019 data and extrapolated for each subsequent year up to 2050. The resultant number of vehicle-km within each age category for each year from 2019 to 2050 was recalculated as a proportion of the total fleet in each year and assigned a Euro category.

The long-term effect of this projection was to flatten the age profile, and to remove some of the detailed features present in the baseline (2018) profile; e.g. the dip in 2008 related to the economic event becomes less prominent as older vehicles leave the fleet, whereas no further disruptive events were introduced in future years.

The change in vehicle-km and age were converted to a corresponding Euro classification for each year and examples are presented in Appendix C, which demonstrates how older vehicles will rapidly leave the fleet and be replaced predominantly by Euro 6. It is noted that the 2008 event is not evident in the percentage age breakdown.

These data also indicate that the heavier (HGV) goods vehicles have a much higher proportion of Euro 6 adoption than the lighter (LGV) vehicles in the existing baseline.

4.3 Fleet Assignment

The annual ratios were used to project the individual county car fleets forward from the 2018 CSO database profiles. This was intended to recognise the baseline conditions, with growth applied consistently with national policy-based changes.

The CSO data for goods fleets are available at county resolution, although these vehicles tend to operate predominantly across different counties; the DoT HGV and CNG infrastructure review indicates that 84.3% of road freight activity in 2017 was carried out over distances greater than 50 km.

Therefore, a national goods vehicle fleet stock projection was used for all links rather than applying a local breakdown for each county. It is suggested that future iterations may be able to use journey origin-destination data to assign a proportion of different traffic on each link based on the road-type; e.g., local or strategic road, and apply a different fleet emissions profile to represent the difference between county-based or cross-border traffic.

4.3.1 Fleet Origin Assignment

The traffic patterns for all links within each County in the NTpM were analysed to calculate the overall proportion of traffic originating, and travelling to, each county. This was done to represent the fleet breakdown more accurately by assigning an adjusted proportion of each county-based fleet profile to NRN links flagged as 'TII', with a different profile assigned to links flagged as 'other'. It is also a user-selectable option in the TII REM so the link may use the fleet profile solely based on the county it is in and disregard any cross-county movement.

The origin data from the NTpM was calculated from AM (morning peak hour 8-9) and IP (average hour between 12-14) models. Based on the assumption that every journey on the NRN is two-way traffic data has been extracted from 272 TMUs (Traffic Monitoring Units) across the NRN and analysed.
The analysis showed that half of the daily journeys happen between hours 6:00 and 15:00. Travel patterns from AM peak hour were assumed to represent traffic between 6:00 and 11:00 (5 hours), and inter-peak between 11:00 and 15:00 (4 hours).

No expansion factors were applied to convert peak hour journeys from the NTpM to represent 24-hour daily travel patterns as both AM and IP peak hour to AM and IP peak period were the same and, therefore, it would have no impact on the calculation of the overall proportions of traffic patterns.

These calculations were all undertaken based on outputs from the 2018 NTpM only and were assumed to be representative of subsequent years, in scenarios where future population is in line with existing patterns.

4.4 Fuel Profiles

The national fuel mix projections for cars for the scenarios extracted from the UCC Stock Model and examples are provided in Appendix D. These proportions were used to project the individual 2018 county fleet data into the future years.

The existing goods fleet fuel profile is predominately diesel-fuelled for all weight classes, although the LGV fleet is expected to adopt increasing proportions of plug-in hybrid electric vehicles (PHEV) and battery-electric vehicles (BEV) in the future. Therefore, without better data, it was assumed this growth will occur in the same proportions as the car fleet based on limited evidence of these vehicle types becoming increasingly available on the market.

The existing HGV fleet is almost entirely diesel-fuelled, with negligible proportion of other fuel-types. It is also very uncertain how alternative fuel technologies, such as hydrogen, fuel-cell (FCEV) or BEV may be adopted in the future as they are not yet adopted widely in commercial fleets and the charging/ fuelling infrastructure is currently relatively small. It is recognised that the DoT HGV and CNG infrastructure review highlights the opportunity for adoption of compressed natural gas (CNG), although there is currently no roadmap for adoption of the necessary infrastructure. Similarly, other technologies such as hydrogen fuel cells are not incorporated as there is limited data on the potential rates of adoption of this technology.

Therefore, in the absence of further information, the projected HGV fleet in the business as usual scenario was cautiously assumed to be 100% diesel. This assumption can be varied through sensitivity testing to assess alternative scenarios, such as the adoption of a national carbon reduction policy.

5. Air Quality Tool

The emissions tool described in Section 3 calculates the rates at which pollutants are released from each road link source as a product of the traffic flow and composition. This is reported as a mass rate of release in g/km, g/km/s or annual link emissions as kg/year.

The air quality tool uses the emissions calculated by the emissions tool to predict atmospheric pollutant concentrations as a product of dispersion, which increases with distance. Concentrations are reported as a mass per volume of air as $\mu g/m^3$ over annual durations (consistent with annual air quality standards).

Pollutant concentrations are used to determine whether air quality standards (see Section 2.1) are achieved at locations of human exposure (e.g. residential properties) and at sensitive designated habitats. Information on pollutant concentrations and how they change with a scheme is required within air quality impact assessments which are used in scheme consenting activities.

5.1 Dispersion

The dispersion algorithm replicates the function of the Design Manual for Roads and Bridges (DMRB) screening tool v1[67].

The tool applies a factor to disperse the road-source emissions with increasing distance from the source, and so determine the atmospheric pollutant concentration as a product of the distance from the road. As a screening tool this excludes the effects of meteorology (i.e. wind speed and direction) on dispersion.

For the purpose of project-level assessment multiple emissions source links and distances may be manually assigned by the user to each receptor location to capture multiple road contributions of pollutants at junctions.

5.2 Non-road Emissions

The total pollution concentration in a given location is the sum of contributions from multiple sources, including anthropogenic source such as roads, rail, industry, agriculture, and natural sources such as sea-salt.

Sources may be local and immediately impact a given location, such as an individual point source adjacent to the study site, or they may represent part of a larger cross-boundary contribution, such as a large urban area several km from the receptor location.

Therefore, to properly represent the total concentration in a given location it must incorporate the sum of both the modelled contribution; in this case the road emissions and, additionally, the wider non-modelled contribution.

There is limited regional monitoring or modelling currently available to inform the background contribution. Therefore, the monitoring undertaken by the Environmental Protection Agency (EPA) and reported online was used to inform representative values.

[67] Method for using the output from Casella Stranger (2007) EFT in the Local Air Quality Assessment and Regional Impact Assessment application of DMRB Screening Method Version 1.02

5.3 NO_X to NO_2 Conversion

The emissions of oxides of nitrogen (NO_X) from vehicle exhaust are converted to NO_2 as a function of ozone (O_3), temperature and sunlight.

The ratio of NO_X and NO_2 is calculated using the same process as the DEFRA conversion tool[68] whereby mixing of nitric oxide, ozone and nitrogen dioxide in the surface stress layer of the atmospheric boundary layer are used in a one-dimensional finite difference model.

Use of this conversion method by means of the DEFRA tool is endorsed in the National Roads Authority (NRA) air quality modelling guidance[69]. Within this guidance document it is stated that regional concentrations of ozone, NO_X and NO_2 above the surface layer for Craigavon in Northern Ireland form a reasonable representation of those across Ireland and for the purpose of using the NO_X to NO_2 calculator are relevant. These concentrations are used in the TII REM as a default.

5.3.1 Ecology

The air quality also considers effects on ecological sites, where the user-selectable option in the inputs interface defines these receptors.

The outputs predict the concertation of NO_X, and the rates of nitrogen deposition (N-deposition) and acid deposition.

5.4 Verification

Computer models are subject to systematic confidence limits due to methodological bias and propagation of uncertainties. These uncertainties generally include those associated with traffic data, vehicle emissions and meteorology, etc.

However, it is possible through model verification to try and account for this underestimate by applying a verification factor to uplift tool predictions if monitoring data is available that is subject to multiple link contributions (e.g. at junctions). In this approach a comparison of the modelled and monitored concentrations is used to determine a numerical adjustment to the model to ensure it achieves greater confidence. This approach should be used cautiously and performed by someone with suitable experience and / or qualifications.

There are a number of important considerations in calculating a systematic model adjustment, but the most important are:

- Background pollutant concentrations represent the non-modelled emission sources. The residual road-source contribution is a result of the air quality tool.
- Monitor location is important in terms of proximity to sources, where it may be affected differently by multiple links.

Both of the two factors above have been carefully reviewed to establish where sites are representing background conditions and whether locations can be used to verify the current strategic level air quality tool.

[68] DEFRA (2020) NO_X to NO_2 Calculator https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html
[69] National Road Authority (2011), Guidelines for the Treatment of Air Quality During the Planning and Construction of National Road Schemes.

5.4.1 Validation Assurance

A preliminary model validation exercise was undertaken for a small part of the network around the M50 motorway where there was a relatively high density of monitoring for annual mean NO_2 undertaken near the NRN. Details of the data used in the verification exercise are provided in Table 16.

Details of the validation exercise are provided in Appendix I.

The model validates well for this section of the road, although it required specialist time and skills, and careful review and sifting of the monitoring data. This means the adjustment is not necessarily transferable to other areas due to the highly localised zoning and backgrounds.

The validation exercise, in identifying variations in model performance due to local conditions, supports the development of an air quality specific monitoring network, with sites close to the NRN. Furthermore, the verification exercise highlighted the importance of accurate data to inform the contribution from background pollutant concentrations. In this case it was possible to identify two sites that were suitable, although even within this relatively small area there was a significant difference in the values (13.5 $\mu g/m^3$ to 17.6 $\mu g/m^3$). Therefore, any development of monitoring networks along the NRN would significantly benefit from a range of site classifications:

- Kerbside / roadside;
- Intermediate;
- Urban background; and
- Rural

6. Assumptions & Limitations

The full set of assumptions applied to the first iteration of the TII REM are presented in Table 6.1. These assumptions will be refined during further development later iterations of the TII REM.

Table 6.1 Emissions Model Assumptions

Factor		Data	Comment
Fleet	Bus	No data currently in model but user option is enabled	Buses are the only vehicle that currently has an accredited retrofit programme for Euro emissions compliance.
			Buses will not be a significant emissions component on the SRN, but may be more significant on local, and urban centre, roads.
			Therefore, the current iteration enables a user option to model buses where data is available.
	PHV	Data published by CSO but not in NTpM	This is available from CSO and may be included in future iterations.
Euro	Cars		Euro 1 and 2 assumed to be split equally in the 2018 baseline as CSO provides data only back to 1999, whereas for cars Euro 1 started in July 1992 and Euro 2 in January 1996.
Vehicle weights	Cars	No engine size data	EFT, NI fleet.
	Goods Vehicles	CSO weights are <2t and 2-5t for lights and max at 12t for heavies	LGVs assigned based on proportional split of 2-5t data.
			i.e. 50% 2-5t as LGV (<2.5t) and 50% as HGV (>2.5t).
	LGV		1N(I) and 1N(II) proportionally split using nominal NI EFT for LGV <2t.
			1N(III) 2-3.5t based on 50% split of the 2-5t goods vehicles category.
		Noted potential inconsistency compared to EFT	This biases the LGVs towards lighter vehicles, which is inconsistent with the EFT.
	HGV		Rigid 3.5-7.5t and 7.5-12t category assumes registration data for weight categories up to 12.5t. All Rigid categories >12t use normalised EFT weight classes and >12.5t registration data.
			Euro class split for rigid HGVs 5-7.5t assumed for rigid HGVs 3.5-7.5 t; Euro class split for rigid HGVs 7.5-10 t assumed for rigid HGVs 7.5-12 t.
Fuel	All vehicles	Fuel scaling	Calculated using TRL (2009) Emission Factors - scaling factors for mileage and improvements in fuel quality and EMEP/EEA air pollutant emission inventory guidebook 2016 Chapter 1-a-3-b-i.
	Cars and LGVs	Engine degradation	Calculated using DEFRA (2017) Method for Applying Emission Degradation Correction Factors to the COPERT 5 NOx Emission Factors for Petrol Cars and LGVs.

Factor		Data	Comment
	Car		Petrol / diesel split as CSO registration data for 2018 baseline and projected using ratios derived from UCC data.
			Alt tech split using average of NI DfT.
			Assume 0% FCEV.
			Assume 0% LPG.
			Normalised Euro split applied to alternative fuel classes, based petrol/diesel equivalent.
	LGV		petrol / diesel split as registration data.
			Alt tech split using NI DfT.
			Normalised Euro split applied to alternative fuel classes, based petrol/diesel equivalent.
	HGV	No classification data.	Split into rigid / artic using average of NI DfT.
		Note integration / precision point	There are significant variations between different road classes; i.e. more rigid HGV on rural road-types, and so this may represent an iteration point in future tool updates.
		No fuel data.	Assume all diesel.
			No alt fuel data in EFT.
			Assume no B100.
Model resolution		The resolution of the profiles will be reported as 'county' to align with CSO data	It is assumed that all vehicles operate in county of registration and so modelled with no cross-border traffic.
			A national average profile may to a nominal segment of the traffic to represent inter-county traffic. This may be applied in a later iteration.
			Similarly, data is available for NI and may be assigned to a segment to the border counties based on nominal EFT profiles in a later iteration.
		Speeds	Vehicle speeds are binned in 5 km/hr extents between 5 – 140 km/hr. Speeds below were assumed to equal 5 km/hr.
Non-exhaust PM emissions (NEE)			Based on BTWA values published by TRL in the EFT for urban, rural and motorway road types.

Table 6.2 Stock Model Assumptions

Factor	Data	Comment
Car	UCC Stock Model and CSO	Cars are based on national fleet projection and normalised for each county, so assumes no cross-border movement in this iteration.
	UCC Stock model	Assumes a linear decrease in mileage with age of vehicle.
	UCC Stock model	Alt technology spits based on UCC as no data in CSO.
LGV	UCC Stock model	Use car fuel technology rate of turnover.
	CSO	Goods vehicles in 2-5t category split 50/50 into <3.5t and 3.5-7t emissions categories.
HGV	CSO	CSO data for good vehicles does not project before 2000, so assumed there are no pre-Euro vehicles.
	CSO	HGVs assumed to be all diesel in all years due to lack of data.
	CSO	Goods vehicle model is based on the national fleet and is not normalised for individual counties.
	CSO	Goods projection assumes continued growth in-line with past 5-years with no disruption.
LGV and HGV	CSO	Projected weight splits are based on an extrapolation of the past 5-years of data and assumed to continue linearly.

Appendix A

Data Sources

Table A1 Data Sources

Data Type	Data Source	Description	Limitations
Traffic Metrics			
Road Network	NTpM	Updated NTM originally based on NAVTEQ data for the island of Ireland, suitably refined to accurately represent the road network in the base year.	
Road Types	NTpM	Six key link types: Motorways, Dual Carriageways, National Primary Roads, National Secondary Roads, Regional Roads and Local Roads.	
Zones	NTpM	Wide range of zones including: Ports and Airports as 'Special Zones, Regions and NTM zones.	
Scenario Years	NTpM	2016 to 2050, inclusive	
Average AM Peak hour (07:00 – 09:00)	NTpM	Peak hourly flow	Not used for annual average emissions
Average Inter Peak hour (12:00 – 14:00)	NTpM	Inter-peak hourly flows	Not used for annual average emissions
Annual Average Daily Traffic	NTpM	24-hour flow	
Vehicles	NTpM	Total classified flow per period	Data required as vehicles rather than PCUs data converted via scaling factors
Speed	NTpM	Congested and free flow average speed (kph)	
Light duty vehicles (LDV)	NTpM	Vehicles <3,500kg	
Heavy duty vehicles (HDV)	NTpM	Vehicles >3,500kg	
Fleet Metrics			
Age	CSO– Road Traffic Volumes	Vehicle numbers by year, vehicle type, fuel type, county of ownership and year of registration 1999 - 2018	Vans not shown as a vehicle type
	CSO– Road Traffic Volumes	Volumes by type of ownership, engine capacity, fuel type, county of ownership, registration year (1999 -2018) and year of analysis (2014 - 18)	Private cars only

Data Type	Data Source	Description	Limitations
	CSO– Road Traffic Volumes	Goods vehicle volumes by county of ownership, unladen weight, registration year (1999 -2018) and year of analysis (2014 - 18)	Goods vehicles only
	Vehicle Disposals	End of life vehicle statistics, 1998 - 2007 including year of registration / disposal.	Not disaggregated by vehicle type. Data for 2002 -03 and 2005 - 07 not published
	Fleet sector	Various discussions with commercial and private vehicle fleet sector in Ireland	Anecdotal evidence, general trends, often depends on vehicle finance selected
Fuel / Vehicle type	Irish Bulletin of Driver Statistics 2019	Number of vehicles by fuel and vehicle type in 2019	2019 only. Vans not shown as a vehicle type
	CSO– Road Traffic Volumes	See 'Age' category above	
	Statistics of the Irish Motor Industry	New and used imports for cars, lights, heavies for all counties. Includes fuel types, engine capacities, 2007 - 20. New Registrations and New/Used Imports.	No data for individual vehicle types. Also subject to UK and UK(NI) data
Mileage / vehicle km	CSO– Road Traffic Volumes	Car volumes by million veh km travelled, ownership, engine capacity, fuel type, county of ownership, registration year (1999 - 2018) and year of analysis (2014 - 18)	Data for private cars only. Vehicle Kilometre and Average Kilometre estimates for Motorcycles and Tractors & Machinery are unreliable due to minimal odometer data is available for these categories of vehicles.
Forecast	CSO– Road Traffic Volumes	Extrapolation of fleet profiles from preceding years	Used for goods vehicles only
	UCC Forecast Car Fleet Model	Car mileage projections up to 2050 for multiple scenarios	Data for cars only. Full references in main text Section 4.1.
	CSO historical data	Extrapolation and projection of 5-years historical data	Data for freight only.
Emissions Tool	NAEI	Emission factors for transport	Includes scaling for failed exhaust abatement, fuel scaling and engine degradation.
	Emissions Factors Toolkit	UK (DEFRA) emissions toolkit based on COPERT 5.3. EFT currently at v11	Emissions profiles are suitable but will need to be scaled for individual fleet components.

Data Type	Data Source	Description	Limitations
	COPERT	EU vehicle emissions model. Currently at version 5.3.26.	Research model not intended for multiple complex runs.
Ambient Air Quality Metrics			
Baseline/verification	EPA - Air Quality in Ireland latest report (2018)	Limited suitable data.	
		Annual Concentrations of NO_2, NO_x, PM_{10} and $PM_{2.5}$ for 2018 (data available for the period 2012 - 2018) (From the National Network of Air Quality Monitoring – continuous monitoring).	
		There is also a Local Monitoring Network operated by local authorities (also continuous), however no reports/data have been identified from desktop review	
		TII data anticipated to be available for the M50.	
Continuous monitoring	EPA - Air Quality in Ireland latest report (2018)	Within the National Network of Air Quality Monitoring: 9 “background” sites for NO_X 20 “background” sites for PM	
Dispersion	Design Manual for Roads and Bridges (DMRB) screening tool v1	Screening tool to calculate dispersion of road-source emissions with increasing distance from the source.	
Diffusion tubes	EPA – Urban Environmental Indicators Report 2019	The EPA Report (2019) refers to Dublin specific diffusion tube monitoring for 2016 and 2017.	No nation-wide monitoring identified. Local networks are suitable for limited spatial zones, such as data recorded along the M50 motorway provided by TII.
Mapped / modelled data	CERC - Urban air quality modelling of Dublin 2019	Modelled NO_2, PM_{10} and $PM_{2.5}$ concentrations for Dublin for 2015 – Results are presented in contour maps	No nation-wide modelled data identified.
Background Pollutant concentrations	Environmental Protection Agency Air Quality Zones	According to the CERC study mentioned above - background concentrations deriving from continuous monitoring units of the EPA network classified as “background” can be suitable.	Alternative method is to use nominal zoned values; Dublin, Cork, other cities, rural.

Data Type	Data Source	Description	Limitations
NO_X:NO_2 conversion	DEFRA – NO_X to NO_2 Calculator	Historical projects have used the DEFRA NO_x to NO_2 calculator for Northern Ireland LAs. The district of Armagh Banbridge and Craigavon was used for this iteration, in accordance with the NRA (2011) guidance.	

