PROPER PROJECT
WP1 - PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF
Task 1.5. State of the art of models used for emission calculations and air quality assessment

Conference of European Directors of Roads (CEDR)

Utrecht, October 2018

DELIVERABLE 1.5

Title

PROPER PROJECT - WP1.PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF
Task 1.5. State of the art of models used for emission calculations and air quality assessment

Authorship and institution

RIANNE DRÖGE (TNO)

ROMAN LICBINSKY (CDV)

JAN HULSKOTTE (TNO)

SANDER JONKERS (TNO)

LEOS PELIKAN (CDV)

PROPER PROJECT - WP1.PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF

T 1.5. State of the art of models used for emission calculations and air quality assessment

Abstract

This reports represents project deliverable 1.5 and concerns the results from task 1.5 of the Proper Project – State of the art of models used for emission calculations and air quality assessment. A large variety in regional and national scale models for emissions and air quality calculations is available. The emission and air quality models described in this deliverable are more advanced than most runoff models. Runoff models are often regression models, which are developed for a specific region, while air quality models are based on physical atmospheric processes.

Emission models can be applied for calculating the pollutant load in surface waters. For this goal, the emission model should mainly focus on tyre, brake and road wear, because these particles relatively large and will be deposited on or near the road

A potential large part (>50%) of the pollutants could be transported to the road side environment via drift and spray at specific conditions. Deposition of particles in the road side environment can be calculated, but to include deposition in air quality models would be very difficult.

Keywords: Road runoff, emission models, air quality models, review

Table of contents

List of Figures

List of tables

Acronyms and glossary

AD	Activity data
ADMS	Atmospheric Dispersion Modelling System
AFOLU	Agriculture, Forestry and Other Land Use sector
ARTEMIS	Assessment and Reliability of Transport Emission Models and Inventory Systems
As	Arsenic
Cd	Cadmium
CDV	Transport Research Centre,Czech Republic (Centrum dopravního výzkumu)
CENIA	Czech Environmental Information Agency
CH4	Methane
CLRTAP	Convention on Long-Range Transboundary Air Pollution (UN ECE)
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO2	Carbon dioxide
COPERT	Computer Programme to calculate Emissions from Road Transport
Cr	Chromium
CS	Country Specific
Cu	Copper
CZ	Czech Republic
CzSO	Czech Statistical Office
DPF	Diesel Particulate Filter
EEA	European Environment Agency
EF	Emission factor
EIG	Emission Inventory Guidebook
EMEP	European Monitoring and Evaluation Programme
FCEV	Fuel Cell Electric Vehicle
FOEFL	Swiss Environmental, Forest and Landscape Protection Agency
GDI	Gasoline Direct Injection
HBEFA	Handbook of Emission Factors for road transport
HDT	Heavy duty truck loading

HDV	Heavy duty vehicle
Hg	Mercury
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre of the European Commission
kt	Kiloton
LDV	Light duty vehicle
LPG	Liquified Petroleum Gas
LRTAP	Long-Range Transboundary Air Pollution
MoE	Ministry of the Environment of the Czech Republic
MoT	Ministry of Transport of the Czech Republic
N/A	Not available
N2O	Dinitrogen oxide
NH3	Ammonia
Ni	Nickel
NMVOC	Non methane volatile organic compounds
NNM	New National Model (Netherlands)
NO	Nitrogen oxide
NO2	Nitrogen dioxide
NOx	Nitrogen oxides
NR	Not relevant
OSPM	Operational Street Pollution Model
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead
PC	Passenger car
PCDD	Polychlorinated dibenzodioxins
PCDF	Polychlorinated dibenzofurans
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate Matter
PM10	Particulate Matter smaller than 10 micrometer
PN	Particle number

SCR	Selective Catalytic Reduction
SO2	Sulphur dioxide
SYMOS	Stationary Sources Modelling System (Czech Republic)
TSP	Total Suspended Particles
TÜV UVMV	Motor Vehicle Research Institute in Czech Republic
UBA	German Environmental Protection Agency
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
vkm	Vehicle kilometer
VOC	Volatile Organic Compounds
Zn	Zinc

