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Emissions Modelling: An Analysis of the Average Speed Emission Function with Copert Emission Factors in a Spreadsheet

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Preface

Air pollution and the consequent increase in the concentration of toxic and Greenhouse gases in the atmosphere continues to pose both immediate and futuristic health hazards. The need to monitor and control air pollution has been asserted over 30years ago by the 1979 Geneva Convention on Long-Range Transboundary Air Pollution (CLRTAP). Unsurprisingly, measuring and monitoring emissions is amongst the easiest things to agree on when it comes to the environmental debates. Nonetheless, it is necessary to adopt a unanimous methodology that can represent national emission inventories in a fair and efficient manner. In this direction the United Nations Economic Commission for Europe (UNECE), via its CLRTAP programme, signed the 1984 Geneva Protocol on Long-term Financing of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (now EMEP). The EMEP (European Monitoring and Evaluation Programme) programme provides scientific support to the Convention on: Atmospheric monitoring and modelling; Emission inventories and emission projections; Integrated assessment modelling. Experts of the EMEP Task Force developed and continuously update the Emissions Inventory Guidebook that is being published by the EEA (European Environmental Agency). The guidebook seeks to provide a standardized methodology to be used by member countries for measuring and reporting emissions.

In parity to the Road Transport chapter of the guidebook, the Copert model financed by the European Environmental Agency (EEA) has been developed. EEA recognises that emission from road transport is a significant source of both air pollution and green house gases. Copert, “A European Road Transport Emission Inventory Model”, has been updated a number of times to the recent version Copert 4 which adopts the Tier 3 methodology of the Emissions Inventory Guidebook.

Copert assumes the fundamental structure of emission models by using the product of at least two variables to estimate emission. EMEP/CORINAIR Guidebook 2007 mention two general cases of emission estimation in which one can multiply:

- an activity statistic and a typical average emission factor for the activity, or
- an emission measurement over a period of time and the number of such periods emissions occurred in the required estimation period.

The first ideology has been adopted to measure and forecast road transport emissions in Copert. In this research minimal attention has been devoted to how average emission factors have been generated. Rather focus is on activity statistics, particularly driving conditions and environment. Overall the study looks into how various activity and circulation data contribute to emission factor generation.

Our curiosity is to check on the robustness of emission factor generation tools when applying for policy impact assessment, in a model like TREMOVE.

- The report list possible tools with strengths and weaknesses, with focus on COPERT because this is in TREMOVE and is widely recommended by European agencies.
- When using this tool in TREMOVE, what is the impact of using average speeds?

These have been investigated by constructing and using a spreadsheet version of Copert to analyse speed aggregation effects in a case study.

Gilbert YELLA
Leuven, Belgium
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Summary

Road transport emission inventory has undergone considerable improvement over the last two decades. A multiple of generic model types seek to optimise capturing driving behaviour (pattern) and vehicle circulation data. In all, the most widely used model types are average speed dependent, like Copert. More striving instantaneous models lack the prowess of data availability and user friendliness of Copert. The level of detail in Copert is sufficiently good to concentrate research on improving the methodology of application. The paper concentrates on measuring hot exhaust emissions, whilst the case study is on passenger cars hot emission in Flanders. All regulated (minus PM10) pollutants and other important pollutants have been covered.

This research delivers distinctive improvement in emissions inventory by rendering the Copert average speed approach more robust. Copert average speed functions are compared with other emission tools with focus on how it is used in TREMOVE. The TREMOVE decision tool generates disaggregate input data for use in Copert, yet computes emissions with a single national or regional average speed. The case study clearly denotes how the robustness of emission factor generation is improved by applying speed distributions rather than a single average speed input. Cumulative gains from applying the research methodology were up to; 9.7% for particulate matter (PM2.5), 7.1% for carbon monoxide, 4.3% for nitrogen oxides and 2.3% for hydrocarbons.

A look into different modelling approaches let to the classification of models according to a combination of the geographic scale of application, the generic model type, and the nature of the emission calculation approach. After laying the framework, we begin by describing Copert input data in a manner that the Copert methodology can be easily followed. The data is grouped into Geographic scale, Vehicle categories, and Driving environment which are the main characteristics of the average speed technique. We then look into how Copert data has been collected and processed by a selection of European applications. It is evident the tool is being used: in multiple geographic scales (nationally or locally); as a stand alone model or emission factors embedded in another model; for emission measurements and/or emission projections; and to measure effects of policy measures and/or new technology.

To be able to analyse the bulk of data needed for testing the Copert speed function, we need the tool to be flexible and adaptable. Emission functions and correction algorithms have been utilised to construct the model in Excel. The resulting tool, Copert in Excel, is very robust and efficient and allows for sensitivity analysis to various input parameters. Amongst the need of having Copert in Excel, other methodological needs have been outlined in the text. Pollutants estimated by the tool include European regulated pollutants (CO, NOx, VOC (NMVOC + CH_4), PM ($PM_{2.5}$), SO_2, NH_3), and non-regulated pollutants (NMVOCs, CH_4, CO_2, N_2O). Detail of the methodology, layout (architecture), activity input variables, calculation of emission factors, emission corrections, and output are described. The application of Copert in Excel will be undoubtedly valuable for road transport emission research and in inventory collection.

Adopting a speed distribution methodology checks several limitation of the average speed approach. Principally, driving cycles used in the development of emission functions represent real world driving conditions. However, the real distribution of these driving conditions is not normally taken into account (for example via weightings). Also, a change in average speed can be poorly translated into the emission function and emission functions are only valid for prescribed speed range.

Interesting findings were deduced from testing the effect of mean speed distributions over using a single average speed per period as input for emission calculation. Gains in applying the methodology vary amongst different pollutants. The highest improvement is on PM estimates followed by CO, NOx, and least of all in VOC calculation. Having such adaptations into TREMOVE would allow it generate appropriate speed distributions to relate with disaggregate vehicle kilometre from its vehicle stock module.

Applying mean speed distributions will certainly improve emission inventories making use of the average speed approach especially for congested networks. The effect of spatial aggregation (Flanders or E19 link) is inconclusive for all the pollutants considered.

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1 Introduction

1.1 Background

Road transport is a major contributor to environmental pollution and climate change. The combustion of hydrocarbon fuels leads primarily to the formation of water vapour and carbon dioxide which are green house gases. In addition there are several other gases and residue emitted as by products or as a result of incomplete combustion. Most of these by-products have direct effects on human health like; nitrogen oxides (NOx), residual hydrocarbons (HC or VOC), carbon monoxide (CO), particulate matter (PM), and traces of heavy metals. Others affect climate change as green house (CO_2, CH_4, N_20) whilst ozone precursors (CO, NOx, NMVOC “non methane volatile organic substances”) indirectly affect human health and climate. In 2005, road transport’s shares of the overall anthropogenic emissions within the EU-25 territory were around 40% for NOX, 35% for CO, 20% for CO2 and 15% for NMVOC (WebDab, 2010; UNFCCC, 2007). This certainly highlights the need for accurate road transport emission inventories in any European policy addressing air pollution or climate change.

The effect of transport emissions monitoring and mitigation as seen in Figure 1.1 has been successful in reducing CO, NOx, Pb, SO2, NMVOCs and PM10 pollutants emission in Europe. Owing to manufacturers, who have been pushed by legislation, in producing more fuel efficient and environmental friendly cars, whilst cleaner fuels have been produced over the years. Growth in global mobility has upset these gain, yet still leaves Europe as a high energy consumer and polluting continent. A majority of European countries will fail in meeting their 2010 National Emission Ceiling (NEC) especially for NOx emissions (Annexe A). Europe has seen an increase of other regulated pollutants like PM2.5 and Greenhouse gases (CO2) due to increase in overall mobility (fuel consumption). The global target for the European Union is to reduce pollutant emissions by 8% of CO2 equivalent by 2008–2012 with respect to the values of 1990, resulting to individual reduction quotas for each Member State (Buron et al, 2004).

In order to achieve unanimity, fairness, and accuracy in reporting under the UNECE Convention on Long-Range Transboundary Air Pollution and the EU directive on

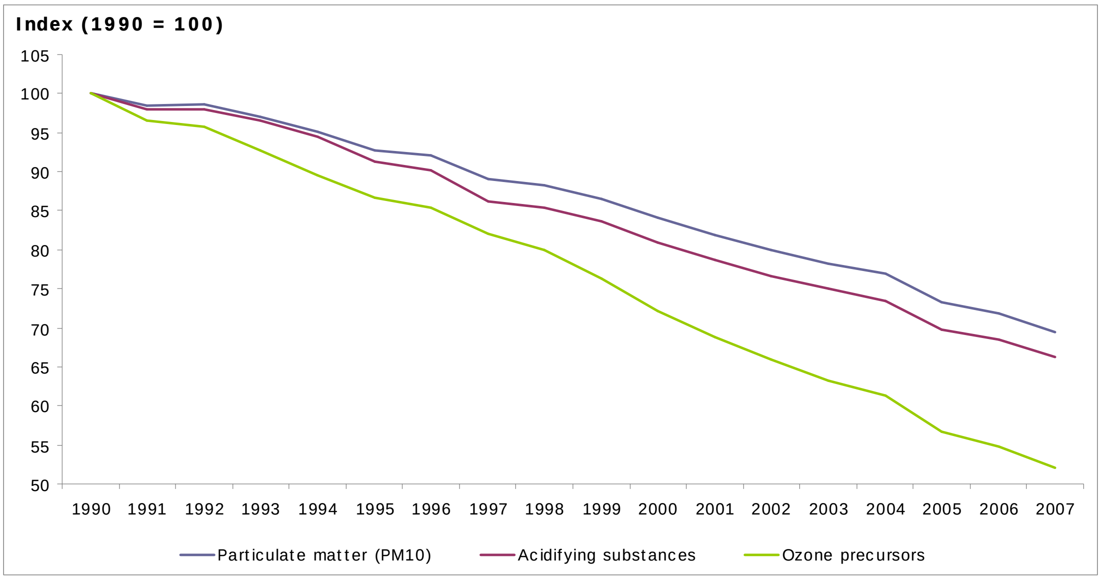


Figure 1.1: Transport emissions of air pollutants for 32 EEA member countries (acidifying substances, ozone precursors and particulate matter)
Source: EEA aggregated and gap-filled air emission dataset, based on 2009 officially reported national total and sectoral emissions to UNECE/EMEP Convention on Long-Range Transboundary Atmospheric Pollution.
Note: The transport emissions data include all of ‘road transport’ and ‘other transport/mobile sources’, less the ‘memo’ items, which include international aviation (LTO (Landing and Take Off) and cruise) and international marine (international sea traffic

national emission ceilings, the UNECE Task Force on Emissions Inventory and Projections has come up with a set of acceptable methods for calculating emissions. These methodologies are specified in a guidebook and are updated periodically. The Executive Body for the Long Range Transboundary Air Pollution mandates parties to use as a minimum the methodology specified in the Guidebook (ECE/EB.AIR/97, 2009). In view of attaining a transparent and standardized measurement procedure the EEA further financed the development of a software tool, Copert, based on the methodology at the highest level of detail in the guidebook. Copert4 methodology is specified by the Tier 3 method described in the EMEP/EEA Emissions Inventory Guidebook 2009 chapter on Exhaust Emissions from Road Transport (Ntziachristos et al, 2009). The Copert tool in cognisance with updates of the guidebook has gone over a number of reviews to the current version Copert 4.

Over the years the methodology for the generation of emission inventories has experienced large progress. In general a two step approach is used to collect mobile source inventories.

- The first step includes the development of a set of emission factors, which represent the emission rate per unit of activity, based on measurements on randomly sampled vehicles. These emission factors are determined either under laboratory-controlled conditions for pre-determined driving cycles, which attempt to both capture and harmonize the actual conditions experienced by on-road vehicles or from real-world driving using on-board emissions measurement instrumentation (Joumard et al., 1995). In any case, an emission inventory model will be derived from a limited amount of experimental data upon which its calculations are based, and it cannot be assured that this sample would accurately reflect either local or contemporary conditions when applied in another occasion.
- The second step in the procedure includes the determination of an estimate of vehicle types and traffic activity. This activity data can be derived either from traffic surveys/counters or transportation models. As with on-board emissions measurement, data from traffic surveys are more desirable, as they provide information on actual traffic patterns on real carriage-ways. However, such surveys have the major limitation that they only supply data pertaining to particular time periods and specific locations, rather than a complete view of the study area.

1.2 Legislation

Emission models are developed in parity with legislations and directives in place. In Chapter 3 we see how data are collected and processed in a model according to emission legislation of the vehicle category. Regulation of pollutant emissions for light-duty vehicles (cars and light vans) is treated separately from heavy-duty vehicles (trucks and buses). The legislations usually embody realizable reduction targets of specified pollutants for particular vehicle categories in accordance with existing or expected technology.

The current emission standard for light-duty vehicles is Euro 4 whilst the Euro 5 emission standard was scheduled to go into force in September 2009. Euro 6 was also agreed to go into force in January 2014. For heavy-duty vehicles the emission standard currently in force is Euro V which went into force in October 2008. The legislations are enacted by various directives of the European Commission.

1.3 Aim and Scope of Study

The aim here is to investigate key areas that would make emission inventory more robust while increasing adaptability at the same time. To realise this, two principal objectives were set aside:

- Study the speed function used in Copert in comparison with other emission tools and replicate the Copert (hot emission) emission tool in Excel
- Carry out a case study to analyse the benefits of using speed distributions over a single average speed in Copert.

In general, direct emissions of air pollutants from road transport emanates from 3 main sources:

- Vehicle exhausts emissions
- Fuel evaporation
- Tyre and brakes wear
- Road wear

Copert treats all four sources. However for the purpose of this research only the most relevant source, hot vehicle exhausts emissions, has been dealt with in detail. Hot exhaust emissions are produced by vehicles when their engine and exhaust after treatment system are at their normal operating temperature. Exhaust emissions takes an ample share of total pollutants with the exemption of PM.

The study covers all regulated (minus PM10) and other important pollutants:

- Ozone precursors (CO, NOx, NMVOC);
- Greenhouse gases (CO2, CH4, N2O);
- Acidifying substances (NH3, SO2);
- Particulate matter mass (PM 2.5);

The model developed here does not include heavy metals, POPs and PAHs that are in Copert. These are not very important for the analysis of Copert average speed dependent function, although they can be added to provide completeness or for meeting the relevance of another study. Credited to the adaptability and flexibility of Copert in Excel, this can be conveniently done.

2 Emission Modelling Approaches and Types of Emission Models

Actual vehicle emissions are largely characterised by their legislative emission standards as well as other parameters. The underlying parameters can be either vehicle related or operationally related and are affected by the vehicle operating environment.

- Vehicle related factors: Fuel type, model, technology level, weight, and mileage.
- Operational factors: Speed, acceleration, gear selection.
- Environmental factors: Road gradient, ambient temperature.

Emission models are built by defining interrelationships amongst the aforementioned factors for estimating the quantity of a pollutant emitted per vehicle category/type. Models account for all or most of the parameters in a variable manner and at various levels of detail. Amongst others, most widely used emission models concentrate on speed as a significant determinant of the variability in pollutant emissions and fuel consumption of vehicle of the same category.

In this section a variety of model types for modelling hot exhaust emissions in Europe is reviewed. Models tend to be classified according to a combination of the geographic scale of application, the generic model type, and the nature of the emission calculation approach (Barlow and Boulter, 2009; EC-METI, 2009). The classification of reviewed models in Table 2.1 is followed with a discussion of the various generic types and a summary of some of the models. It must be noted however that it may still be valid to classify some of the models in another generic type than the once specified in the table. A broader classification would simply be three categories; average speed, traffic situation, and instantaneous models.

2.1 Aggregated emission factor models

Aggregated emission factor models operate at the simplest level, with a single emission factor being used to represent a particular type of vehicle and a general type of driving – the traditional distinction is between urban roads, rural roads and motorways (Barlow and Boulter, 2009). Vehicle operation is therefore only taken into account at a very rudimentary level and the approach cannot be used to determine emissions for situations which are not explicitly defined.

Table 2.1: Models for estimating hot exhaust emissions

Generic type	Example	Type of emission Factor/function	Type of input data	Typical application
Aggregated emission factors	COPERT, NAEI	Discrete	Road type	Inventories, EIA, SEA
Average speed	COPERT, NAEI, ARTEMIS,	Continuous	Average trip speed	Inventories, dispersion modelling
Corrected average speed	TEE	Continuous	Average speed, congestion level	Emission inventories, assessment UTM schemes
Traffic situation	HBEFA, ARTEMIS	Discrete	Road type, speed limit, level of congestion	Inventories, EIA, SEA, area wide assessment of UTM schemes, dispersion modelling
Multiple linear regression	VERSIT+	Discrete	Driving pattern	Inventories, dispersion modelling
´Simple` modal	UROPOL	Discrete	Distribution of driving modes	Assessment of UTM schemes
Instantaneous, speed based	MODEM	Discrete	Driving pattern	Detailed temporal and spatial analysis of emissions, dispersion modelling
Instantaneous, power-based	VeTESS, PHEM, CMEM	Discrete	Driving pattern, gradient, vehicle-specific data	Detailed temporal and spatial analysis of emissions, dispersion modelling

The emission factors are calculated as mean values of measurements on a number of vehicles over given driving cycles, and are usually stated in terms of the mass of pollutant emitted per vehicle and per unit distance (g vehicle^{-1} km^{-1}) or per unit of fuel consumed (g litre^{-1}) (EC-METI, 2009).

Copert4 uses aggregated emission factors only for unregulated road transport pollutants (CH_4, N_2O, NH_3, heavy metals) and PM (for gasoline and LPG vehicles). The simple emission factors may only be valid at large spatial scale, such as national and regional inventories, where little detailed information on vehicle operation is required. The United Kingdom's NAEI (National Atmospheric Emission Inventory) model also has aggregated emission factors for unregulated pollutants.

2.2 Average-speed models

As the name suggests, such models use average trip speed as input to predict pollutant emission. They are based on the principle that the average emission factor for a certain pollutant and a given type of vehicle varies according to the average speed during a trip (Barlow and Boulter, 2009). The emission factor is again usually stated in grams per vehicle-kilometres (g vehicle^{-1} km^{-1}). Emission factors for several vehicles over a range of driving cycles, with each cycle representing a specific type of driving, including stops, starts, accelerations and decelerations are measured. The measured emission factors alongside their corresponding average trip speeds are fitted to an emission function – the average speed emission function.

Barlow et al (2000) plotted measured NOx (Figure 2.1) emission factors for Euro 3 diesel cars and CO_2 (Figure 2.2) emission factors for Euro 2 medium size petrol cars against individual vehicle's average speed. The points show the emission measurements and the curve is the fitted function. An average speed emission model will, therefore, simply fit average speed to the pollutants emission function (the curve line) leading to a corresponding emission in grams per vehicle kilometre of the pollutant. What we realise from the plots is that the data scatter, especially for NOx measurements. This means that a model predicted emission level may be significantly different from the real value. CO_2 however fits better and hence there is less uncertainty compared to other exhaust pollutants.

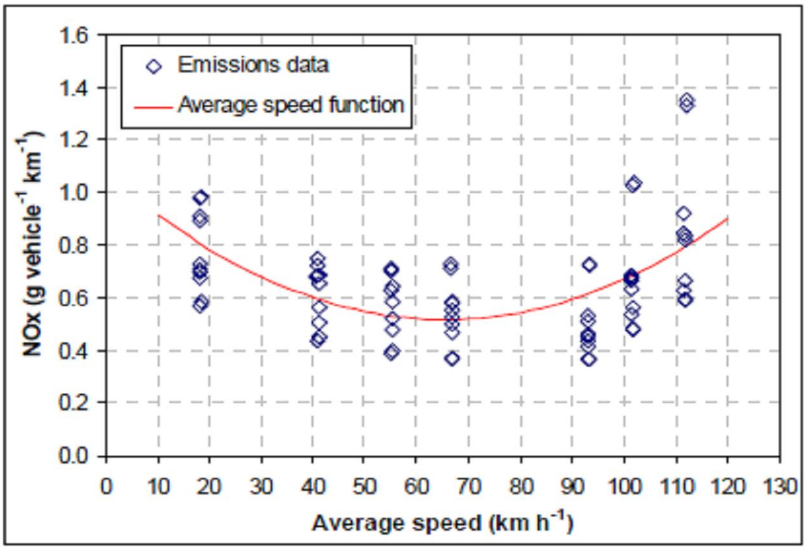


Figure 2.1: Average speed emission function for NOx emissions from Euro 3diesel cars <2.0 litres (Barlow et al., 2001)

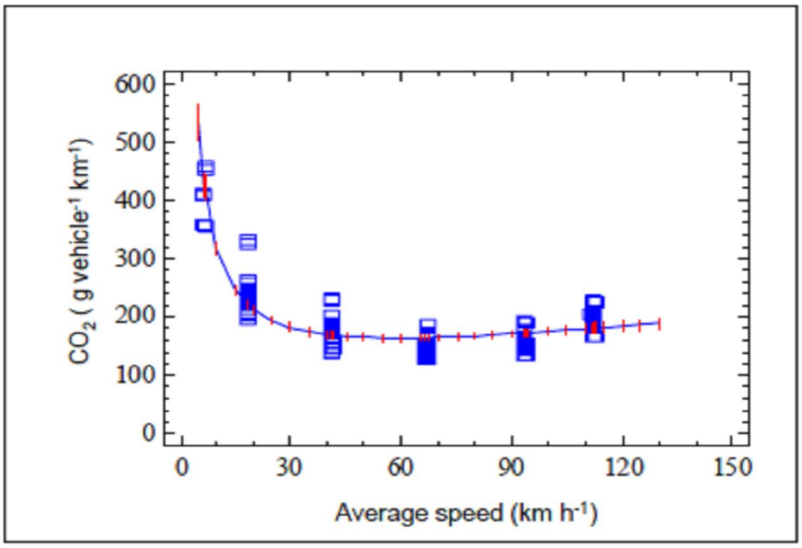


Figure 2.2: Average speed emission function for CO2 emissions Euro 2 medium size petrol car with the base data and 95% confidence interval (Barlow et al., 2001)

Artemis average speed model

The Artemis project WP300 tried to make some improvements on the average speed approach. Two average speed models for light vehicles were developed similar to the Copert model (Further discussion on Copert's average speed function is dealt with in chapter 5). It used two different statistical approaches, with different data clustering, leading to two alternative sets of speed dependent emission equations (Joumard et al.,2007):

- A first model based on emission data clustering through speed range averaging
- And a second model designed from the 15 Reference test pattern emission factors.

Instead of using individual average speed over driving cycles, the first model further average the speeds with tens of speed range. Each average emission was then associated with an average speed. The methodology eliminates average speeds that are a result of low number of data to prevent data scatter and remove outliers. Though, one may argue that on aggregate the outliers represent a very significant share of driving pattern. Also data were homogenised against ambient temperature and humidity.

For the second model, emission data of the Artemis LVEM database are firstly averaged per Reference Test Pattern, producing the Reference Test Pattern emission factors. Then an emission function is calculated by regression between these 15 Reference test pattern emission factors, expressed according to the average speed. The emission factors cover CO, HC, NOx, PM and CO2 for pre-Euro to Euro 4 petrol and diesel vehicles.

Apart for CO_2 the models do not take engine size into account yet. The experimental models have not been tasted for all main pollutants. The first model is based on a lot of assumptions which on its own may skew the data. Artemis average speed emission factors for light vehicles have been used in the recent HBEFA V3 model.

Another average speed model, the NAEI (National Atmospheric Emission Inventory) is more or less similar to Copert.

2.3 Corrected average-speed model

An approach for modelling vehicle emission by taking into account the variability in vehicle speed along the road was developed by the Italian National Agency for New Technologies (ENEA). The model termed TEE (Traffic Emissions and Energy) is based on a ‘correction’ of emissions calculated from the average speed with a ‘Congestion Correction Factor’ (CCF) taking into account the infinite different ways an ‘average speed’ can be experienced along a link (Negrenti, 1999). The speed variability expressed by means of the correction factor is derived from traffic density, link length, average speed, and green time percentage input variables.

The methodology separates driving cycle into “free flow” cycle (far from intersection) and “intersection cycle”. Phase one is dominated by traffic density where time spent in acceleration, deceleration, cruising are calculated. The second part depends on duration of green lights at intersections. The TEE model calculates emissions on the basis of such a cycle with instantaneous emission factors (from MODEM) and by means of average speed based emission factors.

2.4 Traffic situation models

Two parallel vehicles of the same category/type, travelling at the same average speed may complete a trip with different emission levels of pollutants. This implies there are cycle dynamics which alongside average trip speed affect emissions. Traffic situation modelling therefore correlates cycle average emission rates with various driving cycle parameters. These, in turn, are related to specific traffic situations which are known to the model user. Different traffic situations relate to conditions for which there is a specific emission problem, and for which the average speed may not be the best indicator of emissions (EC-METI, 2009). Such models are best suited to local applications, where emission estimates are required for individual road links, but can also be used for regional and national inventories. At regional level the “situations” can be criticised for not taking into consideration absolute characteristics of traffic in cities.

The traffic situation model developed in the ARTEMIS project by INRETS (Joumard et al, 2009) was an advancement of the HBEFA 2.1 methodology. Most of the findings and recommendations have been adopted in the recent version of HBEFA.

HBEFA traffic situation emission factors

HBEFA 3.1 relies on the instantaneous model, PHEM, to calculate its emission factors. The PHEM model output had to be described in terms of parameters that depict “technology average” (average emission for specific vehicle legislation and fuel type) emission behaviour. This leads to the compilation of “average transient maps” and the “average transient correction functions”. The methodology makes reference to the “average transient maps” by applying a linear combination of measured driving patterns that is most representative for the driving pattern whose emissions are to be predicted. Each emission factor is associated with a particular traffic situation, characterised by the features of the road section concerned. Corrections are then applied based on particular situations.

For HDVs 7.8million emission factors covering various vehicle categories, legislation, gradient, load percentage, in a total of 272 “traffic situations” were calculated with the firm model (Hausberger et al, 2009). Unlike the case for HDVs which covers 19 vehicle categories, light vehicles have only been dealt with in two broad categories (gasoline and diesel). PHEM provided 142 800 passenger car emission factor to Infras taking into account every variable as in HDVs apart from the load effect.

These scenarios together with associated parameters are the bases of the HBEFA methodology. The pollutants covered are CO2, NOx, NO2, HC, CO, PM, PN.

The recent version, HBEFA 3.1, tackles a number of criticisms posed on the former HBEFA2.1 of 2004. Other than Germany, Austria and Switzerland, traffic situations now cover additional five new countries. There are new definitions of traffic situations that match the standardised format proposed by ARTEMIS. These have also been harmonised between the countries. Emission factors for most post euro 3 vehicles had to be reproduced.

The Handbook employs definitions which are road or traffic based, rather than emissions based (EC-METI, 2009). That is, the relationship amongst road characteristics, vehicle operation, and traffic characteristics cannot yet be firmly translated to vehicle emissions. This may be seen as a general weakness of emission modelling variables though the effect here seems pronounced.

2.5 Multiple linear regression models

The Netherlands Organisation for Applied Scientific Research (TNO) developed *VERSIT* (1987) from a simplistic model to the recent versatile and more detailed *VERSIT+*. To compute hot exhaust emissions, *VERSIT+* consults a set of models that have been estimated by means of multiple linear regression techniques. The model is based on data that embodies a large number of emission measures covering a range of distinctive speed–time profiles and uses a large sample of vehicles that reflect the actual fleet composition (Smit et al, 2007). Model inputs include driving cycle/pattern, vehicle parameters, traffic composition and activity data. Instantaneous speed and acceleration values are computed by filtering the speed-time profile data and then associate it with a best fitting emission factor equation for any given driving pattern. The model makes predictions at different geographic scales for many different traffic situations

To develop a regression model for calculating hot emissions the model adopts a stepwise procedure. First it has to specify the variables to be incorporated in the emission factor. VERSIT+ (v.2b version) quantifies a particular traffic situation by capturing the main features of recorded speed–time profiles. With this, it applies Mallow's Cp criterion to select a combination of variables that best fit the test data. The second step involves estimation of the model parameters. The first generation of VERSIT+ models used the ''method of least squares'' (Smit et al., 2005) but it now uses weighted generalised regression estimation deploying (glm) maximum likelihood methods (Smit et al, 2007). This current version link VERSIT+ directly to traffic simulation models that allows for direct evaluation of impact of traffic measures.

2.6 'Simple' modal model

Models that capture sufficient temporal and spatial characteristics by appropriately defining vehicle operation during a trip should certainly be superior and robust. The shortcoming is that, collecting data for running or even validating such models can be very difficult and sometimes may be infeasible with existing technology; especially for regional and national studies. Depending on the level of detail required and data availability modal models range from simple operational modal models to more detailed instantaneous models.

Simple modal model categorise vehicle operation according to a small number of vehicle operational modalities like; idle, acceleration, deceleration, and cruise. For each of the modes the emission rate for a given vehicle category and pollutant is assumed to be fixed, and the total emission during a trip, or on a section of road, is calculated by weighting each modal emission rate by the time spent in the mode (EC-METI, 2009). UROPOL (Urban Road Pollution) model (Hassounah and Miller, 1995) combines the number of vehicles that are accelerating, decelerating, queuing, or cruising at any point along a road segment, with emission rates relating to each driving mode. Though the model has been used for impact assessments it lacked sufficient detail to assert reality.

2.7 Instantaneous models

As mentioned in the previous subsection, instantaneous models (also referred to as micro, modal, or on-line models) seek to capture precise vehicle emission behaviour in time and space. It tries to limit the behavioural gap as much as possible to even a second. Older models like MODEM relate fuel consumption and/or emissions to vehicle speed and acceleration during a driving cycle, typically at one second interval. Other models use some description of engine power requirement (ARTEMIS' PHEM model). With the level of details involved, the models are usually not suitable for national inventories but local assessments. However the models are commended for a variety of enhanced capabilities and are widely used in simulators and other tests to generate emission factors used in other models.

The models can accept input of any vehicle operation profile, thus generate new emission factors for every situation. It can therefore be used to explain some of the variability associated with the average speed approach. The EC-METI taskforce (2009) report summarised the advantages of instantaneous models and also provides a well structured methodological summary of the PHEM, CMEM, and MOVES models. A review of other instantaneous models is also given by Boulter et al (2006).

Atjay and Weilenmann (2004) found out that some instantaneous measurements experience difficulties in allocating emission signals to the precise vehicle operating condition, hence distortions in the resulting model.

3 Copert4 Approach

At least 22 out of the EU27 countries use Copert for collecting national road transport emission inventories. The methodology is widely popular within Europe and has also been adapted in a few cases to estimate emission in Asia and Africa. Although originally developed for estimating road transport emission at national level, it is being used in several instances for local and regional inventories and research.

It is the main reference tool funded and validated by the European Environmental Agency, through the European Topic Centre on Air and Climate Change. The United Nations Economic Commission for Europe also support and promote the methodology via its Convention on Long-range Transboundary Air Pollutions' EMEP (European Monitoring and Evaluation Programme) programme. A joint EMEP/EEA (2009, 2007) Emissions Inventory Guidebook is produced and updated periodically. The guidebook's chapter on road transport outline the Copert4 approach as its most detailed (tier 3) of three recommended methodologies for reporting under CLRTAP or UNFCCC.

3.1 Copert 4 Input Data: Description by Methodological Framework

A clearly structured format has been used to compile emissions inventory in Copert. It uses vehicle types as entities on which activity statistics are compiled and average emission factors (determined by experimental or comparability methods) used to estimate emissions in tonnes of pollutants. The structure summarised below best suits compilation of national emissions for which Copert was principally designed. Table 3.1 list the various data types entered into the tool according to the level it has been estimated. Data can be inputted either manually or imported from a specially configured Excel or Access data file.

One will get to realise that data is not always distinctively available in the specified format. The following subsection (3.2) on *data collection and processing* highlights practical cases on how Copert data has been compiled for national, regional and urban inventories.

Table 3.1: Categorisation of Copert data types

Specificity	Geographic Scale	Vehicle categories	Driving Environment
Data types	Mean trip distance Vehicle fleet composition Annual fuel consumption Fuel specifications Mean & Maximum temperature	Vehicle population Annual mileage Mean fleet mileage Evaporation related	Average Speed Mileage percentage Evaporation share Mean gradient

3.1.1 Geographic scale

The default and only geographic magnitude specified in Copert is at country level. Though the methodology applied best suits this level of detail, Copert has also been used in sub-regional and local studies. Country level is the largest unit of information held in Copert, thus, only one 'country' can be analysed at a time.

Data types: Virtually all data entered in the software are an average of the geographic scale. Most of these data types are distinguished into specific vehicle categories or sub-categories. However, some are aggregated at national level only, without any subgroups distinction. They include:

1) Mean trip distance. A national average trip length in kilometre and the average time it takes to do the trip in hours are included once the country is selected or added. It must be noted that this data is not actually relevant for the computation of emissions. It may be reasonable to see this as information not data since it simply signifies the average trip length and time that has been used for calculating vehicle average speeds.

2) Vehicle fleet composition. There are six sectors (passenger car, light duty vehicles, heavy duty trucks, buses, mopeds and motorcycles) by modality for which various vehicle categories are stored. Copert holds a database of European vehicles from which national fleet selection can be made. It also gives

allowance for additional vehicle types to be added. Vehicle categories follow the EEA's SNAP code format and should be associated to applicable European vehicle legislation standard or technology class. Vehicle category data in the SNAP code-like format ("07 xx xx" for road transport) will automatically match the fuel type used and possibly the cylinder capacity of the vehicle.

The Fleet Configuration Menu in Copert4 is used to enter and edit country fleet data. Meanwhile for "Copert in Excel" this is entered via the Fleet sheet.

3) Annual fuel consumption. Annual consumption of different fuel types (gasoline, diesel, LPG, CNG, Biodiesel) sold in the country is entered in tonnes. Depending on the way national statistics is collected this data can directly reflect road transport consumption or may need adjustments. For pollutants like CO2, whose emission is calculated directly from fuel consumption, the data is used to make adjustments to model estimated fuel consumption values. Statistics of fuel types sold in a country is one of the most important data type according to current UNECE directive on "Guideline for Reporting Emission Data under the Convention on Long-Range Transboundary Air Pollution (EMEP)". Paragraph 15 of the Guideline requires countries in the EMEP region to calculate and report transport emissions consistent with national energy balances reported to Eurostat or the International Energy Agency (ECE/EB.AIR/97). Users of Copert4, thus, have to make adjustments in calculating emission factors of Fuel Consumption to minimise the statistical/calculated fuel balance percentage. Fuel balance statistics can be accessed via the Emissions menu in Copert4 or the Analysis sheet for "Copert in Excel".