Appendix B

Examples of Projected Car Age Profiles

B1 Examples of Rural Car Age Profiles, Carlow

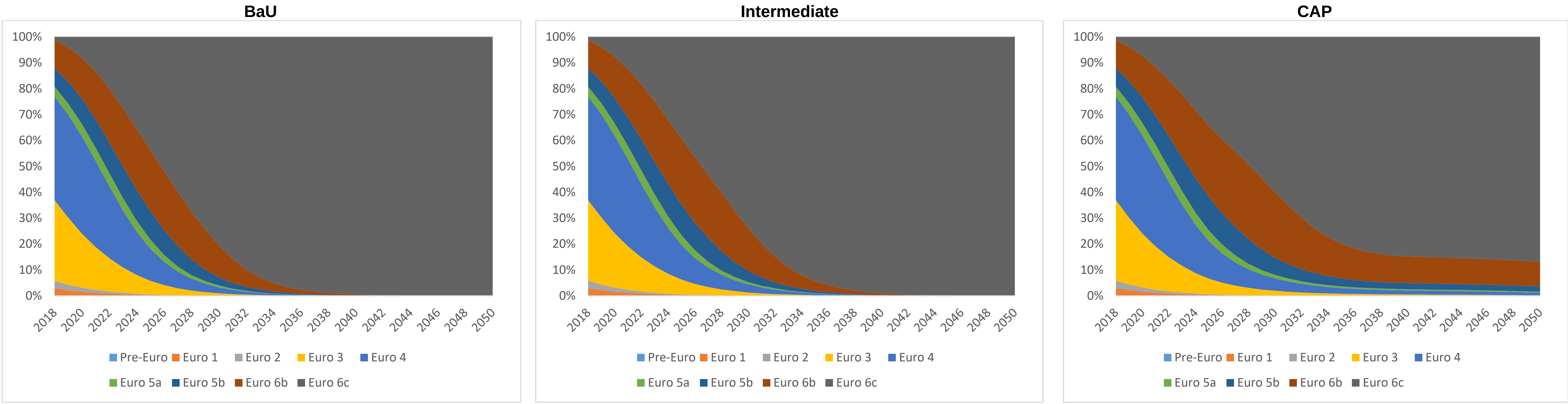

Figure B1 Projected Petrol Car Age Profile

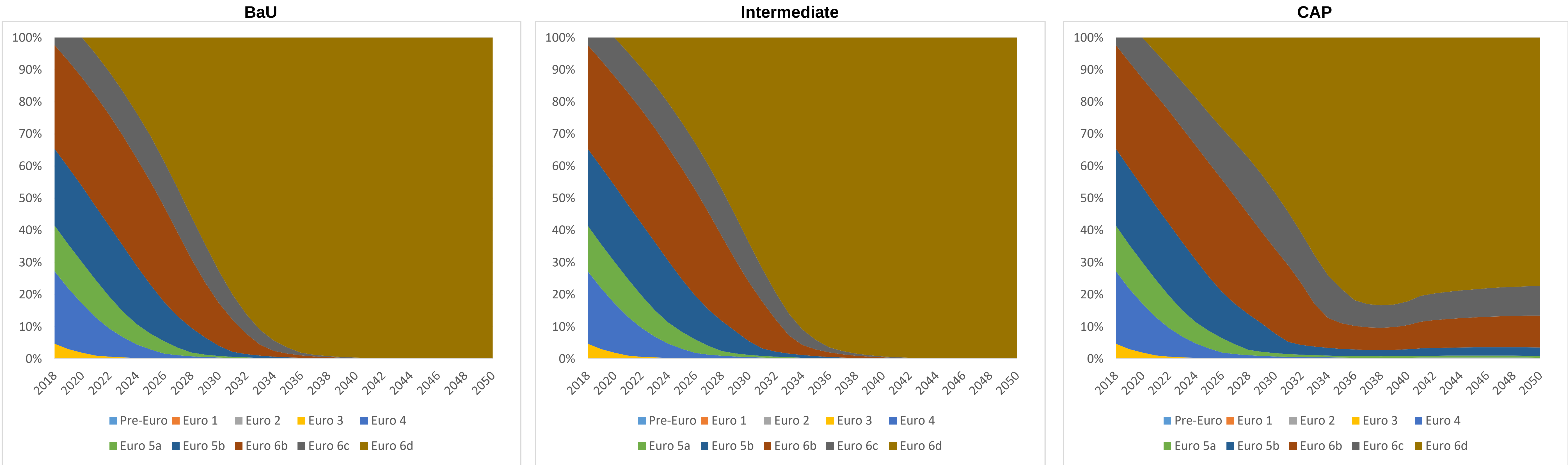

Figure B2 Projected Diesel Car Age Profile

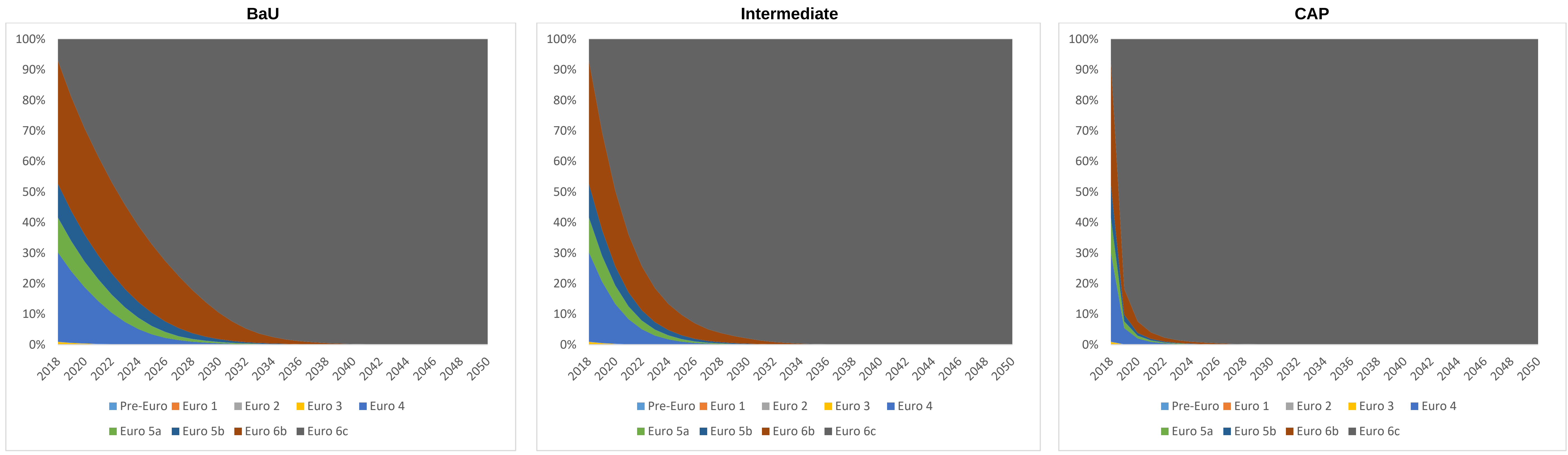

Figure B3 Projected Hybrid Car Age Profile

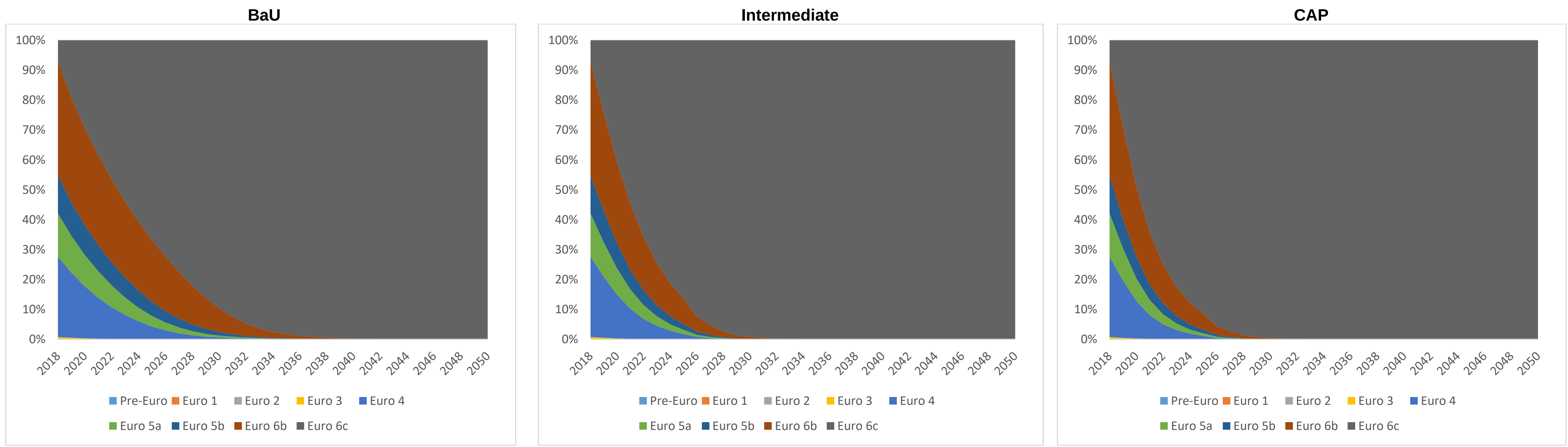

Figure B4 Projected PHEV Car Age Profile

B2 Examples of Car Age Profiles, Dublin

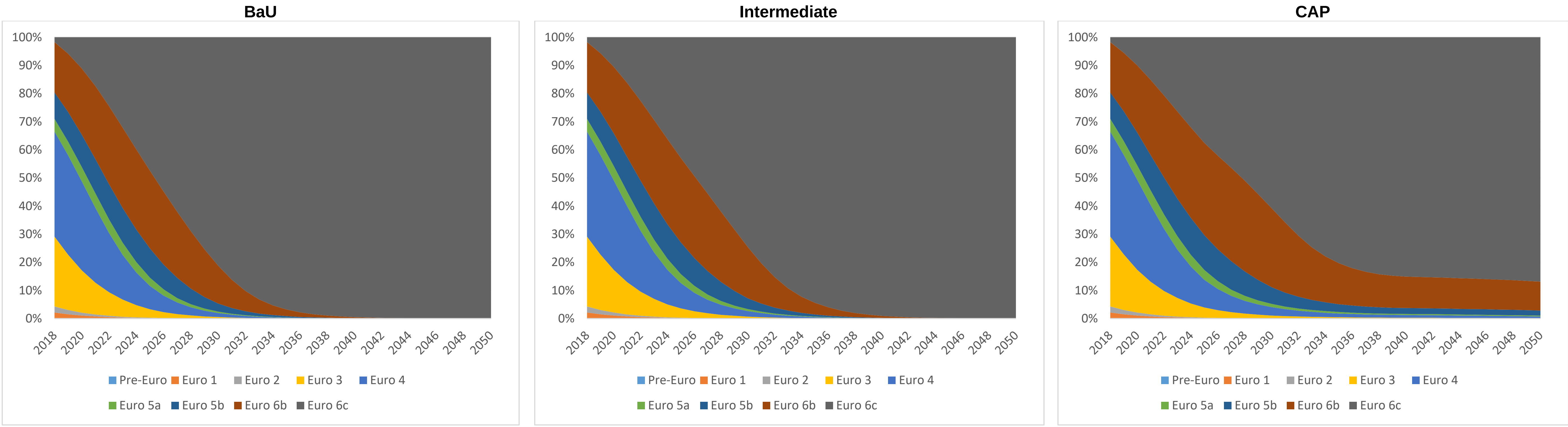

Figure B5 Projected Petrol Car Age Profile

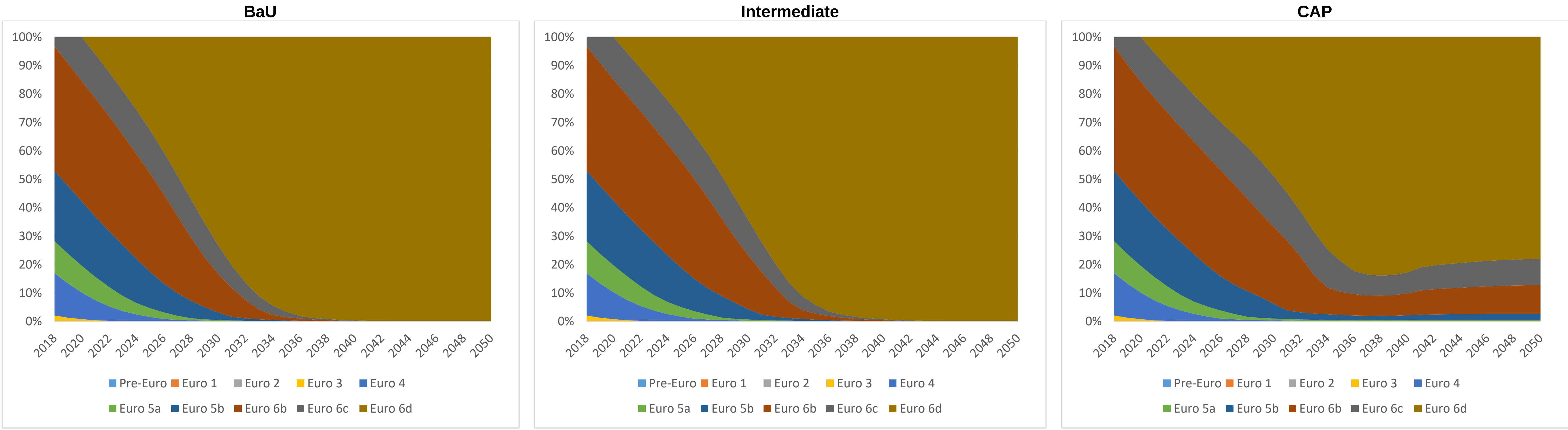

Figure B6 Projected Diesel Car Age Profile

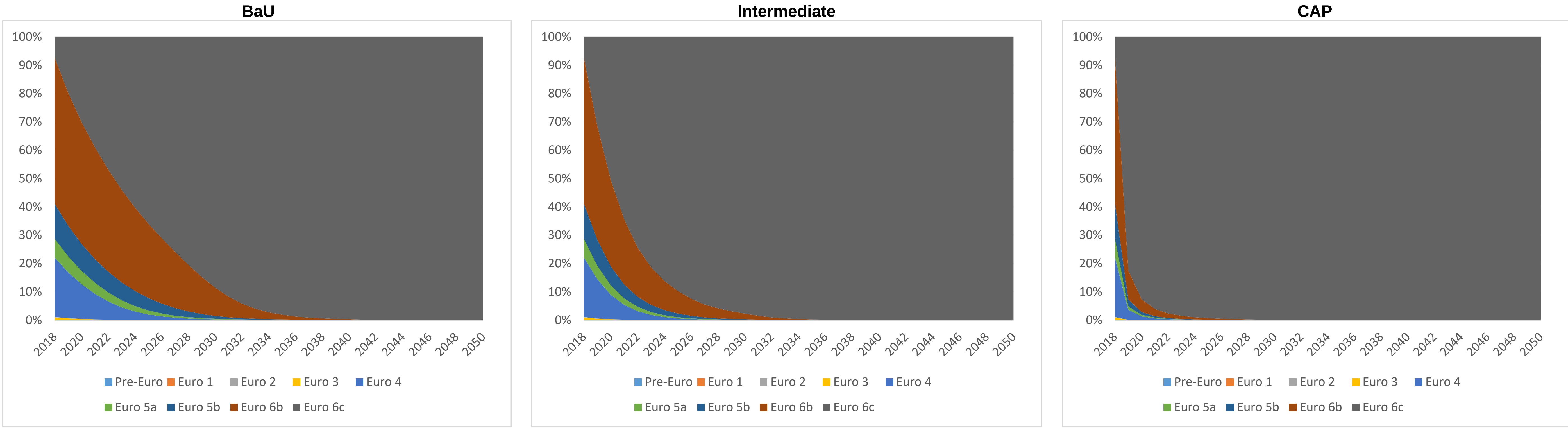

Figure B7 Projected Hybrid Car Age Profile

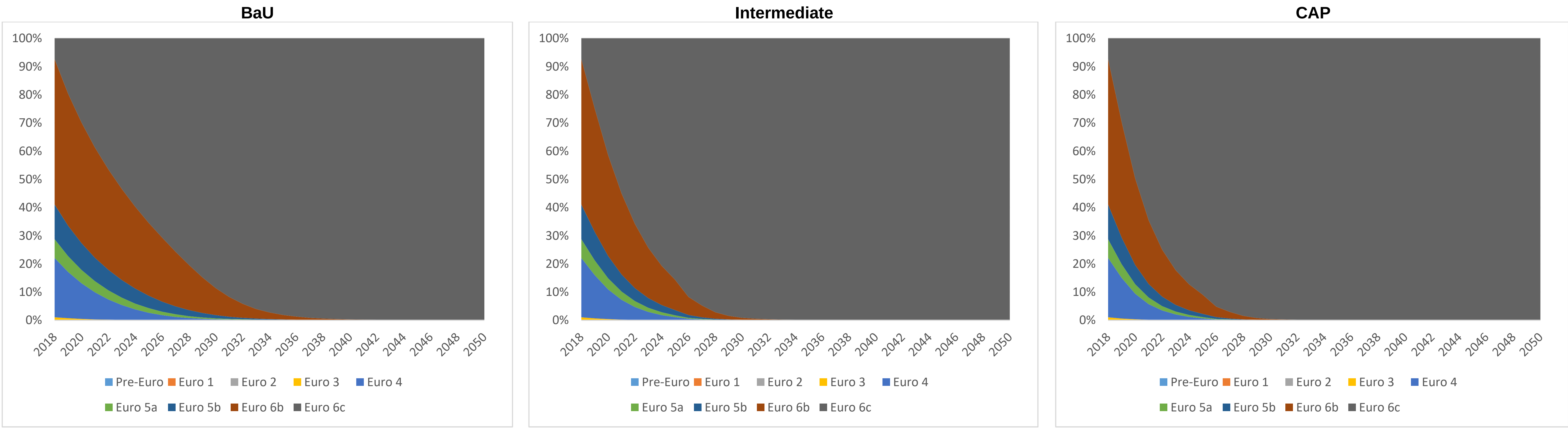

Figure B8 Projected PHEV Car Age Profile

Appendix C

Projected National Goods Vehicle Profiles

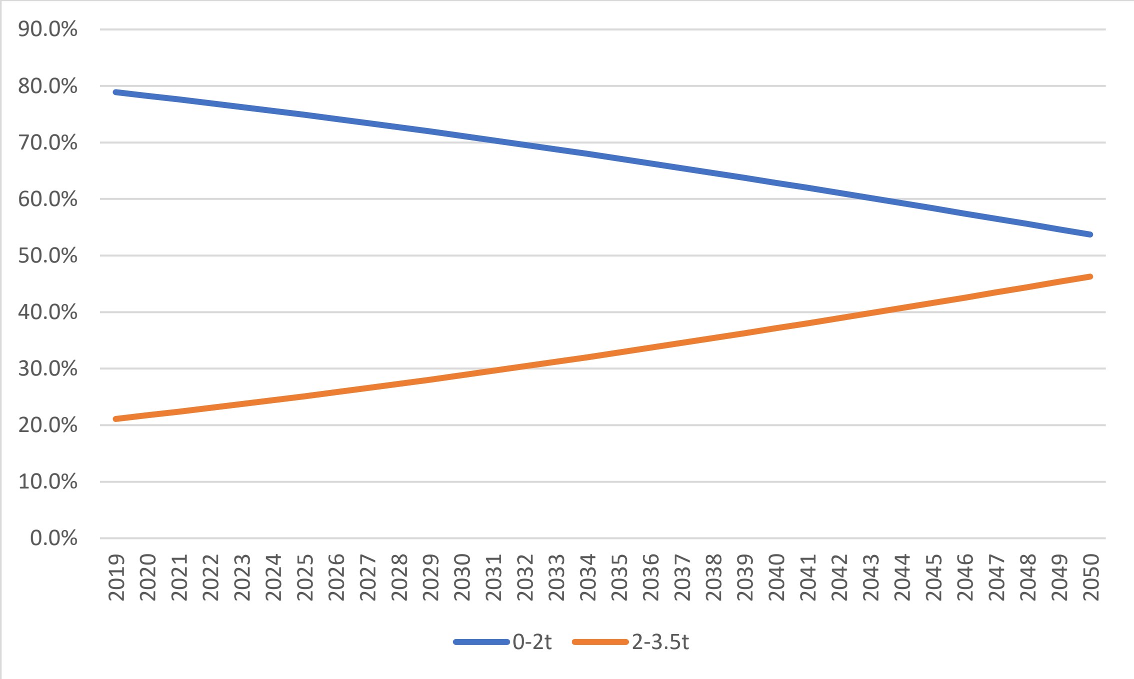

Figure C1 Projected BaU National LGV Weight Profile Projections

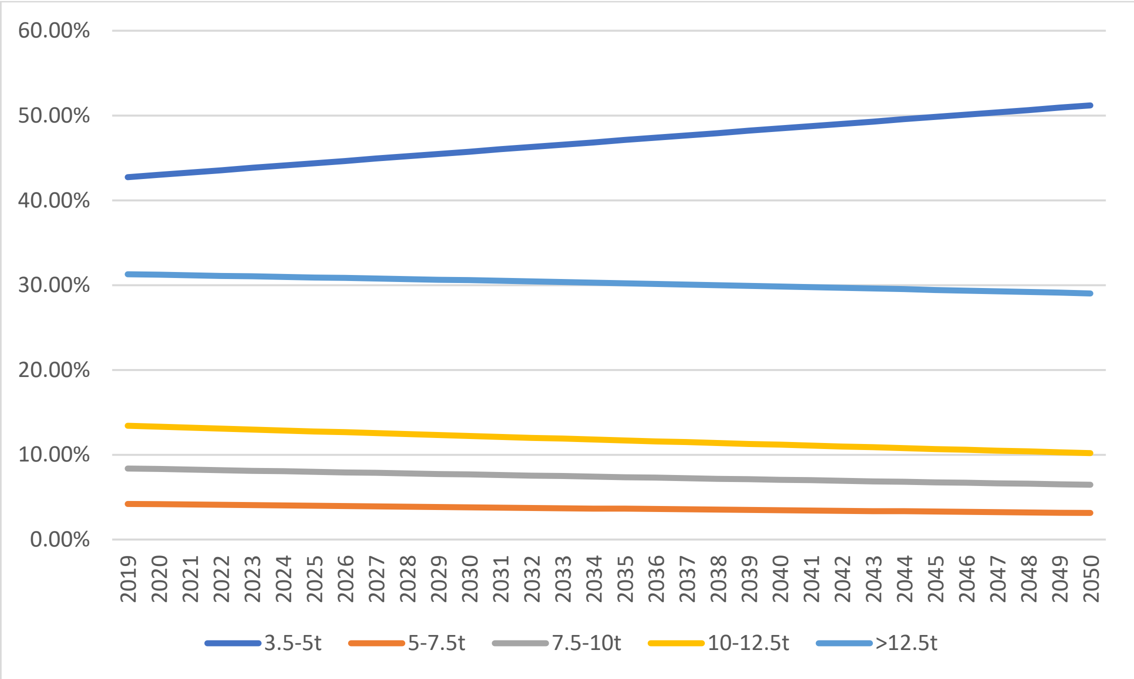

Figure C2 Projected BaU National HGV Weight Profile Projections

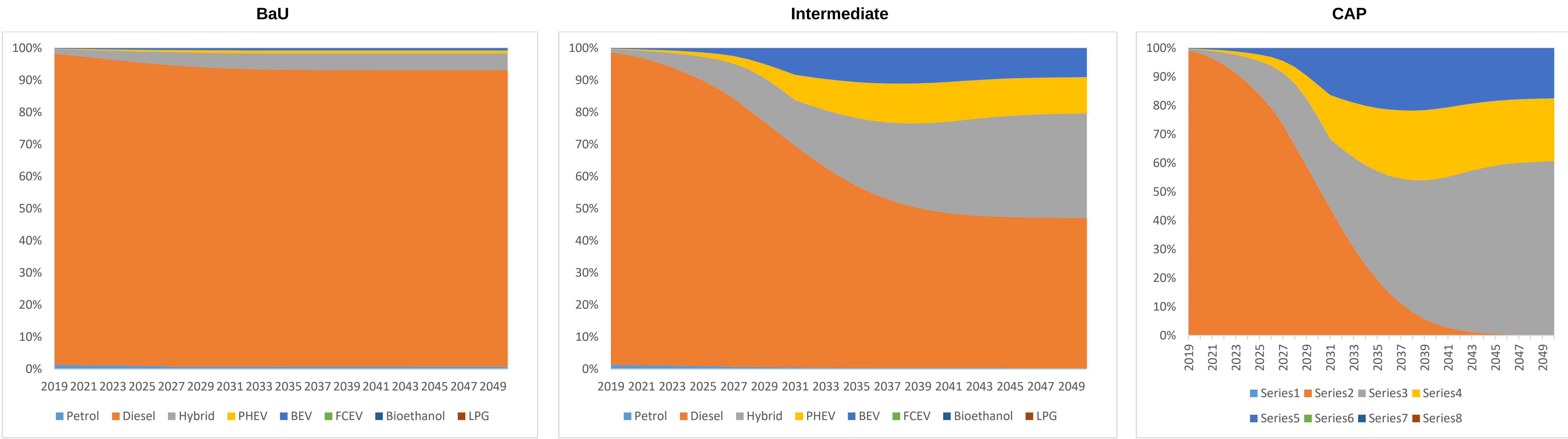

Figure C3 LGV Fuel Technology Projections

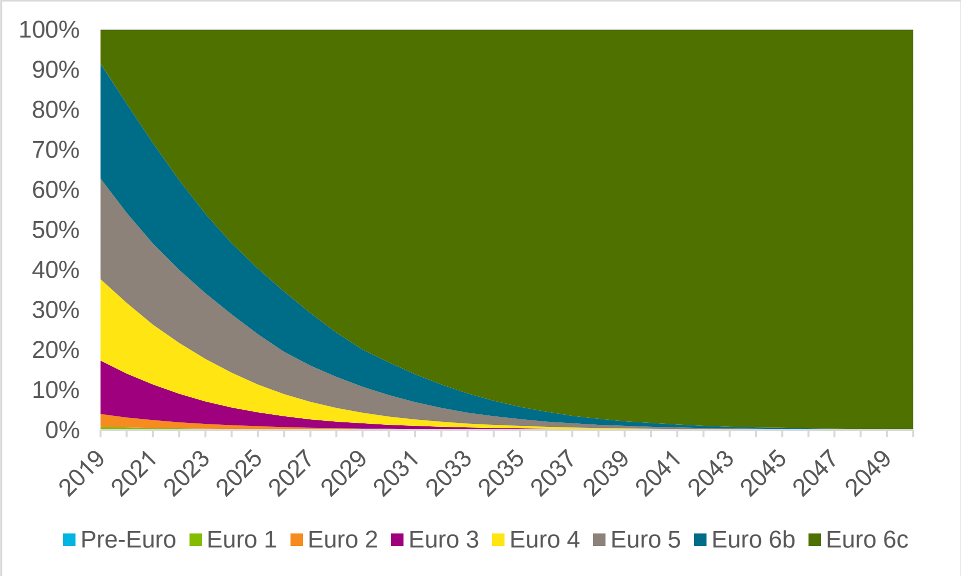

Figure C4 Projected National LGV 1N1(I) Petrol Age Profile

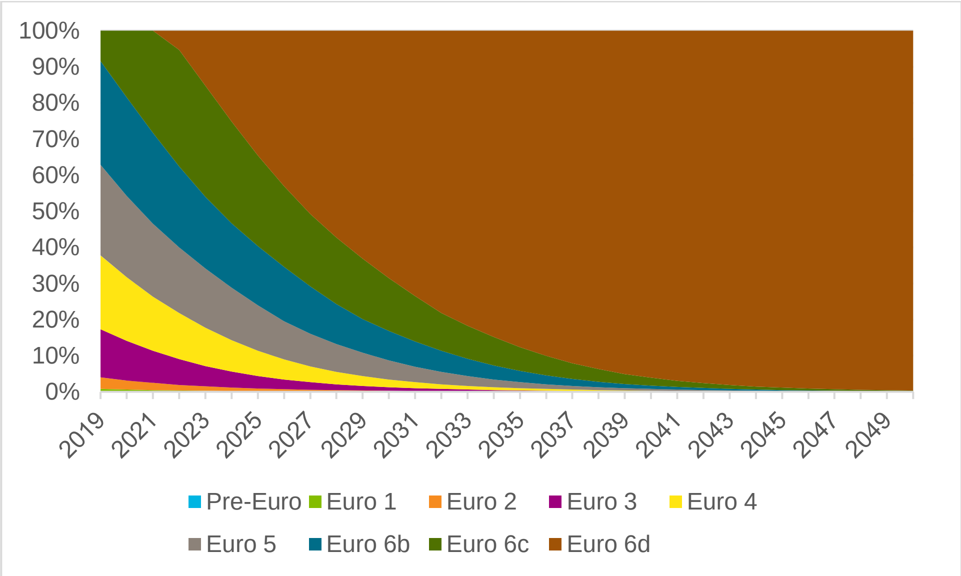

Figure C5 Projected National LGV 1N1(I) Diesel Age Profile

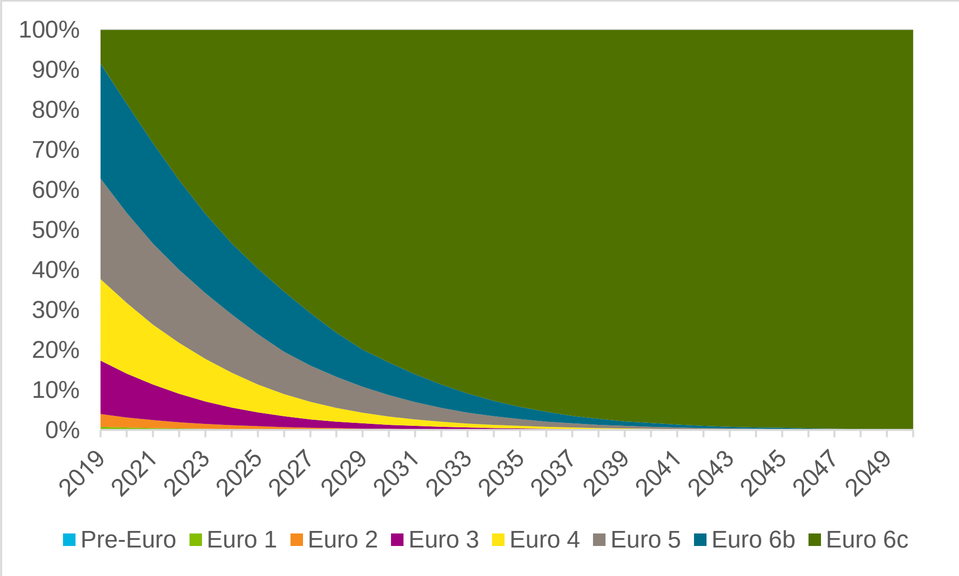

Figure C6 Projected National LGV 2N1(II) Petrol Age Profile

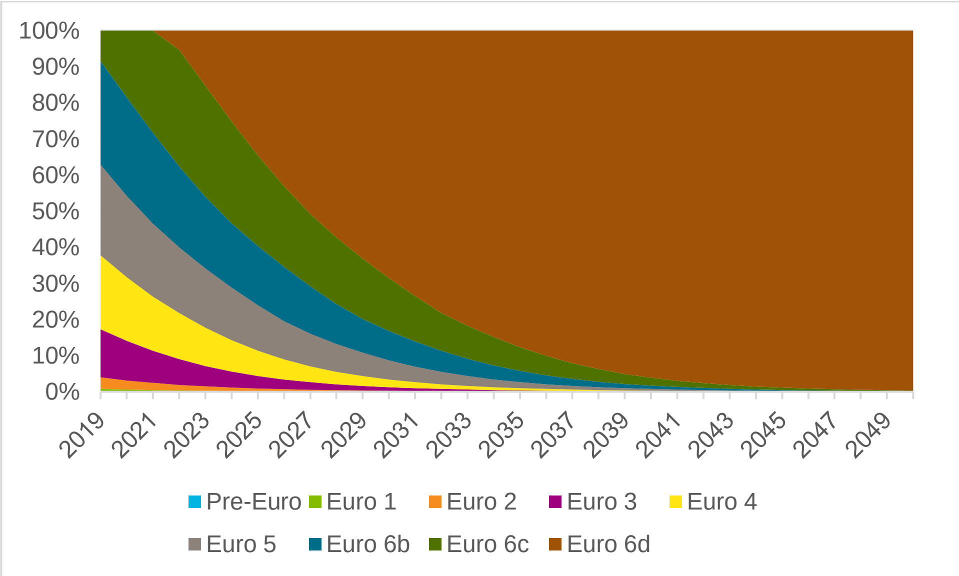

Figure C7 Projected National LGV 2N1(II) Diesel Age Profile

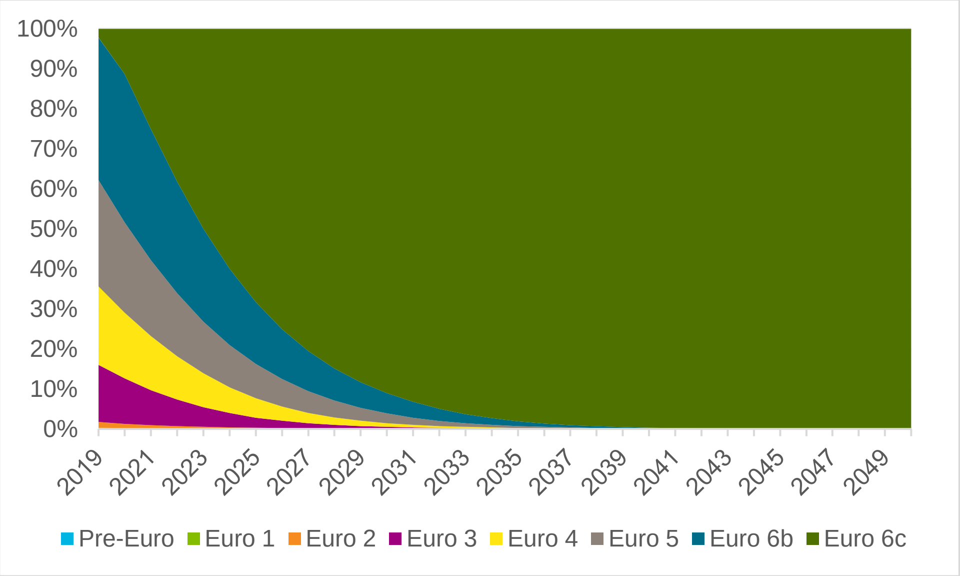

Figure C8 Projected National LGV 3N1(III) Petrol Age Profile