1 Introduction

The increasing environmental burden associated with transportation is most commonly spoken about in relation to air pollution and the significant risks this poses to human health. Atmospheric emissions from vehicle engines are caused by exhaust gases formed during the fuel combustion. They are complex mixtures containing hundreds of chemical substances in various concentrations contributing to atmospheric pollution and to the so called "greenhouse effect", often with toxic, mutagenic and carcinogenic effects on humans. A specific pollutant is particulate matter (PM) generated by both combustion processes and the mechanical abrasion of pavement, tyres, brake lining and corrosion of car bodies and road infrastructure (guardrails, traffic signs etc.). All of these processes can also lead to the pollution of runoff waters (with heavy metals, polyaromatic hydrocarbons etc. which make-up or are associated with the generated PM).

Surface waters are loaded with traffic-related pollutants via several pathways: runoff, splash/spray and dispersion. De Best (2002) studied the amount of pollutants that are removed from a road via runoff and via drift. Of the measured roads, 46-92 % of the pollutants from traffic and roads are removed from the roads via drift, while 8-54 % of the pollutants are removed from the road via runoff. Boller et al. (2006) reported that 36 % of water is removed from a road via runoff and 64 % is removed via drift and spray. The POLMIT-model (POLMIT, 2002) estimates 35 % of the pollutants from traffic and roads to be transported by run-off. The other fraction of 65 % probably is re-emitted by air. Based on these studies, drift and spray could be a significant pathway to move pollutants from the road to a nearby surface water body. Pollutants transport in run-off waters as an important pathway of environment contamination was described theoretically by Folkeson et al. (2009).

Models to calculate atmospheric emissions and concentrations are more advanced than runoff models. Atmospheric emissions and concentration models are based on physical processes, while most runoff models are analytical or regression models based on monitoring data. Possibly, methods from atmospheric emission and concentration models could be used to improve runoff models. This report will provide an overview of a selection of atmospheric emission and concentration models. The selected models are widely used European models, and country-specific models for 2 countries in Europe.

Traffic related atmospheric emissions are calculated using specific software and applications of which COPERT 5 (www.copert.emisia.com) is the most often used, but some countries use their own emission models for road transport. Data on emission factors to soil (and water) of road traffic for brakes, tyres and road abrasion as reported in several national emission inventories are described in chapter 2.

Several air quality models are used to predict atmospheric concentrations and compare this to air quality standards and limit values or develop and test policy and action plans for air quality improvement at scales from street level (hotspots) to urban areas as well as rural road networks including e.g. ADMS Urban (CERC, 2013) and some national ones such as the Czech model SYMOS '97 or the Dutch model NNM (see paragraphs 3.2.3 and 3.2.4). However, to assess the atmospheric concentration in connection with possible runoff contamination, more specific applications should be used if available. The dispersion and deposition of particulate matter depends on particle sizes, meteorological circumstances and land use. Air quality models in connection to road runoff contamination is described in chapter 3.

2 Emission models

2.1 Introduction

For atmospheric emission inventories in Europe, emissions are calculated by each European country following the 'Guidelines for Reporting Emissions and Projections Data' set out under the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP).

Multiple emission models exist to calculate atmospheric emissions of traffic. Some of the emission models can also be used to predict the pollution concentration and load in road runoff. Depending on vehicle mileage of different vehicle types, the emissions of particulate matter from non-exhaust emission sources (e.g. tyre, brake and road wear) can be calculated. COPERT 5 is the most common traffic emission model, but some countries use their own emission models for road transport.

This chapter will provide a description of emission models and relevant PM emission factors (to soil and water), namely:

(i) EMEP/EEA Emission Inventory Guidebook (subchapter 2.2);
(ii) COPERT 5 (subchapter 2.3);
(iii) country specific emission models (subchapter 2.4).