4) Fuel specifications. This data corresponds to specific chemical compositions of the various fuel types used in road transport. According to legislation and technology improved fuels in the market will have reduced g/km of regulated pollutants like sulphur and lead. Thus, it is necessary that entries correspond to fuel used in calculations. Oxygen to carbon ratio and hydrogen to carbon ratio together with heavy metals content are also entered. Copert proposed values can be changed with national specific values if the local fuel has been tested to differ from the regional average in the tool.

5) Temperature & RVP. On the Country menu, minimum & maximum national monthly temperatures are entered in the Country Info item. These variables serve as input for measuring cold emissions and fuel evaporation. The Reid vapour pressure (RVP) of gasoline can also be entered. RVP is a measure of the volatility of hydrocarbons in the fuel. Together with temperature statistics they are used in the calculation of fuel evaporation. The Copert replicate in Excel however does not include evaporation nor cold start emissions.

3.1.2 Vehicle Categories

The methodology of emission inventories (for non fuel dependent air pollutants which are categorised as group 1 and 3 pollutants in the 2009 emissions inventory guidebook) is build around vehicle types or technology. Pollutants in this category are not strongly correlated with fuel consumption but have been found to relate more with other variables like vehicle operation. More detail models as at now are often models with more categories per vehicle class. The other option is to include a more representative disaggregate driving condition which has been investigated in this research (see chapter 5).

Calculation of hot exhaust emission inventories is therefore done per vehicle technology disaggregated by driving condition (urban; rural highway). A basic algorithm (equation 1) for corresponding pollutants applies to all vehicle categories.

emission [g] = emission factor [g/km] × number of vehicles [veh]× mileage per vehicle[km/veh] (1a)

Each category has distinctive parameters for calculating emission factors which together with average mileage and number of vehicles (population) in the vehicle category are multiplied. In Copert, the more detail Artemis classification for HDV has been introduced while the standardised European SNAP code is used for classifying passenger cars and other light vehicles.

Data types: All data here can be entered via Input Fleet Data on the Activity Data menu in Copert4 or the Fleet sheet of “Copert in Excel”. Evaporation calculation is not treated in this study so related data will not be discussed further.

6) Vehicle population. National totals of vehicles belonging to every vehicle category should be collected. The agency responsible for vehicle registration in a country can easily afford this data. Apart from cases of high transboundary traffic, this should be a very reliable variable.

7) Annual mileage. For every vehicle category listed the average annual distance travelled should be calculated. Since motorists are not generally required to report their annual mileage, the variability in the dataset can be very high.

8) Mean fleet mileage. Base emission factors have been determined by experimenting (or extrapolating) with vehicles that are within 30,000 to 60,000km of age. New (or old) vehicles emit less (or more), so vehicle age is needed to correct emissions by mileage degradation. Mean fleet mileage is the average cumulative annual mileage of a particular vehicle category since its introduction into the market. The methodology only requires this data for Euro1-6 gasoline passenger cars and light duty vehicle categories.

3.1.3 Driving Environment

The core distinguishing factor amongst existing emissions models is how driving condition is incorporated into the model. Driving condition is characterised by mainly the vehicle environment and vehicle operation. The later definitely requires a minimum level of detail which is not easy to attain for establishing correlation of emission factors for same vehicle types. Environmental factors like road category, traffic situation, and road topography are practically feasible for modelling emissions. Copert4 mainly distinguishes driving environment by urban, rural, and highway roads. It also accounts for elevation, though only for HDVs.

The technique for integrating both operational and environmental characteristics is by using a traffic variable that is environmentally dependent and at the same time varies with vehicle operation. In an ideal traffic situation with the environment and all drivers' behaviour always similar, such a variable would yield consistent results. Vehicle speed is certainly the most realistic and measurable variable having a correlation between driving condition and emissions. Models with a more representative speed function are thus superior because they better reflect vehicles operational characteristics. A separate section (chapter 5) of this report is devoted to analysing the speed function used in emission models

9) Average Speed. A trip-based average speed for a given type of vehicle on a particular road type (urban, rural or highway) is measured and recorded. All vehicle categories should therefore have a distinctive average speed for urban, rural and highway driving conditions. Using the Input Circulation Data tab on the Activity Data menu one can enter average speed data and driving share (mileage percentage) for all vehicle categories in the 3 driving conditions. A Circulation sheet has being reserved for this purpose in Copert in Excel.

10) Mileage Percentage. Vehicles of a particular category are assumed to operate in three driving environments. To rationally allocate emissions it is necessary to know what percentages of trips are driven in a particular driving condition by vehicles of same type. The values arrived at affect emission output because the various driving environments (urban, rural highway) have different emission factors for a given pollutant.

    How mileage percentages should be derived is not specifically directed by EMEP, leaving it open to rough estimations that mostly allocate same driving share for all vehicle categories. Considering that Copert uses a macro level of discreteness it is important for the amount of driving in a particular condition to be optimally represented. Besides it is reasonable to think that different vehicle categories/technologies operate variably on the urban, rural and highway networks. This can be an interesting area for future research to optimise average speed emission models.

11) Mean gradient and load factor. The methodology considers effect of road slope only for HDVs and Buses. Most countries assume an aggregated balance in their national network gradient so do not consider gradient effects even for HDVs. Ascending over-emission is also complemented by reduced emissions when descending making it reasonable to ignore gradient effect. In cases where HDVs load factor can be biased towards ascending driving then its worthwhile to include load and gradient effects. Copert allocates a default 50% (of vehicle gross weight) load factor for buses and HDVs with possibility for users to

modify. The methodology has 7 slope classes ranging from -6, -4, -2, 0, 2, 4, and 6, with zero being the default value. Statistics on road gradient is obtainable from transport department or highway agency of most countries

Gradient and load data entry has been reserved for the Advanced menu in Copert4 for those who which to use or modify the data. The Circulation sheet in Copert in Excel is available for entering load factor.

3.2 Data collection and processing: An overview of European use of Copert

Copert was principally designed to assist national experts to compile national inventories for each country (Ntziachristos et al, 2009). 22 out of the EU27 countries have relied upon the tool for compiling their emission inventories either directly or by using the methodology in an application. In this section, published literature on a few cases of the Copert application is reviewed and analysed.

The purpose and way Copert is being utilised in Europe can be grouped into different headings. Findings from literature indicate its being used:

- In multiple geographic scale; nationally or locally
- As a stand alone model or emission factors embedded in another model
- For emission measurements and/or emission projections
- To measure effects of policy measures and/or new technology

A number of applications with specifications on how they have been used is summarised in table 3.2 below.

Table 3.2: Summary of some European applications of Copert

Application	Scale	Method	Type of Application
SETISMO project	National - Spain	CopertIII	Inventory, forecast
Turkish Road Transport	National – Turkey	CopertIII	Inventory
Urban areas of Italy	Urban relational – Italian provinces	CopertIII	Inventory
Antwerp Urban Transport Model	Urban – Antwerp	CopertII emission factors	Inventory
North Athens	Urban – Northern Athens	CopertIII	Inventory, research
TREMOVE	National – 31 EU countries, urban possible	Copert4 emission factors	Inventory, forecast, decision tool

An important facet to pay attention is how the different applications collect data needed for implementation. National and local inventories adopt data collection methodology in parity with available budget and technology. The data collection process has been eased and improved over the years as countries have adjusted the aggregation of statistics to better suit data needs of model applications.

3.2.1 SETISMO Project (Study of the Transportation Sector in Spain)

Since 1988 the SETISMO Project in Spain via its Development and Application of Analysis Models for a Sustainable Growth of Mobility has being using Copert to estimate emission inventories. The first face of the project covering road transport emission calculations from 1988-1999 adopted a methodology with six deliverables (Buron et al, 2004). The first five of these six deliverables are all aimed at data collection to be executed by the Copert software in stage six. The various stages as explained by Buron et al, is summarised below.

1. Fuel data compilation: Collection of data for fuel consumption and specifications of different fuel types. It accounts for the change in legislation relating to fuel types and composition which affect mainly SO_2 and heavy metals.
2. Study of the temperature distribution in Spain: The methodology for calculating minimum and maximum monthly temperature is by simply weighing average provincial monthly temperature by vehicle population (i.e. provincial vehicle population divided by national vehicle population).
3. Study of the introduction of emission regulations in Spain: Recently the European Union is taking an increasing edge in classifying vehicles by emission regulations. However national governments can also introduce specific legislations and regulations to achieve their emission targets. In this light a re-categorisation which effectively also means adjusting parameter estimates for emission factor calculations may be necessary.
4. Study of vehicles in Spain, in number and categorisation, estimation of overcount: Vehicle classification, fuel type, and population are core inputs to the Copert methodology. These data are not always available in the format required by Copert hence data fixing is necessary. Though, most local institutions have now updated their data banks so that new vehicles statistics are in compliance with European standards. Vehicle overcount was minimised by computing a reduction factor (from vehicle category life cycle) where older vehicles ended up with a

count less than one. This takes care of both inoperative vehicles which have not been officially retired and reduction in usage of vehicles with age.

5. Estimations of route distribution, average speeds and fuel consumption: Driving condition in Copert is indicated by the average speed per vehicle category on different types of roads (urban, rural & highway) and the proportion of driving share on the road types. The Spanish used a number of hypotheses to construct a model for estimating missing circulation data. It included broad assumptions and generalisations in vehicle types rather than categorisation. A listing of the assumptions can be found in Buron et al (2004). The hypotheses were structured into developing four separate sub models (for passenger cars, vans, buses, and HDVs) used to generate circulation and activity data.
6. Data introduction and execution of COPERT III. Lastly all the collected and generated data were introduced into CopertIII for each year from 1988-1999.

A continuation study for 2000-2010 was designed in another manner. Instead of concentrating on obtaining and generating Copert input data directly, they rather built two models for predicting mobility and forecasting emission (Buron et al 2005).

- Economical model. The economical model used a number of macroeconomic variables (GNP, Population, infrastructural investment) to predict mobility per year.
- Emissions forecast. The vehicle emission forecast in this case is sensitive to policy interventions and technological improvement that would affect emission level of existing vehicle categories. Emission evolution of previous years (1989-1999) is the bases of the forecast.

Core to this methodology is forecasting Copert input data to concurrently predict road transport emissions.

3.2.2 Estimation of Turkish Road Transport Emission

The Turkish method of applying the Copert Methodology to estimate emissions for 2004 is straight forward compared to others. Input data is directly gotten from relevant local departments or TURKSTAT and where data is not available the European averages as given by Ntziachristos and Samaras (2000) are used. Adjustment on local data set to fit Copert categorisation is done in a very simple manner.

3.2.3 Urban Areas of Italy

The way EMEP/EEA emission factors have been derived will mostly lead to misleading results when used at high resolution where driving, road and environmental characteristics are very specific. EEA/EMEP Guidebook proposed emission factors are aggregated and averaged over large number of driving cycles; therefore not representative of instantaneous emissions of vehicles driven under actual conditions (Ntziachristos et al, 2009). This does not discredit the need for spatial and temporal disaggregating emission inventories towards which remission measures can be targeted. The Italian case neither uses the bottom-up nor the top-down approach but derives a methodology for optimising the easier top-down approach in reaching more realistic estimates of urban emission. Since Copert has also being used in Italy for the compilation of national inventories, comparison with urban estimates ensure validity of the findings.

The methodology uses 17 socio-economic and vehicle categories variables to capture traffic intensity and characteristics of 103 provinces. The choice of the variables is justified by easy availability of the relative data and relevance to traffic flows (Saija and Romano, 2002). A hierarchical cluster analysis is applied to find similarities between units and to identify groups in the data. Any similarity measurement (correlation coefficient, Eucledian distance) or clustering tendency (mean, maximum, Ward method) can be used to group units (provinces) hierarchically.

The distribution of surrogate variables in the clusters is used to allocate corresponding Copert input variables for analysis by the Copert methodology. Lastly for each cluster, population units greater than the minimum population considered as urban, are allocated the cluster's share of urban emission proportionally.

3.2.4 Antwerp Urban Transport Model

The urban transport emission model of Antwerp developed by Mensink et al (2000) was designed to work in parallel with the city's urban traffic flow model (Nys, 1995). The urban traffic flow model provides actual vehicle numbers per road segment (1963 road segments). It is designed according to the four step trip modelling approach with notably six road categories in the network module. Traffic assignments to the road categories are used as data input for the transport emission model. By combining the hourly traffic volumes computed per road segment with fleet statistics and the corresponding emission factor, the hourly urban transport emissions can be obtained (Mensink et al, 200).

Emission factors as defined in Copert II methodology are used to construct the emission model. The major difference with Copert here is the computation of pollutant emissions from the factors given. It rather multiplies emission factor (EF, in gkm^{-1}) by a time dependent traffic flow rate (F, in h^{-1}) and the road length (L, in km). A similar approach is proposed by the UK NAEI (National Atmospheric Emissions Inventory) for compiling emissions on local road segments (Boulter et al, 2009).

Like other urban “bottom-up” emission models it is not always possible to cover the whole emission area. Doing detailed measurements of individual vehicle contributions to urban emission is not only expensive and time consuming but does not also guarantee improved results. A test study to compare measured emission factors with computed emission factors (using base emission factors from laboratory test) revealed large standard deviations in the results (Mensik et al, 2000). The test revealed an over estimation of NOx emission factors and an underestimation of CO and VOC emission factors. This showed that vehicle operation and maintenance can have a significant influence, leading to even four times higher amounts of emission for certain pollutants.

3.2.5 Southern European Urban Agglomeration – Athens, Greece

A situation of using real traffic data collected on the field to calculate urban emission is described by Kassomenos et al (2006). On a typical weekday traffic data was collected from seven major roads in the city of Athens. Simple counting provided the traffic volume and vehicle classification. Vehicle speed was calculated as a quotient of the distance (a part of the road, some 500m long) by the time needed to cover that distance. One would expect the use of some technology like automatic license plate identification to automatically assign vehicles to their emission legislation classes. The collected data sets are introduced into Copert for computing emission of speed dependent pollutants on each of the roads.

This bottom-up approach is definitely expensive, the reason why even at urban level it could only cover the Northern part of Athens where more than half of the population lives. Differences in average speed brought about by congestion during peak hours and varying also amongst the different roads cannot be properly handled by Copert since Copert emission factors are derived at high level of activity aggregation.

3.2.6 TREMOVE decision tool

The European Commission's transport decision tool, TREMOVE 2.5, is composed of a vehicle demand module, vehicle stock module, and transport emission modules, covering 1995-2030 estimates for each of the 31 countries. It analysis and develop trends from historical transport statistics of travel behaviour, technology, modal allocations and socio-economic effects. Specific variables describing the aforementioned travel determinants will lead to the projection of vehicle demand. The aim is to test how various policy decision scenarios will affect future vehicle stock or use and hence road transport emissions. Output is also important for policy decisions like congestion relief or making comparison of travel statistics amongst regions.

Although some modifications have been made, the TREMOVE fuel consumption and emissions module is based on the Copert4 methodology for the calculation of road transport emissions (De Ceuster et al, 2007). The key difference of the method adopted in TREMOVE lies on the data available from the vehicle stock module. Other than Copert detailed vehicle category and corresponding activity data on network level, TREMOVE also provide disaggregate data on regional and period of day (peak and off peak) basis. As a result, TREMOVE contains the most detailed vehicle structure compared to more aggregate European impact assessment models, such as PRIMES and GAINS (Kousoulidou et al, 2008). Being able to compile its own data, TREMOVE can be a more reliable tool for computing urban emissions inventory. Kousoulidou et al (2008) describes the application on EU15+3 including scenarios reflecting effects of legislation and technology.

In combining its travel demand, infrastructure, and different policy directives, TREMOVE calculate speeds that are used to derive network average emission factors in Copert. If transport demand goes up, network average speed decreases. The resulting average emission factor is thus lower, which is not logical. On the other hand, if we rather use speed distributions resulting from increased demand, we should end up with a higher emission factor. The application will be enhanced by the fact that the TREMOVE Vehicle Stock module already calculates disaggregate vehicle kilometres (in terms of network, region, period of the day etc.) for which speed distributions can relate to.

In summary, Copert is a tool that is widely used in applications for emission inventories, research, and policy development. More striving instantaneous models lack the prowess of data availability and user friendliness of Copert. The level of detail is sufficiently good to concentrate research on improving the methodology of application.

4 Copert in Excel

The Tier 3 methodology for exhaust emissions specified in EMEP/EEA Emissions Inventory Guidebook 2009 chapter on Road Transport has been put together in a spreadsheet. This comprises one of the main tasks of this study. The resulting tool, Copert in Excel, can be used for various methodological analyses. Copert4 which has been developed with Microsoft Visual Studio .NET 2003 provides limited adaptability and flexibility for methodological testing. Amongst this research need for using the tool to perform Copert average speed's dependency study, (chapter 5) other needs of having Copert in a spreadsheet like MS Excel are outlined below.

- Easy to integrate as a stand-alone model in decision tools or other models with multiple extension modules.
- Gives room for the model to be extended. Other pollutants like non-exhaust PM may be added to vehicle emissions
- Effect of policy changes specific to a country or region can be included. This may be say, need to include the effect of car supplementary features like air-conditioning and fuel efficient tyres as in TREMOVE.
- Adaptability to scenario testing on policies or legislations that will lead to new emission factors.
- Where new technologies are increasingly being used it can be necessary to include their effect in more detail. Technologies like hybrids, LPG and CNG are not fully included in Copert. While effect of intelligent systems like tyre pressure monitoring system (TPMS), gear shift indicators and even use of low viscosity lubricants may significantly affect fuel consumption and pollution.
- Having required input data is a major pitfall in using a model. On a spreadsheet it is more viable to adapt other forms of data so it can be used as input for the model. Especially considering that most vehicle counts do not provide detail of vehicles categories in circulation but rather a broader class is often specified.

Pollutants estimated by the tool include:

- European regulated pollutants: CO, NOx, VOC (NMVOC + CH_4), PM ($PM_{2.5}$), SO_2, NH_3
- Non regulated pollutants: NMVOCs, CH_4, CO_2, N_2O

It must be noted that CO_2, CH_4, and the ozone precursor – NMVOCs, N_2O are important greenhouse gases monitored by the European Commission as a party to the UNFCCC. Transport contribution of CO_2 is required to be included in National Emission Inventory of member states according to UNFCCC guidelines.

4.1 Methodology

Emissions from vehicle engine and after treatment devices has been categorised as exhaust emissions in the EEA emissions guidebook. Copert in Excel computes fuel consumption and emissions of hot exhaust pollutants in tons. These emissions are called "hot" because the engine and their after treatment devices have reached their normal operation temperature (Ntziachristos et al, 2009). Otherwise exhaust emissions are considered as cold. The general equation for exhaust emissions is:

$$E_{exhaust} = E_{hot} + E_{cold} \qquad (1b)$$

Although emission levels at cold start (E_{cold}) is substantially higher than when the engine is operating at normal temperature (E_{hot}), this only constitutes a small share of total emissions. Improved catalyst technology with vehicle preheating systems continues to reduce cold emissions. Copert in Excel, thus considering the time limit for this study, measures only hot emissions which is necessary for analysing Copert's average speed function.

As mentioned in the *introduction*, emission calculation is generally done by multiplying an activity statistics by a typical average emission factor for the activity. Equation (2) below represents the final stage of the algorithm.

$$E_{hot} = Activity_r * e_{hot} \qquad (2)$$

Where Activity level is total vehicle-kilometres (for vehicle type r) driven in the period and hot emission factor (e_{hot}) is mean emission for vehicle type r given in grams per kilometre (g km^{-1})

In Copert, discrete aggregated emission factors and continuous average speed emission factors are used. The latter characterises the methodology because it is more superior and is used for most pollutants. In the spreadsheet, the Guidebook's parameters and equations for different pollutants corresponding to particular vehicle types and legislation are put together for easy computation of hot emissions.

4.2 Layout

The spreadsheet tool consist of two interrelated files listed below and stored in a folder; Copert in Excel.

- Hot_Emissions.xls
- HDVs_Buses emission factor.xls

The main file that is necessary for inputs (Figure 4.1), output and correction adjustments is Hot_Emissions file. The other file calculates pollutants (CO, NOx, VOC, PM, FC) emission factors for HDVs and Buses. Normally no input or adjustments should be done in this workbook except by advanced users wishing to make changes to emission factor parameters or algorithm.

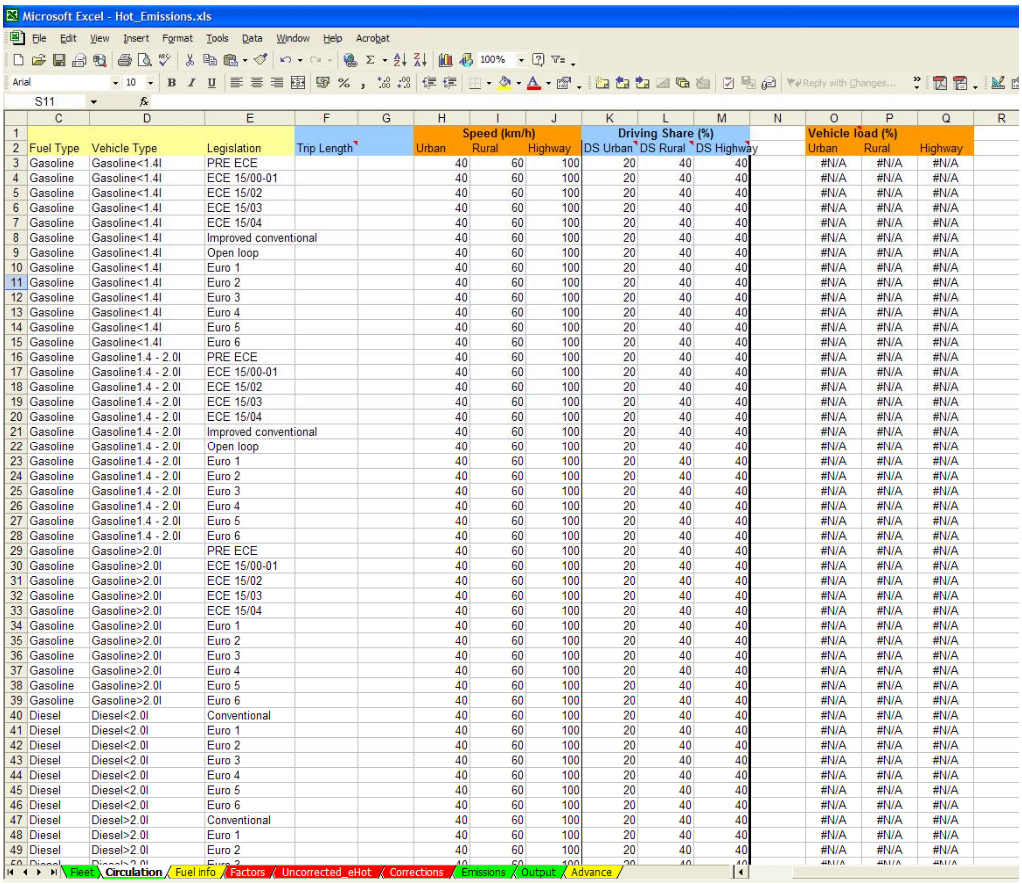


Figure 4.1: Copert in Excel input sheet (Circulation) view.

The architecture of the tool is summarised in Figure 4.2 as a process diagram.

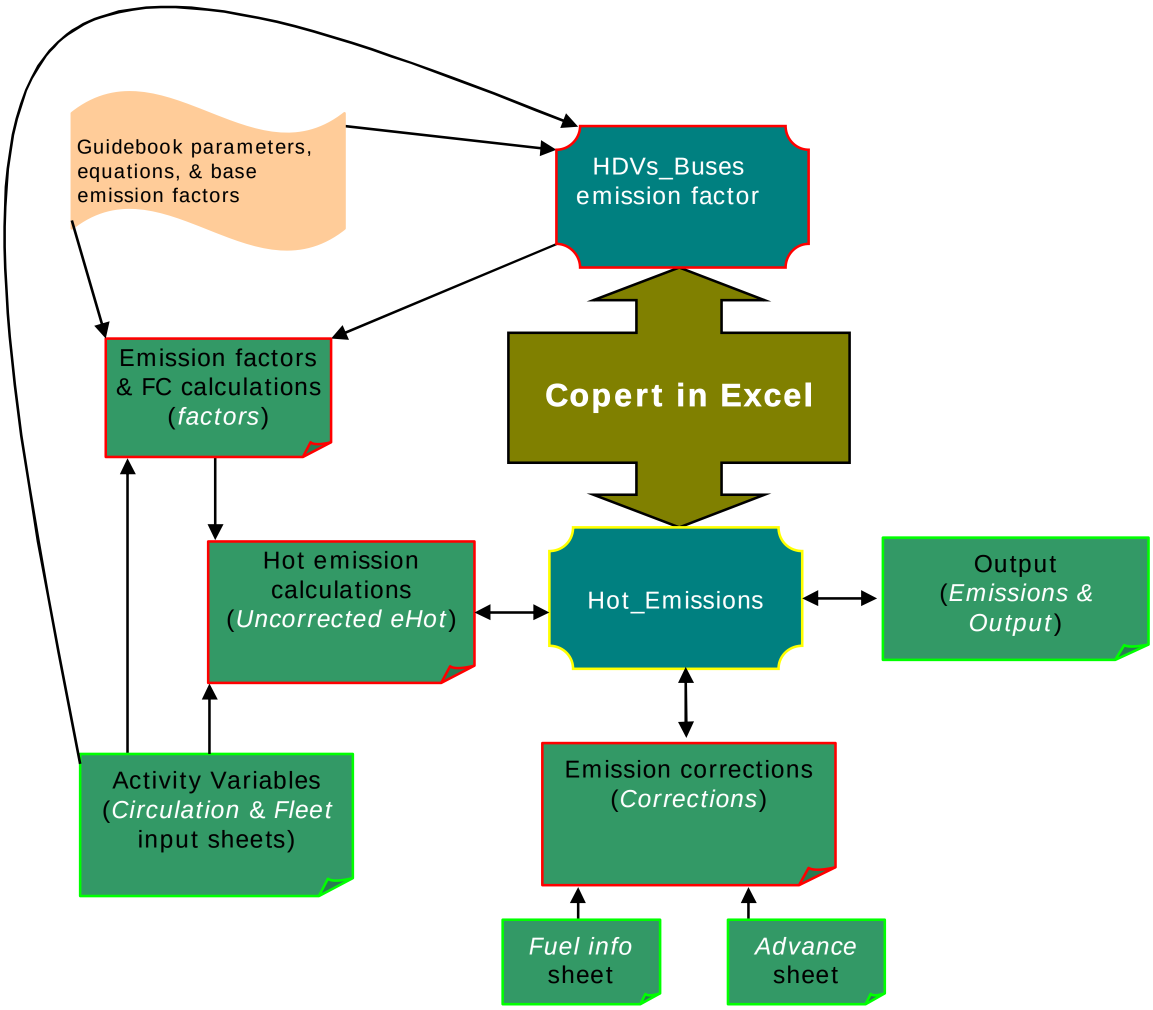


Figure 4.2: Copert in Excel model architecture.

Five distinct phases including a few assumptions or adjustments in some phases for building the Copert in Excel tool are discussed in the ensuing subsections.

- Activity input variables sheets.
- Calculation of emission factors
- Hot emissions calculations
- Emission corrections
- Output sheet.

4.3 Activity Input Variables

Two sheets, *Fleet* & *Circulation*, in the Hot_Emissions file are available for inputting activity data for each vehicle category.

Fleet: The total fleet comprises of 212 vehicle types (UNECE) of four different categories covering three NFR codes; 1.A.3.b.i (passenger cars), 1.A.3.b.ii (light duty vehicles), 1.A.3.b.iii (Heavy duty vehicles and buses).
Particular vehicle types are defined by four columns:

- o Vehicle category: PC (Passenger cars), LDV (Light duty vehicles), Buses, HDV (Heavy duty vehicles)
- o Fuel type: CNG (Compressed natural gas), Diesel, Gasoline, LPG (liquefied petroleum gas).
- o Vehicle type: Separates vehicle category by cylinder capacity for light duty vehicles and by gross weight for heavy duty vehicles.
- o Legislation: European emission standards corresponding to vehicle types are listed in this colon.

In some cases Euro 5(V) and 6 (VI) categories have been added, although the emission factors have not been specified in the guidebook. For such cases the Euro 4(IV) parameters and calculations are replicated for Euro 5 (V) and 6(VI). Where there is difference in output compared to euro 4 then a reduction factor must have been applied. These are based on analytical approximations in Copert4.

The data input of fleet sheet (Population, VKM and Vehicle age) were described in chapter 3. Other vehicle class or categories can always be added in the sheet.

Circulation: Circulation data (Speed, Driving Share, Vehicle load, trip length) has also been discussed in chapter 3. Average vehicle speed (km/h) given here is necessary for computing emission factors that are based on Copert's average speed function.

Vehicle Load: Average percentage of vehicle load per category for buses and HGVs is also inputted via the *Circulation* sheet. Copert guidebook provides emission factor for 0%, 50%, and 100% load factors. However, linear interpolation is used in Copert in

Excel to allow other weights percentages to be accommodated. The interpolation does not affect the 0%, 50%, and 100% load factor units.