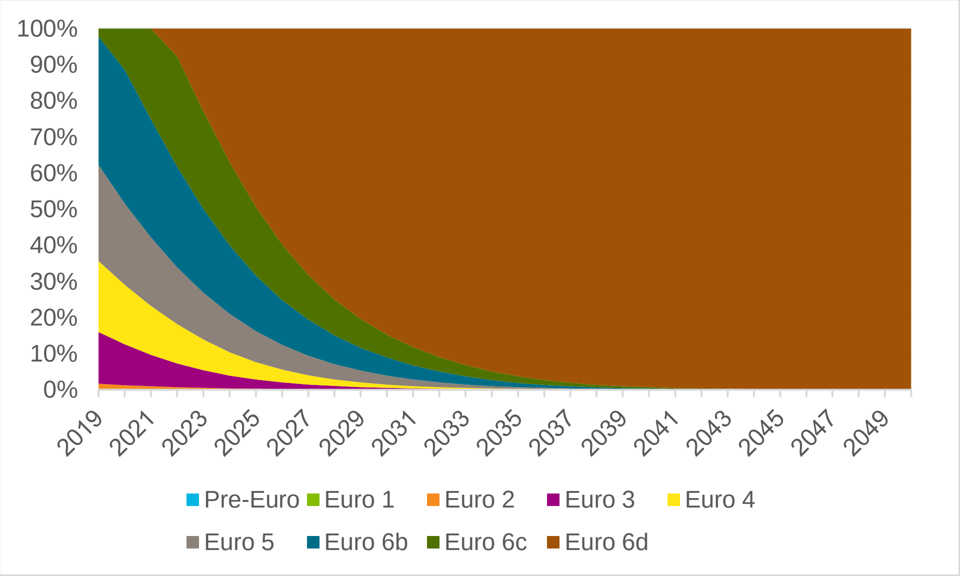

Figure C9 Projected National LGV 3N1(III) Diesel Age Profile

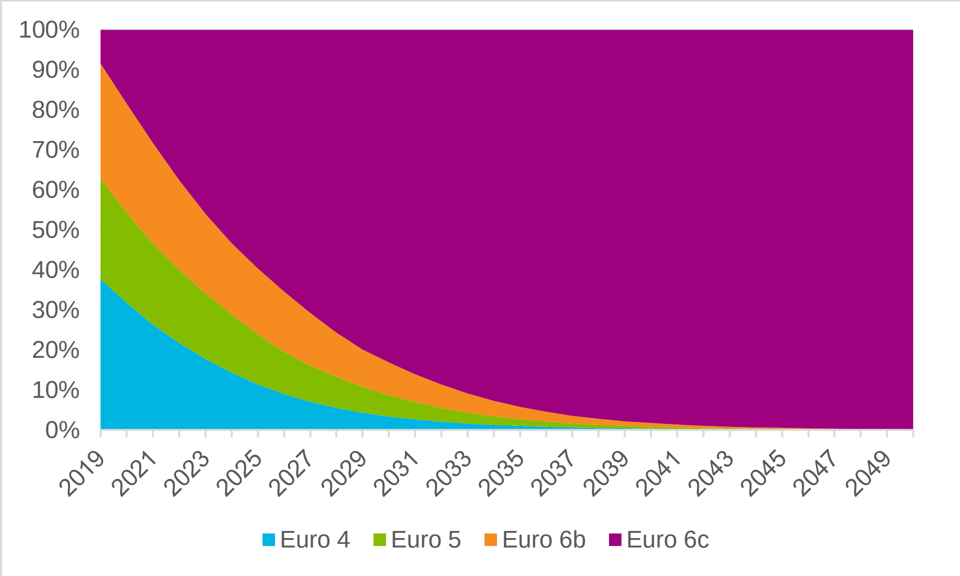

Figure C10 Projected National LGV 1N1(I) Hybrid Age Profile

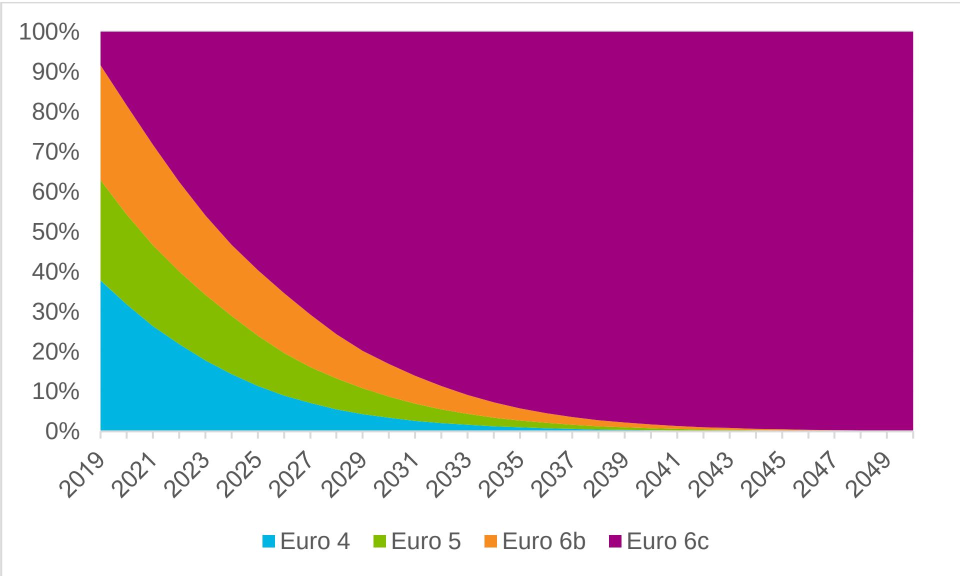

Figure C11 Projected National LGV 2N1(II) Hybrid Age Profile

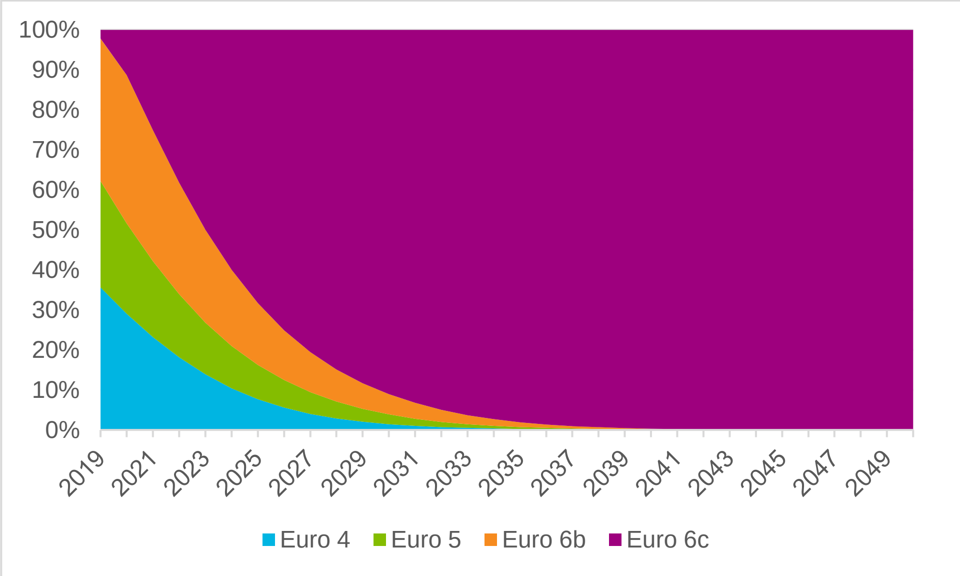

Figure C12 Projected National LGV 3N1(III) Hybrid Age Profile

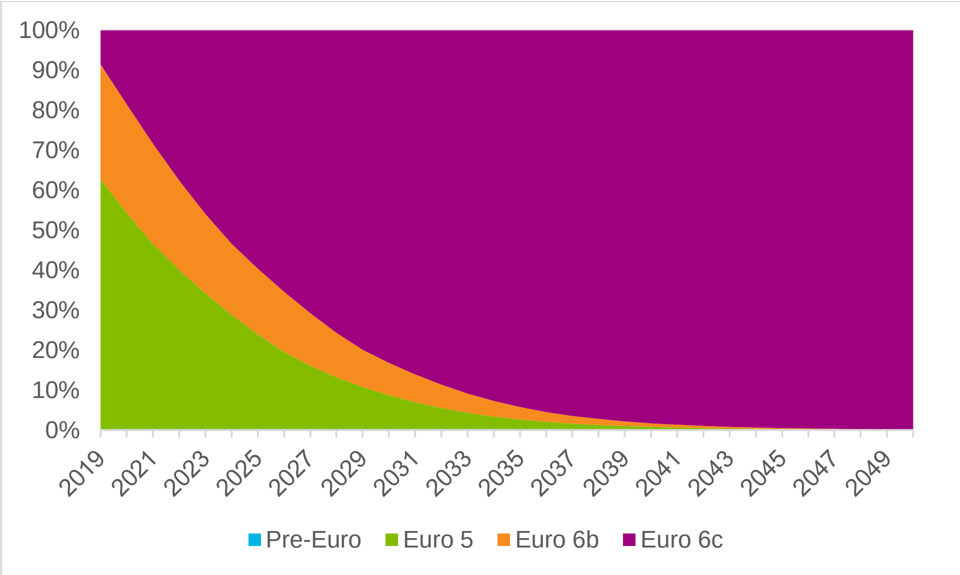

Figure C13 Projected National LGV 1N1(I) Plug-In Hybrid Age Profile

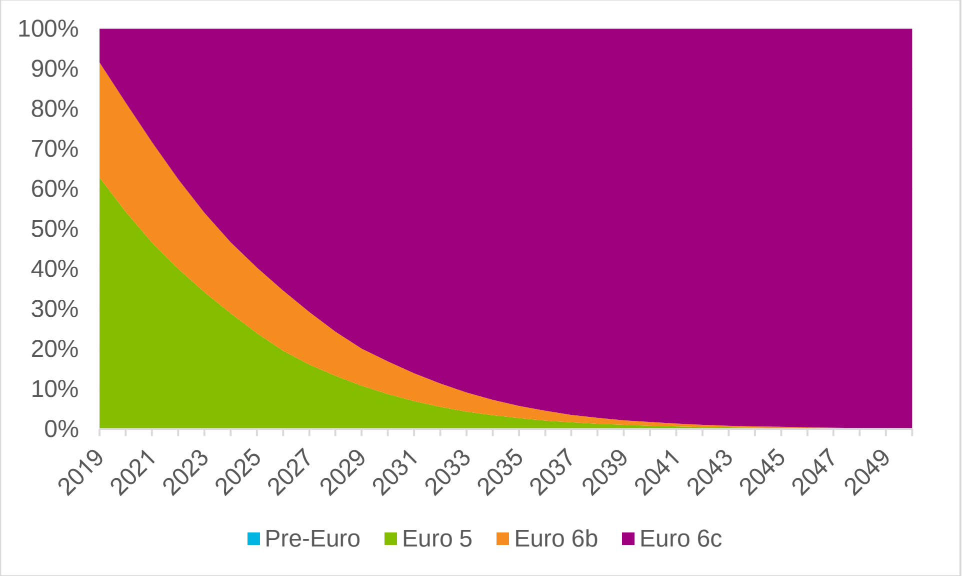

Figure C14 Projected National LGV 2N1(II) Plug-In Hybrid Age Profile

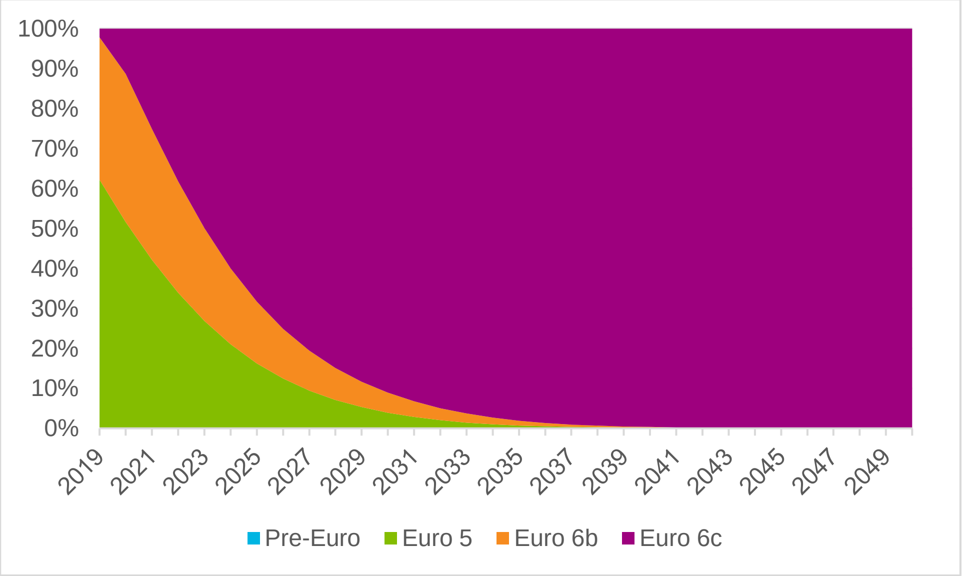

Figure C15 Projected National LGV 3N1(III) Plug-In Hybrid Age Profile

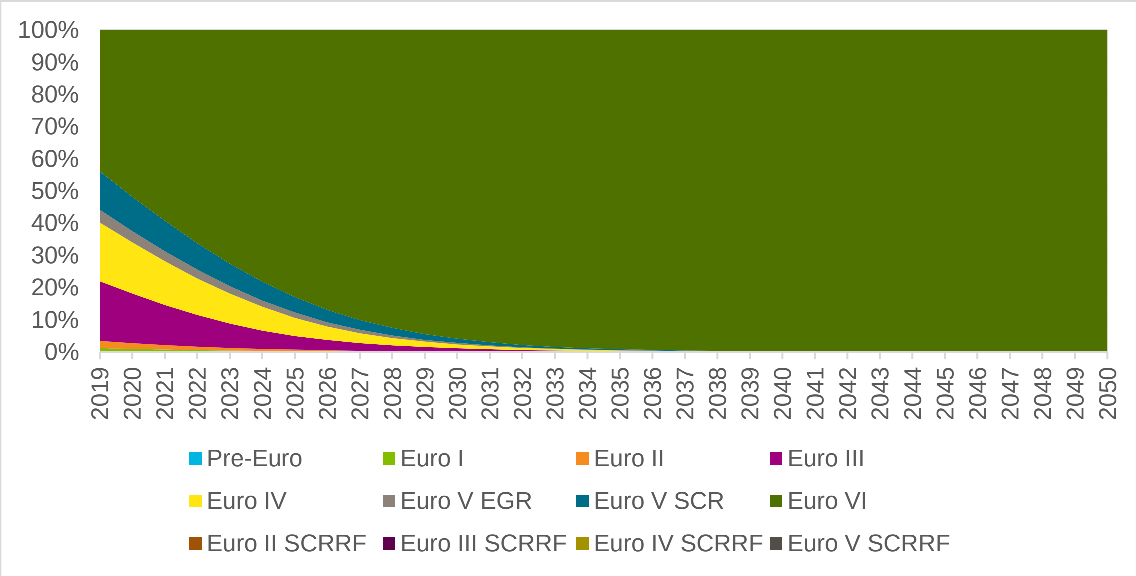

Figure C16 Projected National HGV Rigid <7.5t Age Profile

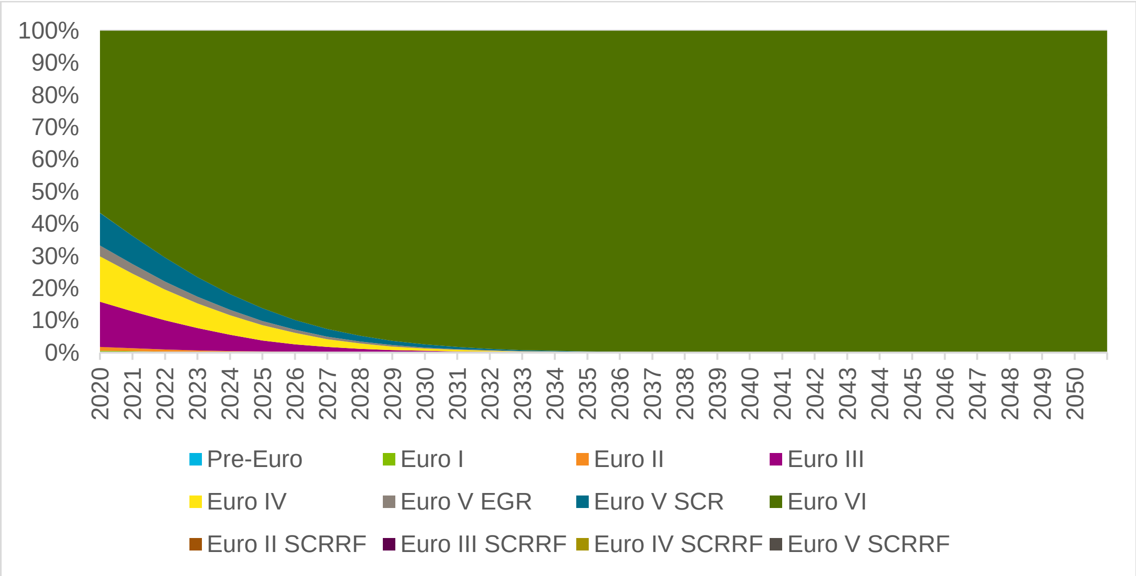

Figure C17 Projected National HGV Rigid 7.5-12t Age Profile

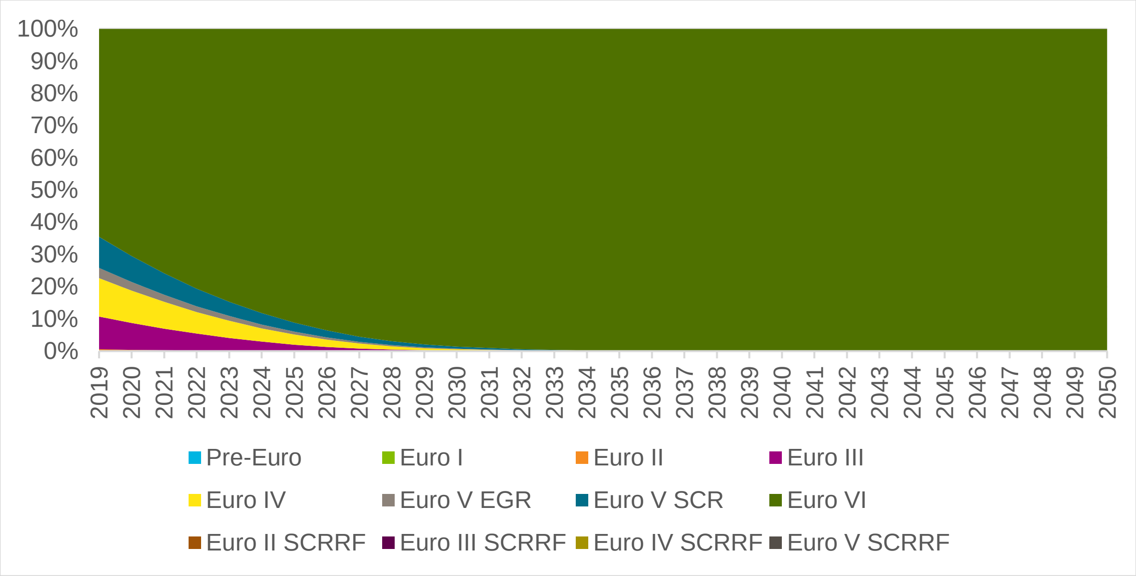

Figure C18 Projected National HGV Rigid 12-14t Age Profile

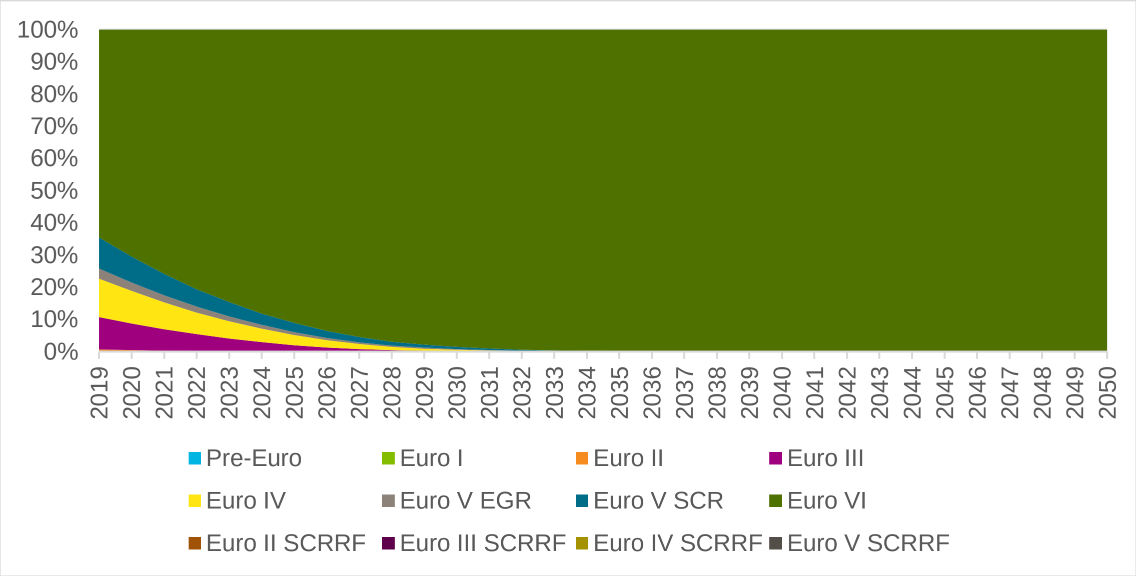

Figure C19 Projected National HGV Rigid 14-20t Age Profile

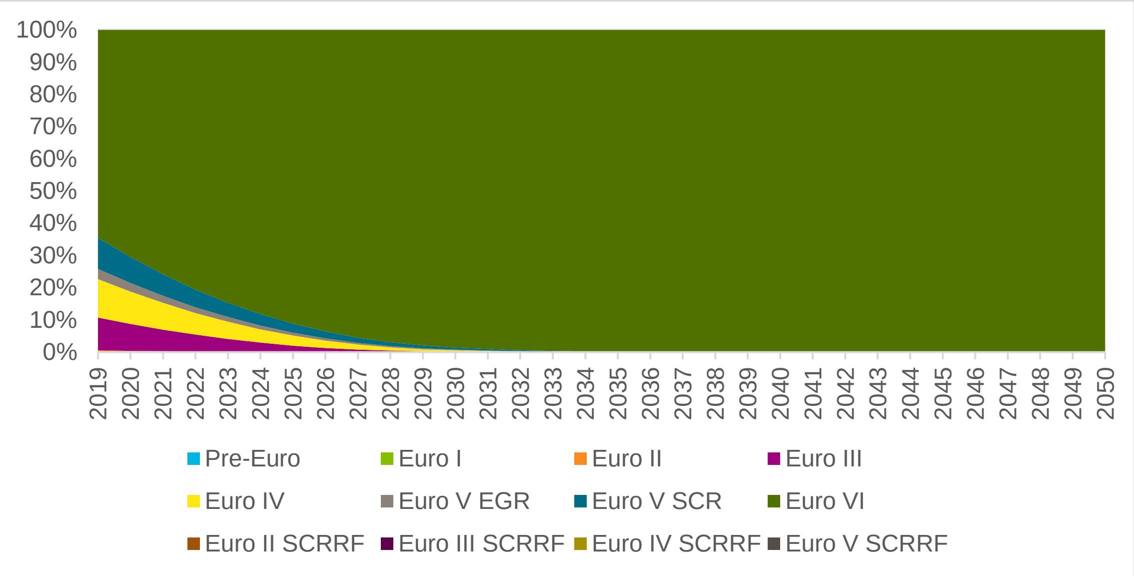

Figure C20 Projected National HGV Rigid 20-26t Age Profile

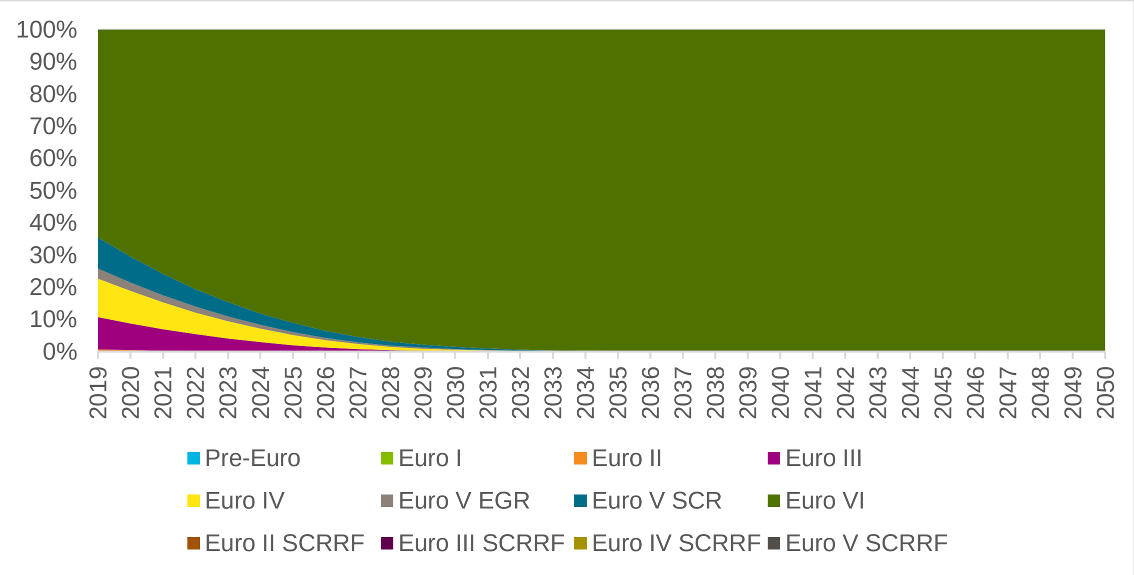

Figure C21 Projected National HGV Rigid 26-28t Age Profile

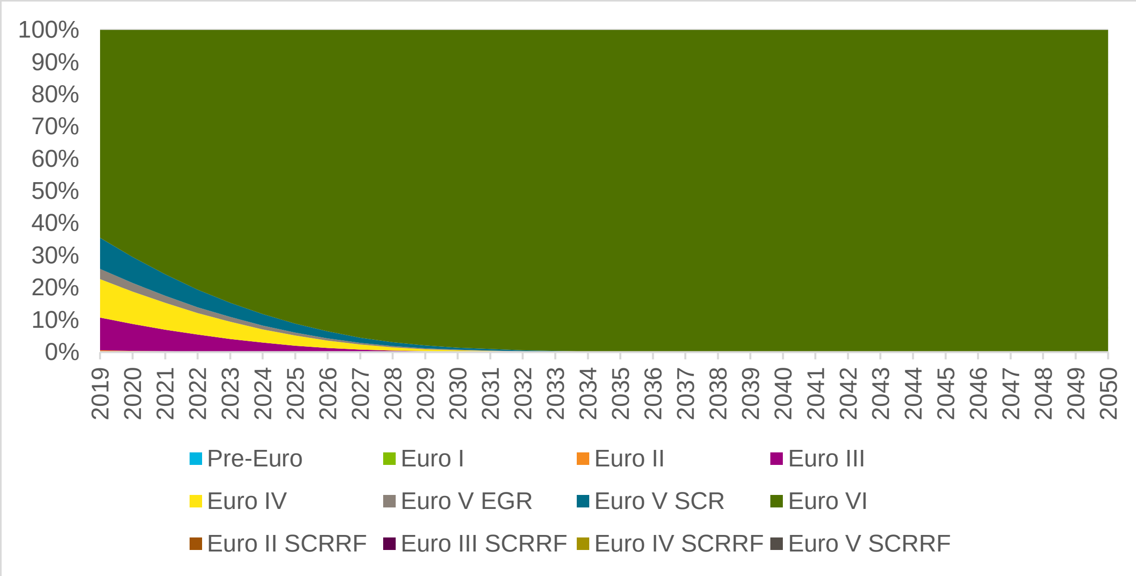

Figure C22 Projected National HGV Rigid 28-32t Age Profile

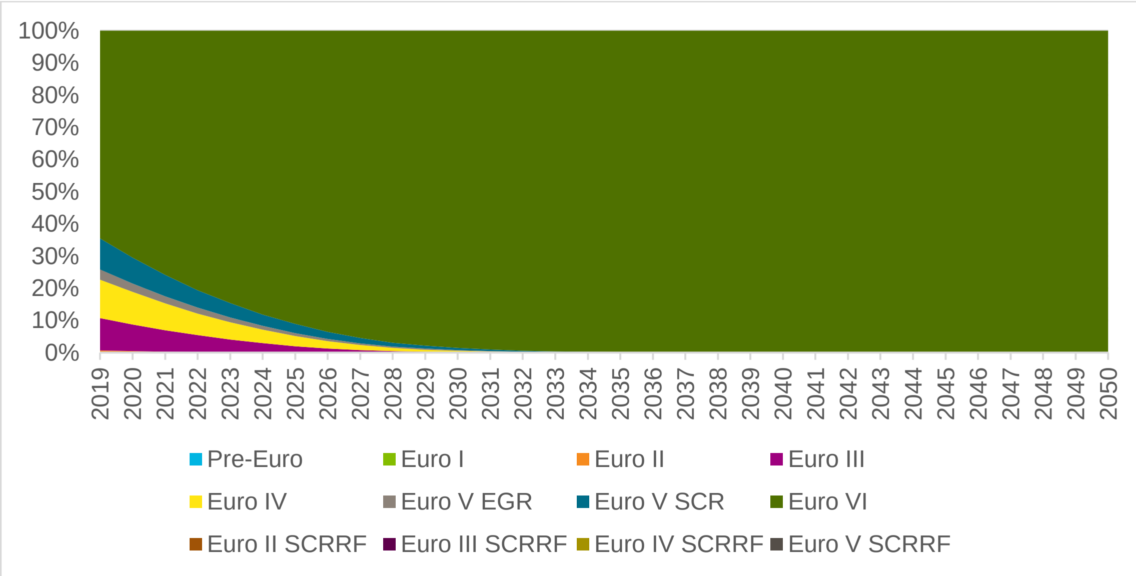

Figure C23 Projected National HGV Rigid >32t Age Profile

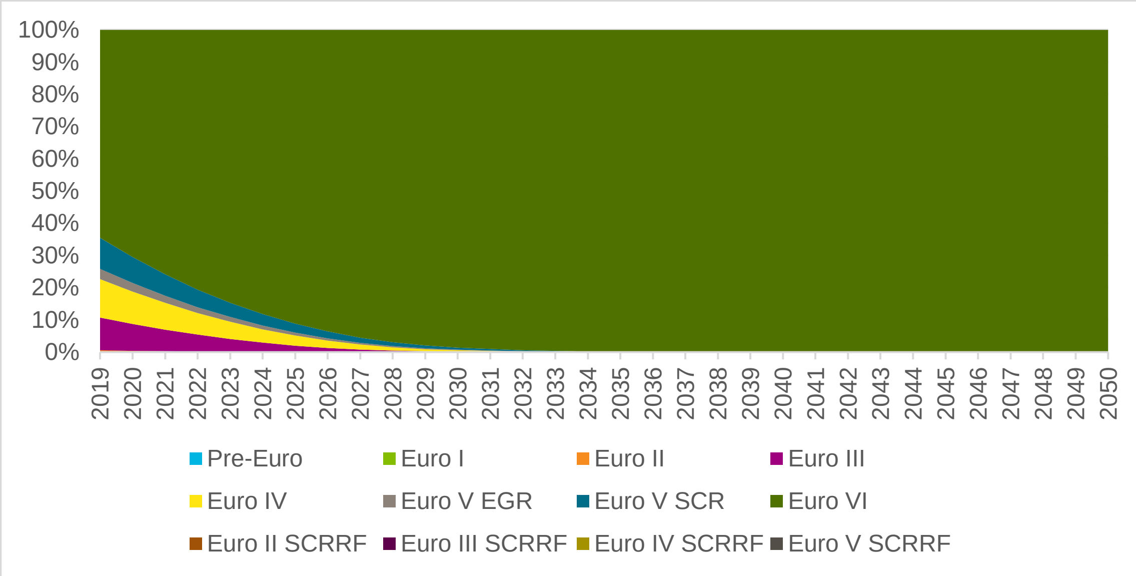

Figure C24 Projected National HGV Artic 14-20t Age Profile