The following terms are used to define the emissions from road transport:

- Atmospheric emissions: Part of the total emissions that ends up in the atmosphere
- Emissions to water and soil: Part of the total emissions that ends up in surface water and soil
- Exhaust emissions: Atmospheric emissions of particulate matter (PM_{10}), nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and carbon dioxide (CO_2), caused by the combustion of fuels
- Gasoline evaporation: Atmospheric emissions of NMVOC from the evaporation of gasoline
- Wear from tyres/brakes/roads: Total wear of tyres/brakes/roads, including both the part that is released to the atmosphere and the part that ends up on the road, in the soil and in surface waters

2.2 EMEP/EEA Emission Inventory Guidebook

2.2.1 Description of the emission calculation guidance in the EMEP/EEA Emission Inventory Guidebook

The EMEP/EEA Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2016) provides the guidance how to calculate national (atmospheric) emissions of NO_x, PM, CO, NMVOC, NH_3, PAH and metals. For each sector, this Guidebook contains a description of the sector, including a description of different techniques that could influence the emissions. This Guidebook also contains a description of the methodology.

The EMEP/EEA Guidebook contains all information that can be used to build a model to calculate the emissions from road transport in a country. This Guidebook does not include a spreadsheet or program that can be used directly to calculate the emissions. A model that is related to the guidance in the EMEP/EEA Guidebook (EMEP/EEA, 2016), and that could be used directly, is COPERT 5 (see subchapter 2.3)

The methodology paragraph of each chapter of the EMEP/EEA Guidebook begins with a decision tree, which indicates which method should be used to calculate the emissions from a specific emission source. All decision trees show more or less the same steps, stating that a country should use the most advanced emission calculation available. Only if no advanced methodology is available and the category is not a key source, then a simple methodology can be used. Figure 1 shows the decision tree for exhaust emissions from road transport in the EMEP/EEA Guidebook (EMEP/EEA, 2016).

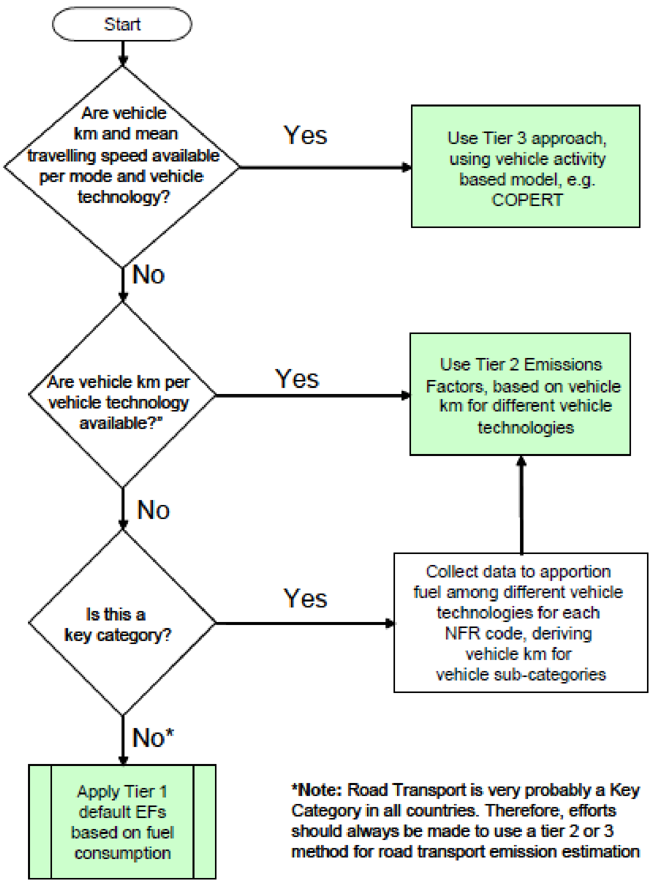

Figure 1 Decision tree to decide which method needs to be used for calculating the exhaust emissions from road transport (figure 3-1 of chapter 1.A.3.b.i-iv of the EMEP/EEA Guidebook (EMEP/EEA, 2016)

The type of input data depends on the method that is used to calculate the emissions. Depending on the data and technology available, three types of methodologies are described in the EMEP/EEA Guidebook (as in Figure 1):

- Tier 1: A simple methodology where total mileage is multiplied with a default emission factor. Input data consist of the amount of vehicle kilometres for four types of vehicles and four types of fuels separately.
- Tier 2: A technology specific methodology where mileage is multiplied with technology specific emission factors. Input data consist of the amount of vehicle kilometres for six types of vehicles, four types of fuels and all the Euro classes separately.
- Tier 3: Detailed methodology, including technical data, effect of cold starts, distinction in urban, rural and highway driving, average speed, aging of vehicles, etc. This includes the use of COPERT 5 or the use of a country-specific model. See subchapters 2.3 and 2.4 for more details on input data.