4.4 Calculation of emission factors

	Hot Emission Factors in grams per kilometre					CO									NOx							
2	ID	Vehicle Category	Fuel Type	Vehicle Type	Legislation	a	b	c	d	e	f	Urban	Rural	Highway	a	b	c	d	e	Urban	Rural	Highway
3	1	PC	Gasoline	Gasoline<1.4l	PRE ECE	281	-0.63	0.112	4.32			27.505	21.304	15.520	1.173	0.0225	-0.00014			1.849	2.019	2.023
4	2	PC	Gasoline	Gasoline<1.4l	ECE 15/00-01	313	-0.76	27.22	-0.406	0.0032		18.966	14.380	18.620	1.173	0.0225	-0.00014			1.849	2.019	2.023
5	3	PC	Gasoline	Gasoline<1.4l	ECE 15/02	300	-0.797	26.26	-0.44	0.0026		15.859	9.220	8.26	1.479	-0.0037	0.00018			1.619	1.905	2.909
6	4	PC	Gasoline	Gasoline<1.4l	ECE 15/03	161.36	-45.62	37.92	-0.68	0.00377		16.752	10.692	7.620	1.616	-0.0084	0.00025			1.68	2.012	3.276
7	5	PC	Gasoline	Gasoline<1.4l	ECE 15/04	260.788	-0.910	14.653	-0.220	0.001163		9.087	5.640	4.283	1.432	0.003	0.000097			1.707	1.9612	2.702
8	6	PC	Gasoline	Gasoline<1.4l	Improved conventional			14.577	-0.294	0.002478		6.782	5.858	9.957	-0.926	0.719				1.726	2.018	2.385
9	7	PC	Gasoline	Gasoline<1.4l	Open loop			17.882	-0.377	0.002825		7.322	5.432	8.432	-0.921	0.616				1.351	1.601	1.916
10	8	PC	Gasoline	Gasoline<1.4l	Euro 1	1.12E+01	1.29E-01	-1.02E-01	-9.47E-04	6.77E-04		1.766	1.410	1.754	5.25E-01		-1.00E-02		9.36E-05	0.275	0.262	0.461
11	9	PC	Gasoline	Gasoline<1.4l	Euro 2	6.05E+01	3.50E+00	1.52E-01	-2.52E-02	-1.68E-04		0.659	0.574	0.748	2.84E-01	-2.34E-02	-8.69E-03	4.43E-04	1.14E-04	0.154	0.145	0.180
12	10	PC	Gasoline	Gasoline<1.4l	Euro 3	7.17E+01	3.54E+01	1.14E+01	-2.48E-01			0.517	0.613	1.142	9.29E-02	-1.22E-02	-1.49E-03	3.97E-05	6.53E-06	0.076	0.066	0.052
13	11	PC	Gasoline	Gasoline<1.4l	Euro 4	1.36E-01	-1.41E-02	-8.91E-04	4.99E-05			0.195	0.247	0.527	1.06E-01		-1.58E-03		7.10E-06	0.054	0.037	0.019
14	12	PC	Gasoline	Gasoline<1.4l	Euro 5	1.36E-01	-1.41E-02	-8.91E-04	4.99E-05			0.195	0.247	0.527	1.06E-01		-1.58E-03		7.10E-06	0.041	0.028	0.014
15	13	PC	Gasoline	Gasoline<1.4l	Euro 6	1.36E-01	-1.41E-02	-8.91E-04	4.99E-05			0.195	0.247	0.527	1.06E-01		-1.58E-03		7.10E-06	0.041	0.028	0.014
16	14	PC	Gasoline	Gasoline1.4 - 2.0l	PRE ECE	281	-0.63	0.112	4.32			27.505	21.304	15.520	1.360	0.0217	-0.00004			2.164	2.518	3.13
17	15	PC	Gasoline	Gasoline1.4 - 2.0l	ECE 15/00-01	313	-0.76	27.22	-0.406	0.0032		18.966	14.380	18.620	1.360	0.0217	-0.00004			2.164	2.518	3.13
18	16	PC	Gasoline	Gasoline1.4 - 2.0l	ECE 15/02	300	-0.797	26.26	-0.44	0.0026		15.859	9.220	8.260	1.663	-0.0038	0.0002			1.831	2.155	3.283
19	17	PC	Gasoline	Gasoline1.4 - 2.0l	ECE 15/03	161.36	-45.62	37.92	-0.68	0.00377		16.752	10.692	7.620	1.29	0.0099				1.917	2.336	3.472
20	18	PC	Gasoline	Gasoline1.4 - 2.0l	ECE 15/04	260.788	-0.910	14.653	-0.220	0.001163		9.087	6.283	4.283	1.484	0.013	0.000074			2.122	2.530	3.524
21	19	PC	Gasoline	Gasoline1.4 - 2.0l	Improved conventional			8.273	-0.151	0.000957		3.764	2.658	2.743	1.387	0.0014	0.000247			1.838	2.360	3.997
22	20	PC	Gasoline	Gasoline1.4 - 2.0l	Open loop			9.446	-0.230	0.002029		3.492	2.950	6.736	-0.761	0.515				1.139	1.348	1.611
23	21	PC	Gasoline	Gasoline1.4 - 2.0l	Euro 1	1.12E+01	1.29E-01	-1.02E-01	-9.47E-04	6.77E-04		1.766	1.410	1.754	5.25E-01		-1.00E-02		9.36E-05	0.275	0.262	0.461
24	22	PC	Gasoline	Gasoline1.4 - 2.0l	Euro 2	6.05E+01	3.50E+00	1.52E-01	-2.52E-02	-1.68E-04		0.659	0.574	0.748	2.84E-01	-2.34E-02	-8.69E-03	4.43E-04	1.14E-04	0.154	0.145	0.180
25	23	PC	Gasoline	Gasoline1.4 - 2.0l	Euro 3	7.17E+01	3.54E+01	1.14E+01	-2.48E-01			0.517	0.613	1.142	9.29E-02	-1.22E-02	-1.49E-03	3.97E-05	6.53E-06	0.076	0.066	0.052
26	24	PC	Gasoline	Gasoline1.4 - 2.0l	Euro 4	1.36E-01	-1.41E-02	-8.91E-04	4.99E-05			0.195	0.247	0.527	1.06E-01		-1.58E-03		7.10E-06	0.054	0.037	0.019
27	25	PC	Gasoline	Gasoline1.4 - 2.0l	Euro 5	1.36E-01	-1.41E-02	-8.91E-04	4.99E-05			0.195	0.247	0.527	1.06E-01		-1.58E-03		7.10E-06	0.041	0.028	0.014
28	26	PC	Gasoline	Gasoline1.4 - 2.0l	Euro 6	1.36E-01	-1.41E-02	-8.91E-04	4.99E-05			0.195	0.247	0.527	1.06E-01		-1.58E-03		7.10E-06	0.041	0.028	0.014
29	27	PC	Gasoline	Gasoline>2.0l	PRE ECE	281	-0.63	0.112	4.32			27.505	21.304	15.520	1.5	0.03	0.0001			2.860	3.660	5.500
30	28	PC	Gasoline	Gasoline>2.0l	ECE 15/00-01	313	-0.76	27.22	-0.406	0.0032		18.966	14.380	18.620	1.5	0.03	0.0001			2.860	3.660	5.500
31	29	PC	Gasoline	Gasoline>2.0l	ECE 15/02	300	-0.797	26.26	-0.44	0.0026		15.859	9.220	8.260	1.87	-0.0039	0.00022			2.066	2.428	3.68
32	30	PC	Gasoline	Gasoline>2.0l	ECE 15/03	161.36	-45.62	37.92	-0.68	0.00377		16.752	10.692	7.620	2.784	-0.0112	0.000294			2.806	3.170	4.604
33	31	PC	Gasoline	Gasoline>2.0l	ECE 15/04	260.788	-0.910	14.653	-0.220	0.001163		9.087	6.283	4.283	2.427	-0.014	0.000266			2.293	2.545	3.687
34	32	PC	Gasoline	Gasoline>2.0l	Euro 1	1.12E+01	1.29E-01	-1.02E-01	-9.47E-04	6.77E-04		1.766	1.410	1.754	5.25E-01		-1.00E-02		9.36E-05	0.275	0.262	0.461
35	33	PC	Gasoline	Gasoline>2.0l	Euro 2	6.05E+01	3.50E+00	1.52E-01	-2.52E-02	-1.68E-04		0.659	0.574	0.748	2.84E-01	-2.34E-02	-8.69E-03	4.43E-04	1.14E-04	0.154	0.145	0.180
36	34	PC	Gasoline	Gasoline>2.0l	Euro 3	7.17E+01	3.54E+01	1.14E+01	-2.48E-01			0.517	0.613	1.142	9.29E-02	-1.22E-02	-1.49E-03	3.97E-05	6.53E-06	0.076	0.066	0.052
37	35	PC	Gasoline	Gasoline>2.0l	Euro 4	1.36E-01	-1.41E-02	-8.91E-04	4.99E-05			0.195	0.247	0.527	1.06E-01		-1.58E-03		7.10E-06	0.054	0.037	0.019
38	36	PC	Gasoline	Gasoline>2.0l	Euro 5	1.36E-01	-1.41E-02	-8.91E-04	4.99E-05			0.195	0.247	0.527	1.06E-01		-1.58E-03		7.10E-06	0.041	0.028	0.014
39	37	PC	Gasoline	Gasoline>2.0l	Euro 6	1.36E-01	-1.41E-02	-8.91E-04	4.99E-05			0.195	0.247	0.527	1.06E-01		-1.58E-03		7.10E-06	0.041	0.028	0.014
40	38	PC	Diesel	Diesel<2.0l	Conventional	5.41301	-5.74E-01					0.651	0.516	0.385	0.918	-0.014	1.01E-04			0.520	0.442	0.528
41	39	PC	Diesel	Diesel<2.0l	Euro 1	9.96E-01		-1.88E-02		1.09E-04		0.418	0.260	0.206	3.10E+00	1.41E-01	-6.18E-03	-5.03E-04	4.22E-04	0.605	0.555	0.666
42	40	PC	Diesel	Diesel<2.0l	Euro 2	9.00E-01		-1.74E-02		8.77E-05		0.344	0.172	0.037	2.40E+00	7.67E-02	-1.16E-02	-5.00E-04	1.20E-04	0.651	0.562	0.665
43	41	PC	Diesel	Diesel<2.0l	Euro 3	1.69E-01		-2.92E-03		1.25E-05	1.1	0.100	0.057	0.013	2.82E+00	1.98E-01	6.69E-02	-1.43E-03	-4.63E-04	0.717	0.668	0.751
44	42	PC	Diesel	Diesel<2.0l	Euro 4	1.75E-02	86.42	1	117.67	-21.99	-1	0.084	0.044	0.022	1.11E+00		-2.02E-02		1.48E-04	0.539	0.431	0.570
45	43	PC	Diesel	Diesel<2.0l	Euro 5	1.75E-02	86.42	1	117.67	-21.99	-1	0.084	0.044	0.022	1.11E+00		-2.02E-02		1.48E-04	0.388	0.310	0.410
46	44	PC	Diesel	Diesel<2.0l	Euro 6	1.75E-02	86.42	1	117.67	-21.99	-1	0.084	0.044	0.022	1.11E+00		-2.02E-02		1.48E-04	0.172	0.138	0.182
47	45	PC	Diesel	Diesel>2.0l	Conventional	5.41301	-5.74E-01					0.651	0.516	0.385	1.331	-0.018	0.000133			0.824	0.730	0.861
48	46	PC	Diesel	Diesel>2.0l	Euro 1	9.96E-01		-1.88E-02		1.09E-04		0.418	0.260	0.206	3.10E+00	1.41E-01	-6.18E-03	-5.03E-04	4.22E-04	0.605	0.555	0.666
49	47	PC	Diesel	Diesel>2.0l	Euro 2	9.00E-01		-1.74E-02		8.77E-05		0.344	0.172	0.037	2.40E+00	7.67E-02	-1.16E-02	-5.00E-04	1.20E-04	0.651	0.562	0.665
50	48	PC	Diesel	Diesel>2.0l	Euro 3	1.69E-01		-2.92E-03		1.25E-05	1.1	0.100	0.057	0.013	2.82E+00	1.98E-01	6.69E-02	-1.43E-03	-4.63E-04	0.717	0.668	0.751
51	49	PC	Diesel	Diesel>2.0l	Euro 4	1.75E-02	86.42	1	117.67	-21.99	-1	0.084	0.044	0.022	1.11E+00		-2.02E-02		1.48E-04	0.539	0.431	0.570
52	50	PC	Diesel	Diesel>2.0l	Euro 5	1.75E-02	86.42	1	117.67	-21.99	-1	0.084	0.044	0.022	1.11E+00		-2.02E-02		1.48E-04	0.388	0.310	0.410
53	51	PC	Diesel	Diesel>2.0l	Euro 6	1.75E-02	86.42	1	117.67	-21.99	-1	0.084	0.044	0.022	1.11E+00		-2.02E-02		1.48E-04	0.172	0.138	0.182
54	52	PC	LPG	LPG<2.5t	Conventional	12.5230	-0.418	0.0039				2.043	1.483	9.723	0.77	0.285				2.203	2.473	2.861
55	53	PC	LPG	LPG<2.5t	Euro 1	0.0011	-0.1165	4.2098				1.310	1.180	3.560	0.00004	-0.0063	0.5278			0.340	0.294	0.298
56	54	PC	LPG	LPG<2.5t	Euro 2	0.0011	-0.1165	4.2098			32	0.891	0.802	2.421	0.00004	-0.0063	0.5278		64	0.122	0.106	0.107
57	55	PC	LPG	LPG<2.5t	Euro 3	0.0011	-0.1165	4.2098			44	0.733	0.661	1.993	0.00004	-0.0063	0.5278		76	0.082	0.071	0.071
58	56	PC	LPG	LPG<2.5t	Euro 4	0.0011	-0.1165	4.2098			66	0.445	0.401	1.210	0.00004	-0.0063	0.5278		87	0.044	0.038	0.039
59	57	PC	LPG	LPG<2.5t	Euro 5	0.0011	-0.1165	4.2098			66	0.445	0.401	1.210	0.00004	-0.0063	0.5278		88	0.041	0.035	0.036
60	58	PC	LPG	LPG<2.5t	Euro 6	0.0011	-0.1165	4.2098			66	0.445	0.401	1.210	0.00004	-0.0063	0.5278		88	0.041	0.035	0.036

Fleet / Circulation / Fuel info / Factors / Uncorrected_eHot / Corrections / Emissions / Output / Advance

Ready

Figure 4.3: Factors sheet for calculating hot emission factors – Copert in Excel.

Hot emission factors for estimated pollutants and fuel consumption is calculated via the *Factors* sheets of the tool. Figure 4.3 above is a Window page section of the *factors* sheet. Guidebook parameters have been entered into the sheet. Formulas used in the calculations have not been copied into the sheet except for HDVs. It may be a good idea to include a separate formula column for each pollutant; however the formulae can always be consulted in the Guidebook.

The calculations for HDVs and Buses emission factors are done in the *HDV_Buses emission factor.xls* file and exported to the *Factors* sheet of *Hot_Emissions.xls*. An interface of the *HDV_Buses emission factor.xls* Workbook displaying the sheet for CO emission factor calculations can seen in Figure 4.4

Apart from CO_2 and SO_2 which are fuel dependent pollutants, emission factors for all other pollutants can be gotten from this sheet. Calculations of fuel dependent pollutants are however done in the proceeding sheet (Uncorrected_eHot).

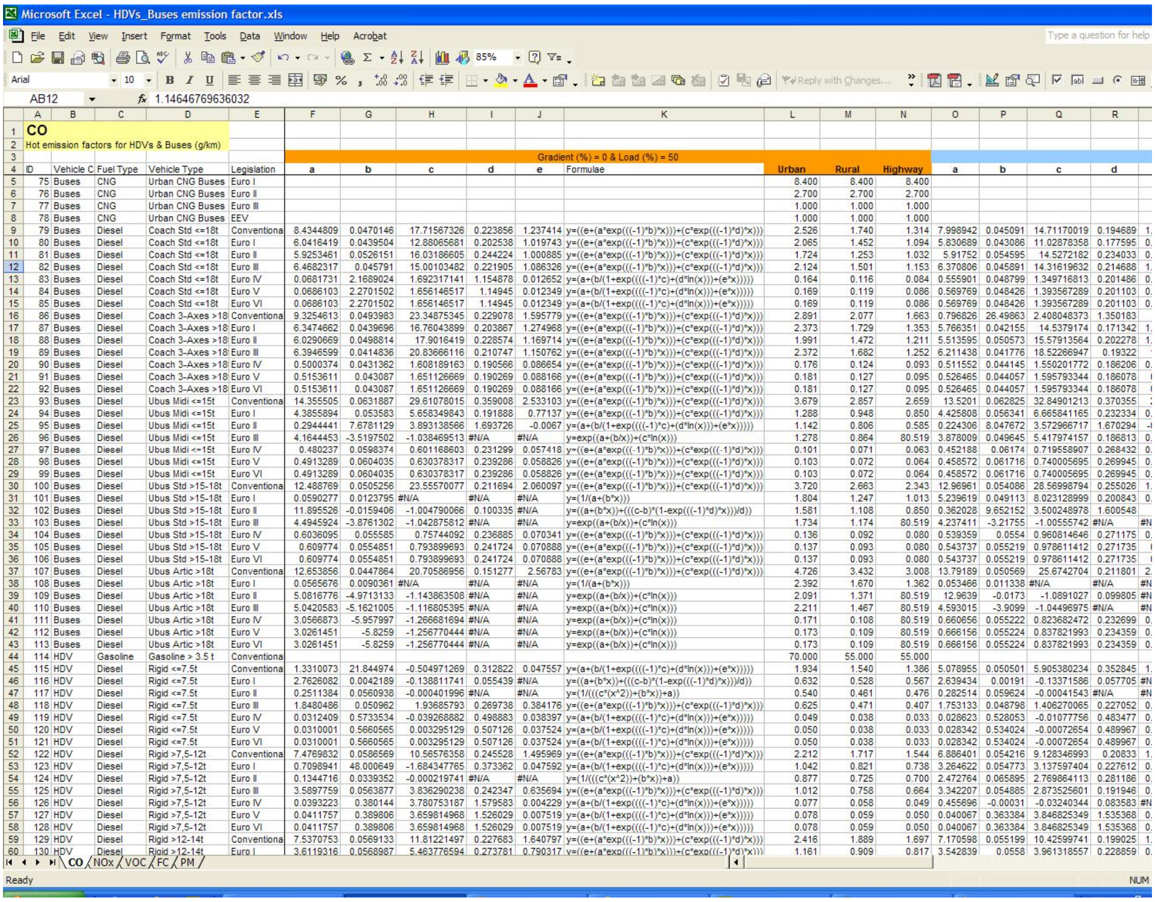


Figure 4.4: Separate file for calculating HDV/Buses emission factors. CO interface is displayed.

EF model types

Two model types can be singled out from the way Copert computes emission factors.

- Aggregated emission factors
- Average speed

Since Copert computes all regulated pollutants (table 4.1) by the average speed approach, this generic type largely defines the Copert methodology. Table 4.1 also indicates which input data have a direct effect on EF output. Carbon dioxide and sulphur dioxide also can be average speed dependent if statistical fuel correction is not done. This is because calculated CO_2 and SO_2 are based on fuel consumption estimated by the average speed approach.

Table 4.1: Model types for estimating emission factors of pollutants and FC

Pollutant	Generic model type	Type of emission factor/function	Input data
CO	Average speed	Continuous	Average trip speed
NOx	Average speed	Continuous	Average trip speed
VOC	Average speed	Continuous	Average trip speed
FC	Average speed	Continuous	Average trip speed
PM	Average speed Aggregated emission factors	Continuous Discrete (gasoline & LPG)	Average trip speed Road type
CH_4	Aggregated emission factors	Discrete	Road type
N_20	Aggregated emission factors	Discrete	Vehicle age
NH_3	Aggregated emission factors	Discrete	Vehicle age
CO_2	Average speed	Continuous	Fuel consumption/type
SO_2	Average speed	Continuous	Fuel dependent/type

Valid speed range for continuous emission factors

Emission calculations for pollutants that are based on the continuous average speed function are only valid for speeds that EF parameters were derived from. The EEA guidebook provides the valid speed range for each of the pollutants. To be consistent, Copert in Excel will return the emission factor of the upper bound speed limit when higher speeds are entered. If the average speed is rather lower than the lower bound limit, an error will be displayed. Generally, an average speed of 10 and above will avoid an error output.

Speed range for discrete emission factors.

Speed ranges are employed to define the urban, rural and highway discrete categories for aggregated emission factors. Since the guidebook does not specify any particular speed range to be considered as urban, rural or highway, logical ranges (Table 4.2) were chosen when computing the algorithm for estimating EF for methane and gasoline PM. The range has simply been included in the formulae. One may consider allocating well defined input cells for the ranges when reviewing Copert in Excel so users can easily alter the values if desired.

Table 4.2: Average speed range for aggregated emission factor pollutants

Pollutant	Urban (km h^{-1})	Rural (km h^{-1})	Highway (km h^{-1})
PM (gasoline & LPG for PC/LDV)	>0	>50	>80
CH_4	>0	>50	>80

4.5 Hot emission calculations

Equation (2) is employed to compute hot emissions by multiplying activity data by emission factors (e_{hot}) estimated in the *Factors* sheet. The algorithms for computations are entered in the *Uncorrected_eHot* sheet for calculated pollutants and fuel consumption. Depending on how the collected data is structured it may be necessary to make some adjustments by using extra cells of the input sheet. The general structure for inputting annual national statistics is discussed below.

Estimation at national level

Total annual activity data for a particular vehicle type and legislation is gotten by multiplying the average annual mileage, VKM (vehicle kilometres), by total population (vehicle count) of the vehicle type/legislation. These are data entered into the *Fleet* sheet. To spatially allocate driving share of each vehicular type unit, the *Circulation* data Driving Share% is further multiplied by the activity statistics. Equation (2) can thus be rewritten to estimate hot emissions (E_{hot}) for vehicles of technology/type K, as:

$$E_{hot,\,k} = Population_k * VKM_k * (Driving\ Share/100) * e_{hot\,,\,k}/1000000 \qquad (3)$$

We divide by 1000000 to convert emissions from grams to tonnes of pollutants.

The resultant national inventory of a pollutant can be used to allocate inventory of local districts. That is by multiplying total emission inventory by weights of the local population. Such an easy top-down approach is only reliable when the population variable used is well representative of the vehicle category distribution with little variations in spatial design, topography, climate and behavioural characteristics. Where resources are available a more detailed bottom-up method for estimating local districts emissions like the one in the following subsection is desirable.

Estimation at regional or district level

For district studies where a detailed bottom-up methodology is desired, circulation data is neither based nor collected at national level. Spatial analysis is mostly based on road sections (Mensik et al, 2000; Boulter et al, 2009; Kassomenos et al, 2006) with a sufficient time resolution. Emission per unit time is calculated by adjusting the variables of equation (3) as:

Population => F (traffic flow rate in vehicles per hour)

VKM => L (road length per road segment in kilometre)

The equation for computing hourly hot emission (gh^{-1}) at road sections for vehicles of technology k will be.

$$E_{hot,\,k} = F_k * L_k * e_{hot\,,\,k} \qquad (4)$$

To obtain an average annual hourly flow rate, F should be adjusted by applying three emission time factors; monthly variations, weekly variations and hourly variations (Mensink et al, 2000).

A simple method for allocating road sectional vehicle counts into various subcategories where data is only available for major vehicle categories is illustrated in a spreadsheet published by the UK DfT (2009).

CO_2 and SO_2 based on fuel consumption are also estimated in the *Uncorrected_eHot* sheet for both the calculated fuel consumption and statistical fuel correction scenarios.

4.6 Emission Corrections

As specified in the EMEP/EEA, 2009 Emissions Inventory Guidebook, the following corrections can be applied to corresponding pollutants in Copert in Excel.

- Used fuel correction: CO, NOx, VOC, PM
- Biodiesel blend correction: CO, NOx, VOC, PM, CO_2
- Mileage correction: CO, NOx, VOC
- Statistical fuel correction: CO_2, SO_2

Formulae computation of used fuel, biodiesel blend and mileage corrections are in the *Corrections* sheet. Statistical fuel correction calculations for fuel dependent pollutants have been done in the *Uncorrected_eHot* sheet.

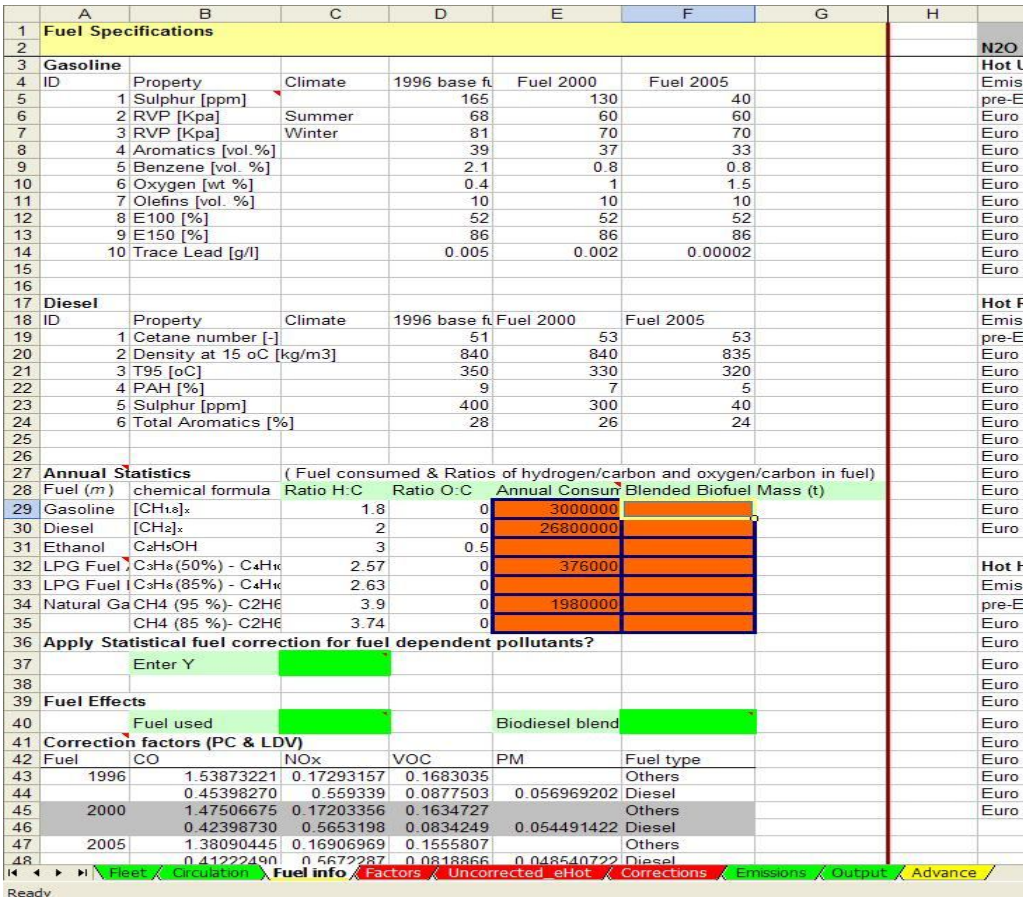
Applying corrections

Corrections effects must be initiated by the user. *Fuel info* and *Advance* Worksheets contains designated cells for initiating appropriate correction effects. To apply corrections, specified characters need to be entered into the green cells.

Fuel info: Figure 4.5 displays the interface of the *Fuel info* sheet. This is also an input sheet for statistical data of different fuel types used. The orange cells records statistics of fuel consumed while other fuel specifications can also be altered if necessary. To invoke a particular correction effect you enter the corresponding characters into the green cells:

Statistical fuel correction: Enter "y"
Used fuel : enter either "1996", "2000", or "2005"
Biodiesel blend: enter either "B10", "B20" or "B100"

Entering an older fuel type (Used fuel) has no effect on vehicle technologies that came into the market after up to date fuel legislation. This is to ensure that only improved fuel corrections are computed.



	A	B	C	D	E	F	G	H	
1	Fuel Specifications								
2									N2O
3	Gasoline								Hot U
4	ID	Property	Climate	1996 base fu	Fuel 2000	Fuel 2005			Emis
5	1	Sulphur [ppm]		165	130	40			pre-E
6	2	RVP [Kpa]	Summer	68	60	60			Euro
7	3	RVP [Kpa]	Winter	81	70	70			Euro
8	4	Aromatics [vol.%]		39	37	33			Euro
9	5	Benzene [vol. %]		2.1	0.8	0.8			Euro
10	6	Oxygen [wt %]		0.4	1	1.5			Euro
11	7	Olefins [vol. %]		10	10	10			Euro
12	8	E100 [%]		52	52	52			Euro
13	9	E150 [%]		86	86	86			Euro
14	10	Trace Lead [g/l]		0.005	0.002	0.00002			Euro
15									Euro
16									
17	Diesel								Hot F
18	ID	Property	Climate	1996 base fu	Fuel 2000	Fuel 2005			Emis
19	1	Cetane number [-]		51	53	53			pre-E
20	2	Density at 15 oC [kg/m3]		840	840	835			Euro
21	3	T95 [oC]		350	330	320			Euro
22	4	PAH [%]		9	7	5			Euro
23	5	Sulphur [ppm]		400	300	40			Euro
24	6	Total Aromatics [%]		28	26	24			Euro
25									Euro
26									Euro
27	Annual Statistics		(Fuel consumed & Ratios of hydrogen/carbon and oxygen/carbon in fuel)						Euro
28	Fuel (m)	chemical formula	Ratio H:C	Ratio O:C	Annual Consum	Blended Biofuel Mass (t)			Euro
29	Gasoline	[CH1.8]x	1.8	0	3000000				Euro
30	Diesel	[CH2]x	2	0	26800000				Euro
31	Ethanol	C2H5OH	3	0.5					
32	LPG Fuel	C3H8(50%) - C4H1	2.57	0	376000				Hot H
33	LPG Fuel	C3H8(85%) - C4H1	2.63	0					Emis
34	Natural Ga	CH4 (95 %)- C2H6	3.9	0	1980000				pre-E
35		CH4 (85 %)- C2H6	3.74	0					Euro
36	Apply Statistical fuel correction for fuel dependent pollutants?								Euro
37		Enter Y							Euro
38									Euro
39	Fuel Effects								Euro
40		Fuel used			Biodiesel blend				Euro
41	Correction factors (PC & LDV)								Euro
42	Fuel	CO	NOx	VOC	PM	Fuel type			Euro
43	1996	1.53873221	0.17293157	0.1683035		Others			Euro
44		0.45398270	0.559339	0.0877503	0.056969202	Diesel			Euro
45	2000	1.47506675	0.17203356	0.1634727		Others			Euro
46		0.42398730	0.5653198	0.0834249	0.054491422	Diesel			
47	2005	1.38090445	0.16906969	0.1555807		Others			
48		0.41222490	0.5672287	0.0818866	0.048540722	Diesel			

Figure 4.5: "Fuel info" sheet for inputting fuel specifications and applying statistical fuel correction effects

Advance

Mileage degradation: Due to increased mileage compared to the average mileage from which the baseline emission factors where developed, a mileage degradation factor is advisable for gasoline passenger cars and light duty vehicles equipped with three way catalyst. Degradation functions and parameters for Euro 1 to 4 gasoline PC &LDV for calculating CO, NOx, and VOC were entered and processed in the *Advance* sheet shown in Figure 4.6

Apply mileage degradation: Enter "y" into the green cell

	A	B	C	D	E	F	G	H	I	J
1	**Mileage Degradation**				Apply mileage degradation?					**Road Gradie**
2										**Load for HDV**
3	Milage correction for **Gasoline Euro 1 & 2 PC, LDV**									
4			MC_Urban parameters			MC_Road Parameters				
5	**Pollutant**	**Capacity**	**A**	**B (at 0 km)**	**MC (at >=**	**A**	**B (at 0 km**	**MC (at >=120000km)**		
6	CO	<=1.4	1.52E-05	0.557	2.39	1.69E-05	0.509	2.54		
7		1.4-2.0	1.15E-05	0.543	1.92	9.61E-06	0.617	1.77		
8		>2.0	9.24E-06	0.565	1.67	2.70E-06	0.873	1.2		
9	NOx	All	1.60E-05	0.282	2.2	1.22E-05	0.424	1.89		
10	HC	<=1.4	1.22E-05	0.647	2.1	6.57E-06	0.809	1.6		
11		1.4-2.0	1.23E-05	0.509	1.99	9.82E-06	0.609	1.79		
12		>2.0	1.21E-05	0.432	1.88	6.22E-06	0.707	1.45		
13										
14	Milage correction for **Gasoline Euro 3 & 4 PC, LDV**									
15	**Pollutant**	**Capacity**	**A**	**B (at 0 km)**	**B (at >=12**	**A**	**B (at 0 km**	**B (at >=160000km)**		
16	CO	<=1.4	7.13E-06	0.769	1.91	1.50E-06	0.955	1.2		
17		>1.4	2.67E-06	0.955	1.38	0	1	1		
18	NOx	<=1.4	0	1	1	0	1	1		
19		>1.4	3.99E-06	0.932	1.57	0	1	1		
20	HC	<=1.4	3.42E-06	0.891	1.44	0	1	1		
21		>1.4	0.00E+00	1	1	0	1	1		
22										
23										CO degradatio
24							Speed (km/h)			Mileage belc
25	ID	Vehicle C	Fuel Type	Vehicle Type	Legislation	Vehicle Ag	Urban	Rural	Highway	MC_Urban
26	1	PC	Gasoline	Gasoline<1.4l	PRE ECE	0	40	60	100	
27	2	PC	Gasoline	Gasoline<1.4l	ECE 15/00	0	40	60	100	
28	3	PC	Gasoline	Gasoline<1.4l	ECE 15/02	0	40	60	100	
29	4	PC	Gasoline	Gasoline<1.4l	ECE 15/03	0	40	60	100	

Figure 4.6: Advance sheet

	A	B	C	D	E	F	G
1	Vehicle Category	HDV					
2	Fuel Type	(All)					
3							
4			Data	Pollutant			
5			Sum of Urban	Sum of Rural	Sum of Highway		
6	Vehicle Type	Legislation	PM exhaust (t)	PM exhaust (t)	PM exhaust (t)		
7	Articulated >14-20t	Conventional	97.001	147.949	129.600		
8		Euro I	57.846	87.772	76.800		
9		Euro II	24.731	41.810	48.400		
10		Euro III	25.456	39.200	34.400		
11		Euro IV	4.915	7.188	6.000		
12		Euro V	4.990	7.291	6.000		
13		Euro VI	4.990	7.291	6.000		
14	Articulated >20-28t	Conventional	103.434	160.957	142.000		
15		Euro I	76.914	117.100	102.000		
16		Euro II	33.683	54.381	69.600		
17		Euro III	32.502	49.808	44.800		
18		Euro IV	6.155	8.934	7.200		
19		Euro V	6.255	9.064	7.600		
20		Euro VI	6.255	9.064	7.600		
21	Articulated >28-34t	Conventional	108.271	168.246	147.600		
22		Euro I	81.055	123.720	107.600		
23		Euro II	36.647	57.215	79.200		
24		Euro III	33.872	51.605	44.800		
25		Euro IV	6.218	8.993	7.200		
26		Euro V	6.314	9.118	7.600		
27		Euro VI	6.314	9.118	7.600		
28	Articulated >34-40t	Conventional	126.323	194.051	169.200		
29		Euro I	96.384	142.922	122.000		
30		Euro II	43.361	66.418	92.000		
31		Euro III	40.260	59.726	50.800		
32		Euro IV	7.268	10.361	8.400		
33		Euro V	7.388	10.518	8.400		
34		Euro VI	7.388	10.518	8.400		
35	Articulated >40-50t	Conventional	138.057	213.506	186.000		
36		Euro I	105.869	159.248	136.800		
37		Euro II	48.847	75.419	102.800		
38		Euro III	43.404	64.695	55.200		
39		Euro IV	7.641	10.897	8.800		
40		Euro V	7.769	11.063	9.200		
41		Euro VI	7.769	11.063	9.200		
42	Articulated >50-60t	Conventional	164.437	253.778	219.600		
43		Euro I	127.487	192.893	165.600		
44		Euro II	59.763	92.296	124.400		
45		Euro III	51.169	76.666	65.200		
46		Euro IV	8.669	12.341	10.000		
47		Euro V	8.814	12.546	10.400		
48		Euro VI	8.814	12.546	10.400		
49	Gasoline > 3.5 t	Conventional	0.000	0.000	0.000		

Fleet / Circulation / Fuel info / Factors / Uncorrected_eHot / Corrections / Emissions / **Output** / Advance

Figure 4.7: Output sheet

4.7 Output sheet

The Excel Pivot Table offers a flexible adaptable output sheet seen in Figure 4.7. In the default layout provided a user can conveniently select category variable by which the output data is to be summarised. Above are tabs for Vehicle Category and Fuel Type. The pollutant tab allows one to display summary of selected pollutant by road types for specified vehicle categories. Users can easily toggle the pivot table variable headings to obtain desired output summaries.

5 Case Study

Effect of Mean Speed Distributions as Opposed to a Single Average Speed in Copert

5.1 Introduction

Copert relies on various average speed functions to calculate emission factors for regulated pollutants and fuel consumption. Alternative methods of application can be found in tools such as Artemis, HBEFA, and other national models (for example NAEI in the UK, and EMV in Sweden). The average speed methodology has been discussed in chapter two of this report. Here a further discussion on specificity of the average speed dependency is presented by analysing a hypothesised weakness of the approach; Failure to consider spatial and temporal mean speed distribution of national or regional vehicle mileage. The case study is for passenger cars (PC) on the highway network of Flanders.

Emissions are strongly dependent on speed in a non-linear fashion. In the EMEP/EEA 2009 Guidebook (EMEP/EEA, 2009) the speed functions needed to calculate hot emissions are given. The methodology requires selection of a single average speed that represents a particular driving condition distinguished by road types; urban, rural and highway. Below is some of the speed functions used for estimating passenger cars hot exhaust emissions in Copert4.

Table 5.1: Extract examples of passenger car emission factors (EMEP/EEA, 2009)

Fuel type	Legislation	Engine capacity	Speed range	Emission function	Pollutants
Gasoline	ECE 15-00/01	All	10-50 50-130	$313V^{-0.760}$ $27.22 - 0.406V + 0.0032V^2$	CO
Gasoline	Euro 1 and later	All	10-130	$(a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2)$	CO, NOx, VOC, FC
Diesel	Conventional	cc<2.0 l cc>2.0 l	10-130 10-130	$0.918 – 0.014V + 0.000101V^2$ $1.331 – 0.018V + 0.000133V^2$	NOx
Diesel	Euro 1 and later	All (except Euro4 CO)	10-130	$(a + c \times V + e \times V^2)/(1 + b \times V + d \times V^2) + f/V$	CO, VOC NOx, PM FC

V = average speed, “a” to “f” = experimental/test derived parameters for corresponding vehicle type

5.1.1 Limitations of the average speed approach

The effect of using aggregated average speed can be deduced from Table 5.1. Notably one can single out a number of limitations of the aggregated average speed approach. The most relevant limitations to the case study are:

- Driving cycles used in the development of emission functions represent real world driving conditions. However, the real distribution of these driving conditions is not normally taken into account (for example via weightings).

- A change in average speed can be poorly translated into the emission function. If we take the case of NOx emission from a Euro 3 diesel car with a derived emission function like that given by Barlow et al (2001) below.

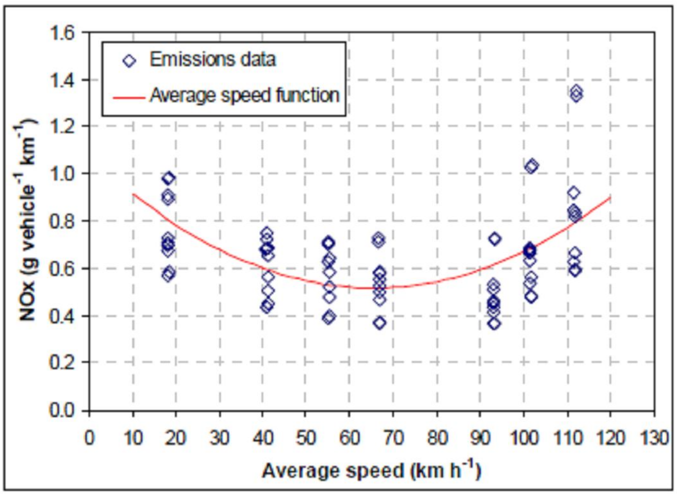


Figure 5.1: Average speed emission function for NOx emissions from Euro 3diesel cars <2.0 litres (Barlow et al., 2001)

An increase in regional average speed from 80 to 90kmh^{-1} (NOx emission increases) may result from the average speed of some links increasing from 30 to 40kmh^{-1} (emission reduces). The approach therefore fails in revealing gains in congestion mitigation and urban traffic management.