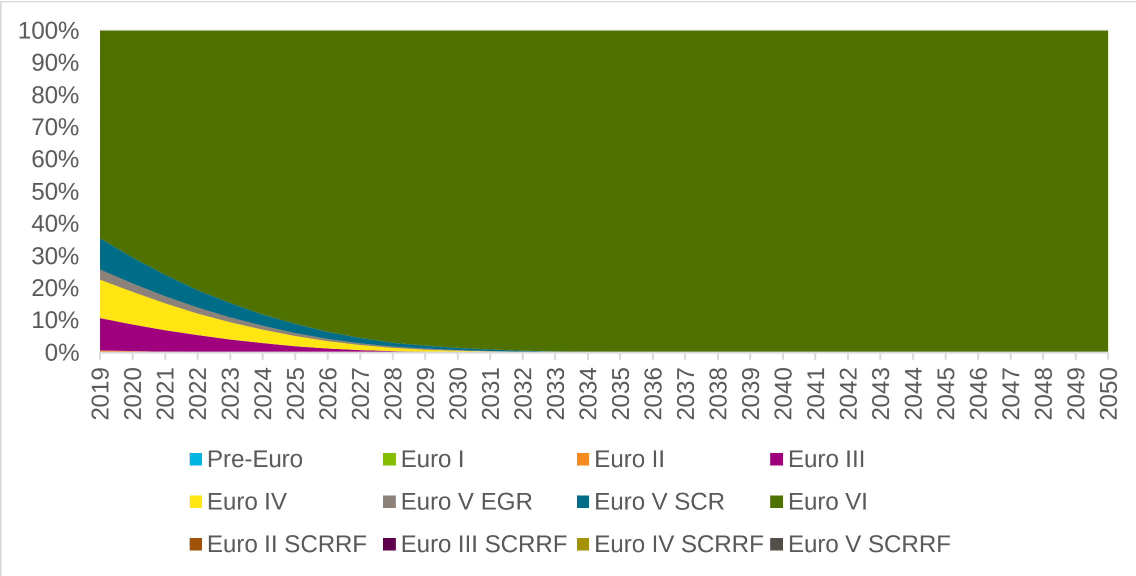

Figure C25 Projected National HGV Artic 20-28t Age Profile

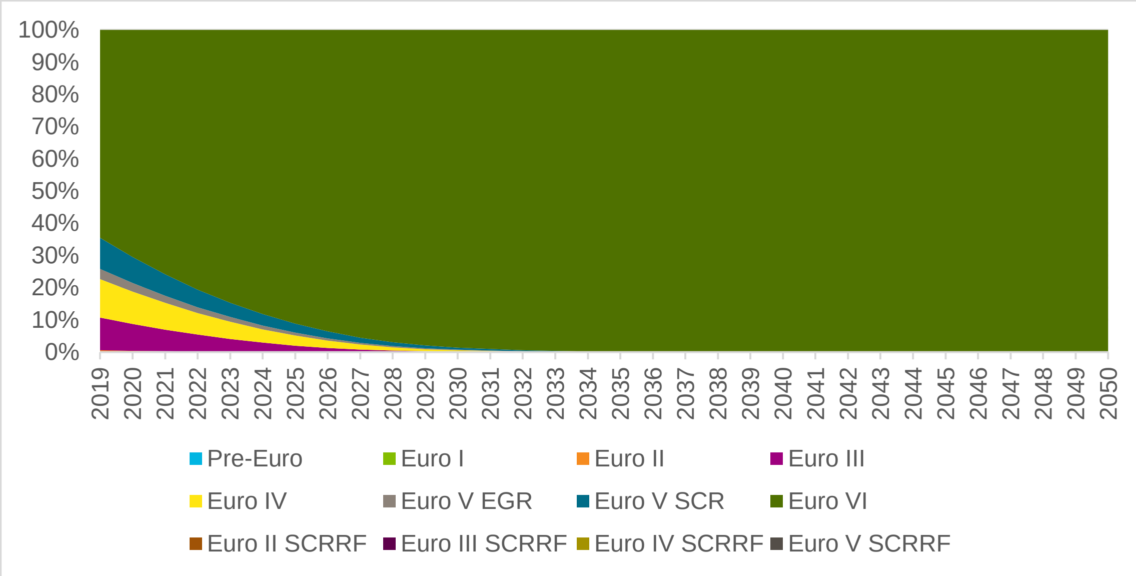

Figure C26 Projected National HGV Artic 28-34t Age Profile

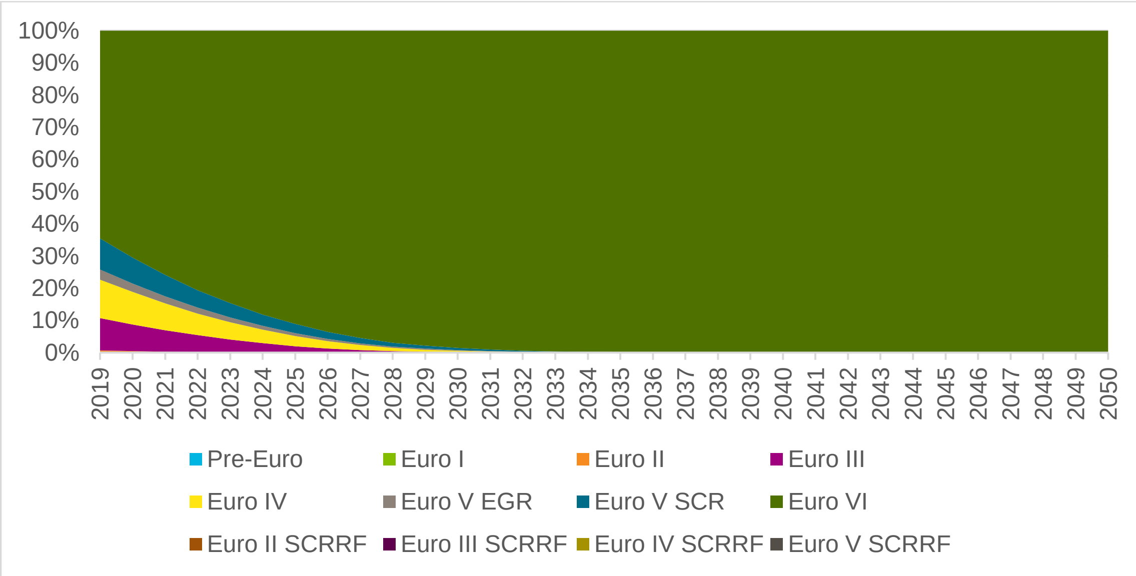

Figure C27 Projected National HGV Artic 34-40t Age Profile

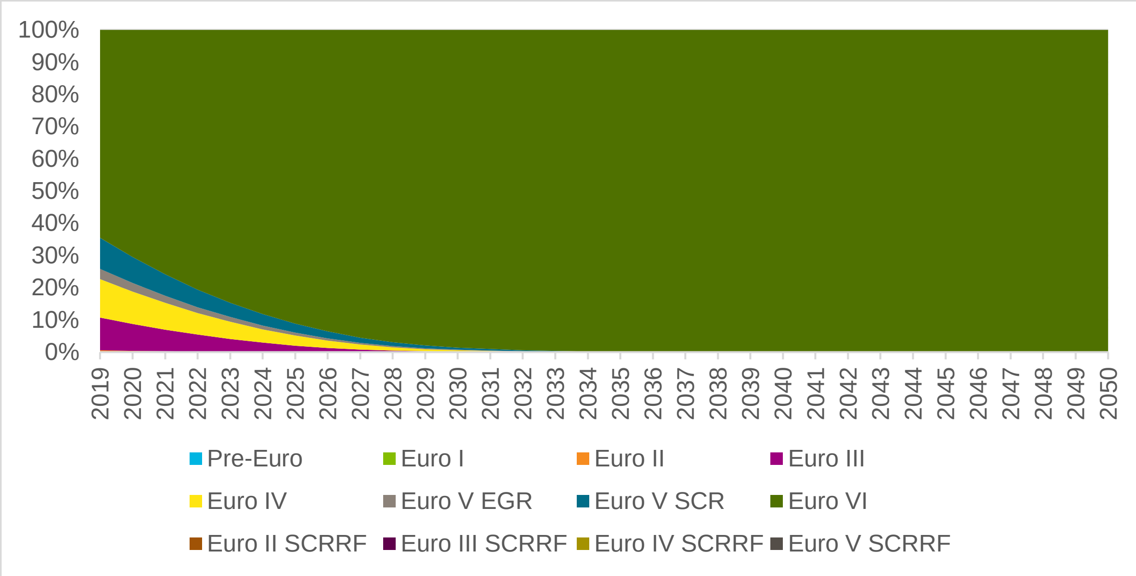

Figure C28 Projected National HGV Artic 40-50t Age Profile

Appendix D

Examples of Car Fleet Fuel Scenario Profiles

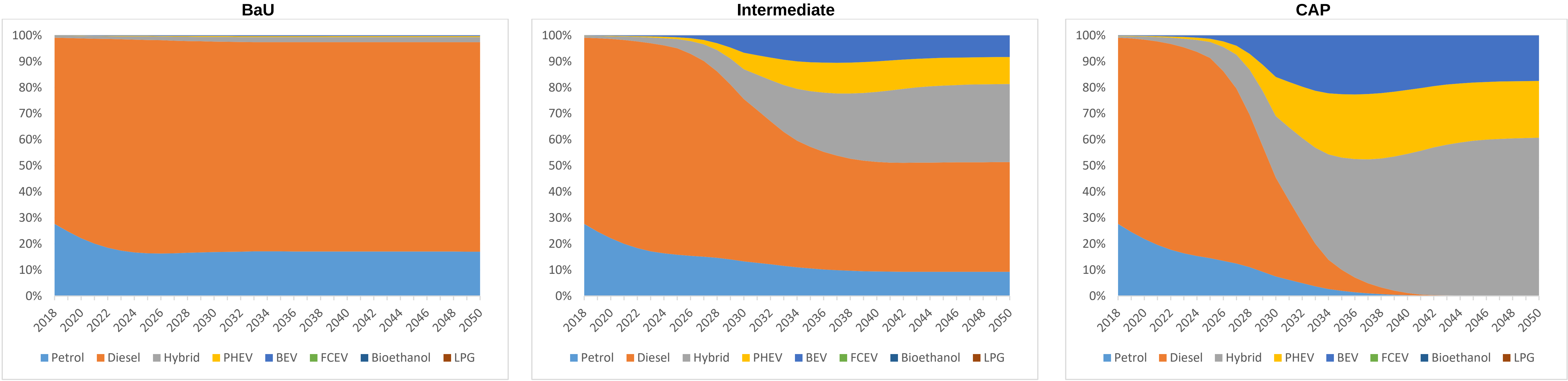

Figure D1 Examples of Rural Car Fuel Technology Profiles, Carlow

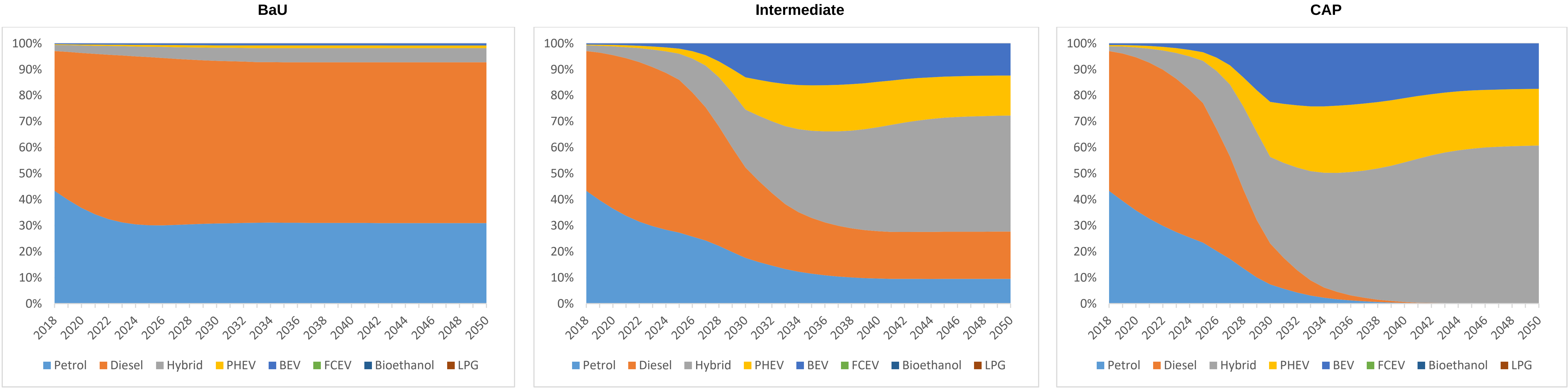

Figure D2 Examples of Urban Car Fuel Technology Profiles, Dublin

Appendix E

Review of Vehicle Emission Data Sources for CO_2 and CO_2e

This note outlines the tools available for calculating vehicle emissions of carbon dioxide (CO_2) emissions, and CO_2-equivalent (CO_2e) which represent emissions of pollutants with global warming potential (see definition box below); e.g. methane (CH_4) has a global warming potential x85 higher than CO_2, and nitrous oxide is (N_2O) x265 higher for a 100-year period.[70]

Definitions:

CO_2: carbon dioxide gas

CO_2e[71]: Carbon dioxide equivalent (CO_2e) is a term for describing different direct greenhouse gases in a common unit. For any quantity and type of greenhouse gas, CO_2e signifies the amount of CO_2 which would have the equivalent global warming impact. The seven direct greenhouse gases recognised by the Kyoto Protocol, and included within the definition of CO_2e, are: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and (NF_3)[3]. Most CO_2e datasets, such as those used in WebTAG, include only CO_2, CH_4, N_2O.