The EMEP/EEA Guidebook (EMEP/EEA, 2016) provides emission factors for calculating atmospheric emissions from many sources, including the 95% confidence interval of these emission factors. It contains three chapters emissions from road transport sources:

- 1.A.3.b.i-iv Exhaust emissions (NO_x, PM, CO, NMVOC, NH_3, PAH and lead),
- 1.A.3.b.v Gasoline evaporation (NMVOC),
- 1.A.3.b.vi-vii Road, tyre and brake wear (PM and metals)

Exhaust emissions and gasoline evaporation will mainly result in a release of pollutants to the atmosphere. Road, tyre and brake wear will end up in the atmosphere and on the road surface. Part of these emissions from road, tyre and brake wear will be released to surface waters.

Input data to calculate emissions using the EMEP/EEA Guidebook (EMEP/EEA, 2016) are:

- Vehicle category (passenger cars, light-duty vehicles, heavy-duty vehicles, busses, mopeds, motorcycles)
- Engine characteristics (2-stroke, 4-stroke, cylinder size)
- Fuel type
- Technology / Legislation classes

The emission factors provided in the EMEP/EEA Guidebook (EMEP/EEA, 2016) are used to calculate national emissions from road transport. The emission factors may not be applicable to a specific road, because emissions also depend on the other road and traffic related factors, due to the speed and congestion, braking, accelerating and cornering, type of asphalt, etc. In case these emission factors are used to calculate the emissions of one specific road, then it is necessary to check the applicability of these emission factors for this specific situation.

2.2.2 Relevance for traffic related emissions to surface water

Exhaust emissions and gasoline evaporation are mainly relevant for atmospheric emissions, while emissions of wear are also relevant for emissions to surface water. The current subchapter provides a short description of the tyre/brake/road wear emissions and their relevance for surface water.

Most of scientific work on particles released by road traffic has been directed on atmospheric emissions especially of exhaust gases. Atmospheric emissions of wear related processes have been studied much less. Wear related particles releases concerning most of the total mass possesses typical sizes that causes these particles to be deposited on or very near to roads.

Tyre wear, road wear and brake wear emissions are calculated by multiplying the amount of vehicle kilometres with emission factors. The input data consist of the amount of vehicle kilometres per vehicle type (passenger cars, light duty vehicles and heavy duty vehicles separately).

Tyre wear

Total wear factors and atmospheric emission factors from tyre wear presented in the EMEP/EEA Guidebook (EMEP/EEA, 2016):

- Total wear factors from tyre wear:
  - Passenger cars and light duty vehicles: 4 – 500 mg/vkm (with an outlier up to 100,000 mg/vkm) with an average of 100 mg/vkm. The differences are caused by driving behaviour, types of tyres, and road type. Urban driving causes more wear than rural/highway driving, due to braking, accelerating and cornering.
  - Heavy duty vehicles: 136-1403 mg/vkm
- Atmospheric emission factors from tyre wear:
  - Passenger cars: 10.7 mg/vkm
  - Light duty vehicles: 16.9 mg/vkm
  - Heavy duty vehicles: 22.7-89.8 mg/vkm

There is a large difference between the total wear factors and the atmospheric emission factors. A large proportion of the total wear is not emitted to the atmosphere, but will end up on the road, in the soil and in surface water. On average, 10-20% of the wear emissions is emitted to the atmosphere, indicating that 80-90% of the wear emissions will end up on the road, in the soil and in surface waters.