- Emission functions are only valid for prescribed speed range. An aggregated average speed may mean there are high proportions of vehicles in links whose emission factors are being calculated with an invalid equation. This can also imply congestion effect is un-proportionately smoothen by free flow links. Findings of Smit et al. (2008) indicates that congestion is indirectly incorporated in average speed functions. However, variability in congestion pattern may not be determined by the average speed approach. An earlier study for an urban network (Brisbane, Australia) indicated that, after traffic activity (expressed as vehicle kilometres travelled), congestion is the most important contributor to predicted total emissions for CO and HC (Smit, 2006). To get more accurate predictions, driving pattern should at least be accounted for by incorporating the spatial and temporal variability in congestion by means of average speed distributions.

Other limitations

Limitations pertaining to effects of vehicle operation and emission function derivation have not been investigated in this report. A summary of such limitations is outlined by the EU-METI Task Force (2009):

- Trips having very different vehicle operational characteristics, and therefore different emission levels, can have the same average speed (termed "cycle dynamics"). The disparity is particularly high when average speed is low (below $50 kmh^{-1}$)
- A large proportion of total emissions of new generation passenger cars occur in small sharp peaks, often during gear changes and high acceleration. The methodology has adopted emission reduction factors with no operational basis for such vehicle categories.

5.1.2 Feasibility and allied studies

Optimising average speed models to use mean speed distribution can be extremely viable. This is because the average speed approach is one of the oldest approaches. The models are very easy to use and data for running the models are easier to collect and compute. It can be easy to generate speed distribution data by treating existing data or at most make minimal corrections to the average speed data collection procedure.

It is unfortunate that there is little published research on the need of average speed distribution adjustments in emission inventories. The EMEP/EEA (2009) Guidebook simply highlights a similar methodology: to define mean speed distribution curves and to integrate over the emission curves.

Some work has been done in testing average speed distributions in urban areas. TNO in the Netherlands did a comparative study in which the effect of mean speed distributions (compared to single mean link speeds) was tested with Copert4 and Versit+ (Smit et al., 2008). Unlike the case of this report data for the TNO study was gotten from a dynamic macroscopic traffic model (Indy) run for Amsterdam network. This certainly is expected to yield detailed input data but not feasible to propose for European wide adaptation any time soon. Generalised findings of the study indicate the magnitude of the speed distribution effect on emissions at network level depends on the pollutant (and for the case, type of model used) and varies between -1% and up to 9%. Trozzi et al. (1996) modified the CORINAIR methodology (Copert) in 1995 to take into account a speed frequency distribution. Here, simulations were run by keeping the average speed constant while different speed distributions are introduced. In the analysis, share of annual mileage driven with specific speed class were the main variables while all other parameters in the emission function are considered constant. Findings also found variable increase in emission by pollutants.

5.2 Methodology

Two emission curves, one with mean speed distributions as input and another with network average speed (conventional methodology) as input, are generated. Analysis on CO, NOx, VOC, and PM emissions resulting from either method is done by comparing outputs. To calculate hot emissions along the highway network of Flanders we refer to the general formula (E_{hot} = $Activity_r$ * e_{hot}) specified in equation (2). Since interest is on emission proportions rather than actual pollutant emission amounts, the Activity statistics on the highway network is given as percentage of vehicle kilometres (VKM) driven by different vehicle categories on the network. Estimation of hot emission factor (e_{hot}) for two principal scenarios results to different emission proportions. One scenario is based on average speed and the other having mean speed distributions per average speed as input. Adjustments on equation (2) for the computation of exhaust emissions are given in equations (6) and (7).

Emission of various pollutants by vehicles of specific technology and fuel type on the highway network is estimated for a number of speed classes. The temporal aggregation of periodic (daily, weekly, monthly or annually) mileage according to the speed class in which the mileage has been done is considered. Thus, the algorithm for the calculation of hot emissions with average speed distribution is given as:

$$E_{hot\ (ijk)} = M_{jk}\ \Big(\sum_{s=1,12} d_{jks} e_{hot(ijks)}\Big) \qquad (5)$$

Where;

$E_{hot\ (ijk)}$ is hot exhaust emission of pollutant i, for vehicle of category k using fuel type j.

M_{jk} is the vehicle or fleet distribution percentage of vehicle kilometres driven in the road network for vehicle category k of fuel type j.

d_{jks} is the periodic mileage share driven on speed class s by vehicle technology k and fuel type j.

$e_{hot(ijks)}$ is the hot emission factor (g/km) for pollutant i of vehicle category k and fuel j in speed class s.

It must be noted that the proportionality constant of vehicle class, M, is an integral factor for emission (E_{hot}) calculation. In this regard equation (5) can simply be rewritten as:

$$E_{hot\ (icv)} = \sum d_{sc} E_{hot(is)} \qquad (6)$$

Where;

$E_{hot(icv)}$ is total hot exhaust emission by speed distribution into c classes, of pollutant i, in a temporal and spatial network resolution having vehicle average speed v.

d_{sc} is the periodic mileage share driven on mean speed s, when mean speed is distributed into c classes

$E_{hot(is)}$ is hot emission of pollutant i, for vehicle on mean speed s.

For emission estimation based on a single average speed for the entire network (conventional Copert methodology) equation (5) is reduced to equation (7) below:

$$E_{hot\ (iv)} = M_{jk} * e_{hot(i)} \qquad (7)$$

It computes a single hot emission factor (e_{hot}) for pollutant i, with the average speed a, as input.

5.3 Data Collection

Analysis based on the entire passenger car population in Flanders is done. Data for activity statistics M (category of passenger car proportions), and vehicle operation (speed) are used.

Test Network

The test network covers highways in the whole of Flanders and the E19 link connecting Brussels and Antwerp (shown in Figure 5.2). Two cases have been chosen so the test effect on network aggregation can be appreciated.

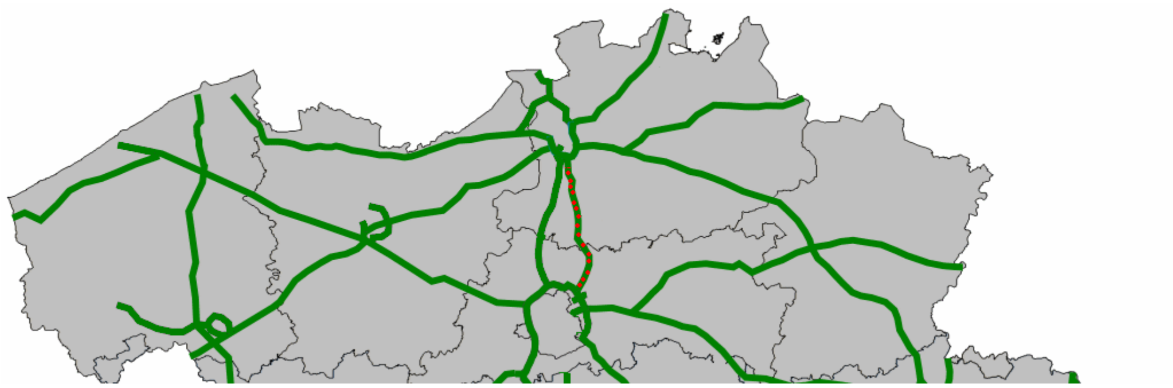


Figure 5.2: Map of Flanders highway network. E19 Brussels-Antwerp link is dotted.

PC Vehicle distribution (M)

As activity data, a fleet composition of passenger cars (PC) in Flanders expressed as a percentage of vehicle category contribution to annual vehicle kilometre (VKM) travelled on the road network is derived by TREMOVE (De Ceuster et al., 2005). The distribution is plotted in Figure 5.3a whereas the data can be consulted in Annexe B. Copert only has emission functions for cc < 2.0l for diesel passenger, so proportions of engine capacities cc <1.4l and 1.4-2.0l are added together.

The vehicle distribution input data goes into the VKM column of the Fleet sheet in Copert in Excel. Pertaining to the fact that we do not want to estimate total emission, but the network average emission factor, vehicle population is not relevant and as such is simply set to one to nullify the effect of the column.

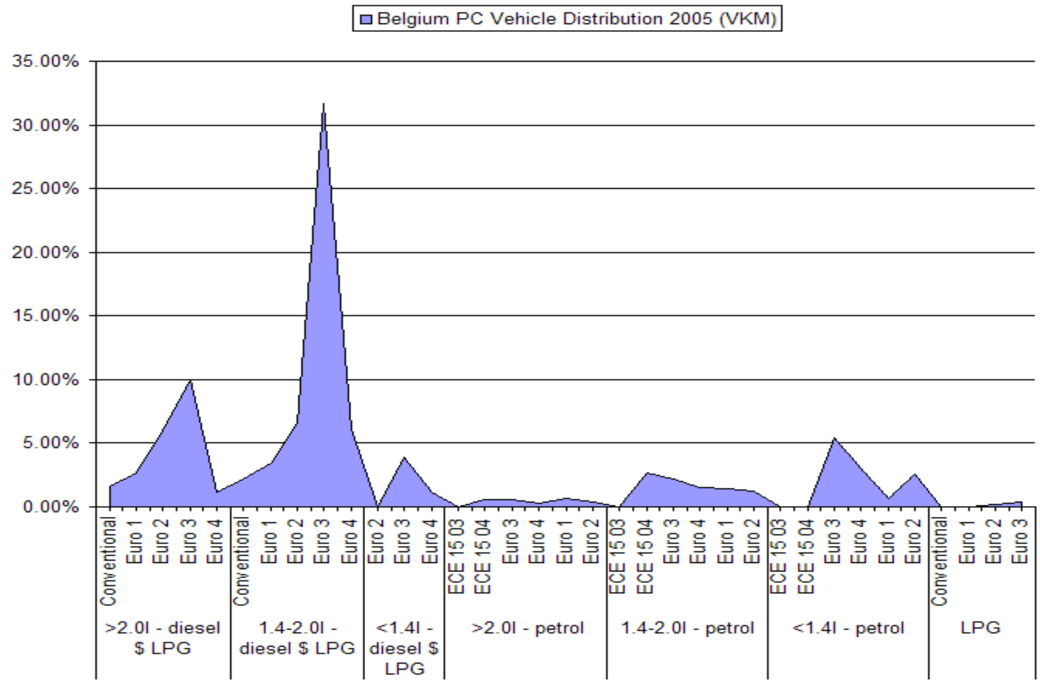


Figure 5.3a: Passenger car distribution in Flanders, 2005. (Data source: De Ceuster et al., 2005)

Average speed (v) and mean speed distribution (s)

A distribution of hourly average speeds over the network is given in passenger vehicle kilometres (VKM). The data establishes a relationship between network average speed and speed class distribution in terms of VKM. In preparing this data, we are able to identify a reasonable range of network average speeds and their corresponding speed distribution profiles.

Data from single loop detectors on the Flemish motorway network in 2007 has been processed by Sven Maerivoet (2010). A summary of the methodology for data collection and processing comprises:

- Collection of hourly mean speed recorded from over 1600 loops detectors along the motorways. We also take the difference between passenger cars and trucks into account, as explained in Sven Maerivoet (2006). All data is stored in the START-SITTER system by the Federale Overheidsdienst Mobiliteit en Vervoer (FOD); it is from this system that we extracted and processed the traffic measurements. The aggregation is two-fold: on the one hand we temporally aggregate all measurements within each hour of the day, on the other hand we spatially aggregate all the measurements from the different loop detectors.

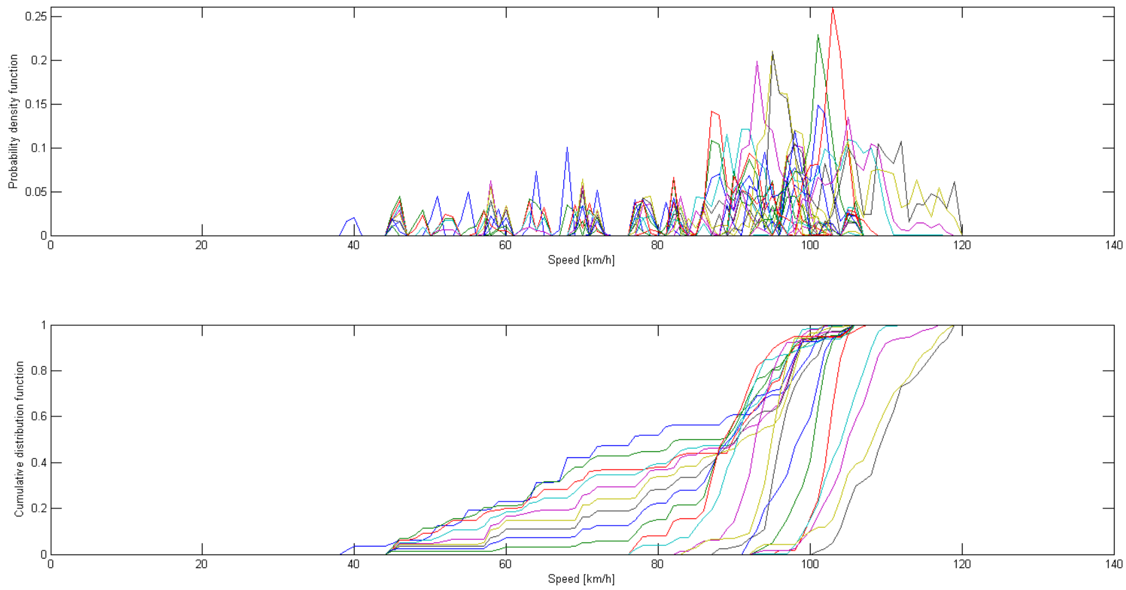


Figure 5.3b: Probability density and cumulative speed distribution functions. Data for Monday 5th March 2007; E19 between Brussels and Antwerp (Maerivoets, 2010)

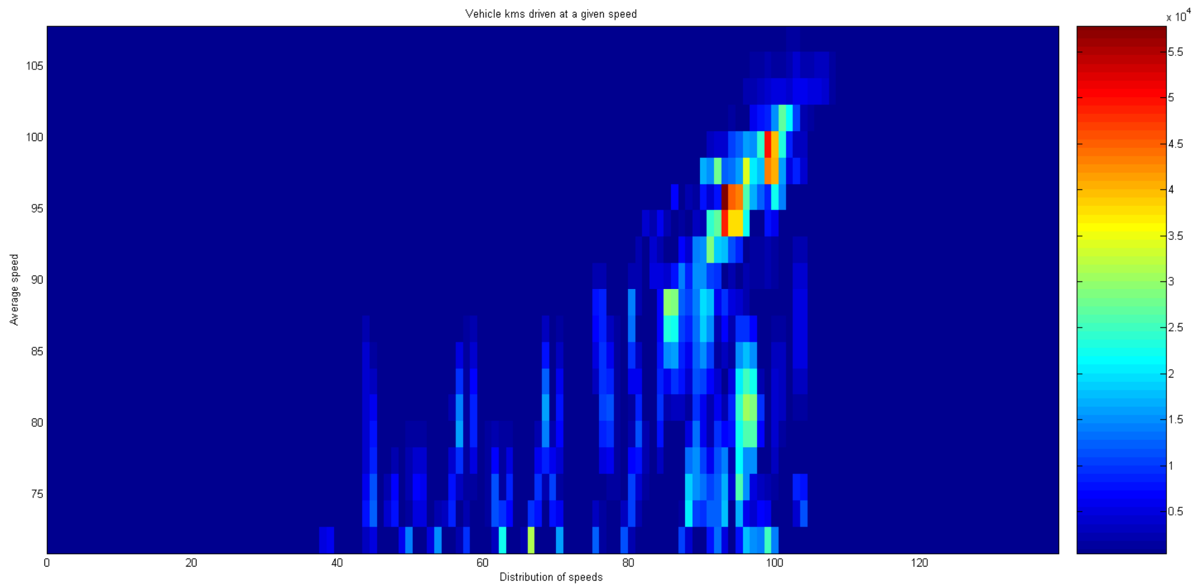


Figure 5.3c: Speed distribution densities per average speed category. Data for Monday 5th March 2007; E19 between Brussels and Antwerp (Maerivoets, 2010)

The associated number of vehicle kilometres driven per mean speed is also collected. This results in a number of vehicle kilometres and a single mean speed for each hour of the day. From these, a network average speed in kilometre per hour is derived.

- The aforementioned procedure can furthermore be done for different periods, say a particular day of the week, weekly, monthly or annually. In this way an analysis based on different temporal aggregations can be performed. Meanwhile, in order to demonstrate the effect of spatial aggregation we also prepared speed distributions for a single link (a section of the E19 connecting Brussels and Antwerp).
- Data cleaning and organisation is also necessary. To this end, data for various periods is binned and extrapolated into a matrix of 21 average speed categories each having 140 mean speed distributions. Zero speeds and statistical outliers were automatically removed.

A sample of the mean speed distribution by vehicle kilometres for various average speeds is shown in Figure 5.3b and 5.3c above. The data is for the E19 motorway stretch between Brussels and Antwerp collected on Monday 5th March 2007.

5.4 Data Processing

Data processing and computation has mainly been done on a spreadsheet. The file (*data_output* in *Case Study* folder) is included in the accompanying CD for the purpose of evaluating this paper. The file is stored in the case study folder alongside a configured copy of Copert in Excel named Flanders_Hot_Emissions.xls. However a detail explanation of the methodology has been given in this chapter. In the following subsection, techniques for computation and underlying assumptions are given.

Speed classes

In the *speed_distribution* sheet of *data_output.xls* file, data is decomposed into two matrixes, one holding mean speed distributions whilst the other is vehicle kilometres. Matrix column headings are the average speed whilst row headings are the speed classes. Data has been processed into three different speed configurations. These have been termed Case 1, Case 2, and Case 3 according to the spacing of the mean speed range.

Table 5.2: A Case 1 matrix of relative mean speeds for 13 speed classes and 21 average speed situations. Data of Flanders motorway network on Monday 5th of March 2007.

Ave speed	Mean speed distribution (10s)												
	10--19	20--29	30--39	40--49	50--59	60--69	70--79	80--89	90--99	100-109	110-119	120-129	130-139
79.2	16.2659	28.14401	3.60E+01	4.68E+01	5.50E+01	6.62E+01	7.59E+01	8.81E+01	9.43E+01	1.03E+02	1.16E+02	1.25E+02	1.35E+02
80.4	16.2659	26.16386	3.73E+01	4.64E+01	5.54E+01	6.56E+01	7.61E+01	8.58E+01	9.55E+01	1.02E+02	1.11E+02	1.24E+02	1.35E+02
81.5	16.2659	25.0821	3.76E+01	4.62E+01	5.56E+01	6.55E+01	7.58E+01	8.61E+01	9.52E+01	1.01E+02	1.11E+02	1.24E+02	1.35E+02
82.7	16.2659	23.72635	3.79E+01	4.60E+01	5.57E+01	6.55E+01	7.55E+01	8.64E+01	9.48E+01	1.01E+02	1.11E+02	1.24E+02	1.35E+02
83.8	16.2659	24.7362	3.79E+01	4.58E+01	5.59E+01	6.55E+01	7.52E+01	8.67E+01	9.44E+01	1.01E+02	1.11E+02	1.24E+02	1.35E+02
84.9	16.2659	25.80177	3.78E+01	4.54E+01	5.57E+01	6.58E+01	7.50E+01	8.69E+01	9.40E+01	1.02E+02	1.17E+02	1.25E+02	1.35E+02
86.1	16.2659	24.7563	3.76E+01	4.56E+01	5.62E+01	6.60E+01	7.62E+01	8.71E+01	9.36E+01	1.02E+02	1.17E+02	1.25E+02	1.35E+02
87.2	16.2659	26.1241	3.81E+01	4.58E+01	5.59E+01	6.64E+01	7.66E+01	8.71E+01	9.31E+01	1.03E+02	1.11E+02	1.29E+02	1.35E+02
88.3	16.2659	26.1241	3.84E+01	4.58E+01	5.53E+01	6.66E+01	7.68E+01	8.67E+01	9.33E+01	1.03E+02	1.11E+02	1.29E+02	1.35E+02
89.5	16.2659	26.1241	3.87E+01	4.58E+01	5.37E+01	6.69E+01	7.83E+01	8.62E+01	9.37E+01	1.03E+02	1.11E+02	1.29E+02	1.38E+02
90.6	16.2659	26.1241	3.79E+01	4.58E+01	5.40E+01	6.83E+01	7.76E+01	8.62E+01	9.46E+01	1.04E+02	1.12E+02	1.29E+02	1.38E+02
91.8	16.2659	26.1241	3.75E+01	4.58E+01	5.90E+01	6.52E+01	7.90E+01	8.86E+01	9.29E+01	1.03E+02	1.12E+02	1.25E+02	1.38E+02
92.9	16.2659	26.1241	3.60E+01	4.58E+01	5.57E+01	6.56E+01	7.35E+01	8.89E+01	9.34E+01	1.03E+02	1.11E+02	1.25E+02	1.35E+02
94.0	16.2659	30.11721	4.04E+01	4.73E+01	5.63E+01	6.86E+01	7.60E+01	8.69E+01	9.54E+01	1.02E+02	1.11E+02	1.25E+02	1.35E+02
95.2	16.2659	26.1241	3.29E+01	4.24E+01	5.57E+01	6.46E+01	7.54E+01	8.77E+01	9.57E+01	1.02E+02	1.13E+02	1.21E+02	1.35E+02
96.3	16.2659	26.1241	3.60E+01	4.18E+01	5.13E+01	6.33E+01	7.75E+01	8.63E+01	9.64E+01	1.02E+02	1.14E+02	1.22E+02	1.37E+02
97.4	16.2659	26.1241	3.60E+01	5.03E+01	5.13E+01	6.56E+01	7.80E+01	8.68E+01	9.68E+01	1.02E+02	1.11E+02	1.29E+02	1.37E+02
98.6	16.2659	26.1241	3.60E+01	4.58E+01	5.57E+01	6.70E+01	7.10E+01	8.80E+01	9.61E+01	1.03E+02	1.11E+02	1.25E+02	1.34E+02
99.7	16.2659	26.1241	3.60E+01	4.58E+01	5.57E+01	6.56E+01	7.24E+01	8.72E+01	9.58E+01	1.04E+02	1.13E+02	1.23E+02	1.32E+02
100.9	16.2659	26.1241	3.60E+01	4.58E+01	5.57E+01	7.00E+01	7.51E+01	8.73E+01	9.57E+01	1.04E+02	1.13E+02	1.23E+02	1.36E+02
102.0	16.2659	26.1241	3.60E+01	4.58E+01	5.57E+01	7.00E+01	7.40E+01	8.82E+01	9.68E+01	1.04E+02	1.13E+02	1.23E+02	1.37E+02

Case 1: The first case has data classed into 13 speed levels, ranging from 10-19, 20-29,... 130-139. This is the lowest level of aggregation that seeks to vividly portray the effect of variations in driving pattern.

Case 2: Here there are 7 speed classes ranging from 10-29, 30-49,... 110-129, 130-139.

Case 3: At this high aggregation level, data is simply grouped into 3 speed classes ranging from 10-49, 50-89, and 90-139.

Each case is handled separately as can be differentiated by shadings in the spreadsheet. We must compute new mean speed for each of the speed classes. A less reliable method is by choosing an absolute value, which will be the central value of the speed class. This does not consider the spread of vehicle kilometres driven under mean speed type. To be more realistic, relative mean speeds need to be calculated. The algorithm for mean speed calculation is shown in equation (8).

$$S_{vr} = \sum_{1,n} s_{vrn} * m_{vrn} \;/\; \sum_{1,n} s_{vrn} \qquad (8)$$

Where

S_{vr} is mean speed of vehicle kilometres driven on speed range r during the overall temporal and spatial consideration having average speed v.

n is the speed distribution levels in speed range r.

s_{vrn} is the ‘point’ mean speed at speed distribution level n, belonging to speed range r, and global average speed v.

m_{vrn} is the ‘point’ mileage driven at speed distribution level n, belonging to speed range r, and global average speed v.

Table5.3: A Case 1 matrix of vehicle kilometres driven on 13 speed classes and 21 average speed situations. Data of Flanders motorway network on Monday 5th of March 2007.

Ave speed	VKM proportions per speed class												
	10--19	20--29	30--39	40--49	50--59	60--69	70--79	80--89	90--99	100-109	110-119	120-129	130-139
79.2	0.00000	0.01508	0.02373	0.04923	0.04956	0.05507	0.04546	0.07520	0.66879	0.01787	0.00001	0.00000	0.00000
80.4	0.00000	0.01300	0.01944	0.04526	0.05835	0.05355	0.04115	0.06031	0.66241	0.04534	0.00119	0.00001	0.00000
81.5	0.00000	0.00839	0.01885	0.03812	0.05058	0.05067	0.04323	0.07244	0.67506	0.04142	0.00123	0.00001	0.00000
82.7	0.00000	0.00519	0.01851	0.03004	0.04280	0.04679	0.04520	0.08578	0.68612	0.03852	0.00105	0.00001	0.00000
83.8	0.00000	0.00585	0.02026	0.02002	0.03442	0.04243	0.04712	0.09901	0.69169	0.03864	0.00055	0.00001	0.00000
84.9	0.00000	0.00718	0.02178	0.00986	0.02519	0.03594	0.05106	0.11876	0.69321	0.03701	0.00001	0.00000	0.00000
86.1	0.00000	0.00432	0.01426	0.00812	0.01888	0.03123	0.07939	0.30141	0.52845	0.01395	0.00000	0.00000	0.00000
87.2	0.00000	0.00000	0.00406	0.00000	0.02600	0.02367	0.08290	0.42864	0.42318	0.01137	0.00017	0.00003	0.00000
88.3	0.00000	0.00000	0.00471	0.00000	0.01700	0.01799	0.04942	0.47423	0.41935	0.01635	0.00087	0.00009	0.00000
89.5	0.00000	0.00000	0.00192	0.00000	0.00205	0.01214	0.02028	0.51390	0.41456	0.03330	0.00164	0.00015	0.00005
90.6	0.00000	0.00000	0.00291	0.00000	0.00797	0.00880	0.02511	0.40248	0.46345	0.08649	0.00240	0.00008	0.00032
91.8	0.00000	0.00000	0.00007	0.00000	0.00200	0.00785	0.01143	0.22893	0.73906	0.01062	0.00003	0.00000	0.00001
92.9	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00170	0.24077	0.73597	0.02155	0.00001	0.00000	0.00000
94.0	0.00000	0.00043	0.00018	0.00620	0.00408	0.01199	0.01287	0.05946	0.83927	0.06353	0.00199	0.00000	0.00000
95.2	0.00000	0.00000	0.00021	0.00065	0.00000	0.01322	0.00000	0.04809	0.82005	0.11723	0.00054	0.00001	0.00000
96.3	0.00000	0.00000	0.00000	0.00362	0.00038	0.02529	0.00320	0.04707	0.71563	0.19644	0.00594	0.00111	0.00132
97.4	0.00000	0.00000	0.00000	0.00006	0.00006	0.00000	0.01375	0.03731	0.74268	0.20068	0.00523	0.00002	0.00022
98.6	0.00000	0.00000	0.00000	0.00000	0.00000	0.01805	0.00008	0.03257	0.48391	0.45675	0.00764	0.00068	0.00032
99.7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02116	0.01746	0.43097	0.49653	0.03261	0.00115	0.00012
100.9	0.00000	0.00000	0.00000	0.00000	0.00000	0.00229	0.01228	0.02510	0.33924	0.52705	0.08227	0.00866	0.00310
102.0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00471	0.02124	0.01411	0.29865	0.55141	0.09687	0.00819	0.00482

Simple summation is employed to derive the second set of matrix (example table 5.3) by adding vehicle kilometres driven under a particular average speed category per speed class. The values (VKM) are weights for estimating emission proportions per speed class. These and associated mean speeds are the main inputs for iterations to compute hot emissions by mean speed distribution. A sheet (*output*) is used to enter the data in columns for easy processing.

5.5 Emission Calculations

Copert in Excel is the tool used to calculate emission of various pollutants. Emission of four regulated pollutants (CO, NOx, VOC, and PM) are calculated and analysed in this study. Computation has been done by introducing the fleet distribution by proportions (percentage of total VKM) of vehicle type in circulation, and either the mileage share by speed class (d proportions) or simply the network average speed as input data into Copert in Excel. Fleet composition is assumed fixed during the entire study period, which is normal for all emission inventory methodologies. Vehicle kilometres are entered via the *Fleet* sheet whereas highway average speeds (and mean speed of distributions) are entered by iteration into the *Circulation* sheet. Speed input and emission output for each iteration have been exported to a separate Excel Workbook titled *data_output*. Details of entering data and making corrections in Copert in Excel are dealt with in Chapter 4 of this report.

The output sheet seen in Figure 5.4 organises and computes data. This file is linked with Copert in Excel such that it can be automated to supply input to and record output from Copert in Excel. The iterative process is not exactly the same since speed input are different per iterations.
For each speed class as in Figure 5.4, absolute emission of studied pollutants is calculated by entering a corresponding speed in the ‘speed distribution’ column and stored under the ‘eHot (absolute)’. This output imply total vehicle kilometres per average speed (V) category (of spatial and temporal aggregation) has been driven at the specified mean speed (S), which is certainly not correct. We therefore apply weights of vehicle kilometres driven per speed class given in the 4th column of Figure5.4 (see equation (6)). The resulting hot emission distributions when average speed (V) is as in column 2 are added together and stored as ∑(eHot distribution). This is our hot emission for pollutant i when mean speed distribution (S) rather than average speed (V) is used as input of Copert average emission functions.

Emissions based on a single average speed (stored as Average eHot in the *output* sheet) is compared with the case of mean speed distribution by charts and deviation calculations.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1															
2					Pollutant: CO					Pollutant: NOx					Pollutant:
3	Speed clas	Average speed	Speed distribut	Weights (VKM)	eHot (absolute)	eHot distribution	∑(eHot distributi	Average eHot		eHot (absolute	eHot distributior	∑(eHot distrib	Average eHot		eHot (abs
4	10--19	**83.9**	17.5	0.002949824	1.265	0.003731856	0.465380526	0.417		0.835	0.002463696	0.662061252	0.619		0.172
5	20--29		26.8	0.008701568	0.897	0.00780511				0.711	0.006186465				0.126
6	30--39		36.3	0.021675179	0.710	0.015381674				0.641	0.013896536				0.100
7	40--49		46.0	0.026902249	0.590	0.015860167				0.602	0.016190309				0.083
8	50--59		55.7	0.028835514	0.510	0.01469872				0.584	0.016836758				0.071
9	60--69		65.7	0.03359348	0.439	0.014758445				0.583	0.019571289				0.059
10	70--79		75.8	0.026481306	0.417	0.011041215				0.597	0.015811299				0.053
11	80--89		86.7	0.059403238	0.420	0.024973784				0.630	0.037395298				0.048
12	90--99		95.6	0.735007527	0.448	0.329244019				0.671	0.493148445				0.046
13	100-109		102.2	0.054363052	0.487	0.026475336				0.713	0.03876198				0.046
14	110-119		113.3	0.001689399	0.608	0.001027118				0.817	0.001379847				0.047
15	120-129		124.0	0.000276305	0.866	0.000239351				0.996	0.000275256				0.051
16	130-139		136.3	0.00012136	1.184	0.00014373				1.187	0.000144074				0.056
17	10--19	**84.8**	18.4	0.000981958	1.220	0.001198114	0.45534505	0.418		0.819	0.000804493	0.654827358	0.622		0.166
18	20--29		27.2	0.009032965	0.887	0.00801337				0.707	0.006388368				0.125
19	30--39		36.3	0.013731636	0.709	0.009737685				0.641	0.008801257				0.100
20	40--49		46.4	0.020742512	0.586	0.012147036				0.601	0.012460291				0.083
21	50--59		56.0	0.029567172	0.508	0.015025006				0.584	0.017257416				0.071
22	60--69		65.7	0.036286212	0.439	0.015939087				0.583	0.02114054				0.059
23	70--79		75.4	0.038682021	0.417	0.016146991				0.596	0.0230593				0.053
24	80--89		87.0	0.096513886	0.421	0.040629597				0.631	0.060873886				0.048
25	90--99		94.6	0.719517082	0.444	0.319162927				0.666	0.478860838				0.046
26	100-109		102.4	0.033618164	0.488	0.016420935				0.714	0.024018052				0.046
27	110-119		113.6	0.000988104	0.612	0.000604923				0.820	0.000810288				0.047
28	120-129		123.5	0.000240132	0.846	0.000203131				0.983	0.0002361				0.051
29	130-139		134.5	9.81557E-05	1.184	0.000116249				1.187	0.000116527				0.056
30	10--19	**85.6**	18.5	0.000929276	1.217	0.001131171	0.454019381	0.419		0.818	0.000760381	0.655681804	0.625		0.166
31	20--29		27.0	0.008085124	0.891	0.007205473				0.709	0.005730511				0.125
32	30--39		36.3	0.011929702	0.708	0.008452026				0.641	0.007643519				0.100
33	40--49		46.3	0.018588207	0.586	0.010892652				0.601	0.011168183				0.083
34	50--59		56.0	0.026580093	0.508	0.013508686				0.584	0.015514176				0.071
35	60--69		65.8	0.032936913	0.439	0.01446027				0.583	0.019190822				0.059
36	70--79		75.5	0.036433068	0.417	0.015204638				0.596	0.021725296				0.053
37	80--89		87.0	0.091881859	0.421	0.03867396				0.631	0.05794025				0.048
38	90--99		94.5	0.736329832	0.443	0.326449855				0.665	0.48983366				0.046
39	100-109		102.3	0.034809429	0.488	0.016995776				0.714	0.024862251				0.046
40	110-119		113.5	0.001134381	0.612	0.000694107				0.820	0.000929959				0.047
41	120-129		123.4	0.000228817	0.843	0.000192897				0.981	0.000224549				0.051
42	130-139		135.5	0.000133299	1.184	0.00015787				1.187	0.000158249				0.056

speed_distribution / output / analysis

Ready

Figure 5.4: Sheet for organising and processing emission calculations. Source: *Output* sheet of *data_output* file used for case study analysis (file in CD)

Iterative Procedure

A total of 21 average speeds are available input for computing emissions by average speed. The more difficult task of manual processing is for the case of mean speed distributions. Considering the three speed ranges (Case 1, 2, & 3) one would have to compute 483 mean speeds and record emissions of all pollutants each of the time. Since a variety of temporal component of data has to be tested it can take an extreme lot of time to do this manually. Besides, entering and copying data is prone to errors due to fatigue and boredom.