Direct Greenhouse Gases: Gases that contribute directly to global warming due to their ability to trap heat in the atmosphere.

Indirect Greenhouse Gases: Gases that contribute indirectly to global warming, such as NOx and CO, which are involved in tropospheric ozone formation, which in turn contributes to warming.

E1 Emissions Models

The primary tools for calculating and reporting CO_2 and CO_2e vehicle emissions are:

- Emissions rates published by TRL on behalf of the UK Dept. for Transport (DfT) derived from real-world testing undertaken in the UK and used in the Emissions Factors Toolkit (EFT) (DEFRA, 2020)[72] used for detailed air quality modelling;
- COPERT (EEA, 2020) emissions model using rates derived from real-world testing[73];
- Transport Appraisal Guidance (TAG) and Design Manual for Roads and Bridges (DMRB) (HE, 2020) toolkits used for strategic roads appraisal with emissions based in the TAG Data Book (HM Treasury, 2020) values[74],
- Transport User Benefits Appraisal (TUBA)[75] software model for strategic economic appraisal using emission rates referring to TAG; and
- UK Dept. for Business, Energy and Industrial Strategy (BEIS) emissions valuation model used for economic auditing and cross referenced in TAG.

Comparison of the vehicle emission sources indicates that annual CO_2 emissions vary significantly, but within a margin dictated by the model parameters.

[70] https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials
[71] CO_2e was also used in air quality modelling pre-2011 to signify when carbon only emissions were being reported as CO_2; this use is now redundant.
[72] https://laqm.defra.gov.uk/review-and-assessment/tools/emissions-factors-toolkit.html
[73] https://www.eea.europa.eu/themes/air/links/guidance-and-tools/copert4-road-transport-emissions-model
[74] https://www.gov.uk/government/publications/tag-data-book
[75] https://www.gov.uk/government/publications/tuba-downloads-and-user-manuals

Emissions calculated using model speeds per individual link (e.g. EFT and COPERT) are similar and tend to calculate higher emissions overall compared to the fleet average models (i.e. TUBA and BEIS) as a result of the greater model resolution in EFT and COPERT.

E2 EFT and COPERT

As outlined above the CO_2 emissions rates calculated by EFT and COPERT are very similar, with the variance interpreted as a result of local factors, such as fuel scaling, and the sample size of the fleet subset used in real-world testing to inform the model profile. Both models apply a non-linear speed-emissions relationship for each component of the fleet (e.g. vehicle type, age, fuel type, engine size) that significantly alter the output, which indicates that a local fleet profile is a potentially significant factor.

EFT calculates only CO_2 emissions, and does not calculate any other GHG, whereas COPERT calculates multiple pollutants, including CO_2 and other GHGs; namely CH_4 and N_2O. However, emissions for CH_4 and N_2O are not calculated using speed-emissions relationship and output values are a function only of the non-speed input parameters.

Both TUBA and TAG CO_2e emissions are based on the TAG A3.3 Data Book. The TAG A3.3 Data Book is linked to a BEIS data source Table 2b: Converting road and rail fuels to CO_2e (emission factors), kgCO_2e/litre[76]. This table confirms that CH_4 and N_2O are included in CO_2e in a footnote '*Note: GHGs include CO_2, CH_4 and N_2O.'*. TUBA calculates emissions of CO_2, as well as CO_2e values for CH4 and N_2O per vehicle based on fuel-consumption for diesel and petrol vehicles (Data Book Table A3.3 Carbon Emissions). No information is provided within these TAG Data Books to outline what vehicle classifications have been used to determine the overall fuel consumption factors and nor are any factors for in the individual components of CO_2e provided.

E3 BEIS Fuel and Vehicle Splits

Separate to the above, BEIS data tables emission rates for CO_2, CH_4 and N_2O as CO_2e as g/km are published in the BEIS 2020 tool and methodology paper (UK Government GHG Conversion Factors for Company Reporting)[77]. This BEIS tool has further differentiation than indicated in the TAG data source and applies an average user-defined speed and market segment (i.e. size of car by fuel type), but still does not use a complex speed-emissions profile. BEIS reports emission rates for CO_2, CH_4 and N_2O as CO_2e as g/km for a range of fuel types. These emissions are based on New European Drive Cycle (NEDC) emissions data uplifted for real-world conditions, and the proportion of the fleet corresponding to each vehicle class.

The methodology paper for this BEIS tool refers to the *UK Greenhouse Gas Inventory 1990 to 2018 Annual Report for Submission under the Framework Convention on Climate Change* published in April 2020 and prepared by Ricardo Energy and Environment (Ricardo, 2019)[78]. This document sets out COPERT as the origin of this data. The document does not set out the full details of the COPERT modelling procedures utilised to generate these non-CO_2 emissions.

[76] Data Table A3.3, BEIS, 2019 hyperlink to Table 2b: Converting road and rail fuels to CO_2e (emission factors), kgCO_2e/litre https://www.gov.uk/government/publications/tag-data-book
[77] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020
[78] https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2004231028_ukghgi-90-18_Main_v02-00.pdf

Comparison of the models indicates that CO_2e emissions for non-CO_2; i.e. CH_4 and N_2O are negligible, and whilst the emissions vary with the fuel and vehicle type the mass of non-CO_2 pollutants as CO_2e are generally around 1% of the total CO_2e; e.g. BEIS predicts that 1.1% of CO_2e is N_2O for average diesel cars, whereas it is only 0.2% of average petrol cars; example data are shown in an extract from the BEIS workbook in Table E1.

As with CO_2, the emissions of non-CO_2 GHG calculated by COPERT are dependent on the fleet parameters applied to the model, albeit at a very small fraction of the total CO_2e emissions.

Table E1 BEIS UK Government GHG Conversion Factors for Company Reporting Workbook Extract

Fuel	Vehicle	Emissions, kg / km				Proportion of Total CO_2e	
		CO_2e	CO_2	CH_4e	N_2Oe	CH_4e	N_2Oe
Diesel	Small car	0.13721	0.13537	0.000003	0.00184	0.0025%	1.3410%
	Medium car	0.16637	0.16453	0.000003	0.00184	0.0021%	1.1060%
	Large car	0.20419	0.20235	0.000003	0.00184	0.0017%	0.9011%
	Average car	0.16844	0.1666	0.000003	0.00184	0.0021%	1.0924%
Petrol	Small car	0.14836	0.14769	0.00031	0.00036	0.2090%	0.2427%
	Medium car	0.18659	0.18592	0.00031	0.00036	0.1661%	0.1929%
	Large car	0.27807	0.2774	0.00031	0.00036	0.1115%	0.1295%
	Average car	0.1743	0.17363	0.00031	0.00036	0.1779%	0.2065%

Note: Emissions are also available for motorbikes (small, medium, large, average), vans (Class I, II, II, average), HGV (Rigid >3.5t – 7.5t, >7.5t – 17t, >17t, All Rigid HGVs, Articulated HGVs>3.5t – 33t, >33t, All Artic HGVs, All HGVs) and the same information is available for refrigerated HGVs.

E4 Summary

There are several emissions tools commonly used for the calculation and reporting of annual CO_2e emissions from vehicles. These tools all predict broadly similar values, although those with greater resolution to include a speed-emissions profile and user-defined fleet parameters tend to result in greater range of variability and higher emissions overall.

Comparison of the models also indicates that non-CO_2 GHG emissions; i.e. CH_4 and N_2O, are negligible components of the total CO_2e emissions. Excluding these sources may result in under-reporting, but well-within the margin that would be achieved with a link-based model and user-defined fleet parameters.

Appendix F

Model Fuel Consumption and Emissions Curves

This note subjectively compares the fuel consumption curves from WebTAG that are used in TUBA with the speed-based CO_2 emissions profiles calculated by the COPERT/EFT-based calculations in the TII emissions tool currently being developed by AECOM to integrate with the National Transport Model (NTpM).

F1 TUBA

TUBA software calculates annualised CO_2 carbon emission equivalents based on fuel consumption which is calculated based on average speed between the start and end point of a journey. This approach does not take into account speed variability on individual roads making up the journey, but rather gives average high-level estimations on carbon emissions.

The data in Table F1 identify the upper and lower speeds for each vehicle type within a fuel consumption range as described in TUBA (version 1.9.7). These data indicate the lowest fuel consumptions are within the speeds of 43 to 94 km/hr for LDV and 52 to 75 km/hr for HDV, with significantly higher fuel consumption for heavier vehicles.

Table F1 Lowest Fuel Consumption Speed Ranges

	Car	LGV	OGV1	OGV2
Approx. min. Fuel Consumption, l/100km	6.63	8.44	21.29	35.92
Speed @ l/100km	67	61	63	71
Lower Speed @ ~min l/100km	46	43	52	68
Upper Speed @ ~min l/100km	94	84	75	74

Figure F1 and Figure F2 present the fuel consumption against speed for LDVs (cars and LGVs) and HDVs (OGV1 and OGV2) respectively.

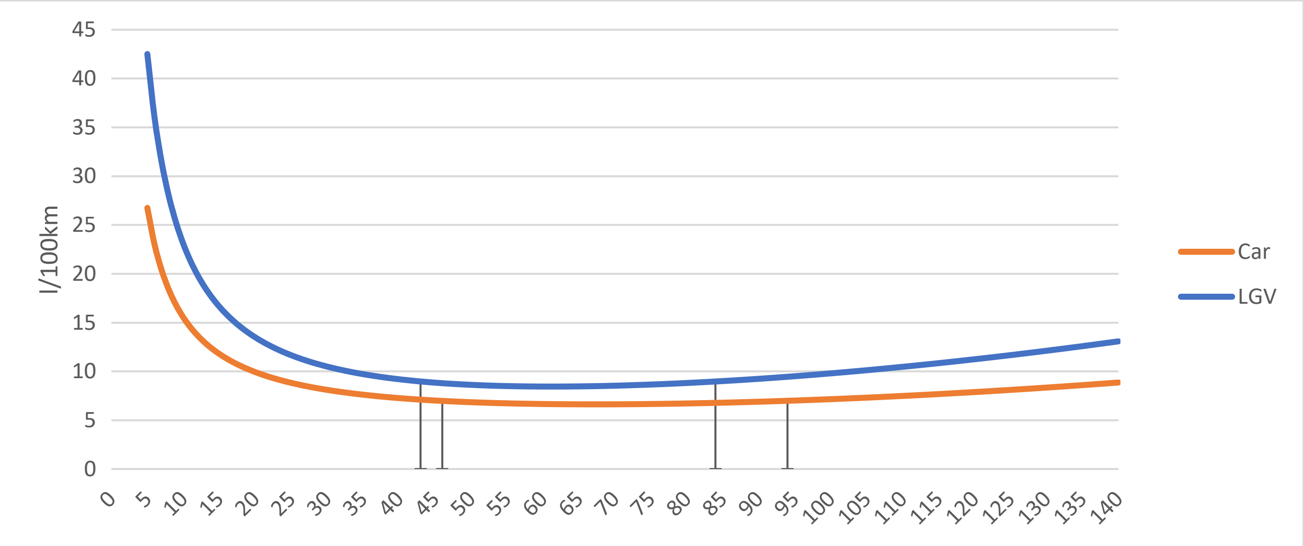

Figure F1 TUBA Fuel Consumption vs Speed Profiles for LDV

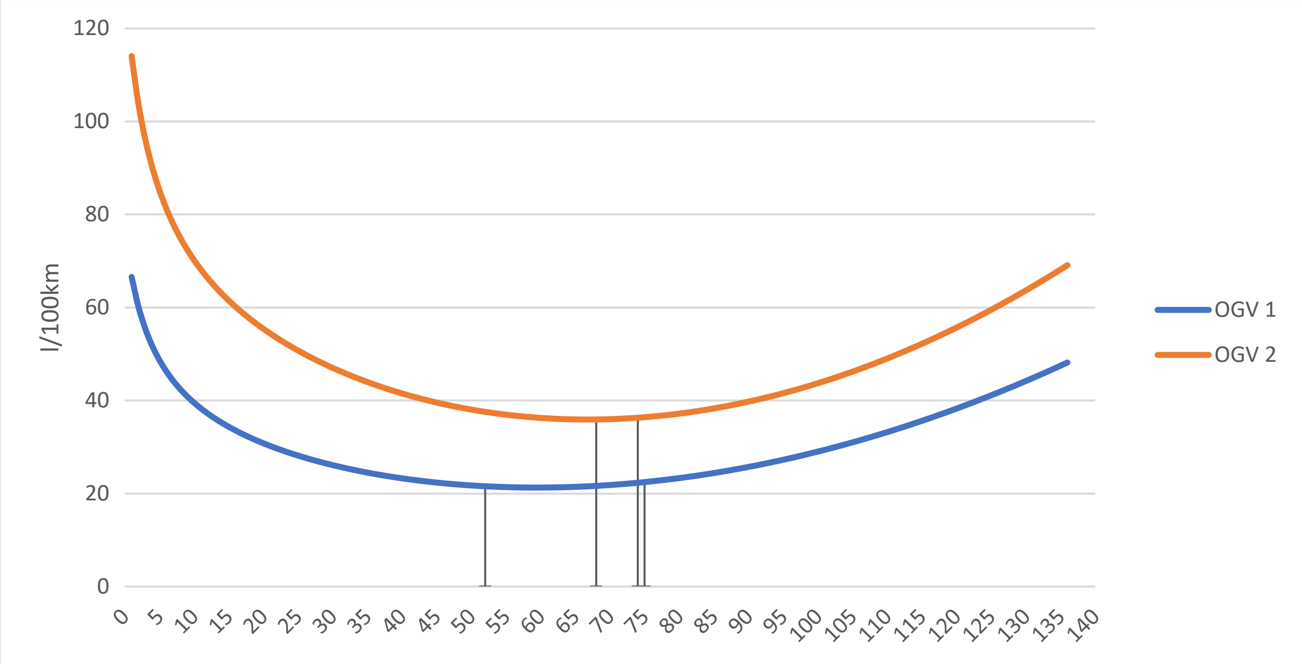

Figure F2 TUBA Fuel Consumption vs Speed Profiles for HDV

F2 TII Emissions Tool

The REM models each traffic link discretely, applying a link-specific speed and flow along with a global fleet profile for fleet characteristics defined by the user; e.g. county-level fleet age or fuel-type.

The data presented in the figure below are the speed-based CO_2 emissions profiles for representative subsets of the vehicle fleet, including the Euro classifications.

The plots indicate the speed-based emissions trends are broadly similar to the TUBA fuel consumption profiles, and within the upper/lower speed ranges for the lowest fuel-consumption rates; the lowest CO_2 emissions are approx. 40-85 km/hr for small petrol cars, approx. 55-95km.hr for large petrol cars, and approx. 60-90km/hr for small and large diesel cars.

The lowest emission rates for lighter HGVs are approx. 40-75 km/hr, whereas the largest HGVs have a relatively flat emission rate at speeds greater than approx. 50 km/hr. It was also noted that the lowest emission rate for the heavy HGVs exceeded the lowest emission rates for the lighter vehicles.

The disaggregation of the fuel-types and engines sizes indicate significant variability in terms of emissions, with larger engine, or heavier, vehicles having significantly higher CO_2 emission rates.

It is also recognised that whilst there is some variability between different Euro classifications, it is not considered to be significantly different for CO_2.