Brake wear

Total wear factors and atmospheric emission factors from brake wear presented in the EMEP/EEA Guidebook (EMEP/EEA, 2016):

- Total wear factors from brake wear:
  - Passenger cars: 8.8-20 mg/vkm,
  - Light duty vehicles: 29 mg/vkm,
  - Heavy duty vehicles and trucks: 29-84 mg/vkm,
  - Buses: 110 mg/vkm
- Atmospheric emission factors from brake wear:
  - Passenger cars: 7.5 mg/vkm
  - Light duty vehicles: 11.7 mg/vkm
  - Heavy duty vehicles: 23.5-42.0 mg/vkm

On average, 50% of the wear emissions is emitted to the atmosphere, indicating that 50% of the wear emissions will end up on the road, in the soil and in surface waters.

Road surface wear

Total wear factors and atmospheric emission factors from road wear presented in the EMEP/EEA Guidebook (EMEP/EEA, 2016):

- Total wear factors from road wear:
  - 3.8 mg/vkm – 24 g/vkm, depending in the type of asphalt (bitumen content), type of vehicles, use of studded tyres, salting and climate variables
- Atmospheric emission factors from road surface wear:
  - Passenger cars: 15.0 mg/vkm
  - Light duty vehicles: 15.0 mg/vkm
  - Heavy duty vehicles: 76.0 mg/vkm

The atmospheric emission factors (EFs) do not include the influence of studded tyres. If studded tyres are excluded from the total wear EFs, then the total wear factors vary between 3.8 mg/vkm and 440 mg/vkm. The range in wear factors is rather large, but on average, approximately 10% of the road surface wear is estimated to be airborne. The remaining 90% of the road surface wear will end up on the roads, in the soils and in surface waters.

2.3 COPERT

2.3.1 program COPERT

COPERT is a MS Windows program, the development of which has been funded since 2007 by the European Environmental Agency (EEA) under the activities of the European Topic Centre and the Air and Climate Change Project. However, the program has been in development since 1988. This program is designed to enable national experts to model emissions from road transport, a category of emissions which must be included in the annual United Nations Framework Convention on Climate Change (UNFCCC) data submissions. The use of COPERT enables a consistent, transparent and comparable calculation in line with all the requirements of international conventions and European legislation. Activity data will be used to calculate in the most up-to-date version of COPERT 5 software.

COPERT is recommended by the EEA and uses emission factors from combustion processes in road transport according to the European methodology EMEP/EEA Guidebook (EMEP/EEA, 2016) and 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

These methodologies were developed on the basis of the Convention on Long-Range Transboundary Air Pollution (CLRTAP) and Regulation No 525/2013/EU of the European Parliament and of the Council on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC.

COPERT (COmputer Program to calculate Emissions from Road Transport) was developed by EMISIA S.A. (Greece) for the EEA. This will ensure that the requirements of CLRTAP and Regulation No 525/2013/EU of the European Parliament and of the Council on a mechanism for monitoring and reporting greenhouse gas emissions, and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC, are complied with.

The main benefits of COPERT are:

- calculation of emissions for up to 447 vehicle categories
- allows fuel evaporation from the tank to be calculated
- takes into account 3 types of traffic environments (urban/rural/highway)
- implements emission factors from European methodologies
- is supported by the EEA

2.3.2 Starting point of COPERT

The history of the COPERT program dates back to 1988. Since then, it has been updated many times; the current version is COPERT 5. The program is based on the outputs of several major research projects including:

- **MEET** (Methodologies to Estimate Emissions from Transport), 1996 – 1998 (TRL, 1999). The project focused on the research of all contemporary combustion technologies in all categories of road vehicles, but also on rail, water and air transport. It defines emission factors for cold starts, evaporation,slope effects and vehicle loading.
- **PARTICULATES** (Characteristics of Exhaust Particulate Emissions from Road Vehicles), 2000 – 2003 (Samaras, et al., 2005). The study focused on emission factors and composition of solid particles emitted in road transport both by combustion processes and resuspensions.
- **ARTEMIS** (Assessment and Reliability of Transport Emission Models and Inventory Systems), 2000 – 2007 (Boulter and McCrae, 2009). The project focuses on national emissions measurement from many vehicle categories in emission laboratories across Europe. The aim was to better understand the uncertainties associated with emission models and the variability of data based on real measurements. Another output was a methodology for estimating emissions from different modes of transport at national and international level.
- **JRC/CONCAWE/ACEA**, 2005 – 2007 (JRC, 2006). Project focused on quantifying the petrol evaporation from tanks of petrol vehicles.
- **HBEFA** (Handbook of Emission Factors for road transport), 1999 – to the present (Knorr, et al., 2004). The German-Swiss emission model is the result of a multi-year research project to determine emission parameters for all emission categories of road vehicles in both countries. The research is constantly updated and implemented under the auspices of the German Environmental Protection Agency (UBA) and the Swiss Environmental, Forest and Landscape Protection Agency (FOEFL).

The results are handled in the form of a comprehensive database of emission factors "Handbook of Emission Factors". The results of the research, produced in the form of an emissions database, make it possible to evaluate the production of emissions from automotive transport at several levels - from the regional scale (using average emission factors) to the assessment of individual buildings.

2.3.3 Structure of input data

Input data for the COPERT programme must follow the structure described below:

- Climate indicators - The data set contains average monthly data on minimum and maximum temperatures and relative air humidity.
- Activity data – stock (number of vehicles), mean activity (mileage per year), lifetime cumulative activity (total mileage)
- Reid vapour pressure (kPa) depending on the year and month
- Average trip length (km) and average trip duration (hours) in the specific country for which emission are calculated
- Average speeds (km/h) in cities (urban peak speed, urban off-peak speed), average rural speeds and highway speeds for all vehicle categories
- Average driving share (%) in cities (urban peak-share, urban off-peak share), average rural driving share and highway driving share for all vehicle categories
- Average fuel tank size (l) for all vehicle categories
- Average canister size with active carbon (l) for all vehicle categories, used for emission control
- Average share (%) between direct and indirect fuel injection for all vehicle categories
- Average share (%) of vehicles with evaporation control for all vehicle categories
- Urban peak and urban off-peak petrol evaporation share, rural and highway petrol evaporation share (%) for all vehicle categories
- Urban peak and urban off-peak load share, rural and highway load share (%) for all vehicle categories
- Average urban peak and off-peak road slope, rural and highway road slope
- Average number of axles for all vehicle categories
- Average share of AC usage while driving for all vehicle categories
- Average share (%) of vehicles equipped with emission reduction technologies for all vehicle categories (GDI, DPF, SCR and others)
- Average fuel properties (density, HC and OC ratio)
- Content of selenium, sulphur and selected heavy metals (Pb, Cd, Cu, Cr, Ni, Zn, Hg, As) in fuels

2.3.4 Structure of activity data

In the COPERT input, a fleet of road traffic vehicles is broken down by type of vehicle and fuel used, by vehicle type and emission standard, and by vehicle type and category (more detailed). An overview of the distribution of the transport fleet of road motor vehicles according to their type and fuel used is shown in the Table 1 and according to their type and emission standard in the Table 2. A more detailed distribution of the road transport vehicle fleet within a vehicle type is shown in Table 3.

Table 1 Overview of the distribution of road motor vehicles according to their type and fuel used based on the COPERT input

Fuel	Vehicle category				
Electrical energy	Passenger Cars				
Biodiesel	Buses				
CNG	Buses				
CNG Bi-fuel	Passenger Cars				
Diesel	Buses	Heavy Duty Trucks	Mopeds, Motorcycles (L-Category)	Light Commercial Vehicles	Passenger Cars
Diesel Hybrid	Passenger Cars				
FCEV	Passenger Cars				
LPG Bi-fuel	Passenger Cars				
Petrol	Heavy Duty Trucks	Mopeds, Motorcycles (L-Category)	Light Commercial Vehicles	Passenger Cars	
Petrol Hybrid	Passenger Cars				
Petrol PHEV	Passenger Cars				

Table 2 Overview of the distribution of the transport fleet of road motor vehicles according to their type and emission standard based on the COPERT input