Looping in excel has been resorted to create a macro (macro in *data_ouput* file) that reads speeds input from, and writes emission output into the *output* sheet. Mainly a 'for… with' loop is used. Within the loop an 'if… then…' condition is added to reduce the time needed for a run by avoiding going through the steps when there is no data (speed) in the speed cell. With this, the run time of the average_speed macro was reduced from about 3minutes to 1/2minute.

The procedure reads speed input from the processing file (*data_output*) into Copert in Excel. Then refreshes and copy output from Copert in Excel, and then paste the result accordingly into the *data_output* file. Emission output for each of CO, NOx, VOC and PM are copied one after the other. The macro for computing emissions by mean speed distributions is shown in Annexe C-1. A similar but separate macro that uses the average speed as input has been included as Annexe C-2. Copert in excel must also be open for the macros to run.

5.6 Results and Analysis

Results of emission calculations are presented according to the various pollutants. This is because emission functions or at least their parameters are pollutant dependent. The emission output includes 3 mean speed distribution levels considered as Case 1, 2, and 3 per data set. Later, an analysis based on spatial and temporal resolution of data set is presented. Analyses are based on the assumption that the speed distribution approach predicts emissions that are closer to reality.

Average speed data has been collected and presented on an per hour basis. To properly reflect emissions for the period considered one has to consider the relative contribution of each average speed category to total emissions. In this way, a cumulative deviation will show the overall effect (advantage) of using mean speed distributions over a single average speed per period.

5.6.1 Results

Tables and figures shown in this section are mostly for one of the test, referring to the data of speed distribution on the highway network of Flanders for Monday 5th March 2007. Results of all tests carried out are given in Annexe D whilst also included in the analysis subsection.

The tables (for example Table 5.4 to 5.7) of each pollutant show hourly average speeds and their corresponding hot emission (eHot) in the first and second columns respectively. Corresponding tables per dataset for other spatial (Flanders or E19-BA) and temporal (day, day of week, month) resolutions are stored in the *results* file.

Cases (1,2,3) hot emissions, calculated with speed distribution as input, in group columns per case are compared against the average speed emissions. Hourly increase in emissions estimate due to the application of the speed distribution approach is recorded as positive percentages in the *deviation* column, while a negative percentage represents the degree to which the emission estimates decrease.

The column of *weighted deviation* indicates hourly contributions to the overall periodic deviation in emissions. The measure is quantified relative to the vehicle kilometres per hour having corresponding average speeds. Weights are therefore a sum of vehicle kilometres per average speed category divided by the total vehicle kilometres covered in the period. For clarity, weights for all datasets can be consulted in the *results.xls* file.

Carbon monoxide (CO)

Table 5.4 shows that CO emission prediction by mean speed distribution clearly deviates from average speed predictions. The average speed approach underestimates emissions the highest when network average speeds are below 85km/h. Up to 12% absolute deviation occurs when network average speed is 80km/h (based on Monday 5th March 2007 dataset). At higher average speeds, above 95Km/h, the effect is not very substantial. Indeed the trend clearly shows that deviations are average speed dependent for all cases tested (spatially, temporally and by speed range).

In relative terms, there is an overall cumulative deviation of over 5%. The best estimator of CO emissions is by Case1 where 13 speed classes are used. However the difference may not be significant for either the 7 or 3 speed classes used in Case 2 and Case 3 respectively. The gaps are graphically depicted by Figure 5.5. Variations by spatial and temporal effects have been looked into in a following subsection.

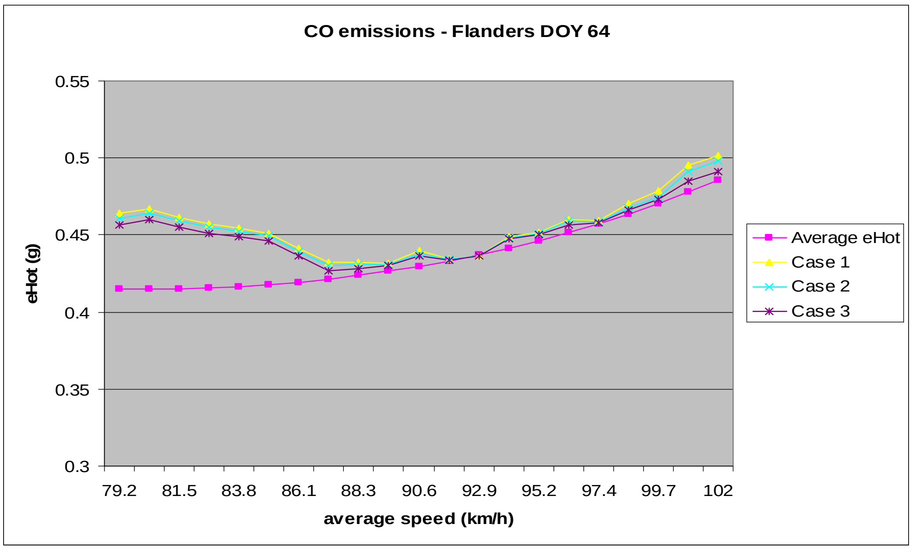


Figure 5.5: Average speed versus mean speed distribution estimates of passenger cars NOx emission on the Flanders highway network (Monday 5th March 2007).

Table 5.4: CO emission of passenger cars on the Flanders highway network on Monday 5th March 2007

CO		Case 1			Case 2			Case 3		
Average speed	Average eHot	Case 1 eHot	deviation	weighted deviation	Case 2 eHot	deviation	weighted deviation	Case 3 eHot	deviation	weighted deviation
79.244	0.414814	0.463827	11.8%	0.009303	0.460939	11.1%	0.9%	0.45649	10.0%	0.8%
80.381	0.41474	0.466768	12.5%	0.00965	0.46415	11.9%	0.9%	0.459862	10.9%	0.8%
81.518	0.41499	0.461682	11.3%	0.008371	0.459278	10.7%	0.8%	0.455218	9.7%	0.7%
82.656	0.415571	0.457032	10.0%	0.007149	0.45481	9.4%	0.7%	0.451008	8.5%	0.6%
83.793	0.416488	0.454161	9.0%	0.00626	0.452074	8.5%	0.6%	0.448561	7.7%	0.5%
84.93	0.417749	0.451222	8.0%	0.005282	0.449288	7.5%	0.5%	0.446224	6.8%	0.4%
86.068	0.419363	0.441197	5.2%	0.003029	0.439353	4.8%	0.3%	0.436222	4.0%	0.2%
87.205	0.421335	0.432338	2.6%	0.001284	0.430351	2.1%	0.1%	0.426997	1.3%	0.1%
88.342	0.423676	0.432158	2.0%	0.000699	0.430731	1.7%	0.1%	0.428171	1.1%	0.0%
89.48	0.426399	0.431666	1.2%	0.000272	0.430836	1.0%	0.0%	0.429909	0.8%	0.0%
90.617	0.429511	0.439839	2.4%	0.000285	0.438088	2.0%	0.0%	0.436592	1.6%	0.0%
91.755	0.433029	0.434448	0.3%	0.000184	0.434062	0.2%	0.0%	0.433353	0.1%	0.0%
92.892	0.436962	0.436564	-0.1%	-5.4E-05	0.436171	-0.2%	0.0%	0.436171	-0.2%	0.0%
94.029	0.441327	0.449201	1.8%	0.001425	0.448345	1.6%	0.1%	0.447591	1.4%	0.1%
95.167	0.446146	0.451791	1.3%	0.000898	0.450912	1.1%	0.1%	0.450188	0.9%	0.1%
96.304	0.451429	0.460128	1.9%	0.000518	0.45897	1.7%	0.0%	0.456662	1.2%	0.0%
97.441	0.457201	0.459489	0.5%	0.000226	0.458459	0.3%	0.0%	0.458091	0.2%	0.0%
98.579	0.463489	0.47018	1.4%	0.00033	0.467701	0.9%	0.0%	0.46652	0.7%	0.0%
99.716	0.470309	0.478382	1.7%	0.000197	0.474805	1.0%	0.0%	0.473174	0.6%	0.0%
100.85	0.477675	0.495299	3.7%	0.0%	0.491163	2.8%	0.0%	0.485009	1.5%	0.0%
101.99	0.485677	0.501207	3.2%	0.000248	0.497892	2.5%	0.0%	0.491175	1.1%	0.0%
		Cumulative deviation		5.6%			5.2%			4.6%

Nitrates (NOx)

A high of 7% emission deviation can be experienced when speeds are below 85km/h. The lowest deviations occur between 85 and 100 kilometres per hour. Difference amongst speed range is not substantial. A 10km/h speed range yield very close emission results compared to the 20KM/h and 40km/h speed distribution ranges. Figure 5.6 show a similar trend in all three cases. The most detailed case (Case1) is generally the best estimator of NOx emissions. In all we can yet establish that deviations are average speed dependent.

Cumulative deviation of NOx emission for a particular Monday in Flanders is shown in Table 5.5. Overall cumulative deviations based on different levels of aggregation range from -0.1% (a free-flow Sunday) to 4.3% (a congested Monday).

Table 5.5: NOx emission of passenger cars on the Flanders highway network on Monday 5th March 2007

NOx		Case 1			Case 2			Case 3		
Average speed	Average eHot	Case 1 eHot	deviation	weighted deviation	Case 2 eHot	deviation	Weighted deviation	Case 3 eHot	deviation	weighted deviation
79.244	0.605317	0.648439	7.1%	0.56%	0.647436	7.0%	0.55%	0.644858	6.5%	0.51%
80.381	0.608445	0.653719	7.4%	0.57%	0.652971	7.3%	0.56%	0.650538	6.9%	0.53%
81.518	0.61177	0.653027	6.7%	0.50%	0.652294	6.6%	0.49%	0.649956	6.2%	0.46%
82.656	0.615298	0.652427	6.0%	0.43%	0.651692	5.9%	0.42%	0.649477	5.6%	0.40%
83.793	0.619028	0.652004	5.3%	0.37%	0.651231	5.2%	0.36%	0.64918	4.9%	0.34%
84.93	0.622966	0.65145	4.6%	0.30%	0.65064	4.4%	0.29%	0.64885	4.2%	0.27%
86.068	0.627121	0.64298	2.5%	0.15%	0.642134	2.4%	0.14%	0.640285	2.1%	0.12%
87.205	0.631489	0.638466	1.1%	0.05%	0.637621	1.0%	0.05%	0.635569	0.6%	0.03%
88.342	0.636081	0.640306	0.7%	0.02%	0.639682	0.6%	0.02%	0.638118	0.3%	0.01%
89.48	0.640907	0.643671	0.4%	0.01%	0.643202	0.4%	0.01%	0.642639	0.3%	0.01%
90.617	0.645966	0.652868	1.1%	0.01%	0.651927	0.9%	0.01%	0.65103	0.8%	0.01%
91.755	0.651273	0.651505	0.0%	0.00%	0.651298	0.0%	0.00%	0.650865	-0.1%	0.00%
92.892	0.656828	0.655419	-0.2%	-0.01%	0.655182	-0.3%	-0.01%	0.655181	-0.3%	-0.01%
94.029	0.662645	0.668055	0.8%	0.07%	0.667594	0.7%	0.06%	0.667137	0.7%	0.05%
95.167	0.66874	0.6733	0.7%	0.05%	0.67277	0.6%	0.04%	0.672327	0.5%	0.04%
96.304	0.675112	0.679799	0.7%	0.02%	0.679109	0.6%	0.02%	0.677767	0.4%	0.01%
97.441	0.681779	0.68279	0.1%	0.01%	0.682168	0.1%	0.00%	0.681958	0.0%	0.00%
98.579	0.688762	0.692803	0.6%	0.01%	0.691313	0.4%	0.01%	0.69061	0.3%	0.01%
99.716	0.696064	0.700873	0.7%	0.01%	0.698718	0.4%	0.00%	0.69775	0.2%	0.00%
100.85	0.703686	0.715937	1.7%	0.01%	0.713478	1.4%	0.01%	0.709946	0.9%	0.01%
101.99	0.711708	0.721227	1.3%	0.01%	0.71926	1.1%	0.01%	0.715472	0.5%	0.00%
		cumulative deviation		3.2%			3.0%			2.8%

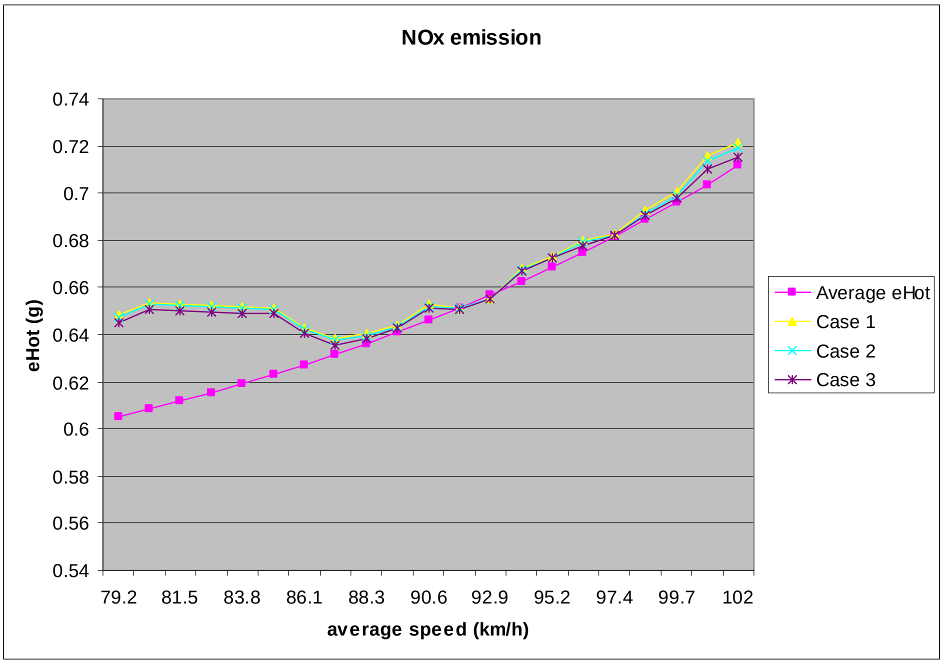


Figure 5.6: Average speed versus mean speed distribution estimates of passenger cars NOx emission on the Flanders highway network (Monday 5th March 2007).

Volatile Organic Compounds (VOC)

Unlike other pollutants, VOC has a decreasing emission curve at higher speeds. This is because a very high proportion of hydrocarbon emission is associated to cold start, the reason why VOC hot emission factors are very low. The Copert emission functions therefore assume improved fuel (hydrocarbon) combustion at higher speeds.

Hydrocarbons do not show high deviations compared to other pollutants. Only in congested situations where global average speeds are below 80km/h that we experience above 3% deviations. The highest VOCs emission deviations in such situations range between 2.7 % and 3.9%.

The trends in levels of speed aggregation shown in Figure 5.7 are similar. Although to obtain any significant improvement it is vital to opt for Case 1 with cumulative gains ranging from 0.2% to 2.5%

Table 5.6: VOC emission of passenger cars on the Flanders highway network on Monday 5th March 2007

VOC		Case 1			Case 2			Case 3		
Average speed	Average eHot	Case 1 eHot	deviation	weighted deviation	Case 2 eHot	deviation	weighted deviation	Case 3 eHot	deviation	weighted deviation
79.244	0.050983	0.052815	3.6%	0.28%	0.052521	3.0%	0.24%	0.052049	2.1%	0.16%
80.381	0.050462	0.05242	3.9%	0.30%	0.052154	3.4%	0.26%	0.051685	2.4%	0.19%
81.518	0.049968	0.051605	3.3%	0.24%	0.051364	2.8%	0.21%	0.050931	1.9%	0.14%
82.656	0.049501	0.05086	2.7%	0.20%	0.050641	2.3%	0.16%	0.050246	1.5%	0.11%
83.793	0.049062	0.050429	2.8%	0.19%	0.050229	2.4%	0.16%	0.049868	1.6%	0.11%
84.93	0.04865	0.05001	2.8%	0.18%	0.049834	2.4%	0.16%	0.049523	1.8%	0.12%
86.068	0.048264	0.0496	2.8%	0.16%	0.049433	2.4%	0.14%	0.049131	1.8%	0.10%
87.205	0.047906	0.048706	1.7%	0.08%	0.048528	1.3%	0.06%	0.048224	0.7%	0.03%
88.342	0.047574	0.048366	1.7%	0.06%	0.048245	1.4%	0.05%	0.048018	0.9%	0.03%
89.48	0.047269	0.047701	0.9%	0.02%	0.04765	0.8%	0.02%	0.047577	0.7%	0.01%
90.617	0.04699	0.047584	1.3%	0.01%	0.047473	1.0%	0.01%	0.047356	0.8%	0.01%
91.755	0.046738	0.046939	0.4%	0.02%	0.046911	0.4%	0.02%	0.046851	0.2%	0.01%
92.892	0.046512	0.046659	0.3%	0.02%	0.046637	0.3%	0.02%	0.046637	0.3%	0.02%
94.029	0.046313	0.046763	1.0%	0.08%	0.046705	0.8%	0.07%	0.046642	0.7%	0.06%
95.167	0.04614	0.046336	0.4%	0.03%	0.046291	0.3%	0.02%	0.04623	0.2%	0.01%
96.304	0.045994	0.046624	1.4%	0.04%	0.046567	1.2%	0.03%	0.04643	0.9%	0.03%
97.441	0.045875	0.046049	0.4%	0.02%	0.045995	0.3%	0.01%	0.045981	0.2%	0.01%
98.579	0.045782	0.046152	0.8%	0.02%	0.046036	0.6%	0.01%	0.045962	0.4%	0.01%
99.716	0.045716	0.046128	0.9%	0.01%	0.045952	0.5%	0.01%	0.045892	0.4%	0.00%
100.85	0.045677	0.046198	1.1%	0.01%	0.04602	0.8%	0.00%	0.04582	0.3%	0.00%
101.99	0.045664	0.046256	1.3%	0.01%	0.046115	1.0%	0.01%	0.045906	0.5%	0.00%
		cumulative deviation		2.0%			1.7%			1.2%

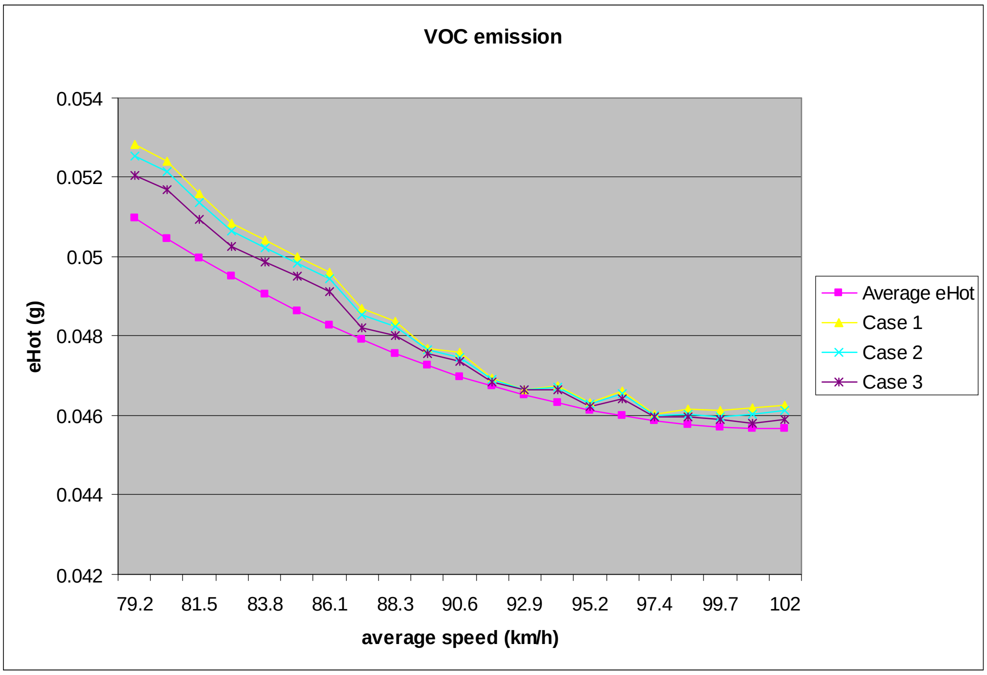


Figure 5.7: Average speed versus mean speed distribution estimates of passenger cars VOC emission on the Flanders highway network (Monday 5th March 2007).

Particulate Matter (PM)

Table 5.7: PM emission of passenger cars on the Flanders highway network on Monday 5th March 2007

PM		Case 1			Case 2			Case 3		
Average speed	Average eHot	Case 1 eHot	deviation	weighted deviation	Case 2 eHot	deviation	weighted deviation	Case 3 eHot	deviation	weighted deviation
79.244	0.031723	0.036656	15.6%	1.22%	0.036564	15.3%	1.20%	0.036277	14.4%	1.13%
80.381	0.032149	0.037235	15.8%	1.22%	0.037167	15.6%	1.20%	0.036909	14.8%	1.14%
81.518	0.032545	0.037184	14.3%	1.06%	0.037117	14.0%	1.05%	0.03686	13.3%	0.99%
82.656	0.032965	0.03714	12.7%	0.91%	0.037072	12.5%	0.89%	0.036821	11.7%	0.84%
83.793	0.033407	0.037102	11.1%	0.77%	0.037029	10.8%	0.75%	0.036794	10.1%	0.70%
84.93	0.033872	0.037047	9.4%	0.62%	0.036969	9.1%	0.60%	0.036761	8.5%	0.56%
86.068	0.034361	0.036108	5.1%	0.30%	0.036025	4.8%	0.28%	0.035819	4.2%	0.25%
87.205	0.034872	0.035631	2.2%	0.11%	0.035546	1.9%	0.10%	0.035307	1.2%	0.06%
88.342	0.035406	0.035843	1.2%	0.04%	0.035783	1.1%	0.04%	0.035604	0.6%	0.02%
89.48	0.035964	0.036222	0.7%	0.02%	0.036185	0.6%	0.01%	0.036126	0.5%	0.01%
90.617	0.036544	0.037221	1.9%	0.02%	0.037147	1.7%	0.02%	0.037057	1.4%	0.02%
91.755	0.037148	0.037157	0.0%	0.00%	0.037139	0.0%	0.00%	0.03709	-0.2%	-0.01%
92.892	0.037774	0.037599	-0.5%	-0.03%	0.03758	-0.5%	-0.03%	0.03758	-0.5%	-0.03%
94.029	0.038423	0.038975	1.4%	0.11%	0.038937	1.3%	0.11%	0.038888	1.2%	0.10%
95.167	0.039096	0.039556	1.2%	0.08%	0.039518	1.1%	0.08%	0.039468	1.0%	0.07%
96.304	0.039792	0.04018	1.0%	0.03%	0.040133	0.9%	0.02%	0.040028	0.6%	0.02%
97.441	0.04051	0.040564	0.1%	0.01%	0.040519	0.0%	0.00%	0.040509	0.0%	0.00%
98.579	0.041252	0.041568	0.8%	0.02%	0.041469	0.5%	0.01%	0.041411	0.4%	0.01%
99.716	0.042016	0.042354	0.8%	0.01%	0.042204	0.4%	0.01%	0.042155	0.3%	0.00%
100.85	0.042802	0.04369	2.1%	0.01%	0.043541	1.7%	0.01%	0.043398	1.4%	0.01%
101.99	0.043614	0.04419	1.3%	0.01%	0.044071	1.0%	0.01%	0.043934	0.7%	0.01%
		cumulative deviation		6.5%			6.4%			5.9%

Application of mean speed distributions is very sensitive to particulate matter mass (PM 2.5). Substantial improvements are realised for speed below 85km/h. Indeed highs of 10% to 20% occur in such traffic situations. The case in Table 5.6 below indicate 15.8% increase at 80km/h. Variations at higher average speed, above 85km/h, are substantially lower.

The trend in Figure 5.8 is similar for all three speed ranges. PM emissions show the lowest variability amongst Cases 1, 2 and 3.

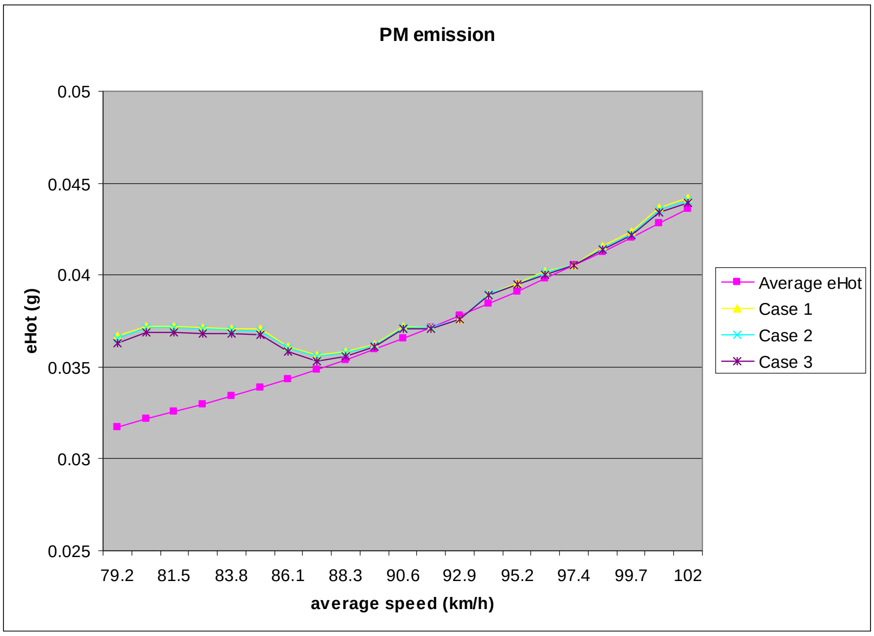


Figure 5.8: Average speed versus mean speed distribution estimates of passenger cars PM emission on the Flanders highway network (Monday 5th March 2007).

5.6.2 Sensitivity Analysis

Speed range

The different speed ranges (10, 20, and 40km/h) used yield analogous average speed emission curves as revealed in the Results section. Case 1 invariably proves to be superior in all resolutions tested, followed by case 2 and finally Case 3. Amongst the three cases of speed distribution there is a marked difference only between Case 1 and Case 3. Case 2 cumulative deviations correlate more with Case 1 than with Case 3.

Table 5.8: Cumulative deviations of CO, NOx, VOC and PM for 10 different spatial or temporal resolutions

	CO			NOx			VOC			PM		
Resolution	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
DOY64-Flanders	5.6%	5.2%	4.6%	3.2%	3.0%	2.8%	2.0%	1.7%	1.2%	6.5%	6.4%	5.9%
DOY64-E19	5.0%	4.3%	3.5%	2.6%	2.5%	2.1%	2.2%	1.7%	1.1%	5.8%	5.6%	4.8%
DOY246-Flanders	5.4%	5.0%	4.3%	3.2%	3.0%	2.8%	1.8%	1.5%	1.0%	6.6%	6.4%	5.9%
DOY246-E19	7.6%	7.0%	5.8%	4.5%	4.3%	3.9%	2.8%	2.4%	1.4%	10.0%	9.7%	8.7%
DOW1-Flanders	4.5%	4.1%	3.6%	2.4%	2.3%	2.1%	1.8%	1.5%	1.1%	4.7%	4.6%	4.2%
DOW1-E19	6.9%	6.5%	5.6%	3.9%	3.8%	3.4%	2.6%	2.3%	1.5%	8.5%	8.3%	7.5%
DOW7-Flanders	2.0%	1.7%	1.2%	0.9%	0.8%	0.6%	1.0%	0.8%	0.6%	1.3%	1.1%	0.9%
DOW7-E19	0.3%	0.1%	-0.2%	0.0%	-0.1%	-0.2%	0.4%	0.2%	0.1%	-0.1%	-0.2%	-0.3%
JAN-Flanders	3.3%	3.0%	2.6%	1.7%	1.6%	1.4%	1.5%	1.2%	0.9%	3.2%	3.0%	2.8%
JAN-E19	4.0%	3.9%	3.2%	2.0%	1.9%	1.7%	1.9%	1.9%	1.2%	4.0%	3.9%	3.4%

Difference between Case 1 and Case 2 deviations range from 0.1% to 0.7% for all test conducted (Table5.8). This implies that although Case 1 is the most detail level of aggregation, it is sufficiently efficient to use Case 2. In this light, subsequent spatial and temporal analysis of the different test has been done with results from data having 7 speed classes (Case 2) per average speed. A simple 3 speed classes' distribution is as well a significant level of detail to apply.

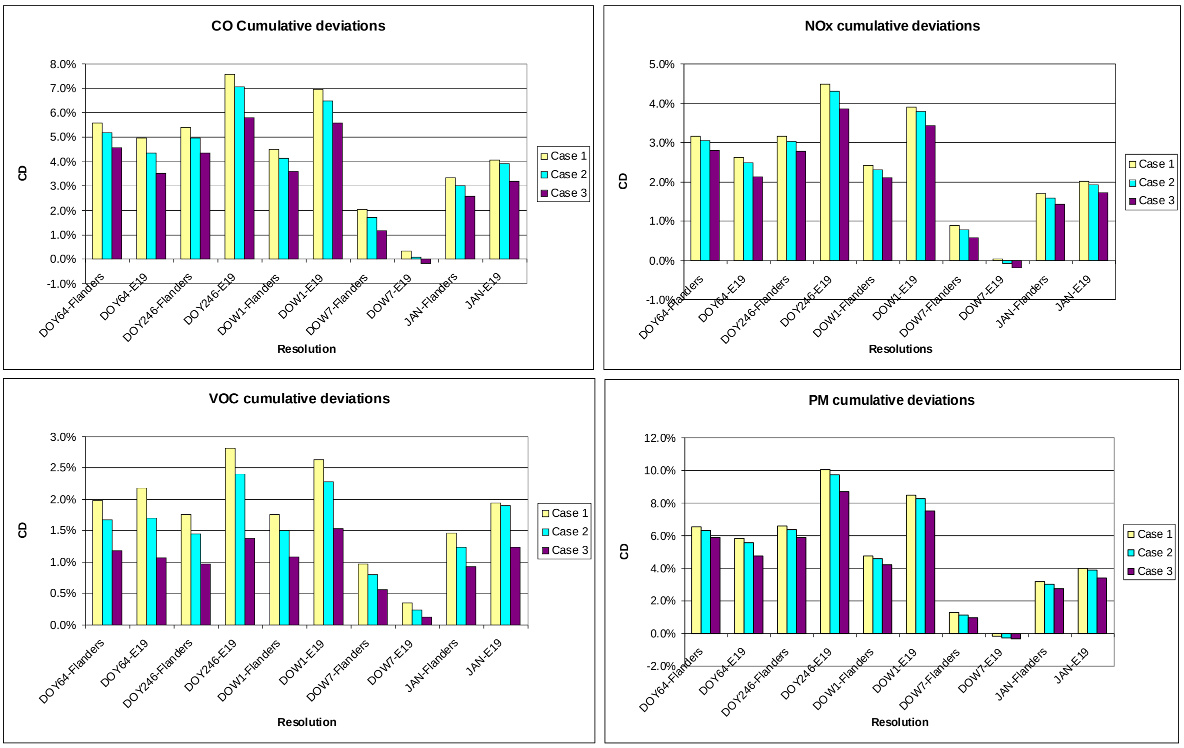


Figure 5.9: Effect of speed distribution range on pollutants emissions shown as comparison among relative deviations from a single average speed emission.

The case of seven speed classes closely fit average speed emission at free flow condition. Figure 5.9 show the research methodology applied to an aggregate of annual Sunday vehicle kilometres driven on the E19 link between Brussels and Antwerp (DOW7-E19). Taking into consideration the fact that mean speed distribution data for this period (see figure 5.10) lies above 85km/h one would expect emissions estimate by the research method to closely match that of a single average speed input.

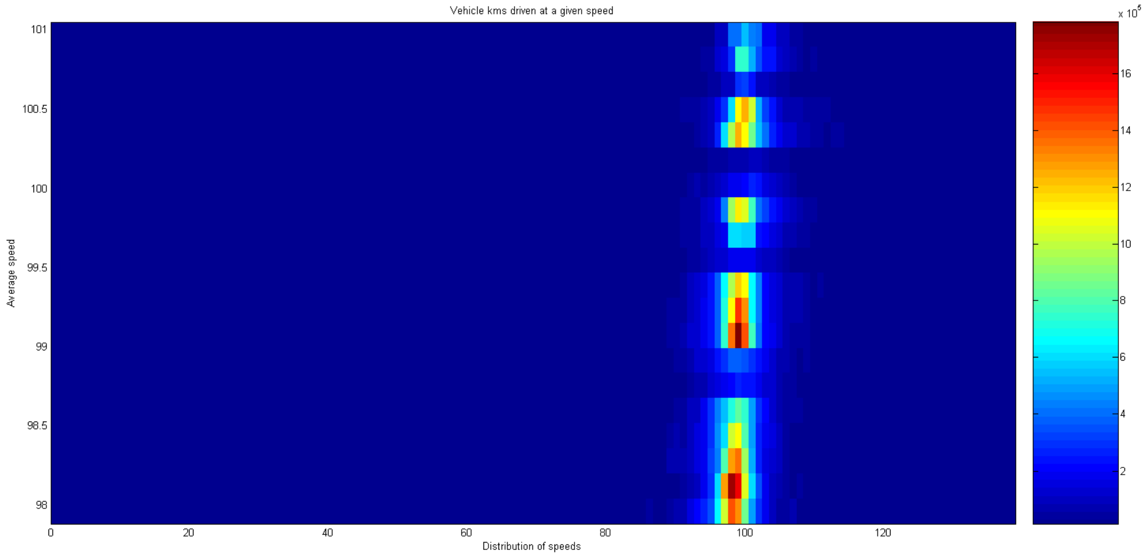


Figure 5.10: Mean speed distribution of average speed vehicle kilometres for an aggregate of Sundays in 2007. Speed density map constructed from data of Brussels-Antwerp E19 link (Maerivoets, 2010)

Free-flow situation

There is marked distinction in the behaviour of the mean speed distribution curve during congested and free-flow conditions on the highway. Free-flow is when vehicle can travel on highway recommended speed with minimal hindrance at intersections to achieve a maximum level of service. Typical free flow conditions are experienced on Sundays (Figure5.10) and during off-peak hours of other days. Nonetheless free-flow is quantitatively defined here as situations were link or network average speed is greater than or equal to 90km/h. The following deductions can be made from the results (Annexe D) of traffic in free-flow:

- In free-flow, emissions estimate by the research method has very low deviations from the conventional average speed methodology. Free-flow periods show deviations of mostly within 0.01% to 2%. The gap is similar for CO, NOx, VOC and PM.