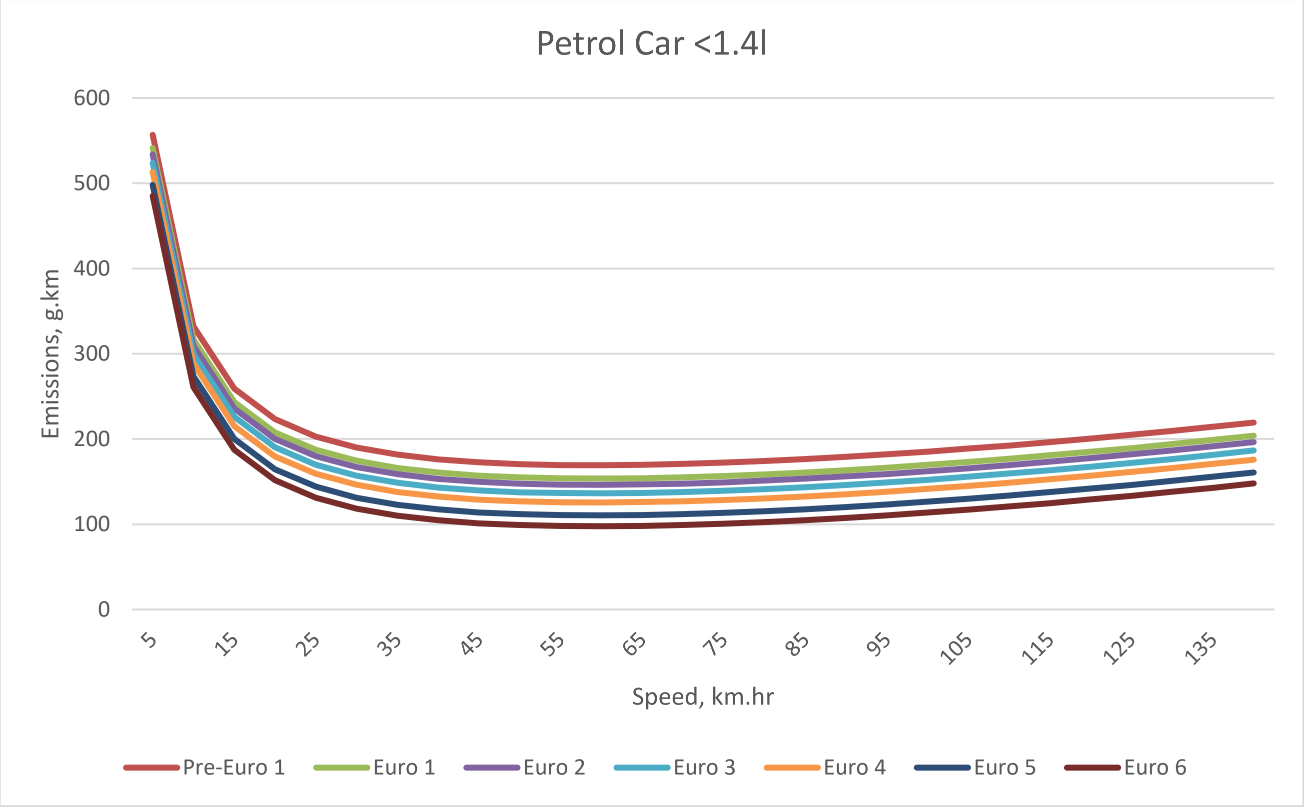

Figure F3 CO₂ Emissions, Small Petrol Cars

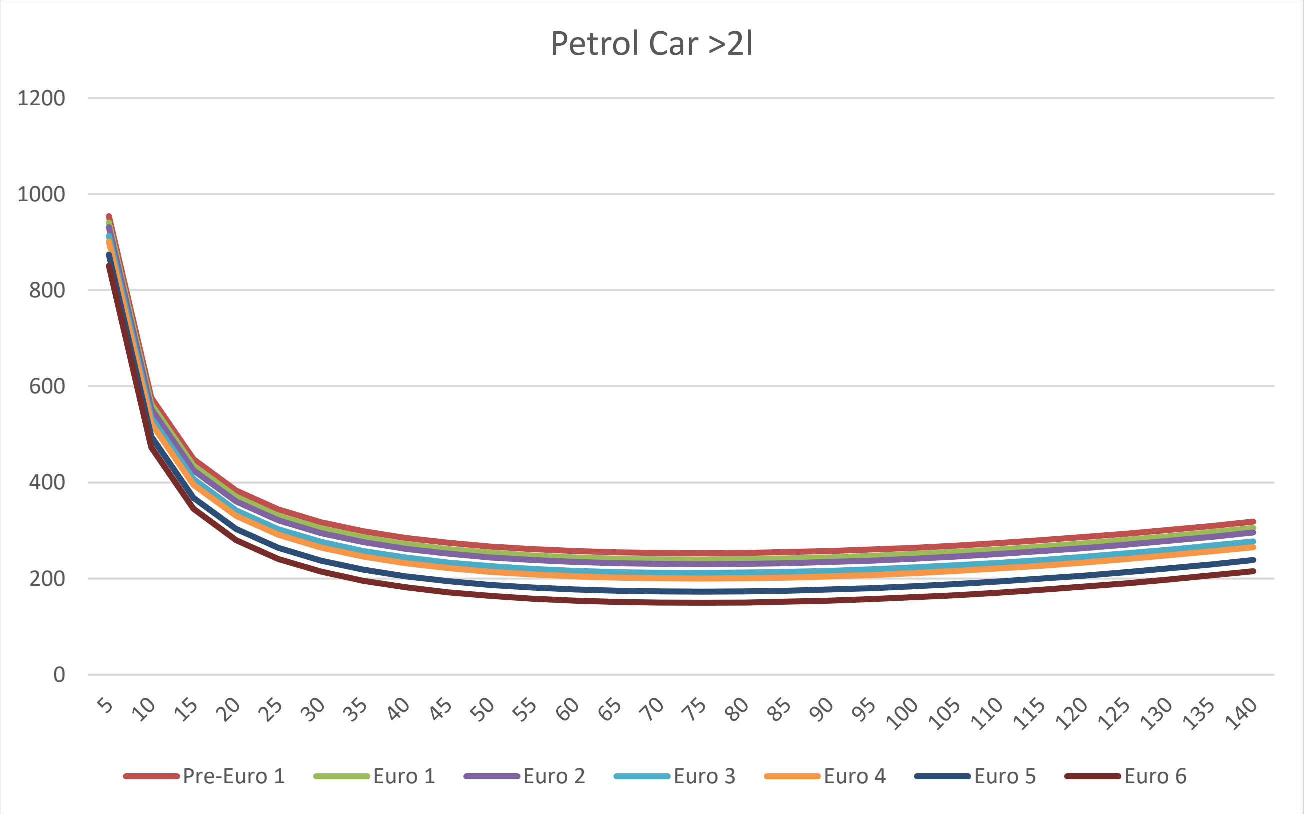

Figure F4 CO_2 Emissions, Large Petrol Cars

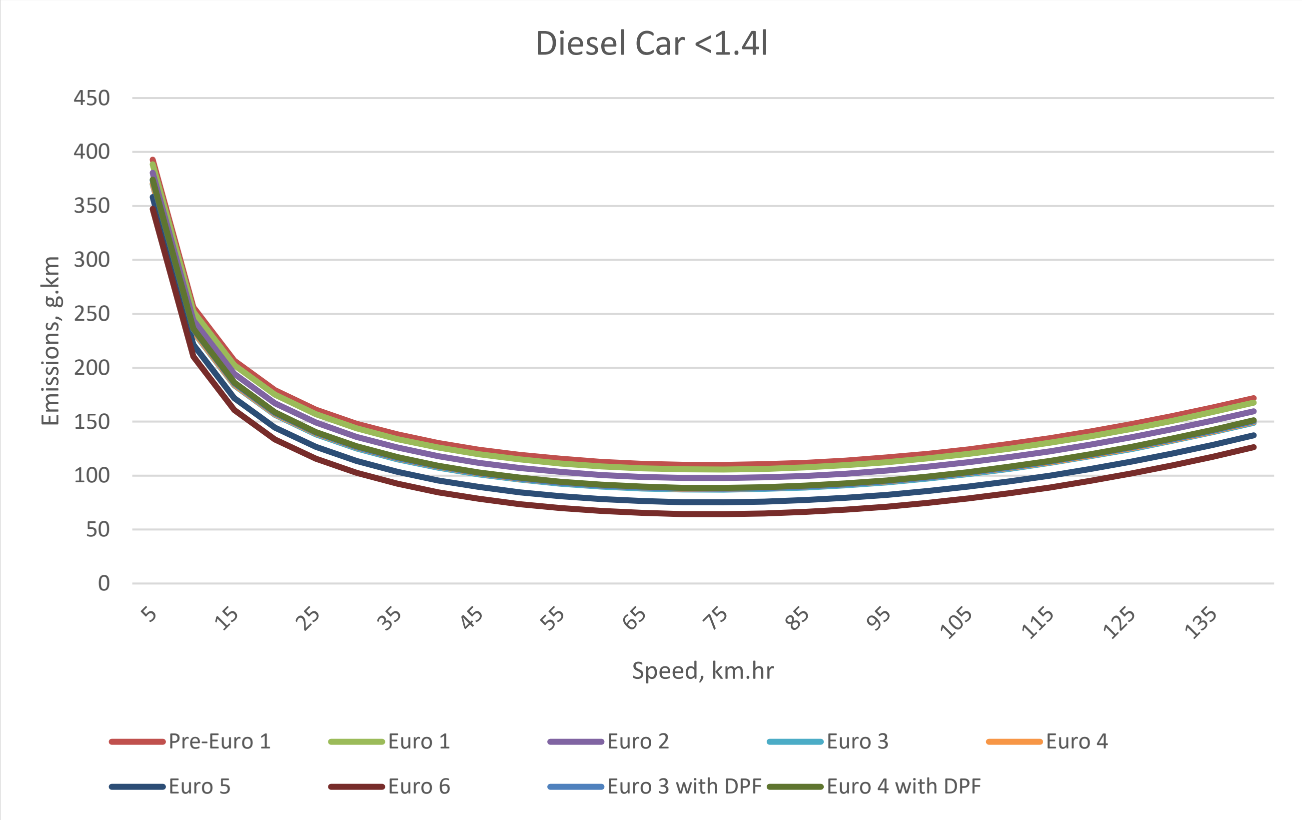

Figure F5 CO₂ Emissions, Small Diesel Cars

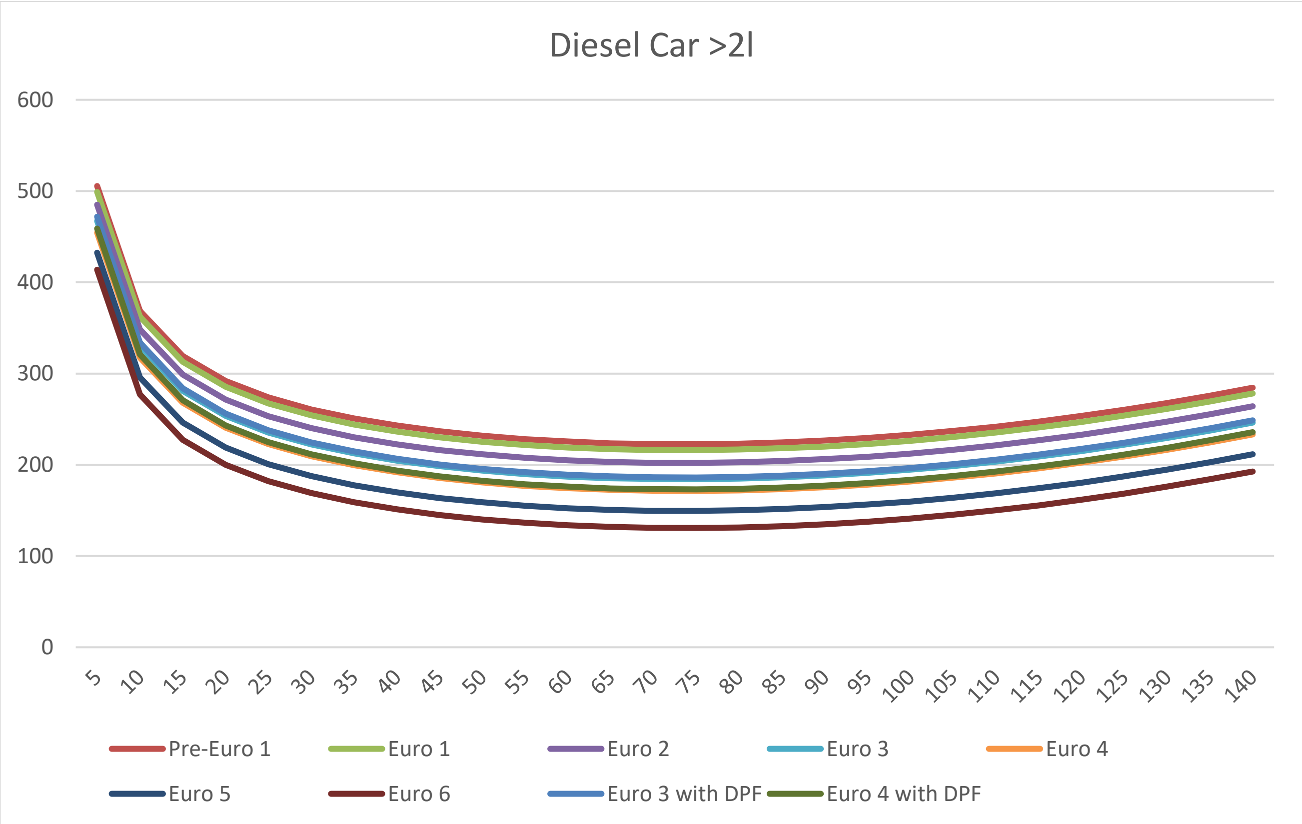

Figure F5 CO_2 Emissions, Large Diesel Cars

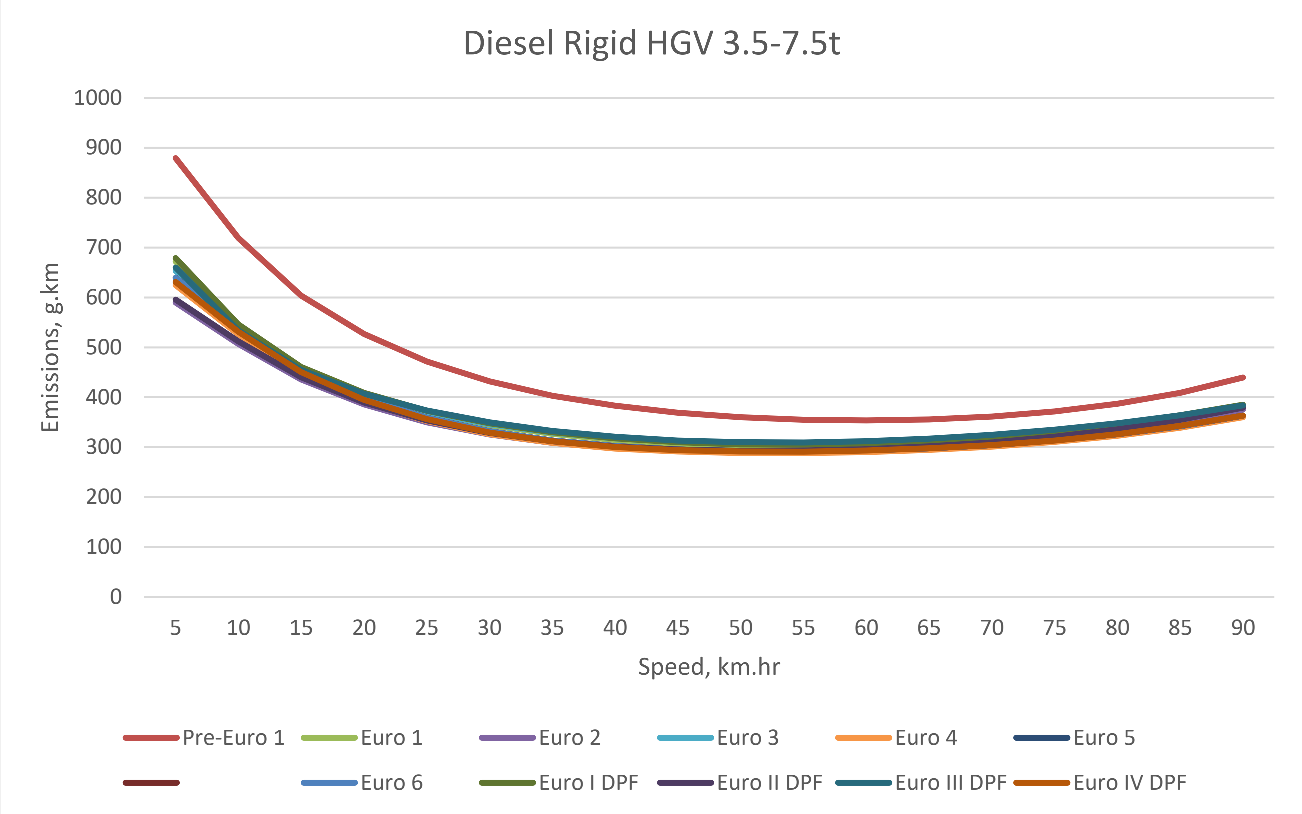

Figure F6 CO₂ Emissions, Rigid Diesels 3.5-7.5t

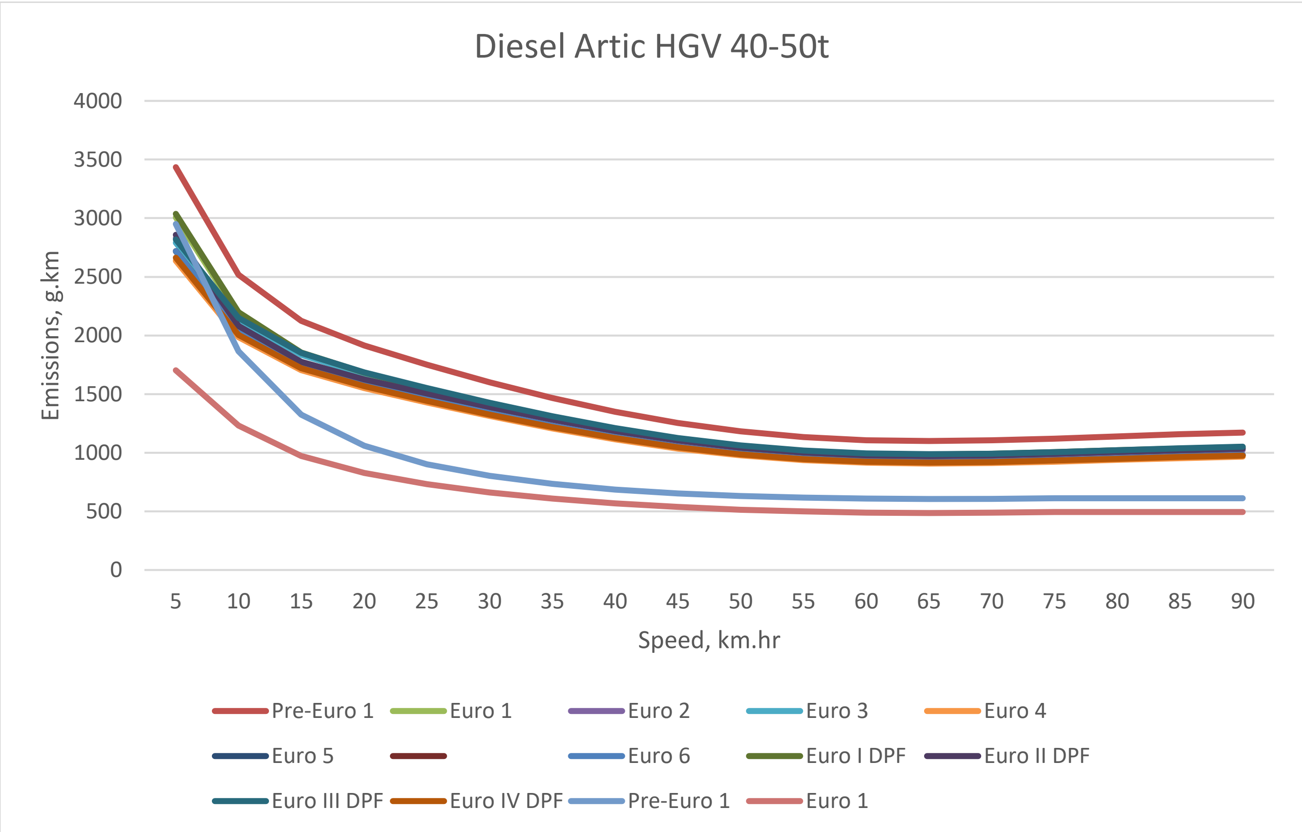

Figure F7 CO_2 Emissions, Artic Diesels 40-50

F3 Summary

The comparison of the EFT/COPERT-based emissions tool with the TAG-based TUBA model fuel consumption profiles indicate broadly similar trends. For cars, CO_2 emissions are at the lowest within the range of approx. 40 to 95kph, which is comparable to the TUBA fuel curve with the lower fuel consumption for cars at approx. 45 to 95kph.

The additional detailed fleet data used in the TII REM, however, clearly indicates potentially significant variability associated with fleet disaggregation.

Appendix G

Emissions Modelling, Exhaust Catalysts and DPF Fails / Removals

This file note outlines the issues associated with failed or removed vehicle catalysts and diesel particulate filters (DPF) and the potential approaches to represent emissions from vehicles with this failed or removed exhaust abatement technology.

Catalyst and DPF fails are modelled based on fleet profiles published by DEFRA as part of the UK National Atmospheric Emissions Inventory (NAEI)[79].

G1 Vehicle Catalysts

Catalysts are used for the conversion of nitrogen oxides (NO_X) to nitrogen, water and carbon dioxide, and so reducing the resultant creation of NO_2. Petrol engines typically use an oxidation catalyst, whereas newer diesel engines use intelligently managed Selective Catalytic Reduction (SCR) that was a key issue in the Dieselgate scandal.

Catalysts have a limited operational lifespan and will fail though thermal and chemical degradation with age and by mechanical contamination by lubrication oil. They can also be removed by owners when they fail, or before then to achieve real or perceived improved performance and fuel-efficiency. A failed or removed catalyst would typically trigger a ‘check engine' warning light and, subject to the vehicle programming it may enter a low-performance limp-mode (i.e. ECU forcing low speed, low power) until it is rectified.

There are also ongoing instances of catalyst theft to remove precious metals, which may incentivise owners to operate without the equipment. However, unless a catalyst is removed, it would tend to fail progressively due to the reduction of active surface area to perform the required chemical reactions.

The NAEI applies a default number of failed catalysts to each vehicle category to represent this portion of the fleet, with larger proportions in older vehicles; e.g. 82.5% of Euro 1 cars would have a working catalyst in all years after 2018, whereas Euro 6c cars have a small number of increasing number of fails each year between these dates (0.9% to 1.1%). This variation year to year is shown for light vehicles in Table G1 for the UK fleet.

Those vehicles with failed catalysts are assigned NO_X emission rates equivalent to pre-Euro classification. This approach applies to light vehicles (i.e. cars and LGVs), and the effect is to slightly increase the emissions of NO_X from these vehicles.

The age breakdown for the national petrol fleet in Ireland for 2018 is shown in Table G2 and adjusted for the proportion of ‘fails'. Table G2 demonstrates that there is very little difference for most vehicles with the greatest differences for Pre-Euro 1.

[79] NAEI (2019) rtp_fleet_projection_NAEI_2017_Base 2019r_v1.1 https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fnaei.beis.gov.uk%2Fresources%2Frtp_fleet_projection_TfL_London_data.xlsx&wdOrigin=BROWSELINK

Table G1 EFT v10.1, Proportion of Failed Catalyst by Euro per Year

Euro	2018	2019	2020	2021	2022
Pre-Euro 1	98.76%	98.73%	98.72%	98.71%	98.71%
Euro 1	17.50%	17.50%	17.50%	17.50%	17.50%
Euro 2	17.49%	17.50%	17.50%	17.50%	17.50%
Euro 3	1.23%	1.23%	1.23%	1.23%	1.23%
Euro 4	1.23%	1.23%	1.23%	1.23%	1.23%
Euro 5	1.23%	1.23%	1.23%	1.23%	1.23%
Euro 6	1.23%	1.23%	1.23%	1.23%	1.23%
Euro 6c	0.92%	1.03%	1.08%	1.11%	1.12%

Note; Proportions remain stable after 2022

Table G2 Irish National Petrol Fleet Age Profile 2018

Euro	2018 Fleet			Fail			Fail Adjusted Fleet		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Pre-Euro 1	0.0%	1.3%	0.0%	0.0%	1.3%	0.0%	2.1%	2.9%	2.1%
Euro 1	2.6%	0.0%	2.6%	0.5%	0.0%	0.5%	2.2%	0.0%	2.2%
Euro 2	2.6%	2.6%	2.6%	0.5%	0.5%	0.5%	2.2%	2.2%	2.2%
Euro 3	27.6%	2.6%	27.6%	0.3%	0.0%	0.3%	27.3%	2.6%	27.3%
Euro 4	38.5%	27.6%	38.5%	0.5%	0.3%	0.5%	38.0%	27.3%	38.0%
Euro 5	12.7%	38.5%	12.7%	0.2%	0.5%	0.2%	12.5%	38.0%	12.5%
Euro 6	14.6%	12.7%	14.6%	0.2%	0.2%	0.2%	14.4%	12.5%	14.4%
Euro 6c	1.3%	14.6%	1.3%	0.0%	0.1%	0.0%	1.3%	14.4%	1.3%

The emissions profile for speed and Euro classification for medium-sized engine petrol-fuelled cars is shown in Figure G1. This indicates that pre-Euro (corresponding to ECE 15/04 standard) have significantly higher emissions rates than subsequent Euro standard and increasing at higher speed.

In summary excluding an adjustment for failed catalysts will underestimate NO_X emissions particularly for pre-Euro 1 vehicles and especially at higher speeds. Although, it should be noted pre-Euro 1 vehicles are a very small part of the vehicle fleet as shown in Table G2 (above) and Table G3 (below). If an adjustment for catalyst fails was made using adjustment this would provide an uplift of these NO_x emissions, albeit with some uncertainty as to the applicability of the factor to the Irish vehicle fleet.

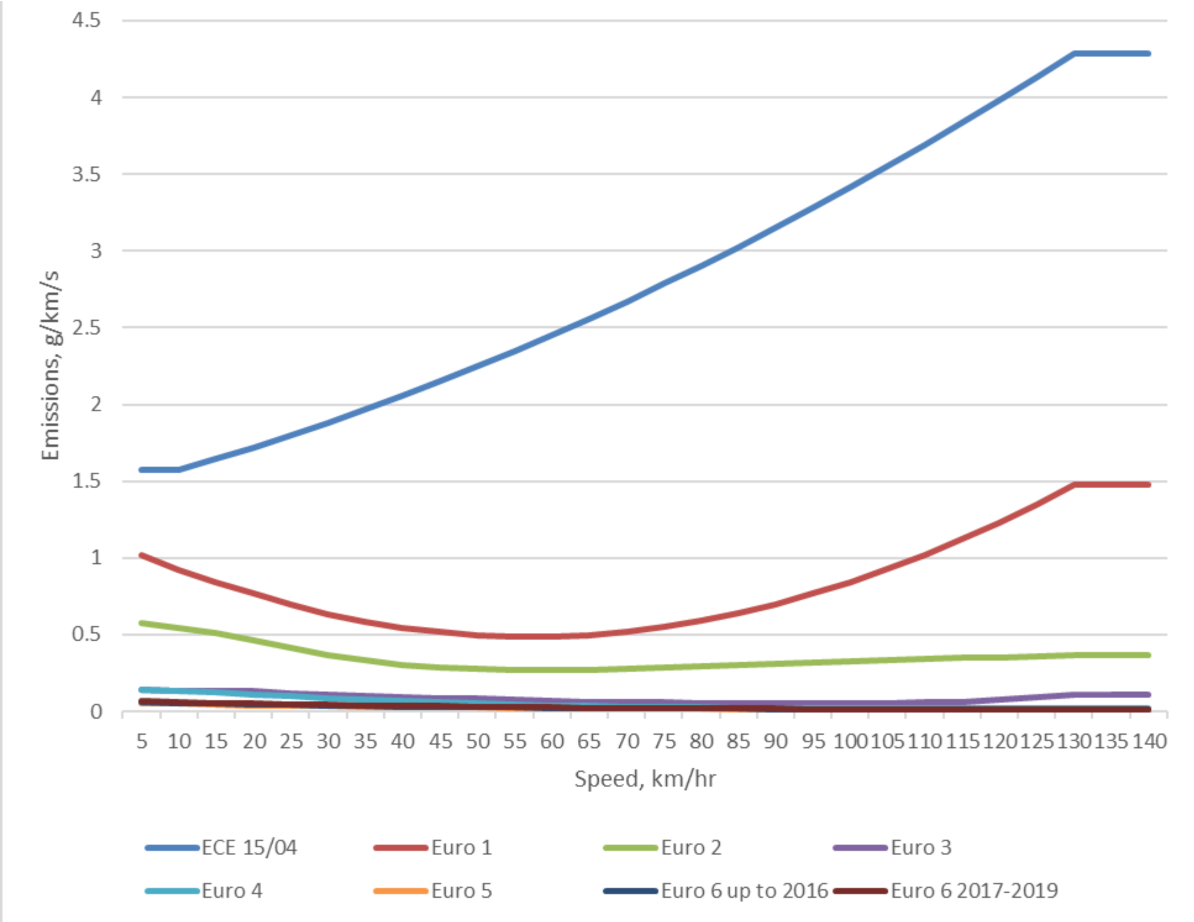

Figure G1 Speed / Emission Profile for Medium Petrol Cars

G2 Diesel Particulate Filters

The Diesel Particulate Filter (DPF) are fine traps that reduce emissions of particulates. They periodically regenerate using a heating cycle to vaporise entrained material. However, as with catalysts they can fail due to incomplete regeneration or may be actively removed by owners to improve fuel consumption and performance.

A fixed proportion of fails is applied to Euro 5 & Euro 6 light vehicles (i.e. car and LGVs), where ~1% fleet are scaled to PM emission rates equivalent to Euro 4. There is no failure rate for earlier vehicles as this technology was not utilised in earlier vehicles. The effect of this approach is to increase the emissions of PM from these vehicles for both PM_{10} and $PM_{2.5}$. The overall effect of this is very small for the total vehicle fleet.

With reference to the 2018 Irish vehicle fleet presented in Table G3, this would lead to approximately 0.8% of cars being assigned as pre-Euro 4, which is not considered to be a significant proportion.

Table G3 Irish National Diesel Fleet Age Profile 2018

Euro	Small	Medium	Large
Pre-Euro 1	0%	0%	0%
Euro 1	0%	0%	0%
Euro 2	0%	0%	0%
Euro 3	3%	3%	3%
Euro 4	20%	20%	20%
Euro 5	39%	39%	39%
Euro 6	35%	35%	35%
Euro 6c	2%	2%	2%
Euro 6d	0%	0%	0%

G3 Summary

The REM includes a user option to adjust the modelled fleet profile to account for exhaust abatement fails. The source of the data is not Ireland specific, although the same Euro standards apply between the UK and Ireland and this considered the most suitable approach based on available data.

Appendix H

Congestion Emissions Validation

This technical appraisal considers the effects of emissions calculated using period average traffic data compared to those based on individual data points. This comparison is intended to highlight the variations between average speed-based calculations of vehicle emissions and higher resolution speed data.

H1 Introduction

A visual review of speed vs vehicle flow per lane per hour per direction scatter plots was undertaken to inform which traffic counter sites should be included in this analysis. Two sites TMU 1111 and TMU 1043 were selected to represent non-congested conditions, where speeds at low flow had predominantly linear distribution and two sites. Traffic counter sites TMU 1504 and TMU 1113 were selected to represent congested conditions due to the flow breakdown visible on the scatter plots available from the processing of the TMU data for the 2016 NTpM update, in relation to speed-flow curves review undertaken at that time, represented by lower half of the speed flow relationship curves back around so that as flow rate decreases, the speed also decreases.

Data recorded from four permanent Transport Infrastructure Ireland (TII) Traffic Monitoring Units (TMU) were used to inform the assessment:

- TII TMU Sites 1111[80] and 1043[81], selected as a comparison location for non-congested conditions (both sites include one lane in each direction).
- TII TMU Sites 1504[82] and 1113[83], selected as representing congested conditions (site 1540 includes 4 lanes in each direction and site 1113 includes 3 lanes in each direction).

Three sets of data were downloaded from the TII internal traffic site for each of the TMU sites mentioned above. Binned data (15 min and 1 hour) was downloaded for the full year of 2016 for all sites, which included information on each lane in each direction and then processed to include only neutral period, and raw individual count data was downloaded for a subset of the year. Due to the size of the raw data, which includes information on each vehicle passing the TMU loop per lane, only three weeks of data between 10th and 26th of May 2016 were downloaded for all TMUs. Due to the limit of rows in excel the datasets for TMUs with more than three lanes in each direction were divided into three files, each covering one week of neutral period data (Monday to Thursday). In each case the data and periods were the same.

The scatter plots of speed vs count for vehicles per hour per lane per direction (veh/hr/lane/direction) are presented in Figure H1. TMU Sites 1111 and 1043 present a predominantly linear distribution, whereas TMU sites 1504 and 1113 are clearly different, with a scattered low-speed distribution at higher speeds that is interpreted as representing congested/flow breakdown conditions occurring as flows increase or incidents occur.

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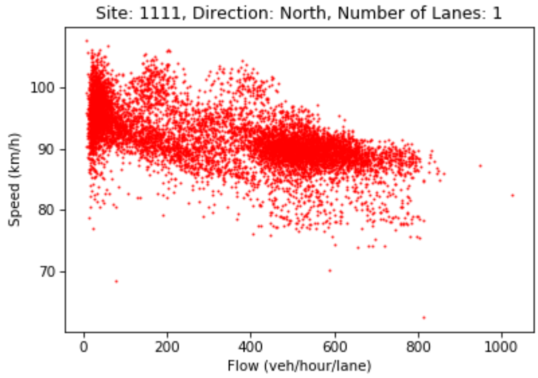
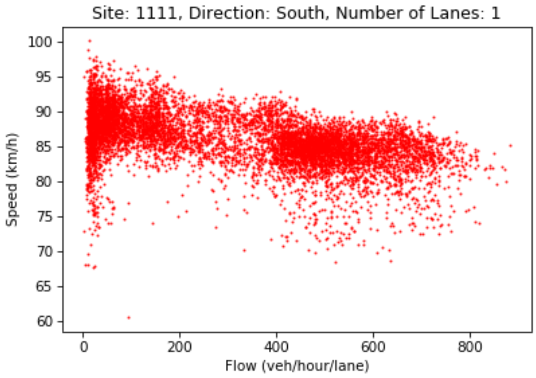
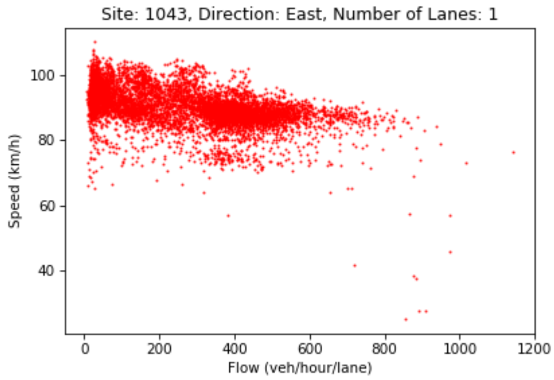
[80] https://trafficdata.tii.ie/sitedashboard.asp?sgid=XZOA8M4LR27P0HAO3_SRSB&spid=EA147DB83639
[81] https://trafficdata.tii.ie/sitedashboard.asp?sgid=XZOA8M4LR27P0HAO3_SRSB&spid=EC4121B54C01
[82] https://trafficdata.tii.ie/sitedashboard.asp?sgid=XZOA8M4LR27P0HAO3_SRSB&spid=A4598463930A
[83] https://trafficdata.tii.ie/sitedashboard.asp?sgid=XZOA8M4LR27P0HAO3_SRSB&spid=269E270D8B8D

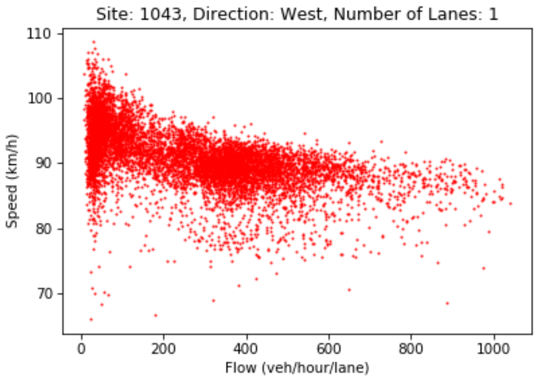
TII TMU Site 1011 (R772 – Old N11 North of Enniscorthy, Type 1 Single Carriageway, 100kph Posted Speed Limit)



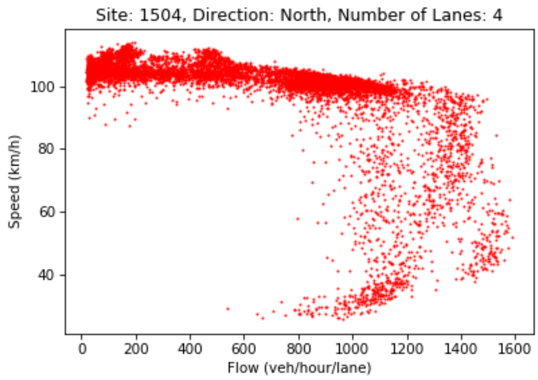


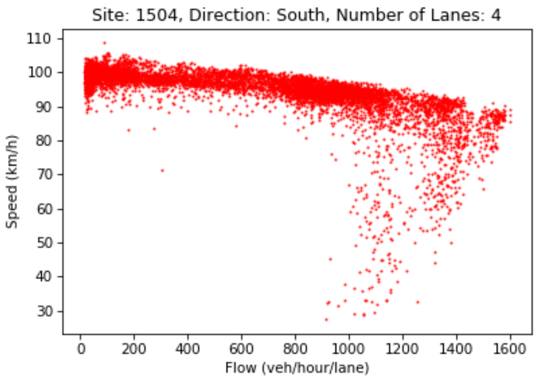
TII TMU Site 1043 (N4 between Edgeworthstown and Mullingar, Type 1 Single Carriageway, 100kph Posted Speed Limit)





TII TMU Site 1504 (M50 between J10 Ballymount and J11 Tymon, 3 + 1 Motorway, 100kph Posted Speed Limit)





TII TMU Site 1113 (M11 North of Bray J5, 2+1 Motorway, 120kph Posted Speed Limit)

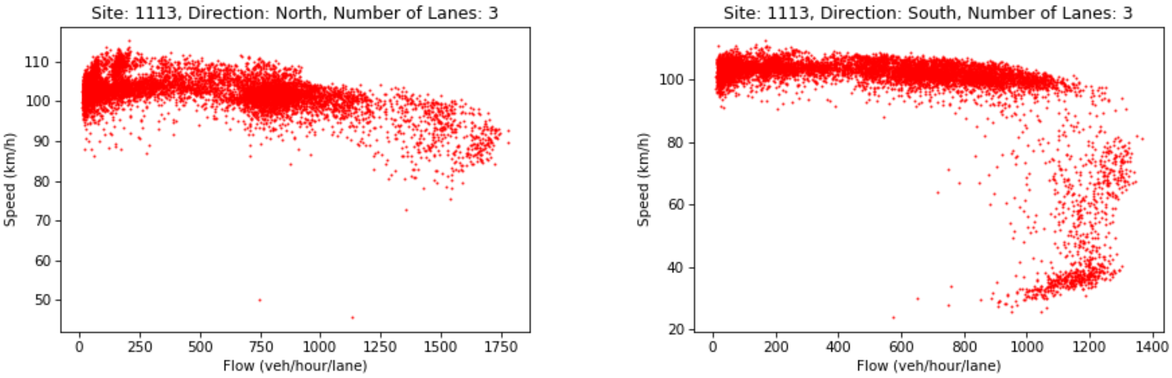
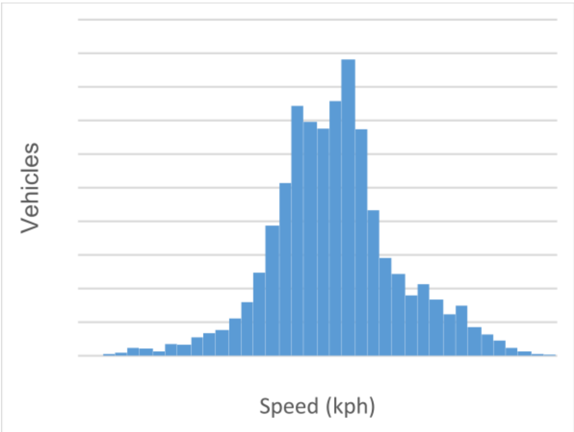


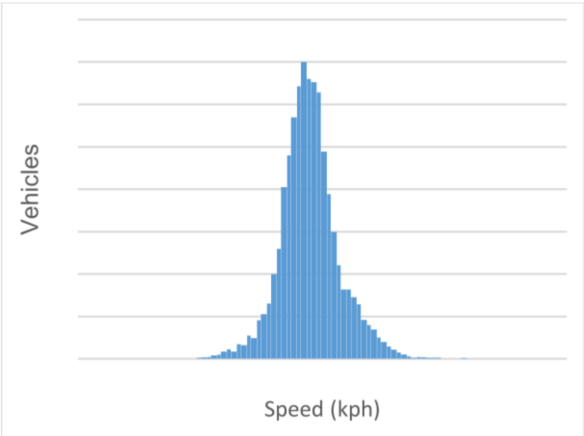
Figure H1 Speed / Count Scatter for Hourly Flows

The histograms of speed variation for different time bins of 1-hour and 15-minute averaged data, and individual count data with no binning for TMU Site 1111, are presented in Figure H2. The speed histograms follow a classic bell-curve using all time resolutions and broadly correlate with the linear trend in Figure H1 for TMU Site 1111 indicating a correlation between flow and speed.

1-hour Binned Data



15-min Binned Data



Individual Count Data

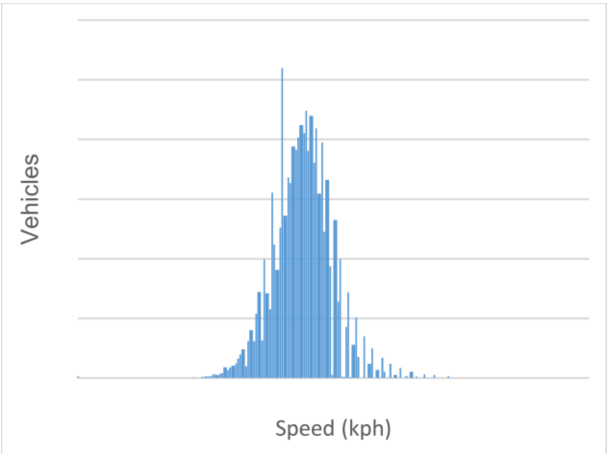


Figure H2 Speed Histograms, TII TMU Site 1111

The speeds from binned and individual count data recorded from TMU Site 1504 are presented as histograms in Figure H3. These data plots clearly demonstrate a different pattern to TMU Site 1111, with a long 'tail' of low-speed data-points indicating congested conditions. The detail of the features changes slightly between the three plots, with increasing resolution of minor features in the raw data, as expected as a result of the binning.

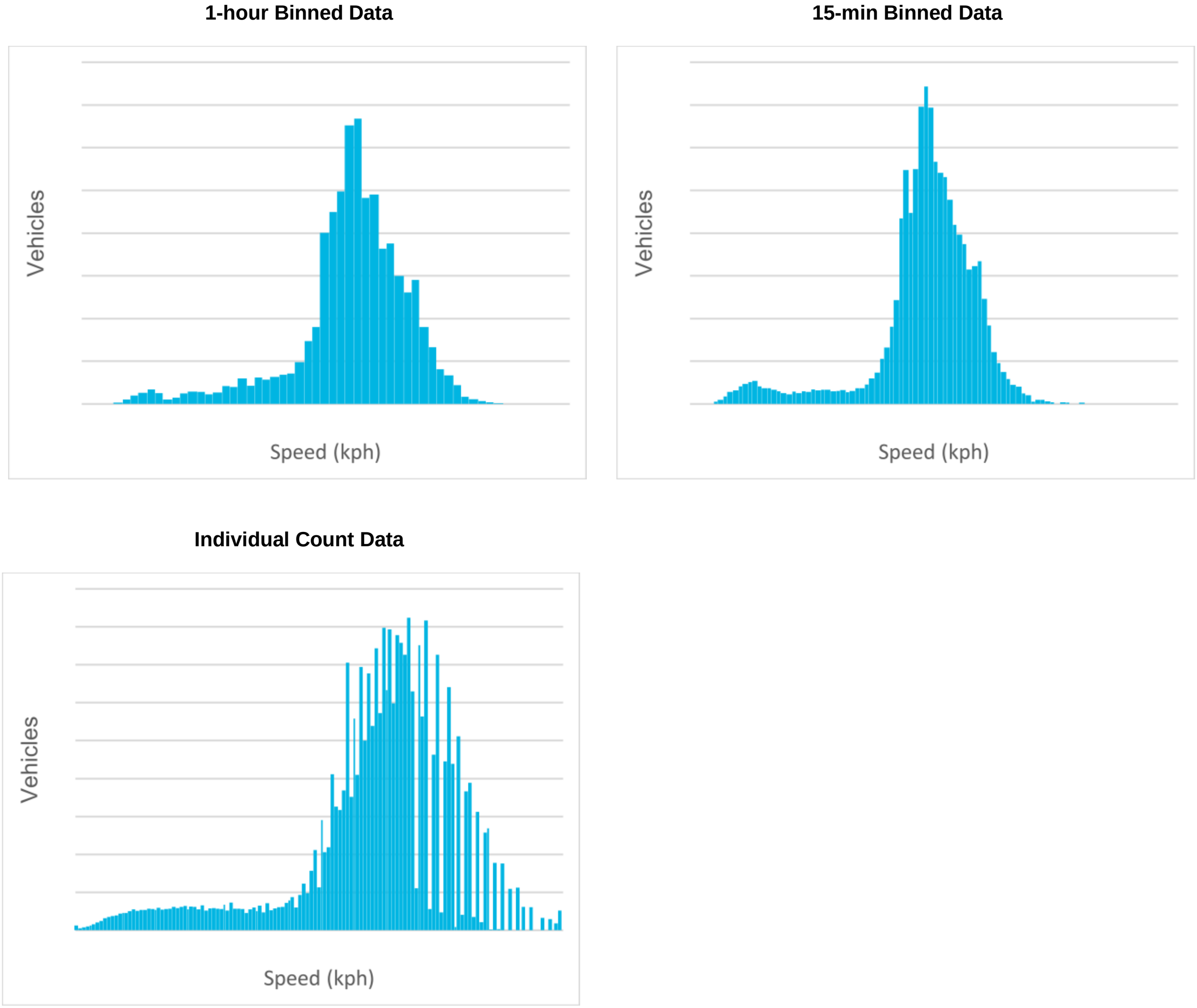


Figure H3 Speed Histograms, TII TMU Site 1504

Further analysis of the TMU Site 1504 speed histograms indicates the AM and PM peak periods each demonstrate a clear low-speed peak indicative of congested periods, whilst the interpeak and off-peak periods are more similar to the bell curve shape indicating less congestion during these periods.

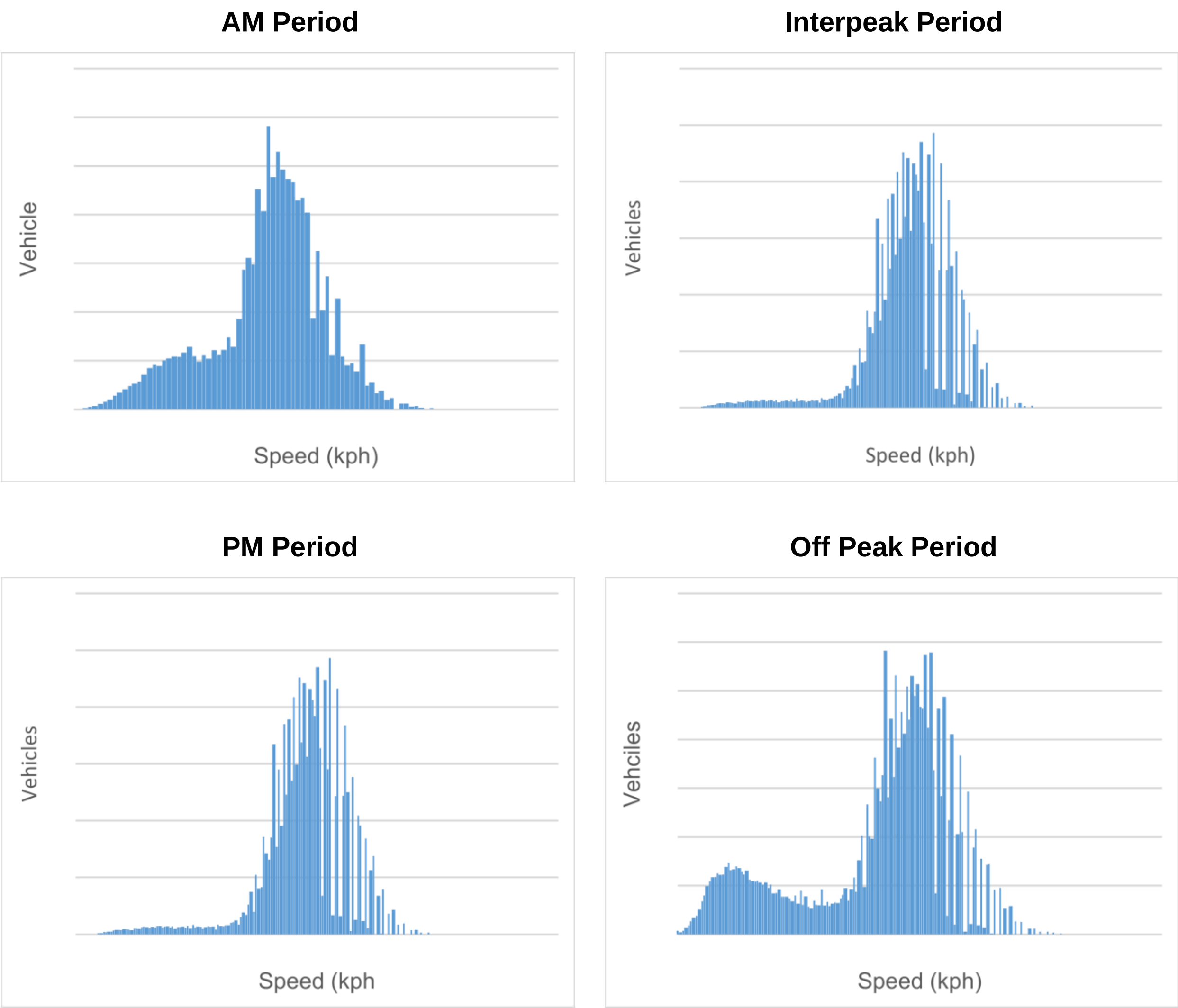


Figure H4 Histograms, Site 1504, Individual Count Data for Peak / Off-peak Periods

H2 Emissions Calculations

The traffic flow data were processed through the TII REM using the total classified counts and average speed, correlating to the AADT used in the strategic tool presentation. However, as outlined in the introduction, the relationship between speed and emissions is not linear and it is expected there may be some difference in total emissions when this data is disaggregated and emissions are calculated using non-average speed data.

The speeds used to calculate the AADT-equivalent emissions were calculated as the geometric mean and were not biased for flow volume; i.e. there will be a slight bias towards bins with higher flows that was not included in the average speed value. This would not affect the average speed from the individual count data as any flow bias would be incorporated in the data.

The emissions calculated from the AADT-equivalent approach whereby flows were aggregated and speeds averaged, were compared to the following higher resolution (compared to actual AADT) disaggregation runs:

- Counts and speeds binned per hour for an average 24-hour period;
- Counts and speeds binned per hour for a monthly period;

- Counts and speeds binned per 15-min for an average 24-hour period; and,
- Individual classified counts and speeds recorded for a period of several days.

In each case the data was reported for a neutral period intended to represent normal conditions.

Emissions for all tests used the same, nominal, fleet profile (age, fuel, etc) regardless of the county in which the counter was located to ensure consistency between the test runs. The unit output from each run were presented as g/km, although this was a nominal unit as each test used a different period of count data, and the evaluation between runs uses the percentage change to allow direct comparisons. The following results present the comparative difference in emissions between the AADT-equivalent data (i.e. summed flow and average speed) compared to the sum of emissions calculated using higher resolution disaggregated traffic flow data.

H3 Non-congested Count Data

TII TMU Site 1111 is considered to represent a non-congested location. The comparison of emissions calculated using binned hourly and 15-min data recorded at TMU Site 1111 indicate negligible difference between the summed data and the binned data in either the hourly or 15-minute periods.

The raw data for individual traffic counts and speeds recorded at TMU Site 1111 were processed through the TII REM, comprising a sample of 10k lines of data. The results of this run are presented in Tables 1 to 3 and indicate more notable differences compared to the binned period data presented above:

- The difference in total NO_X emission rates was subjectively significant; ~3% higher using the raw data compared to the summed flows with average speed.
- The PM_{10} and CO_2 differences were negligible, consistent with changes approx. <1%.
- However, the change in CO_2 emission rate from HGVs was ~4% lower than the summed flows, whereas LGVs were 2% higher. This reflects the relatively small number of these vehicle compared to cars and the effects of averaging the speed, as HDV speeds are ~10% lower than LDV at ~88km/hr average. Therefore, HDV emissions will be reduced slightly and, subsequently, reduce the overall run results.

Furthermore, it was hypothesised at this stage that differences in the two calculation methods would be more extensive at lower average speeds, and so further analysis was necessary at specifically congested links with a larger proportion of low-speed events.

H4 Congested Count Data

TII TMU Site 1504 is considered to represent a congested location. The hourly and 15-minute binned data and the individual count data from TMU Site 1504 was used to calculate the emissions using the same method applied for the non-congested TMU Site 1111.

The hourly binned data indicates a difference in emissions that were similar in magnitude to the non-congested site, in the 2% range for NO_X, with negligible difference for total PM or CO_2 emissions, whereas the 15-minute binned data demonstrates clearly greater differences in emissions compared to the AADT equivalent data.

The difference between the individual count data compared to summed flows was considered to be significant for NO_X and CO_2, with approx. 11% and 6% difference respectively. The difference in PM emissions was negligible. As in the test for TMU Site 1111, the emissions from HDV were lower when using the raw data due to the lower speeds assigned to this source.

Therefore, the trend towards a larger difference in the raw counts compared to the binned data is consistent with that exemplified in the analysis of TMU Site 1111, although, as TMU Site 1504 is a congested site the magnitude of the difference is much larger.

It should be noted the raw count data uses a shorter time period of data collection than the binned data, due to the very large amount of data making further analysis impractical at this stage of analysis. However, the histograms indicate broadly similar patterns, and even if accounting for some uncertainty as a result of this, the difference in emissions within the individual tests clearly supports the overall trend.