- The fit is stronger for single link analysis (E19) than when a regional motorway network (Flanders) is analysed. Certainly link analysis has less noise and data is collected at a lower level of aggregation.
- The findings reveal a few cases where the average speed approach over estimate emissions during free-flow for CO, NOx, and PM. However, this is by very small amounts of absolute deviations lying between -0.1% and -0.8%. Only PM emissions have a relative deviation of -0.2% for E19 data on Sundays of 2007 (Figure 5.9).

In a nutshell, the research method does not provide a significant enhancement to the average speed approach during free-flow conditions.

Congested situation

Congestion occurs when demand or incidents deteriorate the level of service of a link. Congestion on highways is quantitatively referred to in this report as situations were link or network average speed is less than 90km/h. Average speeds in this category always have a wider mean speed distribution than in free-flow (Figure 5.3). Results in Annexe D indicate congestion invariably occur during weekdays and varies over time of the day.

When the research methodology is applied in congested situations, there is substantial increase in CO, NOx and PM emission estimates ranging from 1% to 20% in absolute terms. Absolute gains in hydrocarbon estimates are lower, lying in the threshold of 1% and 4%.

- PM absolute deviations are up to 15% in Flanders and 20% along the E19 Brussels-Antwerp link.
- CO absolute emission increase in congested situations get to 11% high in Flanders and 15% when a single link is considered.
- NOx absolute deviations get to 7% in Flanders and 9% along the E19 Brussels-Antwerp link.
- The range of all the pollutants is wide and can be low as 0.5%. However, looking at the distribution of vehicle kilometres driven (weighted deviations), most of the gains are within the upper bound limit.

- o Congested situations contribute some 85% to over a 100% in periodic cumulative deviation for all pollutants.

The speed distribution approach is worthwhile when there is a spread in mean speeds contributing to the global average speed. Since bulk of vehicle kilometres driven are in congested situations (more vehicles per road length) it is advisable to adopt the hypothesised methodology.

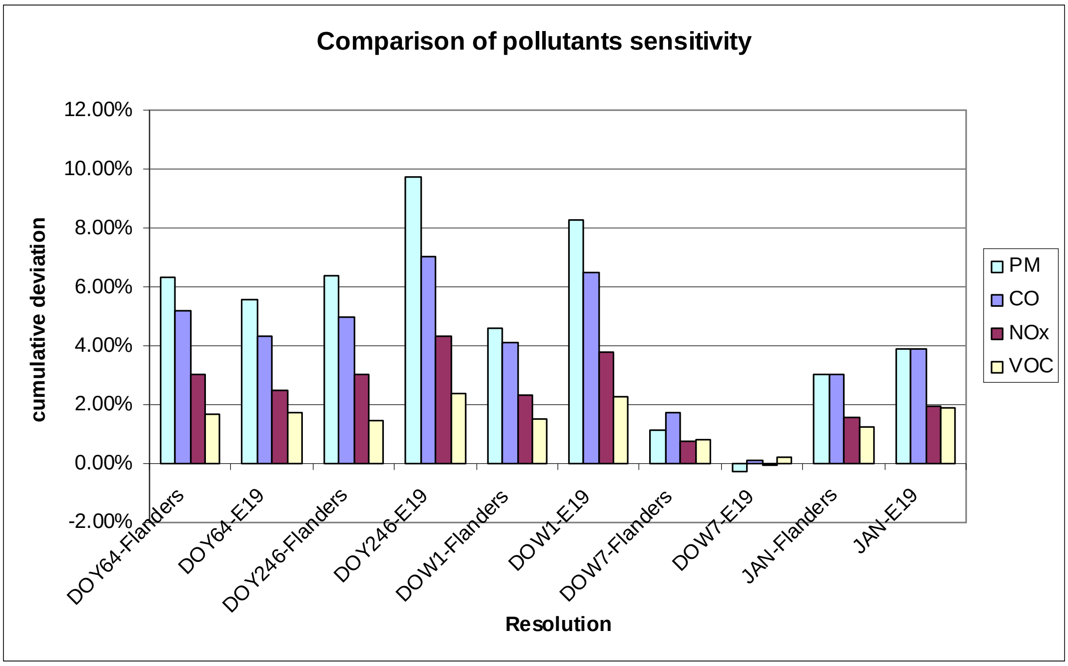


Figure 5.11: A sensitivity ranking of pollutants by speed distribution effects in different spatial and temporal resolutions. Deviations are cumulative deviation per period of specified resolution.

Table 5.9: Cumulative deviation of emission estimates by speed distribution from estimates by average speed approach.

	CO	NOx	VOC	PM
DOY64-Flanders	5.17%	3.04%	1.68%	6.35%
DOY64-E19	4.35%	2.48%	1.70%	5.59%
DOY246-Flanders	4.97%	3.03%	1.46%	6.40%
DOY246-E19	7.05%	4.30%	2.40%	9.72%
DOW1-Flanders	4.13%	2.31%	1.51%	4.59%
DOW1-E19	6.47%	3.78%	2.28%	8.25%
DOW7-Flanders	1.71%	0.77%	0.80%	1.14%
DOW7-E19	0.08%	-0.08%	0.24%	-0.25%
JAN-Flanders	3.01%	1.59%	1.24%	3.03%
JAN-E19	3.91%	1.93%	1.90%	3.87%

Figure 5.11 show that the highest gain in applying the speed distribution method is on PM estimates followed by CO, NOx, and least of all in VOC calculation. Based on findings from tested datasets the effect of spatial resolution is inconclusive. CO, NOx and PM cumulative deviations for two cases on Mondays (DOY64 & DOY246) are in one instance higher for Flanders and in another higher for the E19 link. While for VOC the trend is unchanged. Although when considered for an entire monthly period, the link estimate report higher relative emission in a magnitude of about 0.7% for all

tested pollutants. The effect is reversed when results of a free-flow day (Sunday) are compared.

Thus, the findings of Smit et al. (2008) that congestion is indirectly incorporated into the Copert average speed function may only be justified at high (national) aggregation levels. Indeed, Copert is not really designed for microscopic applications. Even at the highest resolution of 1x1km^2 and 1hour that Copert has been tested there can still be several variations of speed flow resulting to large deviations in emission.

Lastly, there is a noticeable difference in the trend of the emission curve when speed distributions are employed. The curve is not smooth as when a single average speed is used. Fluctuations are an indication of the fact that emission factors were developed from instantaneous driving patterns. The speed distribution approach is therefore a better application of the Copert average speed methodology. At least a simple 3 speed classes' distribution is recommended to properly reflect actual emissions.

6 Conclusions

The process of estimating air pollutants and greenhouse gases from road transport has seen considerable improvements over the last two decades. Emission modelling has adopted both conventional and state of the art modelling approaches; from simple aggregated models to more detailed instantaneous methodologies. In all this improvement, the most feasible approach in terms of applicability has been those near the bottom, continuous average speed models. Such tools like Copert and NAEI are the most used road transport models in Europe. Indeed the models are not that 'simple' as it may seem. Many driving patterns and situations have been taken into account in developing emission functions used by these models. The work of major European projects on emission estimates like MEET, COST 319 action and the recently completed ARTEMIS project are all part of the Copert4 emission functions. Today we have a version of Copert that is build from instantaneous situations whereas work as a continuous average speed emission estimator. Even with such increased complexity and detail in emission functions generation, the input for estimating pollutant emissions has been kept very simple, to trip average speed per vehicle type. The robustness and stability of the Copert methodology can still be maintained while at same time benefiting from the sensitivity of the instantaneous emission factor in improving the capability of the average speed approach.

This report has demonstrated how the Copert user interface and method of application can be improved. Emission functions and correction algorithms have been utilised to replicate the model in Excel. The resulting tool, Copert in Excel, is very robust and efficient and allows for sensitivity analysis to various input parameters. Emission calculations yield similar results like Copert4 while users don't have to refresh emission factors and emission calculations each time a parameter or input variable is changed like in Copert4. Only an update of the Pivot Table output sheet which requires less than a second is necessary in Copert in Excel when changes are made. The spreadsheet tool has proved to be invaluable in running data collected for the case study in this research. Its application therefore, will be undoubtedly valuable for road transport emission research and in inventory collection.

Interesting findings were deduced from testing the effect of mean speed distributions over using a single average speed per period as input for emission calculation. Gains in applying the methodology vary amongst different pollutants. The highest improvement is on PM estimates followed by CO, NOx, and least of all in VOC calculation.

Emission estimates on days experiencing long peak hour congestions (Mondays, single or aggregated) saw a relative increase for:

- PM in the range of 4.5% to 9.7%.
- CO in the range 4.1% to 7.1%
- NOx in the range of 2.1% to 4.3%
- VOC in the range of 1.4 to 2.4%

Days like Sundays characterised by free-flow traffic have lower cumulative gains for:

- PM range between -0.25% and 1.14%
- CO range between 0.1% and 1.7%
- NOx range between -0.1% and 0.8%
- VOC range between 0.2% and 0.8%

The distribution of vehicle kilometres driven during weekdays is considerable higher compared to weekends. Applying mean speed distributions will certainly improve emission inventories making use of the average speed approach especially for congested networks.

The effect of spatial aggregation (Flanders or E19 link) is inconclusive for all the pollutants considered. Data on more scenarios may offer a better relationship amongst spatial consideration which can be analysed. The only noticeable spatial effect is that, at high average speeds above 90km/h, emission estimates by the research method correlate more with the conventional average speed approach when a single link is considered. However, in such cases the variability compared to when the whole of Flanders is considered is not significant.

A major pitfall in applying the methodology is in collecting speed distribution data for urban and rural road networks. In this study speed and vehicle kilometre distribution data has been collected by loops installed along the Flanders motorway network. Road transport telematics has only been widely installed in the European motorway network. Rural and urban roads are extensive and carry the most traffic travelling at low speed. In such conditions speed distribution patterns can be developed by adapting ENEA's corrected average speed approach in the TEE model (Negrenti, 1999). The Congestion Correction Factor estimated by the model represents speed variability along a link which can be translated to speed distribution based on link average speed. This is something which can be researched on, though will largely depend on the applicability of the methodology proposed by the TEE model. Having such adaptations into TREMOVE would allow it generate appropriate speed distributions to relate with disaggregate vehicle kilometre from its vehicle stock module.

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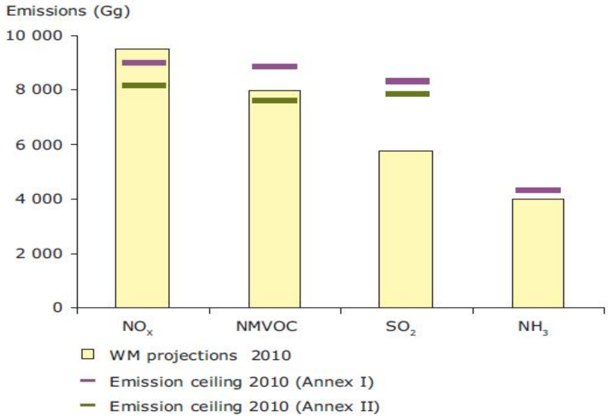
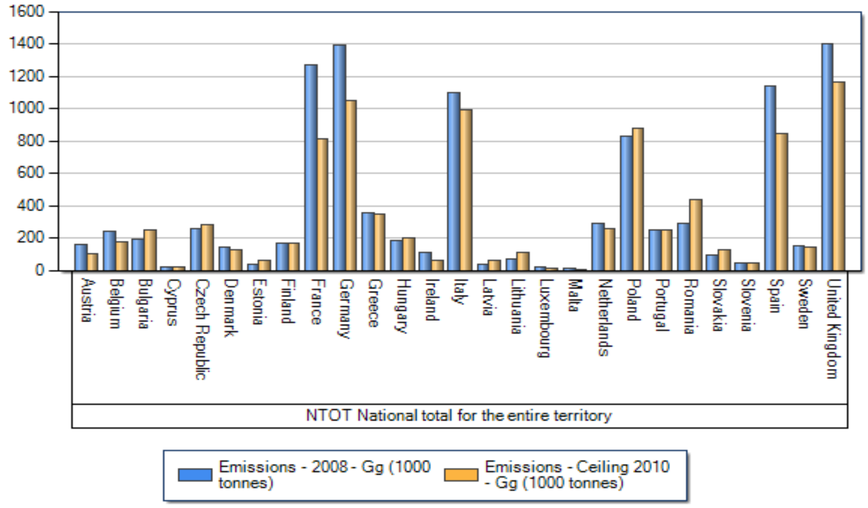
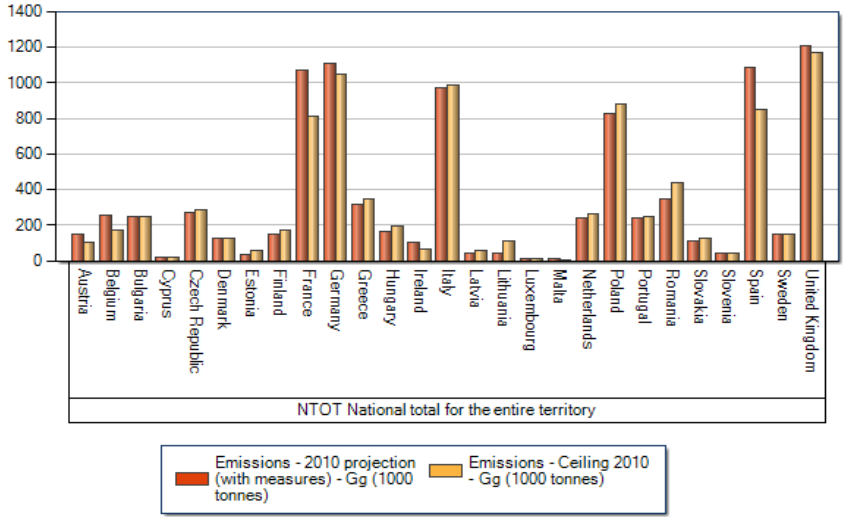
Annexe A: EU27 Emission Ceilings



EU27 emissions and projections compared to 2010 national emission ceiling. Source: NEC Directive status report 2008 (EEA, 2009)



EU27 emissions and projections compared to 2010 national emission ceiling.
Source: Centre for Emission Inventories and Projections (WebDab, 2010)



Annexe B: Passenger car fleet distribution

Belgium passenger car distribution 2005 (De Ceuster et al., 2005)

fuel type	vehicle type	vehicle technology	%VKM
(Blended) road vehicle diesel	car >2.0l - diesel	car - diesel & LPG - Conventional	1.61%
		car - diesel & LPG - Euro 1	2.65%
		car - diesel & LPG - Euro 2	5.99%
		car - diesel & LPG - Euro 3	10.00%
		car - diesel & LPG - Euro 4	1.10%
	car 1.4-2.0l - diesel	car - diesel & LPG - Conventional	2.18%
		car - diesel & LPG - Euro 1	3.44%
		car - diesel & LPG - Euro 2	6.60%
		car - diesel & LPG - Euro 3	31.67%
		car - diesel & LPG - Euro 4	6.04%
	car <1.4l - diesel	car - diesel & LPG - Euro 2	0.00%
		car - diesel & LPG - Euro 3	3.92%
		car - diesel & LPG - Euro 4	1.13%
(Blended) road vehicle gasoline	car >2.0l - petrol	car - petrol - ECE 15 03	0.02%
		car - petrol - ECE 15 04	0.56%
		car - petrol - Euro 3	0.54%
		car - petrol - Euro 4	0.29%
		car - petrol - Euro 1	0.62%
		car - petrol - Euro 2	0.35%
	car 1.4-2.0l - petrol	car - petrol - ECE 15 03	0.00%
		car - petrol - ECE 15 04	2.63%
		car - petrol - Euro 3	2.20%
		car - petrol - Euro 4	1.49%
		car - petrol - Euro 1	1.47%
		car - petrol - Euro 2	1.22%
	car <1.4l - petrol	car - petrol - ECE 15 03	0.00%
		car - petrol - ECE 15 04	0.01%
		car - petrol - Euro 3	5.42%
		car - petrol - Euro 4	3.01%
		car - petrol - Euro 1	0.68%
		car - petrol - Euro 2	2.55%
Liquefied petroleum gas	car - LPG	car - diesel & LPG - Conventional	0.01%
		car - diesel & LPG - Euro 1	0.03%
		car - diesel & LPG - Euro 2	0.22%
		car - diesel & LPG - Euro 3	0.34%
			100.00%

Annexe C-1: Speed distribution macro

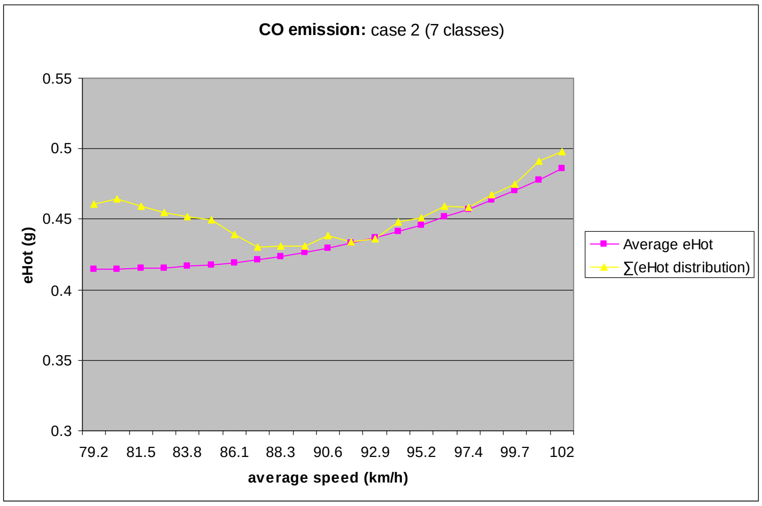
```
Sub speed_distribution()

For i = 4 To 491

    Windows("data_output.xls").Activate
    Sheets("Output").Select
    Range("C" & i).Select
    If Selection <> 0 Then
    Selection.Copy
    Windows("Flanders_Hot_Emissions.xls").Activate
    Sheets("Circulation").Select
    Range("U2").Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    Sheets("Output").Select

    'CO
    Range("D8").Select
    Application.CutCopyMode = False
    ActiveSheet.PivotTables("PivotTable3").PivotCache.Refresh
    Selection.Copy
    Windows("data_output.xls").Activate
    Range("E" & i).Select
    ActiveSheet.Paste

    'NOx
    Windows("Flanders_Hot_Emissions.xls").Activate
    Sheets("Output").Select
    Range("D9").Select
    Application.CutCopyMode = False
    Selection.Copy
    Windows("data_output.xls").Activate
    Range("J" & i).Select
    ActiveSheet.Paste

    'PM
    Windows("Flanders_Hot_Emissions.xls").Activate
    Sheets("Output").Select
    Range("D10").Select
    Application.CutCopyMode = False
    Selection.Copy
    Windows("data_output.xls").Activate
    Range("T" & i).Select
    ActiveSheet.Paste

    'VOC
    Windows("Flanders_Hot_Emissions.xls").Activate
    Sheets("Output").Select
    Range("D11").Select
    Application.CutCopyMode = False
    Selection.Copy
    Windows("data_output.xls").Activate
    Range("O" & i).Select
    ActiveSheet.Paste

    End If
    '...
Next

End Sub
```

Annexe C-2: Average Speed Macro

```
Sub average_speed()

For i = 4 To 491

    Windows("data_output.xls").Activate
    Sheets("Output").Select
    Range("B" & i).Select
    If Selection <> 0 Then
    Selection.Copy
    Windows("Flanders_Hot_Emissions.xls").Activate
    Sheets("Circulation").Select
    Range("U2").Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
    Sheets("Output").Select

    'CO
    Range("D8").Select
    Application.CutCopyMode = False
    ActiveSheet.PivotTables("PivotTable3").PivotCache.Refresh
    Selection.Copy
    Windows("data_output.xls").Activate
    Range("H" & i).Select
    ActiveSheet.Paste

    'NOx
    Windows("Flanders_Hot_Emissions.xls").Activate
    Sheets("Output").Select
    Range("D9").Select
    Application.CutCopyMode = False
    Selection.Copy
    Windows("data_output.xls").Activate
    Range("M" & i).Select
    ActiveSheet.Paste

    'PM
    Windows("Flanders_Hot_Emissions.xls").Activate
    Sheets("Output").Select
    Range("D10").Select
    Application.CutCopyMode = False
    Selection.Copy
    Windows("data_output.xls").Activate
    Range("W" & i).Select
    ActiveSheet.Paste

    'VOC
    Windows("Flanders_Hot_Emissions.xls").Activate
    Sheets("Output").Select
    Range("D11").Select
    Application.CutCopyMode = False
    Selection.Copy
    Windows("data_output.xls").Activate
    Range("R" & i).Select
    ActiveSheet.Paste

    End If
    '...

Next

End Sub
```

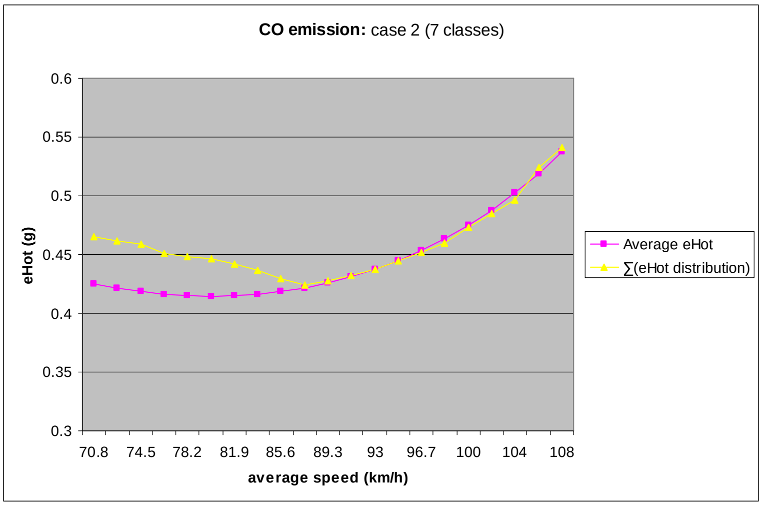
Annexe D: Charts and tables of emission deviations (Flanders and E19-BA)

CO Results



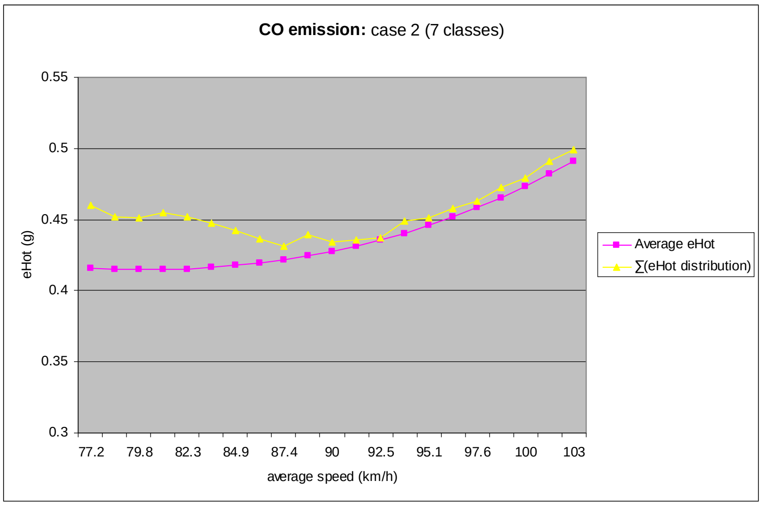
DOY 64-Flanders

Average speed	deviation	Weighted deviation
79.244	11.1%	0.9%
80.381	11.9%	0.9%
81.518	10.7%	0.8%
82.656	9.4%	0.7%
83.793	8.5%	0.6%
84.93	7.5%	0.5%
86.068	4.8%	0.3%
87.205	2.1%	0.1%
88.342	1.7%	0.1%
89.48	1.0%	0.0%
90.617	2.0%	0.0%
91.755	0.2%	0.0%
92.892	-0.2%	0.0%
94.029	1.6%	0.1%
95.167	1.1%	0.1%
96.304	1.7%	0.0%
97.441	0.3%	0.0%
98.579	0.9%	0.0%
99.716	1.0%	0.0%
100.85	2.8%	0.0%
101.99	2.5%	0.0%
		5.2%



DOY64-E19

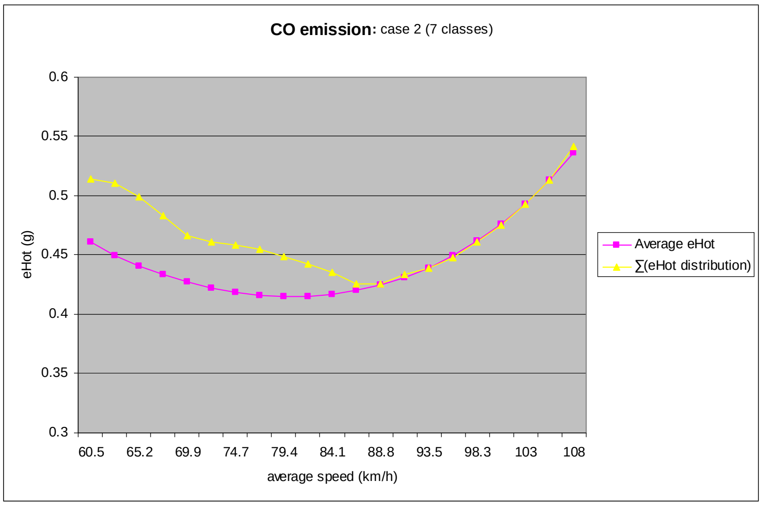
Average speed	deviation	weighted deviation
70.828	9.5%	0.7%
72.678	9.6%	0.7%
74.529	9.7%	0.7%
76.379	8.4%	0.5%
78.229	8.0%	0.5%
80.08	7.7%	0.5%
81.93	6.5%	0.4%
83.78	4.8%	0.3%
85.631	2.6%	0.1%
87.481	0.5%	0.0%
89.331	0.4%	0.0%
91.181	0.2%	0.0%
93.032	0.0%	0.0%
94.882	-0.1%	0.0%
96.732	-0.4%	0.0%
98.583	-0.7%	0.0%
100.43	-0.3%	0.0%
102.28	-0.6%	0.0%
104.13	-1.2%	0.0%
105.98	1.0%	0.0%
107.83	0.7%	0.0%
		4.3%



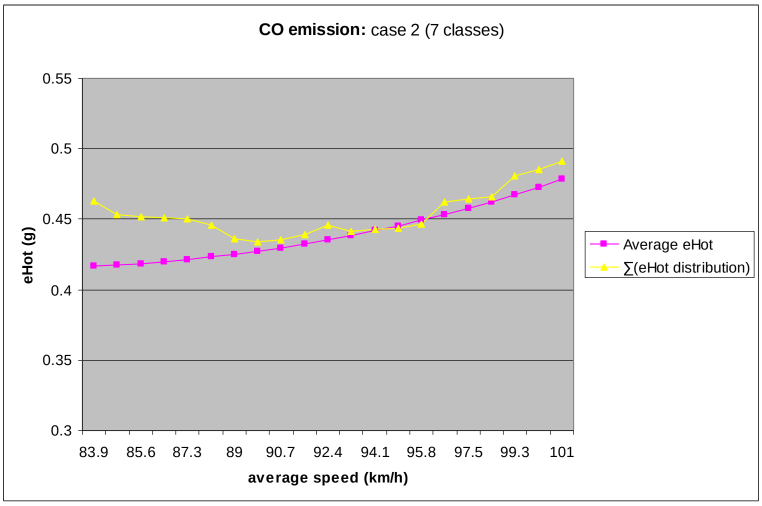
DOY246-Flanders

Average speed	deviation	weighted deviation
77.201	10.7%	0.7%
78.479	8.9%	0.6%
79.756	8.7%	0.6%
81.034	9.7%	0.6%
82.312	8.9%	0.6%
83.589	7.5%	0.5%
84.867	6.0%	0.3%
86.144	4.1%	0.2%
87.422	2.3%	0.1%
88.7	3.5%	0.2%
89.977	1.5%	0.0%
91.255	1.0%	0.0%
92.533	0.4%	0.0%
93.81	2.0%	0.0%
95.088	1.2%	0.1%
96.365	1.4%	0.1%
97.643	1.1%	0.0%
98.921	1.5%	0.0%
100.2	1.2%	0.0%
101.48	1.8%	0.0%
102.75	1.6%	0.0%
		5.0%

DOY246-E19

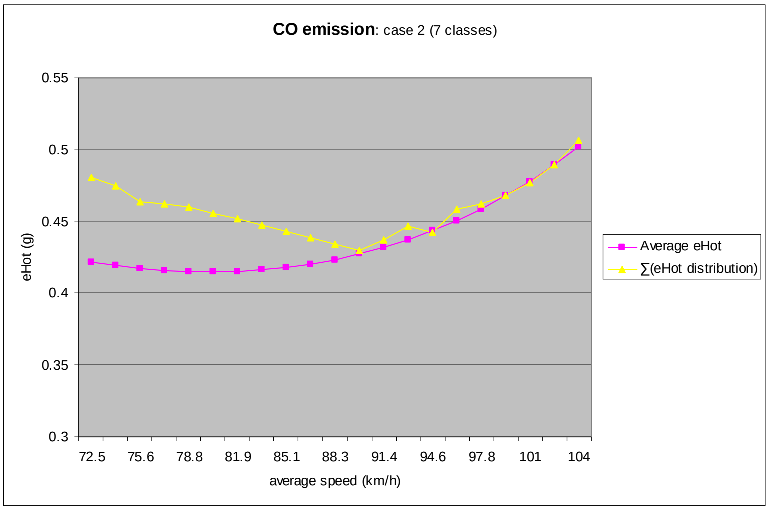


Average speed	deviation	weighted deviation
60.509	11.6%	0.8%
62.868	13.6%	0.9%
65.227	13.1%	0.8%
67.586	11.5%	0.8%
69.945	9.3%	0.6%
72.304	9.2%	0.6%
74.663	9.6%	0.6%
77.022	9.3%	0.6%
79.381	8.3%	0.5%
81.74	6.5%	0.4%
84.099	4.4%	0.3%
86.458	1.4%	0.1%
88.817	0.1%	0.0%
91.176	0.5%	0.0%
93.535	-0.1%	0.0%
95.894	-0.5%	0.0%
98.253	-0.1%	0.0%
100.61	-0.2%	0.0%
102.97	0.0%	0.0%
105.33	0.1%	0.0%
107.69	1.1%	0.0%
		7.0%



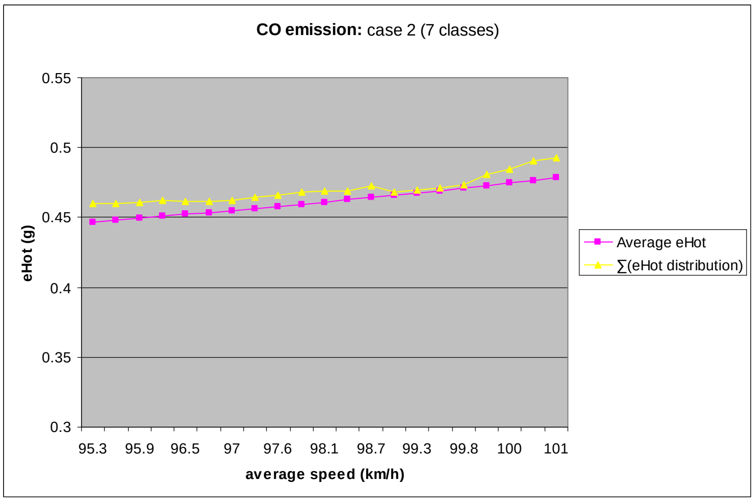
DOW1-Flanders

Average speed	deviation	weighted deviation
83.904	11.2%	0.9%
84.757	8.6%	0.6%
85.609	8.0%	0.6%
86.462	7.4%	0.5%
87.315	6.8%	0.5%
88.168	5.3%	0.3%
89.021	2.6%	0.2%
89.873	1.5%	0.1%
90.726	1.3%	0.0%
91.579	1.6%	0.1%
92.432	2.3%	0.2%
93.285	0.7%	0.1%
94.138	0.2%	0.0%
94.99	-0.4%	0.0%
95.843	-0.6%	0.0%
96.696	1.9%	0.0%
97.549	1.5%	0.1%
98.402	0.7%	0.0%
99.254	2.9%	0.0%
100.11	2.7%	0.0%
100.96	2.7%	0.0%
		4.1%



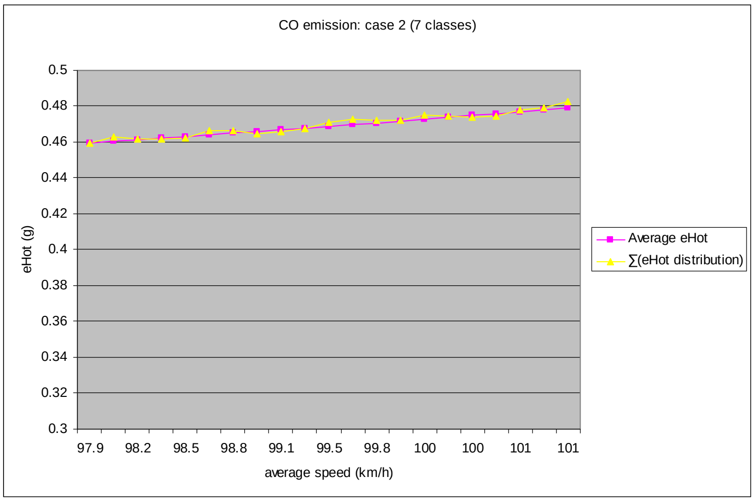
DOW1-E19

Average speed	deviation	weighted deviation
72.453	14.0%	1.0%
74.034	13.3%	0.9%
75.615	11.2%	0.7%
77.196	11.2%	0.7%
78.777	10.9%	0.7%
80.358	9.9%	0.6%
81.939	8.8%	0.5%
83.52	7.5%	0.4%
85.102	5.9%	0.3%
86.683	4.3%	0.2%
88.264	2.6%	0.1%
89.845	0.7%	0.0%
91.426	1.2%	0.0%
93.007	2.1%	0.2%
94.588	-0.3%	0.0%
96.169	1.7%	0.0%
97.751	0.8%	0.0%
99.332	0.1%	0.0%
100.91	-0.2%	0.0%
102.49	0.0%	0.0%
104.08	0.9%	0.0%
		6.5%