TII TMU Site 1113 was identified as another site representing congested conditions. Individual count data recorded over a period of 3-days at TMU Site 1113 (244295 counts) were used to repeat the process of calculating emissions.

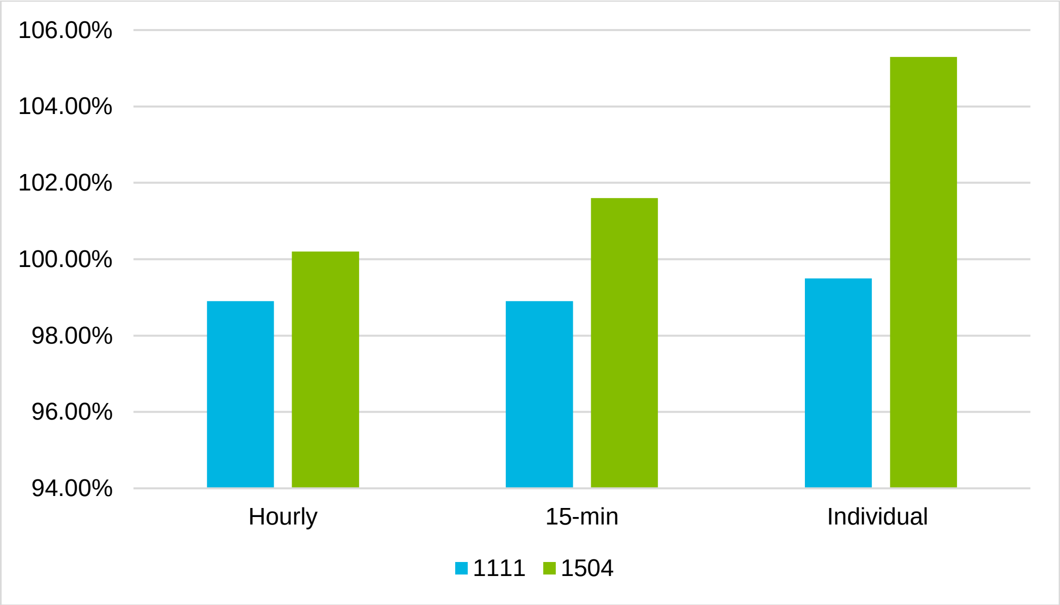


Figure H5 CO_2e Emission Differences from Different Binning Periods

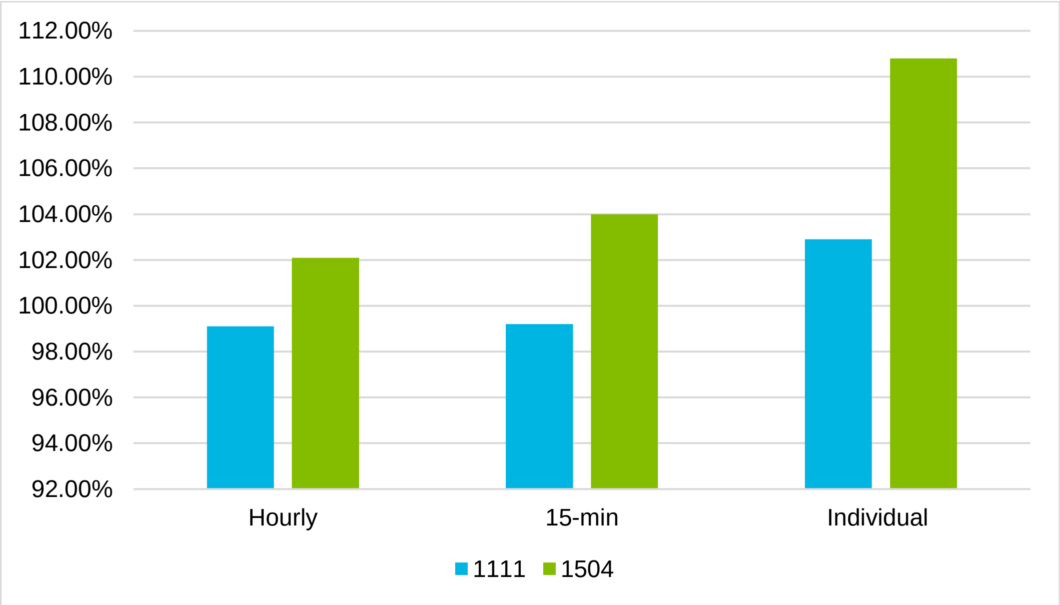


Figure H6 NO_X Emission Differences from Different Binning Periods

H5 Peak and Off-Peak Patterns

The data presented in Figure H7 and Figure 64 indicates the different flow and speed patterns throughout the day in the AM and PM peaks, daytime interpeak (IP) and evening off-peak (OP) periods.

The difference in emissions for each individual period for TMU Site 1504 demonstrates clear variations in contributions to total emissions from each period of the day, when compared to running the AADT-equivalent traffic flows. The AM and PM emissions are considerably higher for NO_X (11.4% and 17.9% respectively), whereas the emissions during the IP and OP are very similar to the AADT-equivalent data for the corresponding period (6.1 and 7.1% higher).

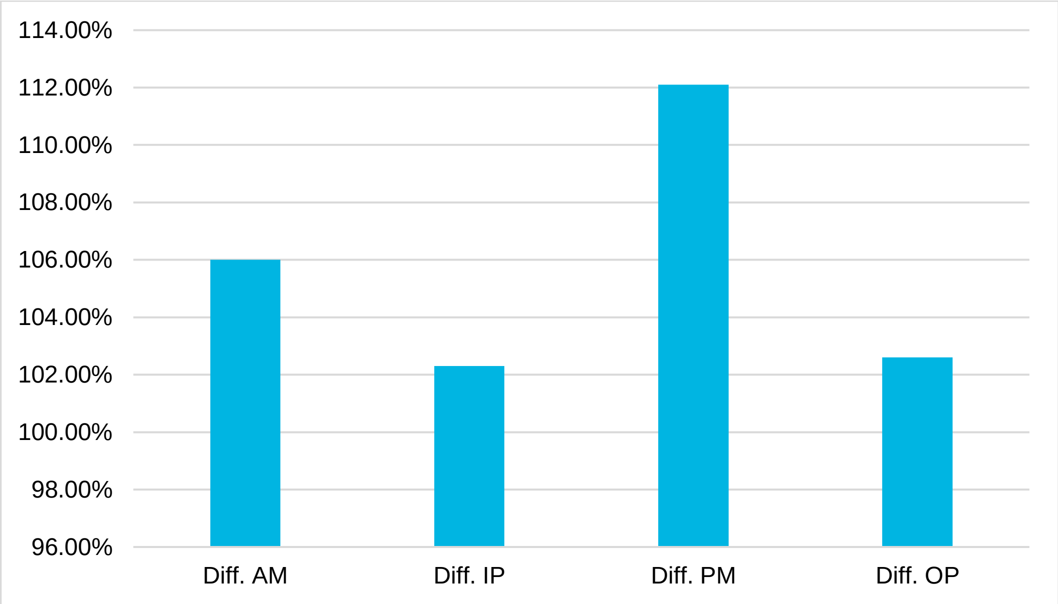


Figure H7 CO_2e Emission Differences from Binning, Congested Site Daily Periods

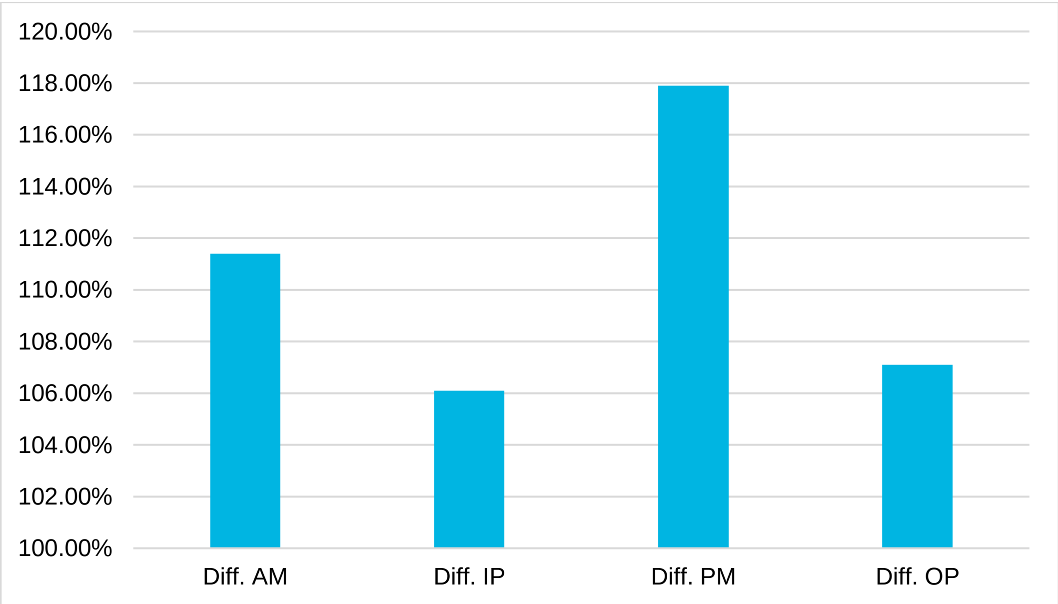


Figure H8 NO_X Emission Differences from Binning, Congested Site Daily Periods

H6 Summary

A series of tests were undertaken to compare the emissions calculated from AADT-equivalent traffic flow data to higher resolution disaggregated data with hourly, 15-min and individual vehicle count intervals. The emissions calculated using each method were compared to indicate whether the approach to national emissions modelling (i.e. using AADT) may over- or under-predict in non-congested or congested conditions. The key findings of the assessment are as follows:

- The difference in Particulate Matter emissions using the different data resolutions is not considered significant. This is likely related to the proportion of exhaust and non-exhaust components, wherein the non-exhaust emissions are related to relatively wide speed bands.
- The emissions of NO_X and CO_2e are significantly affected by congested conditions, whereby a single average speed does not suitably represent the actual speed range, and so tends to under-predict the total emissions due to the disproportionate relationship between speed vs emissions.
- The speed histogram for non-congested count locations has a bell-curve, with a relatively linear profile of hourly counts vs speed.
- The speed histogram for congested count locations has a distinct low-speed feature that correlates with a scattered relationship of hourly flows vs speeds in high-flow conditions and may represent an indication of traffic conditions where the model under-predicts. This will be specifically related to the increasingly disproportionate relationship between speed and emissions at lower speeds, although the average speed is biased towards the bell-shape peak.
- A comparison of modelled speeds with the monitored count speeds indicated the emissions on the model were slightly lower, although within the context of the test they were consistent with the confidence range of the traffic model validation.

Analysis indicates that congested features are most prominent in the AM and PM peak periods, which correlate with the largest difference in emissions resultant from using different data resolutions.

H7 Further Work

The analysis of a subset of count locations has evidenced that congested real-world conditions contribute to an under-prediction of some emissions including: CO_2e and NO_X. Therefore, it is suggested that further analysis be undertaken to determine criteria for the definition of congestion' in the context of emissions. This may be extrapolated across the wider network based on count data, or other data, where available (e.g. fleet telematics data), to calculate the overall magnitude of underprediction for those parts of the network with congestion.

The analysis may also be used to inform local interventions to reduce real-world emissions; where congested conditions are specifically contributing to high roadside pollutant concentrations (namely NO_X/NO_2) and higher CO_2e emissions.

Furthermore, preliminary detailed statistical analysis has indicated a potential method to define the threshold at which traffic becomes congested in terms of speed patterns, and associated emissions. This specifically represents an opportunity to undertake a wider study to validate the approach.

Overall, it is suggested that further work may inform the approach to emissions calculations on the TII network but should also contribute to a publication of the findings.

Appendix I

Air Quality Tool Validation Assurance

A preliminary model validation exercise was undertaken for a small part of the network around the M50 motorway where a total of 33 locations using passive NO_2 diffusion tubes were reviewed, including two sites that were designated as 'background' (locations AQ23 and AQ32).

A total of 10 sites were excluded from the exercise as they were considered to be too far from the model network (>100m), or the location could otherwise not be confirmed sufficiently to be included. The reasons for these sites to be excluded are included in Table I1.

This achieved a reasonable validation, with a Root Mean Square Error (RMSE) of 5.9 $\mu g/m^3$ based on an adjustment factor of 1.49 indicating a slight tendency to under-predict. This validation utilised tubes AQ3, AQ6-14, AQ16-22, AQ24, AQ27, AQ28 and AQ35. However, a subjective review indicated a tendency for the model to specifically underpredict near junctions and local roads, where it was not possible to assign emissions solely to a single predominant road emission source.

Therefore, in order to focus on specific road emissions links and minimise the interference of cumulative effects multiple links the monitoring locations were reviewed again to reduce the subset to 6 sites (AQ3, AQ8, AQ9, AQ18, AQ22 and AQ24) that were relatively close to a single major road source (i.e. the motorway) but not in close proximity to junctions of other road sources (i.e. <100m). This achieved a further improved validation RMSE of 3.4 based on an adjustment factor of 2.20, indicating the model was under-predicting.

All modelled Road NO_2 concentrations were within ±16% of monitored concentrations. For advanced dispersion models, 25% is considered suitable. The largest difference is at AQ 18, where the tool underpredicts concentrations by is 15.3%. AQ18 is located in a business park had an unadjusted road-NO_X adjustment factor >1 (i.e. underpredicting road-source NO_X), indicating there may be other local sources, or dispersion at this site may be screened from the motorway by topography.

The comparison of modelled and monitored annual mean NO_2 before and after verification is provided in Figure I1 and Figure I2, which demonstrates how the scatter is moved closer to the linear comparison line (i.e. representing the ideal relationship). The final adjusted monitored and modelled annual mean concentrations are presented in Figure I2.

Table I1 Verification Data

ID	Distance to kerb (m)	Unadjusted R-NO_X (mg/m^3)	Monitored R-NO_X (mg/m^3)	Adjusted R-NO_X (mg/m^3)	Background NO_2 (mg/m^3)	Monitored NO_2 (mg/m^3)	Adjusted Modelled NO_2 (mg/m^3)	Site Comments
Sites Used in Verification								
AQ3	54	10.5	24.1	23.2	17.6	30.0	29.6	
AQ8	57	10.1	14.8	22.3	17.6	25.4	29.2	
AQ9	56	10.4	15.4	22.8	17.6	25.7	29.4	
AQ18	41	14.7	43.9	32.4	17.6	39.2	34.0	
AQ22	32	16.0	29.6	35.2	17.6	32.6	35.3	
AQ24	40	12.8	19.4	28.2	17.6	27.7	32.0	
Sites Excluded from Final Verification								
AQ2	122	1.9	18.7	-	17.6	27.3	-	Near junction and >100m from modelled road
AQ4	112	2.6	20.7	-	17.6	28.3	-	>100m from modelled road

ID	Distance to kerb (m)	Unadjusted R-NOx (mg/m^3)	Monitored R-NOx (mg/m^3)	Adjusted R-NOx (mg/m^3)	Background NO_2 (mg/m^3)	Monitored NO_2 (mg/m^3)	Adjusted Modelled NO_2 (mg/m^3)	Site Comments
AQ5	175	0.9	21.0	-	17.6	28.5	-	>100m from modelled road
AQ6	25	7.2	14.2	-	17.6	25.0	-	Influence from both motorway and local road
AQ7	30	5.6	11.4	-	17.6	23.6	-	Near junction
AQ10	54	10.9	31.5	-	17.6	33.5	-	Near junction
AQ11	9	8.4	13.0	-	17.6	24.4	-	Influence from both motorway and local road
AQ12	3	9.2	30.0	-	17.6	32.8	-	Influence from both motorway and local road
AQ13	3	14.2	26.5	-	17.6	31.1	-	Near junction
AQ14	28	9.5	29.0	-	17.6	32.4	-	Near junction
AQ15	100	3.5	7.0	-	17.6	21.3	-	>100m from modelled road
AQ16	53	10.3	30.0	-	17.6	32.8	-	Near junction
AQ17	2	17.1	25.5	-	17.6	30.7	-	Near junction
AQ19	40	4.2	4.1	-	17.6	19.8	-	Near junction
AQ20	41	2.4	22.5	-	17.6	29.2	-	Near junction
AQ21	30	10.6	4.1	-	17.6	19.8	-	Near junction
AQ23	45	11.3	N/A	-	Bknd	17.6	-	Background site
AQ25	25	18.2	0.0	-	13.4	13.5	-	Concentration close to background
AQ26	1	1.6	35.7	-	13.4	31.6	-	Influence from both motorway and local road
AQ27	42	5.4	15.5	-	13.4	21.7	-	Near junction
AQ28	45	5.1	15.9	-	13.4	21.9	-	Near junction
AQ29	66	7.0	4.0	-	13.4	15.6	-	Concentration close to background
AQ31	38	1.7	4.1	-	13.4	15.7	-	Near junction & carpark, and concentrations close to background
AQ32	148	0.3	N/A	-	Bknd	13.4	-	Background site, and also near junction & carpark, and >100m from modelled road
AQ33	143	1.1	1.4	-	13.4	14.2	-	>100m from modelled road, and monitored concentrations close to background
AQ34	67	0.1	0.8	-	13.4	13.9	-	Influence from both motorway and local road, and monitored concentrations close to background
AQ35	30	8.1	15.0	-	17.6	25.4	-	Near junction

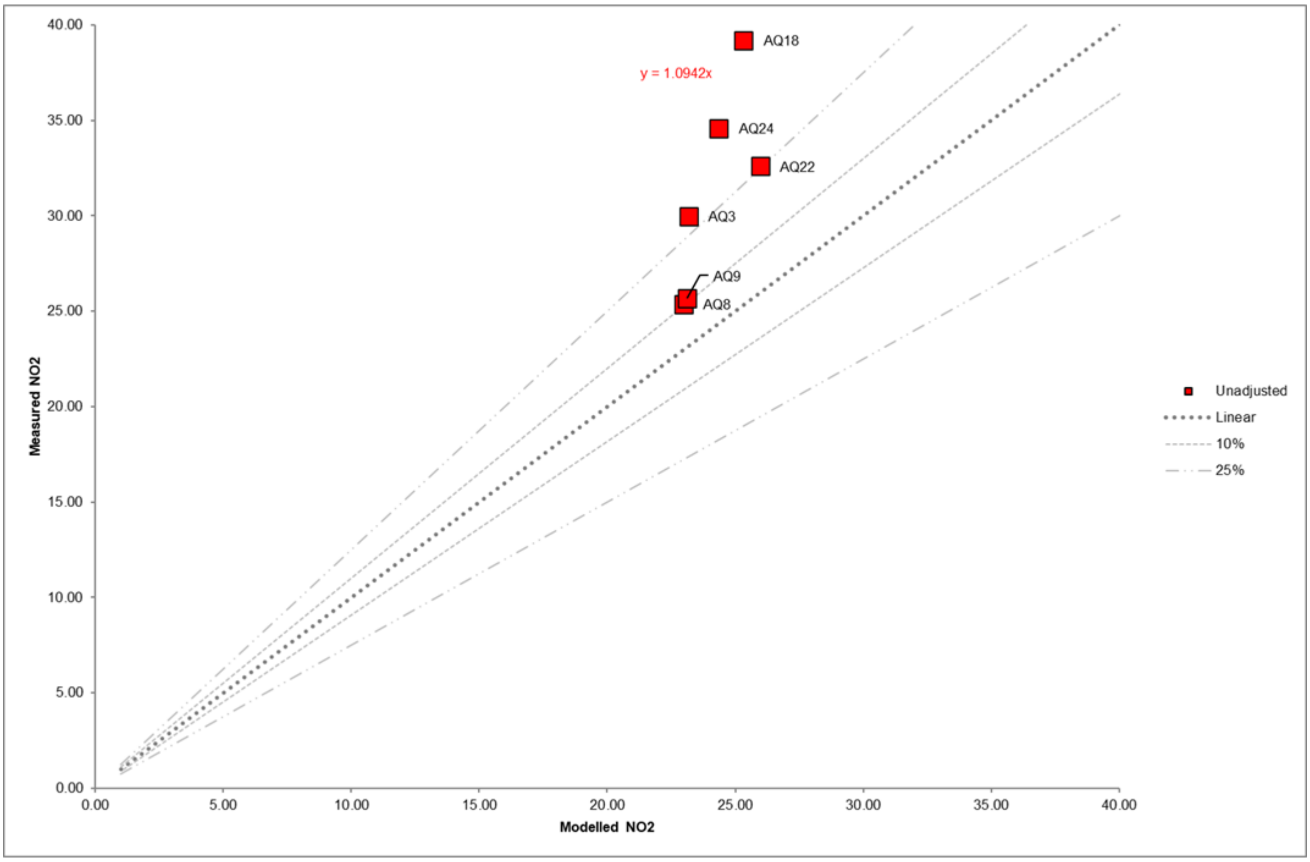


Figure I1 Verification Exercise Modelled vs Monitored Annual Mean Road-source NO_2

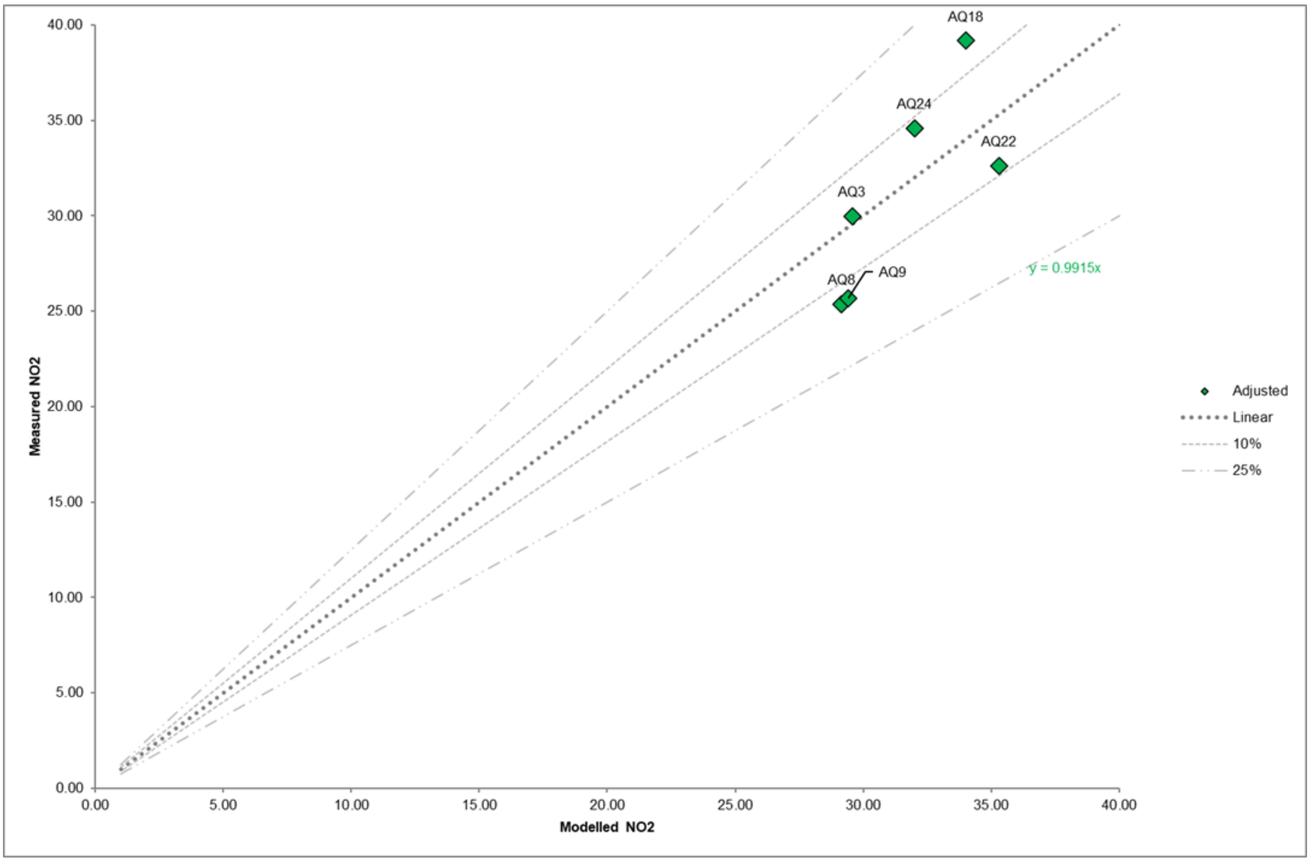


Figure I2 Verification Exercise Adjusted Modelled vs Monitored Annual Mean NO_2

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