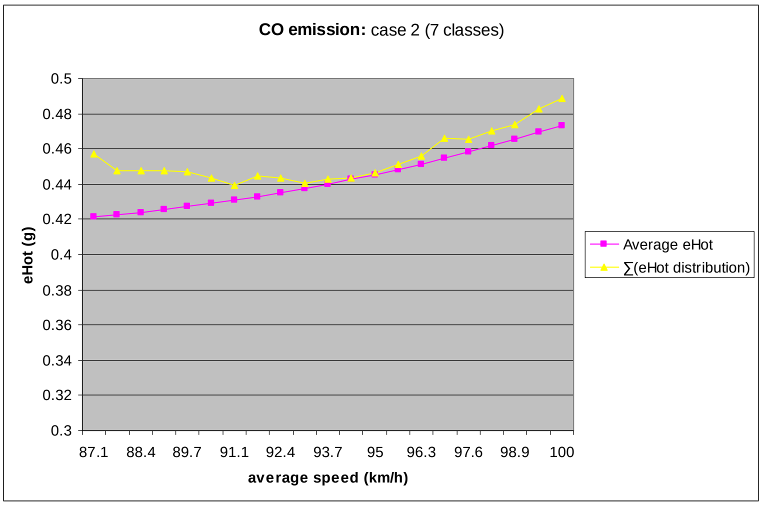
DOW7-Flanders

Average speed	deviation	weighted deviation
95.342	2.9%	0.2%
95.622	2.6%	0.2%
95.902	2.5%	0.2%
96.182	2.5%	0.1%
96.463	2.1%	0.1%
96.743	1.8%	0.1%
97.023	1.6%	0.1%
97.303	1.8%	0.1%
97.583	1.8%	0.1%
97.864	1.8%	0.1%
98.144	1.7%	0.1%
98.424	1.3%	0.1%
98.704	1.8%	0.1%
98.984	0.5%	0.0%
99.265	0.5%	0.0%
99.545	0.3%	0.0%
99.825	0.6%	0.0%
100.11	1.8%	0.0%
100.39	2.1%	0.0%
100.67	3.0%	0.0%
100.95	3.0%	0.0%
		1.7%



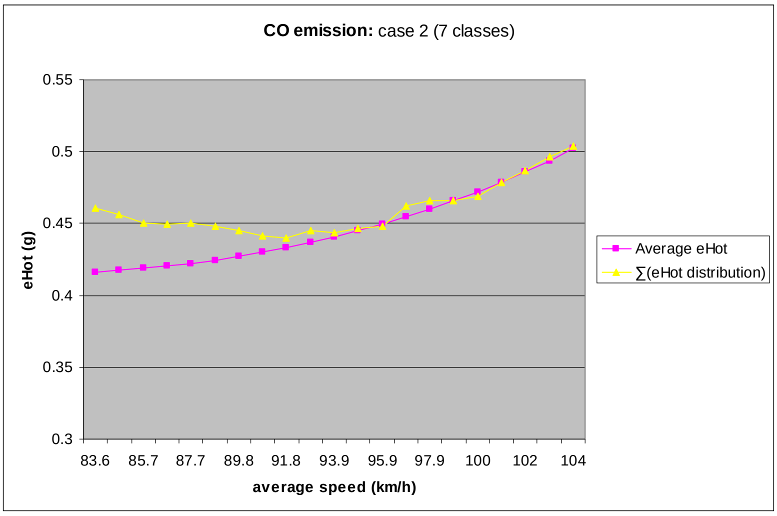
DOW7-E19

Average speed	deviation	weighted deviation
97.881	0.0%	0.0%
98.039	0.5%	0.0%
98.198	0.1%	0.0%
98.356	-0.1%	0.0%
98.515	-0.2%	0.0%
98.673	0.5%	0.0%
98.831	0.3%	0.0%
98.99	-0.2%	0.0%
99.148	-0.2%	0.0%
99.307	-0.1%	0.0%
99.465	0.5%	0.0%
99.624	0.6%	0.0%
99.782	0.3%	0.0%
99.941	0.2%	0.0%
100.1	0.5%	0.0%
100.26	0.1%	0.0%
100.42	-0.2%	0.0%
100.57	-0.3%	0.0%
100.73	0.2%	0.0%
100.89	0.3%	0.0%
101.05	0.8%	0.0%
		0.1%



JAN-Flanders

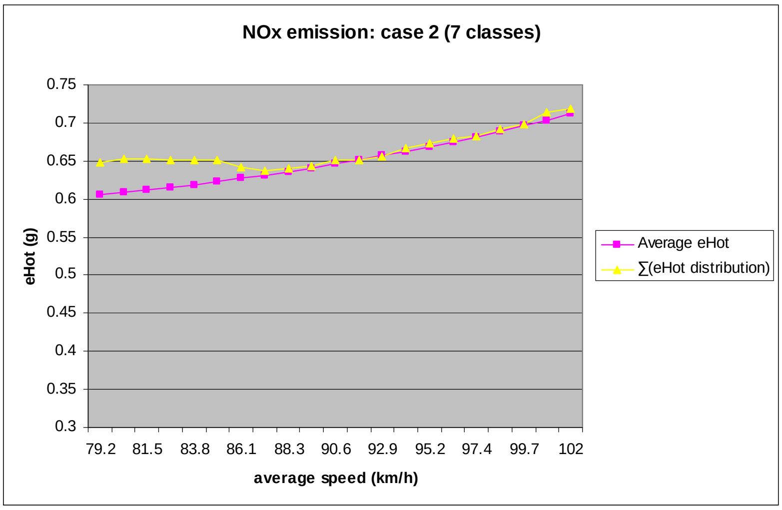
Average speed	deviation	weighted deviation
87.132	8.5%	0.6%
87.786	6.0%	0.4%
88.44	5.7%	0.4%
89.095	5.2%	0.3%
89.749	4.7%	0.3%
90.404	3.4%	0.2%
91.058	2.0%	0.1%
91.713	2.7%	0.2%
92.367	1.9%	0.1%
93.022	0.7%	0.0%
93.676	0.6%	0.0%
94.331	0.2%	0.0%
94.985	0.3%	0.0%
95.64	0.6%	0.0%
96.294	1.0%	0.1%
96.949	2.6%	0.0%
97.603	1.6%	0.0%
98.257	1.9%	0.0%
98.912	1.9%	0.0%
99.566	2.9%	0.0%
100.22	3.2%	0.0%
		3.0%



JAN-E19

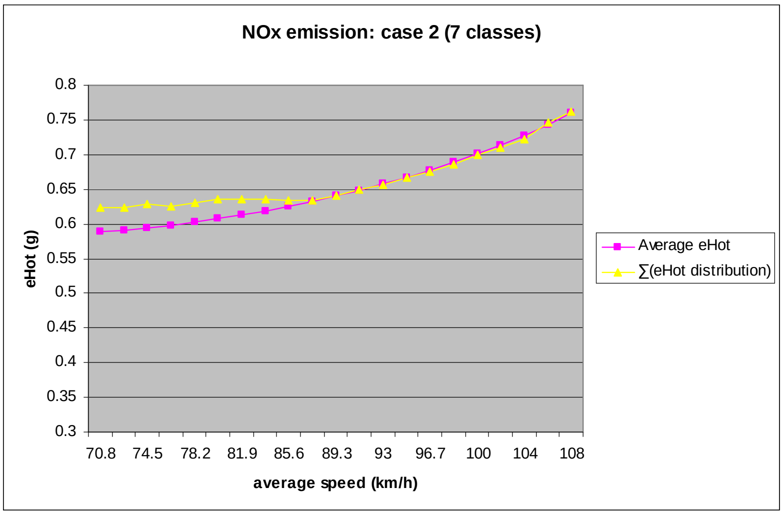
Average speed	deviation	weighted deviation
83.618	10.6%	0.7%
84.642	9.3%	0.6%
85.665	7.6%	0.5%
86.689	7.0%	0.5%
87.712	6.7%	0.4%
88.736	5.6%	0.4%
89.759	4.2%	0.3%
90.782	2.6%	0.2%
91.806	1.5%	0.1%
92.829	1.9%	0.1%
93.853	0.6%	0.0%
94.876	0.4%	0.0%
95.9	-0.4%	0.0%
96.923	1.7%	0.0%
97.946	1.2%	0.1%
98.97	0.1%	0.0%
99.993	-0.6%	0.0%
101.02	-0.1%	0.0%
102.04	0.2%	0.0%
103.06	0.5%	0.0%
104.09	0.3%	0.0%
		3.9%

NOx Results



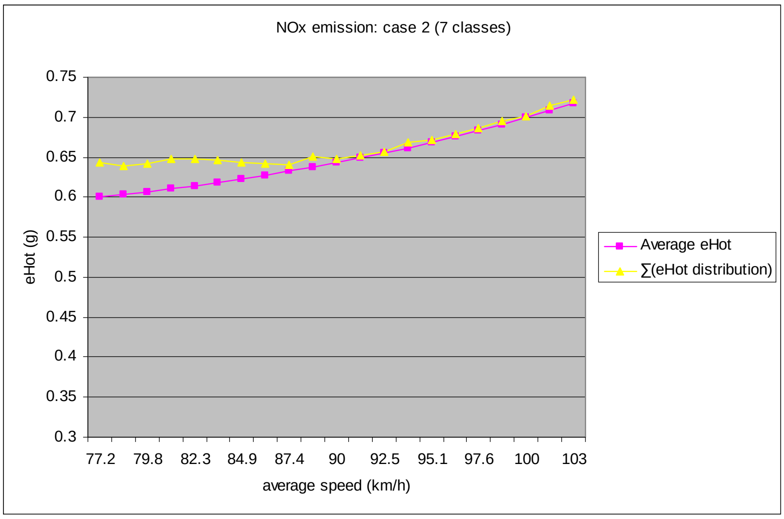
DOY64-Flanders

Average speed	deviation	weighted deviation
79.244	7.0%	0.55%
80.381	7.3%	0.56%
81.518	6.6%	0.49%
82.656	5.9%	0.42%
83.793	5.2%	0.36%
84.93	4.4%	0.29%
86.068	2.4%	0.14%
87.205	1.0%	0.05%
88.342	0.6%	0.02%
89.48	0.4%	0.01%
90.617	0.9%	0.01%
91.755	0.0%	0.00%
92.892	-0.3%	-0.01%
94.029	0.7%	0.06%
95.167	0.6%	0.04%
96.304	0.6%	0.02%
97.441	0.1%	0.00%
98.579	0.4%	0.01%
99.716	0.4%	0.00%
100.85	1.4%	0.01%
101.99	1.1%	0.01%
		3.0%



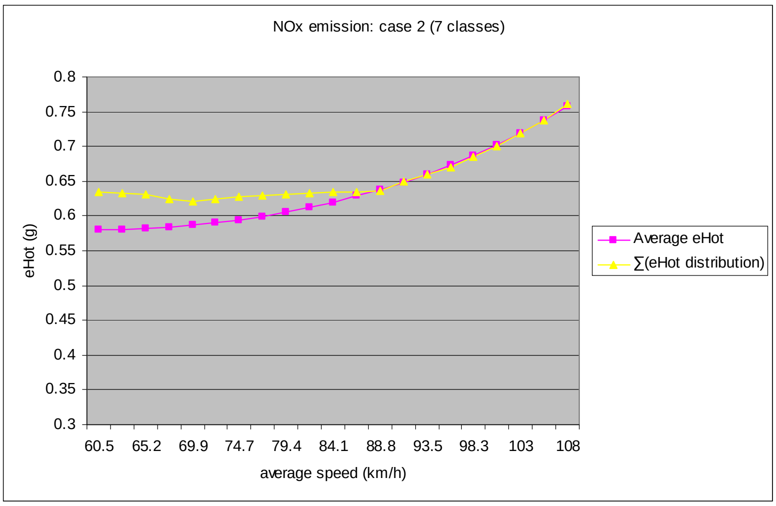
DOY64-E19

Average speed	deviation	weighted deviation
70.828	6.1%	0.5%
72.678	5.6%	0.4%
74.529	5.8%	0.4%
76.379	4.5%	0.3%
78.229	4.6%	0.3%
80.08	4.5%	0.3%
81.93	3.6%	0.2%
83.78	2.6%	0.1%
85.631	1.4%	0.1%
87.481	0.1%	0.0%
89.331	0.0%	0.0%
91.181	0.1%	0.0%
93.032	-0.1%	0.0%
94.882	-0.2%	0.0%
96.732	-0.4%	0.0%
98.583	-0.5%	0.0%
100.43	-0.2%	0.0%
102.28	-0.4%	0.0%
104.13	-0.9%	0.0%
105.98	0.3%	0.0%
107.83	0.2%	0.0%
		2.5%



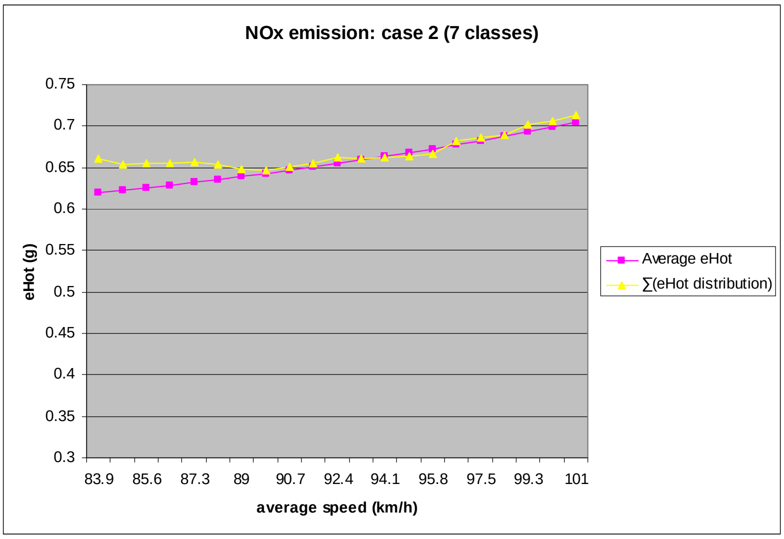
DOY246-Flanders

Average speed	deviation	weighted deviation
77.201	7.1%	0.5%
78.479	5.8%	0.4%
79.756	5.8%	0.4%
81.034	6.2%	0.4%
82.312	5.4%	0.3%
83.589	4.4%	0.3%
84.867	3.4%	0.2%
86.144	2.3%	0.1%
87.422	1.2%	0.1%
88.7	2.0%	0.1%
89.977	0.8%	0.0%
91.255	0.6%	0.0%
92.533	0.2%	0.0%
93.81	1.0%	0.0%
95.088	0.5%	0.0%
96.365	0.5%	0.0%
97.643	0.4%	0.0%
98.921	0.6%	0.0%
100.2	0.4%	0.0%
101.48	0.8%	0.0%
102.75	0.6%	0.0%
		3.0%



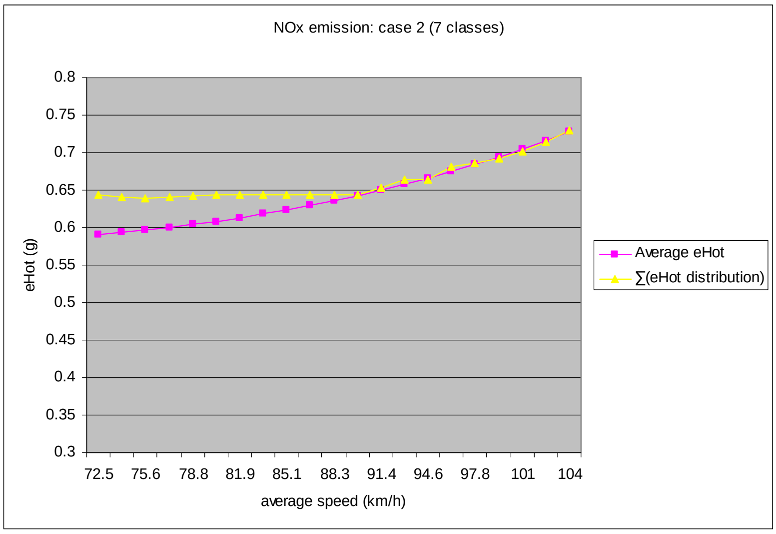
DOY246-E19

Average speed	deviation	weighted deviation
60.509	9.1%	0.6%
62.868	9.0%	0.6%
65.227	8.3%	0.5%
67.586	7.0%	0.5%
69.945	5.8%	0.4%
72.304	5.7%	0.4%
74.663	5.4%	0.4%
77.022	4.9%	0.3%
79.381	4.2%	0.3%
81.74	3.4%	0.2%
84.099	2.4%	0.1%
86.458	0.8%	0.0%
88.817	-0.2%	0.0%
91.176	0.3%	0.0%
93.535	-0.1%	0.0%
95.894	-0.4%	0.0%
98.253	-0.1%	0.0%
100.61	-0.1%	0.0%
102.97	-0.1%	0.0%
105.33	-0.1%	0.0%
107.69	0.4%	0.0%
		4.3%



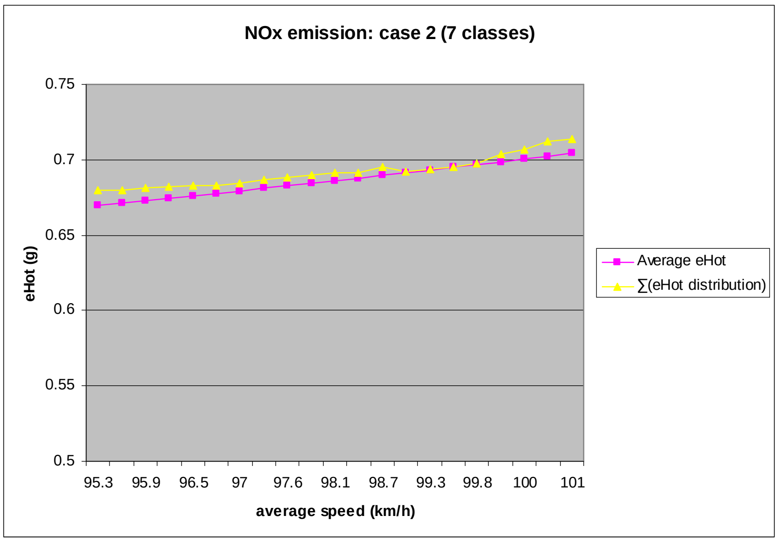
DOY1-Flanders

Average speed	deviation	weighted deviation
83.904	6.8%	0.5%
84.757	5.1%	0.4%
85.609	4.7%	0.3%
86.462	4.3%	0.3%
87.315	3.9%	0.3%
88.168	3.0%	0.2%
89.021	1.4%	0.1%
89.873	0.6%	0.0%
90.726	0.7%	0.0%
91.579	0.8%	0.0%
92.432	1.2%	0.1%
93.285	0.3%	0.0%
94.138	-0.1%	0.0%
94.99	-0.7%	0.0%
95.843	-0.9%	0.0%
96.696	0.7%	0.0%
97.549	0.6%	0.0%
98.402	0.2%	0.0%
99.254	1.3%	0.0%
100.11	1.2%	0.0%
100.96	1.2%	0.0%
		2.3%



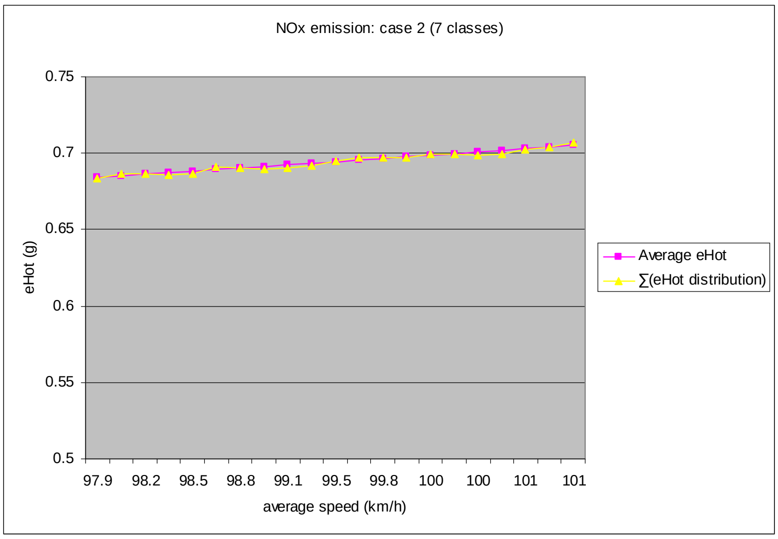
DOY1-E19

Average speed	deviation	weighted deviation
72.453	8.9%	0.6%
74.034	7.9%	0.5%
75.615	7.1%	0.5%
77.196	6.7%	0.4%
78.777	6.4%	0.4%
80.358	5.9%	0.3%
81.939	5.0%	0.3%
83.52	4.1%	0.2%
85.102	3.1%	0.2%
86.683	2.2%	0.1%
88.264	1.2%	0.1%
89.845	0.2%	0.0%
91.426	0.6%	0.0%
93.007	1.1%	0.1%
94.588	-0.3%	0.0%
96.169	1.1%	0.0%
97.751	0.3%	0.0%
99.332	-0.2%	0.0%
100.91	-0.3%	0.0%
102.49	-0.2%	0.0%
104.08	0.3%	0.0%
		3.8%



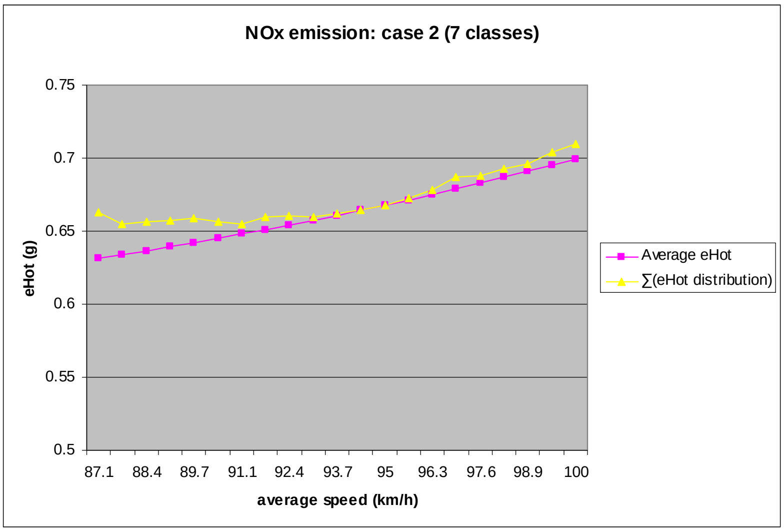
DOY7-Flanders

Average speed	deviation	weighted deviation
95.342	1.5%	0.1%
95.622	1.3%	0.1%
95.902	1.2%	0.1%
96.182	1.2%	0.1%
96.463	1.0%	0.1%
96.743	0.8%	0.1%
97.023	0.7%	0.0%
97.303	0.8%	0.0%
97.583	0.8%	0.0%
97.864	0.8%	0.0%
98.144	0.8%	0.0%
98.424	0.5%	0.0%
98.704	0.8%	0.0%
98.984	0.1%	0.0%
99.265	0.1%	0.0%
99.545	0.0%	0.0%
99.825	0.1%	0.0%
100.11	0.7%	0.0%
100.39	0.9%	0.0%
100.67	1.4%	0.0%
100.95	1.3%	0.0%
		0.8%



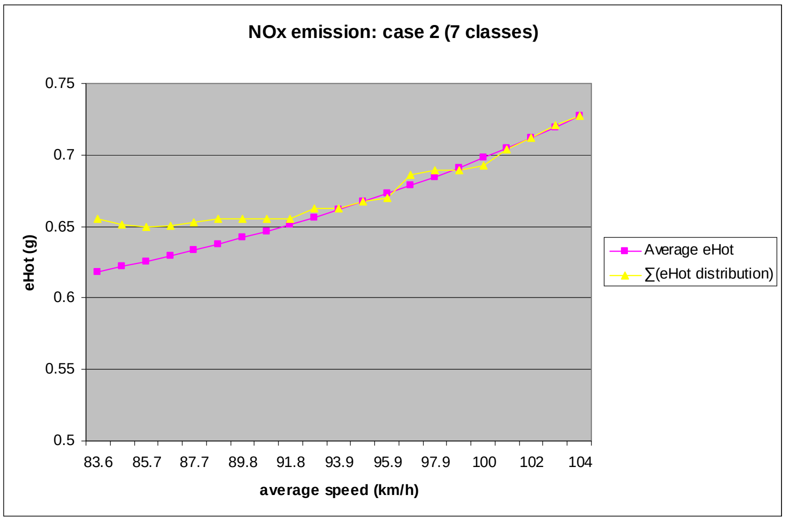
DOY7-E19

Average speed	deviation	weighted deviation
97.881	-0.1%	0.0%
98.039	0.2%	0.0%
98.198	0.0%	0.0%
98.356	-0.2%	0.0%
98.515	-0.2%	0.0%
98.673	0.2%	0.0%
98.831	0.0%	0.0%
98.99	-0.2%	0.0%
99.148	-0.2%	0.0%
99.307	-0.2%	0.0%
99.465	0.1%	0.0%
99.624	0.2%	0.0%
99.782	0.1%	0.0%
99.941	0.0%	0.0%
100.1	0.1%	0.0%
100.26	-0.1%	0.0%
100.42	-0.3%	0.0%
100.57	-0.3%	0.0%
100.73	0.0%	0.0%
100.89	0.0%	0.0%
101.05	0.2%	0.0%
		-0.1%



JAN-Flanders

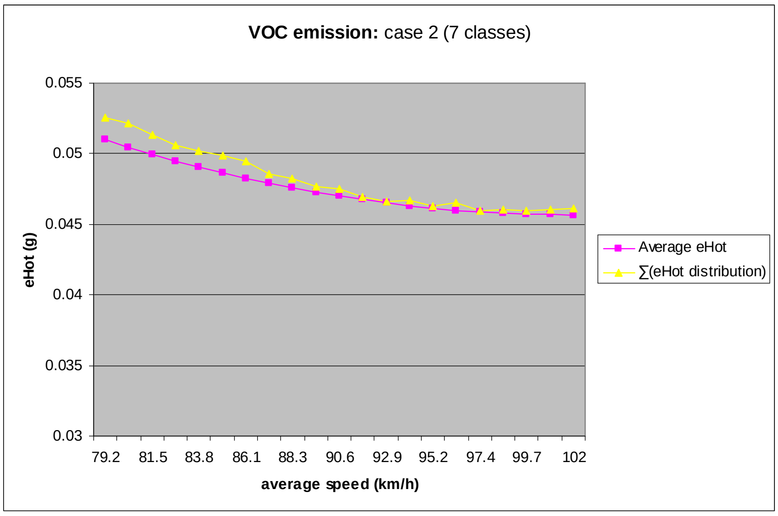
Average speed	deviation	weighted deviation
87.132	5.0%	0.4%
87.786	3.4%	0.2%
88.44	3.1%	0.2%
89.095	2.8%	0.2%
89.749	2.6%	0.2%
90.404	1.8%	0.1%
91.058	1.0%	0.1%
91.713	1.4%	0.1%
92.367	1.0%	0.1%
93.022	0.3%	0.0%
93.676	0.2%	0.0%
94.331	0.0%	0.0%
94.985	0.0%	0.0%
95.64	0.2%	0.0%
96.294	0.4%	0.0%
96.949	1.2%	0.0%
97.603	0.8%	0.0%
98.257	0.9%	0.0%
98.912	0.7%	0.0%
99.566	1.3%	0.0%
100.22	1.5%	0.0%
		1.6%



JAN-E19

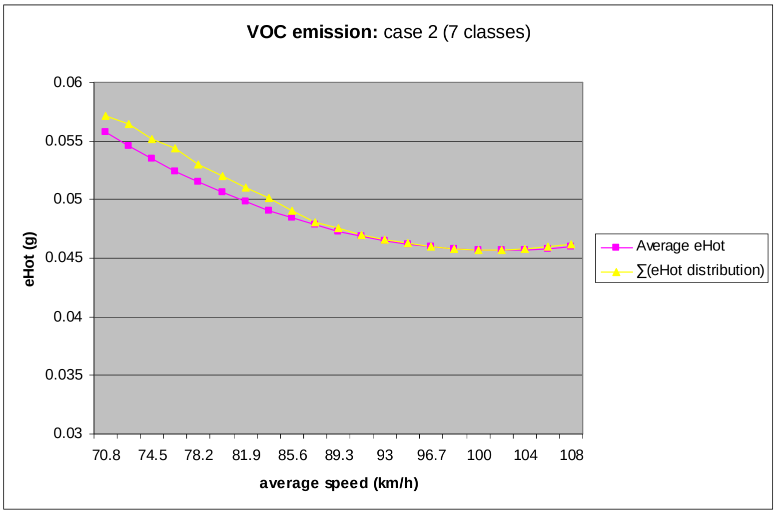
Average speed	deviation	weighted deviation
83.618	5.9%	0.4%
84.642	4.7%	0.3%
85.665	3.8%	0.3%
86.689	3.3%	0.2%
87.712	3.1%	0.2%
88.736	2.8%	0.2%
89.759	2.1%	0.1%
90.782	1.3%	0.1%
91.806	0.6%	0.0%
92.829	1.0%	0.0%
93.853	0.2%	0.0%
94.876	0.1%	0.0%
95.9	-0.4%	0.0%
96.923	1.1%	0.0%
97.946	0.6%	0.0%
98.97	-0.2%	0.0%
99.993	-0.8%	0.0%
101.02	-0.1%	0.0%
102.04	0.0%	0.0%
103.06	0.1%	0.0%
104.09	0.0%	0.0%
		1.9%

VOC Results



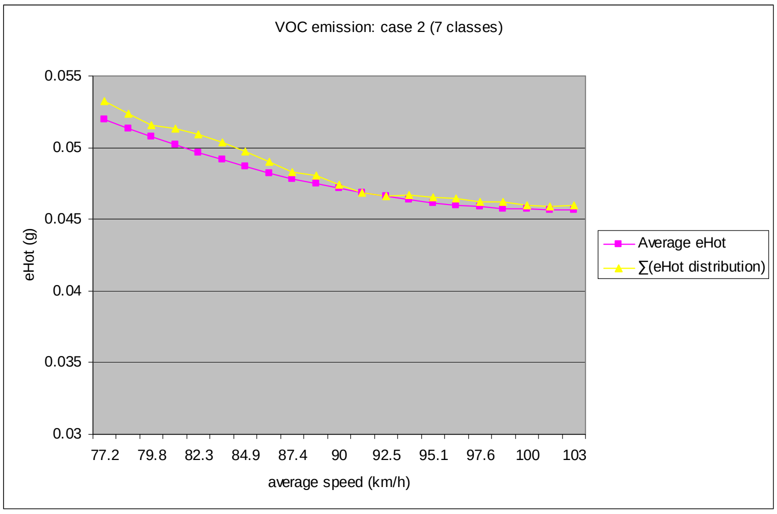
DOY64-Flanders

Average speed	deviation	weighted deviation
79.244	3.0%	0.24%
80.381	3.4%	0.26%
81.518	2.8%	0.21%
82.656	2.3%	0.16%
83.793	2.4%	0.16%
84.93	2.4%	0.16%
86.068	2.4%	0.14%
87.205	1.3%	0.06%
88.342	1.4%	0.05%
89.48	0.8%	0.02%
90.617	1.0%	0.01%
91.755	0.4%	0.02%
92.892	0.3%	0.02%
94.029	0.8%	0.07%
95.167	0.3%	0.02%
96.304	1.2%	0.03%
97.441	0.3%	0.01%
98.579	0.6%	0.01%
99.716	0.5%	0.01%
100.85	0.8%	0.00%
101.99	1.0%	0.01%
		1.7%



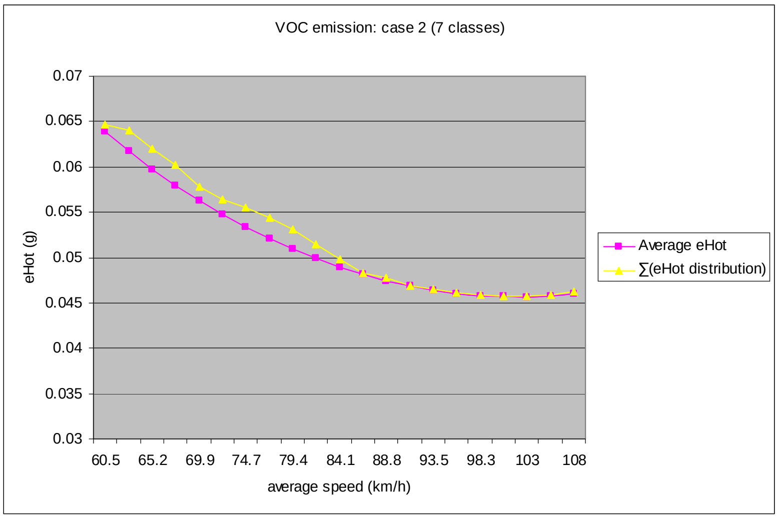
DOY64-E19

Average speed	deviation	weighted deviation
70.828	2.6%	0.2%
72.678	3.6%	0.2%
74.529	3.3%	0.2%
76.379	3.8%	0.2%
78.229	3.0%	0.2%
80.08	2.7%	0.2%
81.93	2.5%	0.1%
83.78	2.1%	0.1%
85.631	1.2%	0.1%
87.481	0.5%	0.0%
89.331	0.6%	0.0%
91.181	0.2%	0.0%
93.032	0.2%	0.0%
94.882	0.2%	0.0%
96.732	0.2%	0.0%
98.583	0.1%	0.0%
100.43	0.0%	0.0%
102.28	0.0%	0.0%
104.13	0.1%	0.0%
105.98	0.4%	0.0%
107.83	0.3%	0.0%
		1.7%



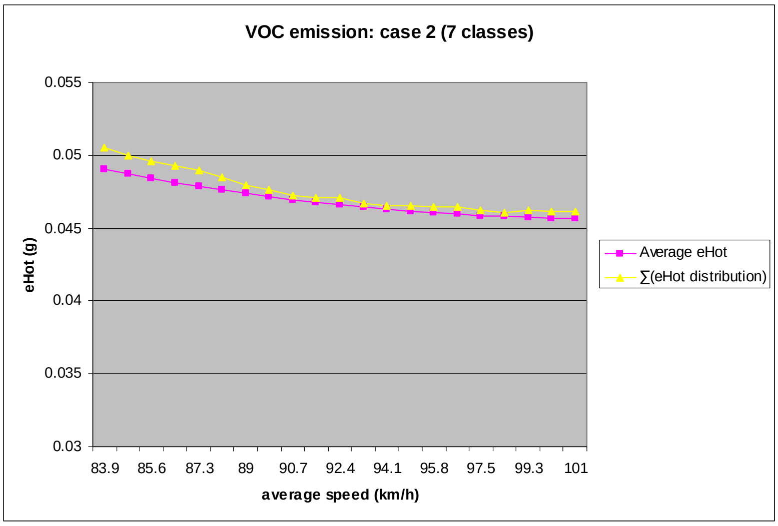
DOY246-Flander

Average speed	deviation	weighted deviation
77.201	2.4%	0.2%
78.479	2.0%	0.1%
79.756	1.6%	0.1%
81.034	2.3%	0.2%
82.312	2.6%	0.2%
83.589	2.5%	0.2%
84.867	2.1%	0.1%
86.144	1.6%	0.1%
87.422	1.0%	0.1%
88.7	1.2%	0.1%
89.977	0.5%	0.0%
91.255	0.1%	0.0%
92.533	0.1%	0.0%
93.81	0.7%	0.0%
95.088	0.8%	0.1%
96.365	1.0%	0.1%
97.643	0.8%	0.0%
98.921	1.0%	0.0%
100.2	0.6%	0.0%
101.48	0.6%	0.0%
102.75	0.6%	0.0%
		1.5%



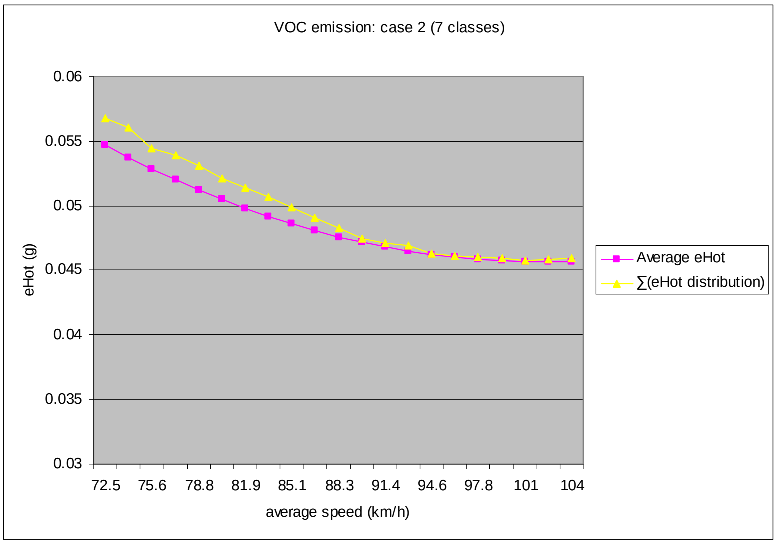
DOY246-E19

Average speed	deviation	weighted deviation
60.509	1.3%	0.1%
62.868	3.7%	0.2%
65.227	3.7%	0.2%
67.586	3.8%	0.3%
69.945	2.7%	0.2%
72.304	3.0%	0.2%
74.663	4.0%	0.3%
77.022	4.4%	0.3%
79.381	4.2%	0.3%
81.74	3.1%	0.2%
84.099	1.7%	0.1%
86.458	0.4%	0.0%
88.817	0.7%	0.0%
91.176	0.1%	0.0%
93.535	0.1%	0.0%
95.894	0.1%	0.0%
98.253	0.1%	0.0%
100.61	0.0%	0.0%
102.97	0.2%	0.0%
105.33	0.2%	0.0%
107.69	0.5%	0.0%
		2.4%



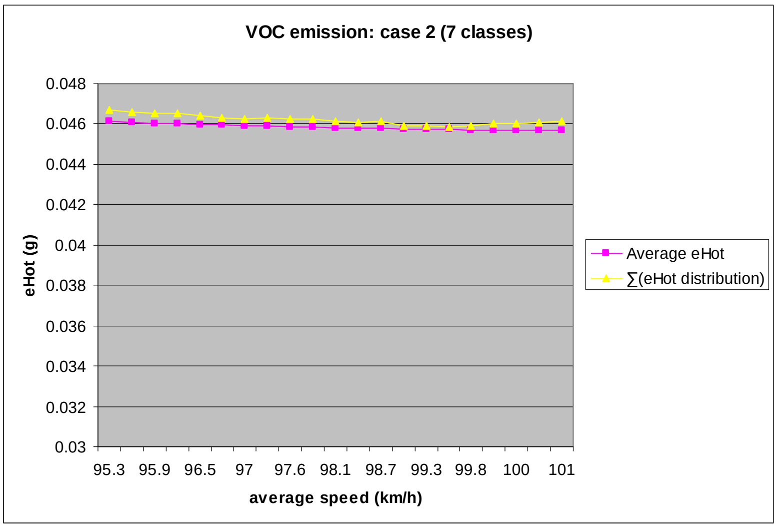
DOY1-Flanders

Average speed	deviation	weighted deviation
83.904	3.1%	0.2%
84.757	2.6%	0.2%
85.609	2.4%	0.2%
86.462	2.3%	0.2%
87.315	2.2%	0.2%
88.168	1.8%	0.1%
89.021	1.1%	0.1%
89.873	1.0%	0.0%
90.726	0.6%	0.0%
91.579	0.7%	0.0%
92.432	1.0%	0.1%
93.285	0.5%	0.0%
94.138	0.5%	0.0%
94.99	0.8%	0.0%
95.843	1.0%	0.0%
96.696	1.1%	0.0%
97.549	0.9%	0.0%
98.402	0.6%	0.0%
99.254	1.1%	0.0%
100.11	1.1%	0.0%
100.96	1.1%	0.0%
		1.5%



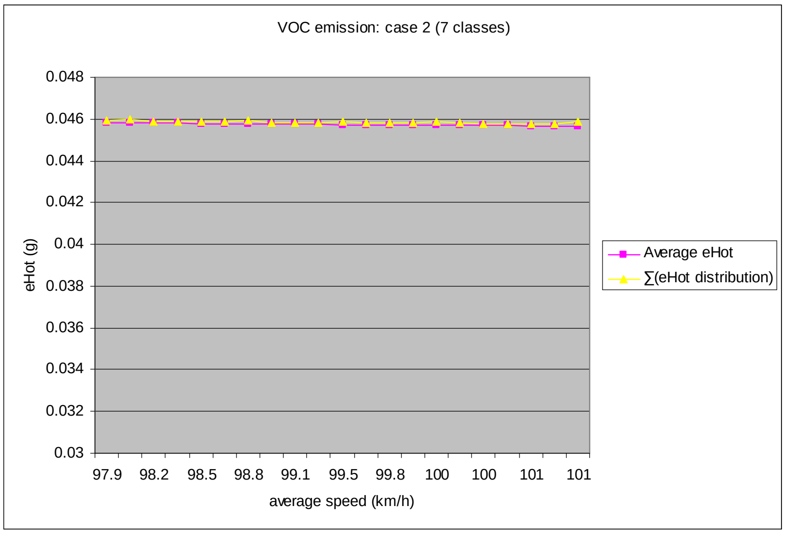
DOY1-E19

Average speed	deviation	weighted deviation
72.453	3.8%	0.3%
74.034	4.4%	0.3%
75.615	3.1%	0.2%
77.196	3.7%	0.2%
78.777	3.8%	0.2%
80.358	3.2%	0.2%
81.939	3.2%	0.2%
83.52	3.0%	0.2%
85.102	2.6%	0.1%
86.683	2.1%	0.1%
88.264	1.4%	0.1%
89.845	0.6%	0.0%
91.426	0.7%	0.0%
93.007	0.9%	0.1%
94.588	0.2%	0.0%
96.169	0.2%	0.0%
97.751	0.5%	0.0%
99.332	0.4%	0.0%
100.91	0.3%	0.0%
102.49	0.3%	0.0%
104.08	0.5%	0.0%
		2.3%



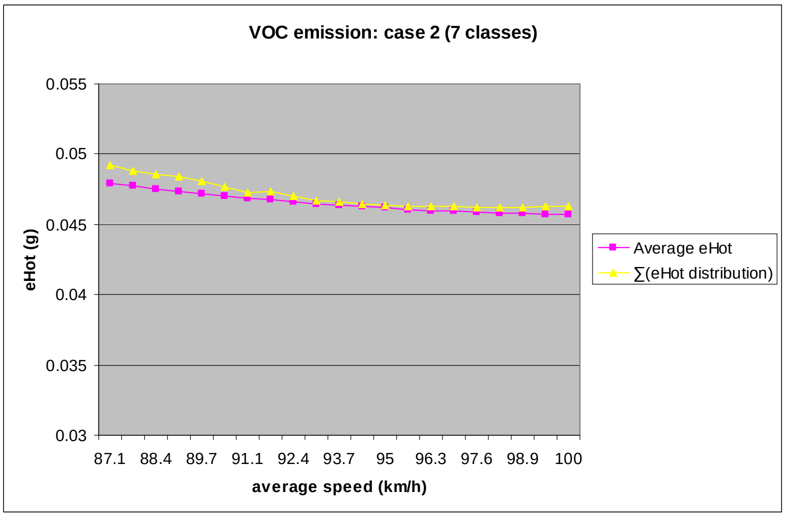
DOY7-Flanders

Average speed	deviation	weighted deviation
95.342	1.2%	0.1%
95.622	1.1%	0.1%
95.902	1.1%	0.1%
96.182	1.1%	0.1%
96.463	0.9%	0.1%
96.743	0.8%	0.1%
97.023	0.8%	0.1%
97.303	0.9%	0.0%
97.583	0.8%	0.0%
97.864	0.9%	0.0%
98.144	0.7%	0.0%
98.424	0.6%	0.0%
98.704	0.8%	0.0%
98.984	0.4%	0.0%
99.265	0.4%	0.0%
99.545	0.3%	0.0%
99.825	0.4%	0.0%
100.11	0.7%	0.0%
100.39	0.8%	0.0%
100.67	0.9%	0.0%
100.95	1.0%	0.0%
		0.8%



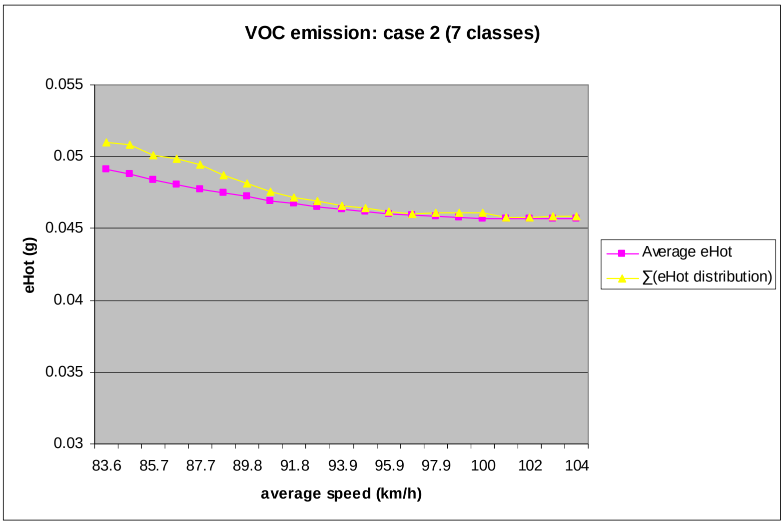
DOY7-E19

Average speed	deviation	weighted deviation
97.881	0.2%	0.0%
98.039	0.4%	0.0%
98.198	0.2%	0.0%
98.356	0.2%	0.0%
98.515	0.2%	0.0%
98.673	0.2%	0.0%
98.831	0.3%	0.0%
98.99	0.2%	0.0%
99.148	0.2%	0.0%
99.307	0.2%	0.0%
99.465	0.3%	0.0%
99.624	0.3%	0.0%
99.782	0.3%	0.0%
99.941	0.3%	0.0%
100.1	0.4%	0.0%
100.26	0.3%	0.0%
100.42	0.2%	0.0%
100.57	0.2%	0.0%
100.73	0.2%	0.0%
100.89	0.2%	0.0%
101.05	0.4%	0.0%
		0.2%



JAN-Flanders

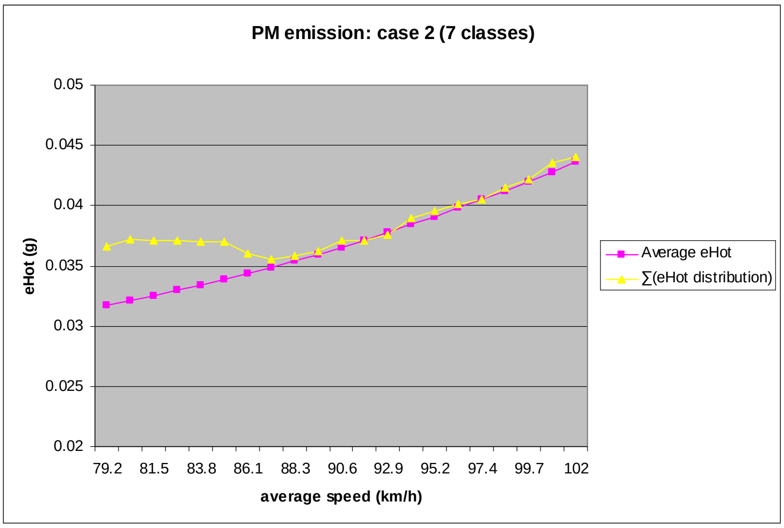
Average speed	deviation	weighted deviation
87.132	2.7%	0.2%
87.786	2.2%	0.1%
88.44	2.2%	0.1%
89.095	2.1%	0.1%
89.749	1.8%	0.1%
90.404	1.4%	0.1%
91.058	0.8%	0.0%
91.713	1.2%	0.1%
92.367	0.9%	0.1%
93.022	0.5%	0.0%
93.676	0.6%	0.0%
94.331	0.3%	0.0%
94.985	0.4%	0.0%
95.64	0.5%	0.0%
96.294	0.6%	0.0%
96.949	0.9%	0.0%
97.603	0.7%	0.0%
98.257	0.8%	0.0%
98.912	1.0%	0.0%
99.566	1.3%	0.0%
100.22	1.3%	0.0%
		1.2%



JAN-E19

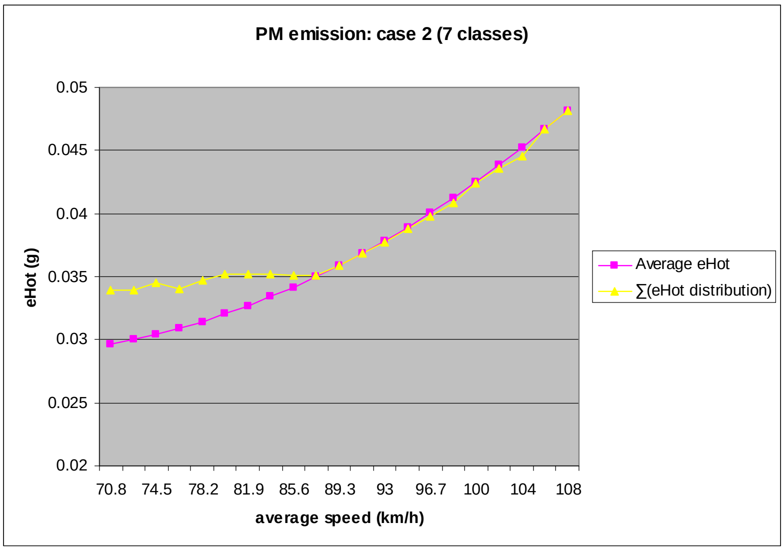
Average speed	deviation	weighted deviation
83.618	3.7%	0.3%
84.642	4.3%	0.3%
85.665	3.5%	0.2%
86.689	3.6%	0.2%
87.712	3.6%	0.2%
88.736	2.6%	0.2%
89.759	2.0%	0.1%
90.782	1.3%	0.1%
91.806	1.0%	0.1%
92.829	0.9%	0.0%
93.853	0.5%	0.0%
94.876	0.5%	0.0%
95.9	0.4%	0.0%
96.923	0.2%	0.0%
97.946	0.6%	0.0%
98.97	0.8%	0.0%
99.993	0.8%	0.0%
101.02	0.1%	0.0%
102.04	0.2%	0.0%
103.06	0.3%	0.0%
104.09	0.3%	0.0%
		1.9%

PM Results



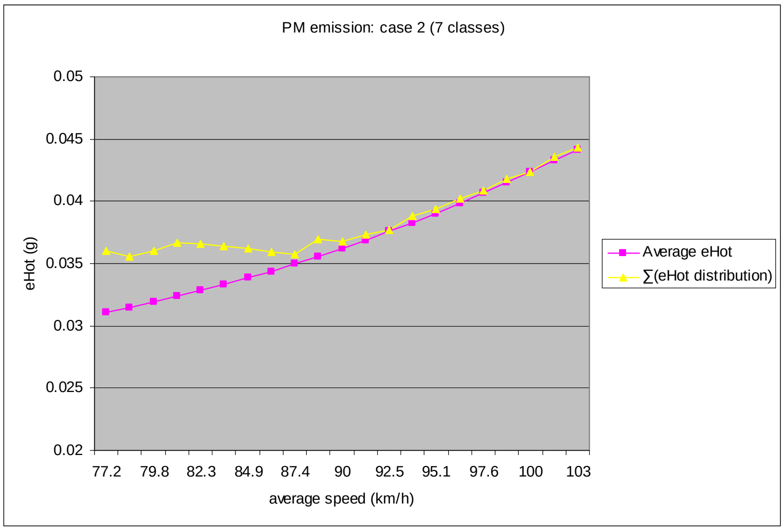
DOY64-Flanders

Average speed	deviation	weighted deviation
79.244	15.3%	1.20%
80.381	15.6%	1.20%
81.518	14.0%	1.05%
82.656	12.5%	0.89%
83.793	10.8%	0.75%
84.93	9.1%	0.60%
86.068	4.8%	0.28%
87.205	1.9%	0.10%
88.342	1.1%	0.04%
89.48	0.6%	0.01%
90.617	1.7%	0.02%
91.755	0.0%	0.00%
92.892	-0.5%	-0.03%
94.029	1.3%	0.11%
95.167	1.1%	0.08%
96.304	0.9%	0.02%
97.441	0.0%	0.00%
98.579	0.5%	0.01%
99.716	0.4%	0.01%
100.85	1.7%	0.01%
101.99	1.0%	0.01%
		6.4%



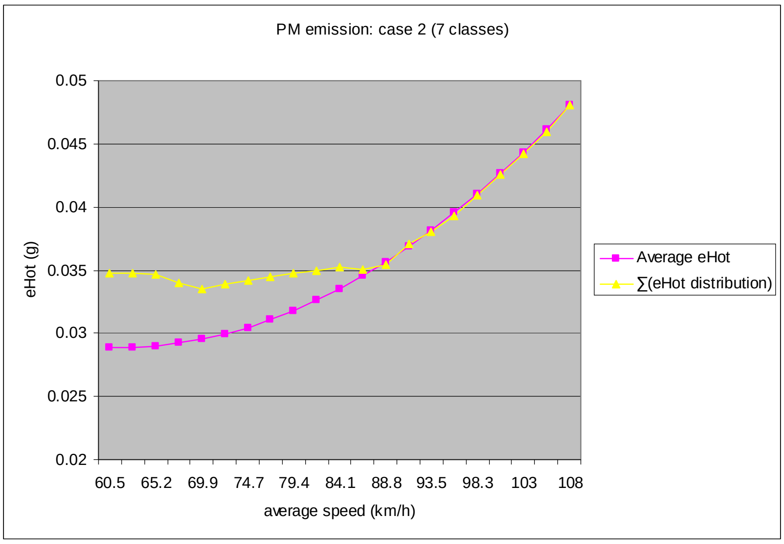
DOY64-E19

Average speed	deviation	weighted deviation
70.828	14.2%	1.1%
72.678	13.0%	0.9%
74.529	13.4%	0.9%
76.379	10.3%	0.6%
78.229	10.4%	0.7%
80.08	9.7%	0.6%
81.93	7.6%	0.4%
83.78	5.4%	0.3%
85.631	2.7%	0.1%
87.481	0.2%	0.0%
89.331	-0.1%	0.0%
91.181	0.1%	0.0%
93.032	-0.2%	0.0%
94.882	-0.3%	0.0%
96.732	-0.7%	-0.1%
98.583	-1.0%	-0.1%
100.43	-0.3%	0.0%
102.28	-0.7%	0.0%
104.13	-1.5%	0.0%
105.98	0.1%	0.0%
107.83	0.0%	0.0%
		5.6%



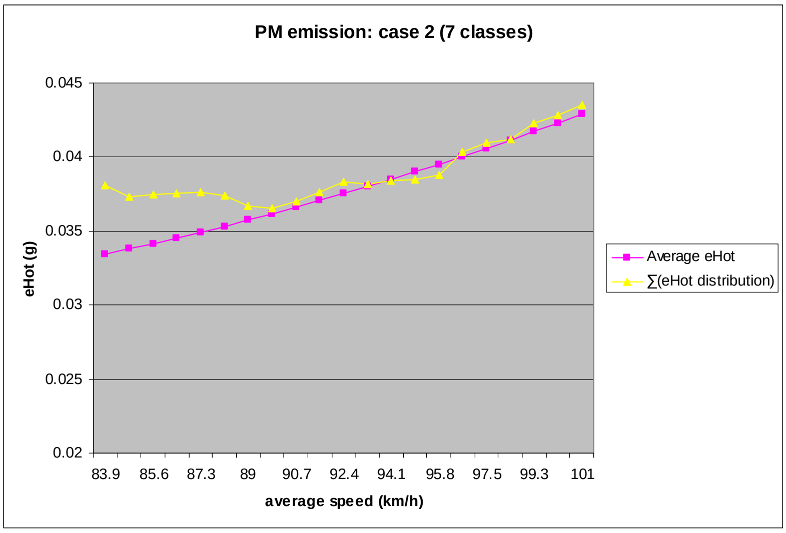
DOY246-Flanders

Average speed	deviation	weighted deviation
77.201	15.8%	1.1%
78.479	12.9%	0.9%
79.756	12.8%	0.9%
81.034	13.3%	0.9%
82.312	11.5%	0.7%
83.589	9.3%	0.6%
84.867	7.1%	0.4%
86.144	4.6%	0.3%
87.422	2.3%	0.1%
88.7	4.0%	0.2%
89.977	1.5%	0.0%
91.255	1.2%	0.0%
92.533	0.4%	0.0%
93.81	1.5%	0.0%
95.088	0.9%	0.1%
96.365	0.9%	0.1%
97.643	0.7%	0.0%
98.921	0.8%	0.0%
100.2	0.1%	0.0%
101.48	0.8%	0.0%
102.75	0.4%	0.0%
		6.4%



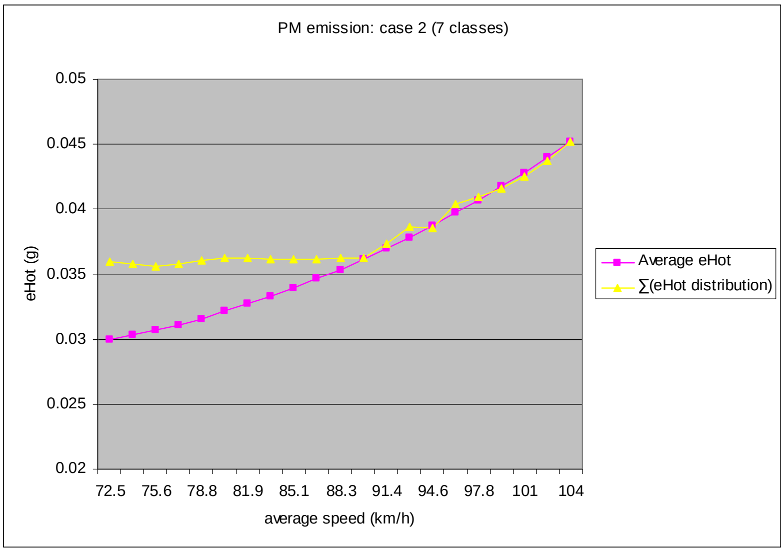
DOY246-E19

Average speed	deviation	weighted deviation
60.509	20.3%	1.4%
62.868	20.3%	1.3%
65.227	19.3%	1.2%
67.586	16.1%	1.1%
69.945	13.5%	0.9%
72.304	13.1%	0.9%
74.663	12.3%	0.8%
77.022	11.0%	0.7%
79.381	9.3%	0.6%
81.74	7.1%	0.4%
84.099	5.0%	0.3%
86.458	1.6%	0.1%
88.817	-0.6%	0.0%
91.176	0.5%	0.0%
93.535	-0.3%	0.0%
95.894	-0.7%	0.0%
98.253	-0.2%	0.0%
100.61	-0.2%	0.0%
102.97	-0.3%	0.0%
105.33	-0.3%	0.0%
107.69	0.0%	0.0%
		9.7%



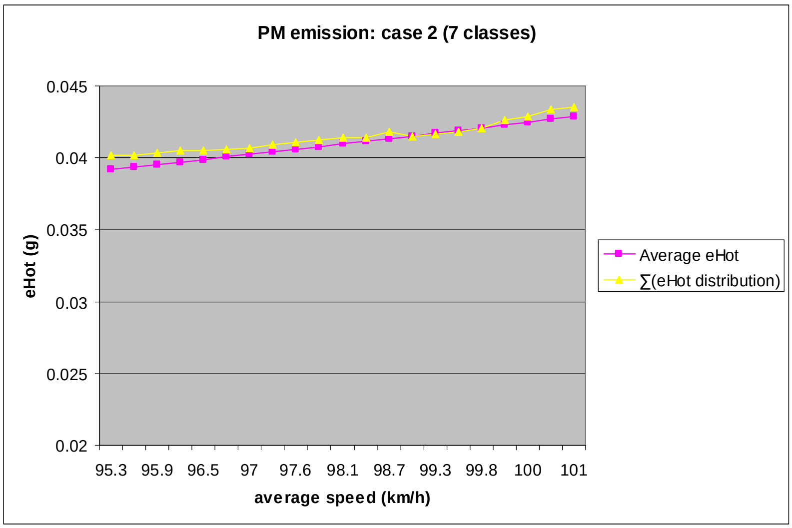
DOY1-Flanders

Average speed	deviation	weighted deviation
83.904	13.9%	1.1%
84.757	10.5%	0.8%
85.609	9.6%	0.7%
86.462	8.7%	0.6%
87.315	7.8%	0.5%
88.168	5.9%	0.4%
89.021	2.6%	0.2%
89.873	1.1%	0.0%
90.726	1.1%	0.0%
91.579	1.5%	0.1%
92.432	2.2%	0.2%
93.285	0.5%	0.0%
94.138	-0.3%	0.0%
94.99	-1.4%	-0.1%
95.843	-1.8%	0.0%
96.696	0.7%	0.0%
97.549	1.0%	0.0%
98.402	0.2%	0.0%
99.254	1.5%	0.0%
100.11	1.3%	0.0%
100.96	1.6%	0.0%
		4.6%



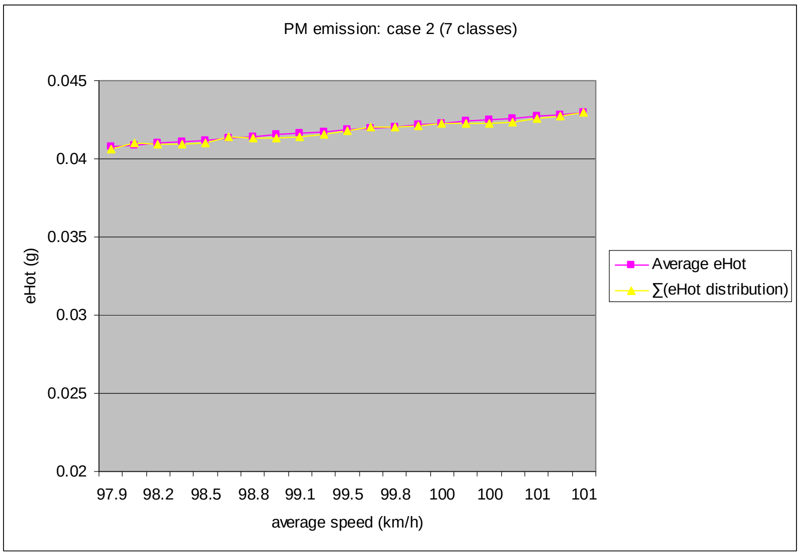
DOY1-E19

Average speed	deviation	weighted deviation
72.453	20.1%	1.4%
74.034	17.9%	1.2%
75.615	15.9%	1.1%
77.196	14.9%	1.0%
78.777	14.1%	0.9%
80.358	12.7%	0.8%
81.939	10.7%	0.6%
83.52	8.6%	0.5%
85.102	6.5%	0.3%
86.683	4.4%	0.2%
88.264	2.4%	0.1%
89.845	0.3%	0.0%
91.426	1.0%	0.0%
93.007	2.0%	0.2%
94.588	-0.6%	0.0%
96.169	1.8%	0.0%
97.751	0.5%	0.0%
99.332	-0.4%	0.0%
100.91	-0.7%	0.0%
102.49	-0.6%	0.0%
104.08	0.1%	0.0%
		8.3%



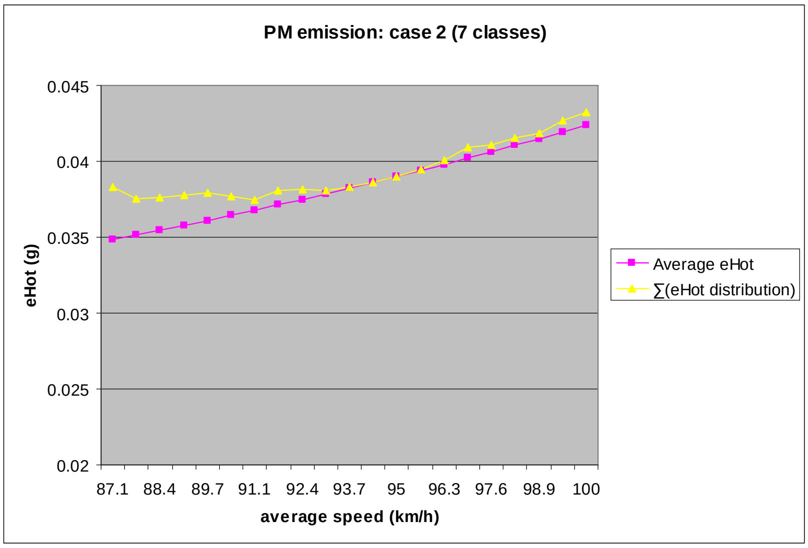
DOY7-Flanders

Average speed	deviation	weighted deviation
95.342	2.4%	0.2%
95.622	2.1%	0.2%
95.902	2.0%	0.1%
96.182	1.9%	0.1%
96.463	1.6%	0.1%
96.743	1.2%	0.1%
97.023	1.0%	0.1%
97.303	1.2%	0.1%
97.583	1.2%	0.0%
97.864	1.2%	0.0%
98.144	1.1%	0.0%
98.424	0.7%	0.0%
98.704	1.2%	0.0%
98.984	0.0%	0.0%
99.265	-0.1%	0.0%
99.545	-0.1%	0.0%
99.825	0.0%	0.0%
100.11	0.7%	0.0%
100.39	0.9%	0.0%
100.67	1.7%	0.0%
100.95	1.4%	0.0%
		1.1%



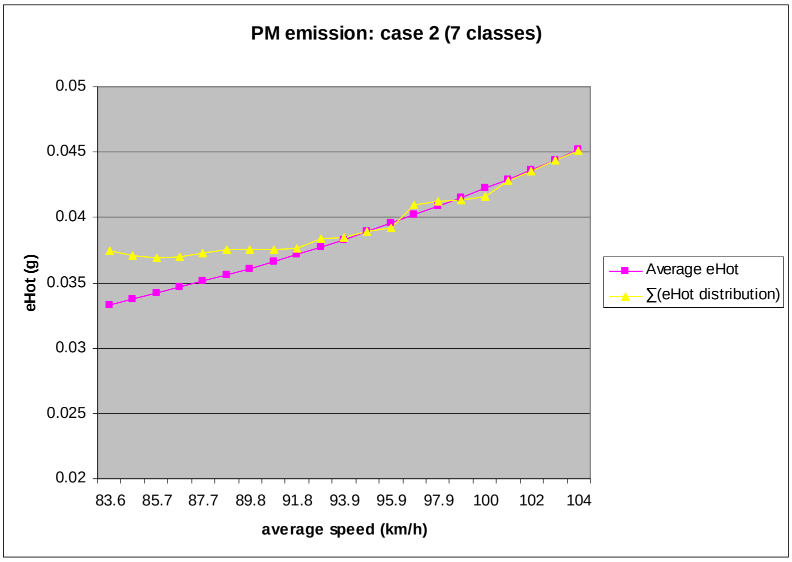
DOY7-E19

Average speed	deviation	weighted deviation
97.881	-0.3%	0.0%
98.039	0.2%	0.0%
98.198	-0.1%	0.0%
98.356	-0.4%	0.0%
98.515	-0.4%	0.0%
98.673	0.3%	0.0%
98.831	-0.1%	0.0%
98.99	-0.5%	0.0%
99.148	-0.5%	0.0%
99.307	-0.4%	0.0%
99.465	-0.1%	0.0%
99.624	0.3%	0.0%
99.782	0.0%	0.0%
99.941	-0.2%	0.0%
100.1	0.1%	0.0%
100.26	-0.3%	0.0%
100.42	-0.6%	0.0%
100.57	-0.7%	0.0%
100.73	-0.2%	0.0%
100.89	-0.1%	0.0%
101.05	0.1%	0.0%
		-0.2%



JAN-Flanders

Average speed	deviation	weighted deviation
87.132	10.0%	0.7%
87.786	6.7%	0.5%
88.44	6.1%	0.4%
89.095	5.6%	0.4%
89.749	5.0%	0.3%
90.404	3.4%	0.2%
91.058	1.9%	0.1%
91.713	2.5%	0.2%
92.367	1.8%	0.1%
93.022	0.5%	0.0%
93.676	0.3%	0.0%
94.331	-0.1%	0.0%
94.985	0.0%	0.0%
95.64	0.3%	0.0%
96.294	0.7%	0.0%
96.949	1.8%	0.0%
97.603	1.2%	0.0%
98.257	1.3%	0.0%
98.912	0.9%	0.0%
99.566	1.8%	0.0%
100.22	2.0%	0.0%
		3.0%



JAN-E19

Average speed	deviation	weighted deviation
83.618	12.4%	0.9%
84.642	9.7%	0.7%
85.665	7.8%	0.5%
86.689	6.7%	0.4%
87.712	6.2%	0.4%
88.736	5.6%	0.3%
89.759	4.1%	0.3%
90.782	2.5%	0.2%
91.806	1.2%	0.1%
92.829	1.8%	0.1%
93.853	0.3%	0.0%
94.876	0.1%	0.0%
95.9	-0.9%	0.0%
96.923	1.9%	0.0%
97.946	1.0%	0.0%
98.97	-0.5%	0.0%
99.993	-1.5%	0.0%
101.02	-0.3%	0.0%
102.04	-0.2%	0.0%
103.06	0.0%	0.0%
104.09	-0.2%	0.0%
		3.9%