Vehicle category / Emission standard				
Passenger Cars	**Mopeds, Motorcycles (L-Category)**	**Light Commercial Vehicles**	**Buses**	**Heavy Duty Trucks**
Conventional	Conventional	Conventional	Conventional	Conventional
Improved Conventional	Euro 1	Euro 1	EEV	Euro I
PRE ECE	Euro 2	Euro 2	Euro I	Euro II
ECE 15/00-01	Euro 3	Euro 3	Euro II	Euro III
ECE 15/02	Euro 4	Euro 4	Euro III	Euro IV
ECE 15/03	Euro 5	Euro 5	Euro IV	Euro V
ECE 15/04	Euro 6	Euro 6 up to 2016	Euro V	Euro VI
Euro 1		Euro 6 up to 2017	Euro VI	
Euro 2		Euro 6 2017-2019		
Euro 3		Euro 6 2018-2020		
Euro 4		Euro 6 2020+		
Euro 5		Euro 6 2021+		
Euro 6				
Euro 6 up to 2016				
Euro 6 2017-2019				
Euro 6 2020+				
Euro 6c				
Open Loop				

Table 3 Overview of more detailed distribution of the road transport vehicle fleet based on the COPERT input

Passenger Cars	Mopeds, Motorcycles (L-Category)	Light Commercial Vehicles	Buses	Heavy Duty Trucks rigid	Heavy Duty Trucks articulated
Mini	Micro-cars	N1-I	Coaches articulated > 18t	> 3.5 t	14 - 20t
Small	Mopeds 2-stroke < 50 cm³	N1-II	Coaches Standard ≤ 18t	≤ 7.5 t	20 - 28t
Medium	Mopeds 4-stroke < 50 cm³	N1-III	Urban Biodiesel Buses	7.5 - 12 t	28 - 34t
SUV	Motorcycles 2-stroke > 50 cm³		Urban Buses articulated > 18t	12 - 14 t	34 - 40t
	Motorcycles 4-stroke < 250 cm³		Urban Buses Midi ≤ 15t	14 - 20 t	40 - 50t
	Motorcycles 4-stroke > 750 cm³		Urban Buses standard 15-18 t	20 - 26 t	50 - 60t
	Motorcycles 4-stroke 250 - 750cm³		Urban CNG Buses	26 - 28 t	
	Quad & ATVs			28 - 32 t	
				> 32 t	

Category of passenger cars in COPERT based on cylinder capacity of their engines:

Mini – vehicles with engine volume less than 0.8 l

Small – between 0.8 and 1.4 l

Medium – between 1.4 and 2.0 l

Large– vehicles with the engine volume bigger than 2.0 l

2.3.5 Emission factors

Emission factors (EF) can be used in Tier 2 or Tier 3 mode (as shown in subchapter 2.2.1) and are based on the EMEP/EEA Guidebook (EMEP/EEA, 2016), namely:

- "Hot" EFs are relevant for all vehicle categories and for all pollutants except those calculated from fuel consumption and are given in g/km.
- "Cold" EFs are relevant for all categories of vehicles, for CO, NO_x, VOC and PM emissions from combustion and fuel consumption. The total EF is adjusted as a share of cold starts in the overall vehicle operation, which increases emissions depending on the particular month of the year. It is a dimensionless unit.
- EFs associated with Reid vapour pressure – depending on the activity of vehicle, units of gram per day, process or ride.
- EF correction due to use of air conditioning – depending on traffic type (city, off-town, highway) in MJ per kilometres.
- Degradation factors depending on distance travelled – expressed as a percentage, depending on traffic type (city, out of town, highway).
- EFs according to lubricant oil consumptions – depending on traffic type (city, out of town, highway), in grams per kilometres.

IMPORTANT: Emission factors for off-road mobile sources and other modes of transport are not included in COPERT 5.

2.3.6 Other factors affecting emissions

There are other factors that affect emission production which can be included into the COPERT calculations including vehicle category and age as described further:

- CO_2 effect - it is possible to set how the year of production of a given vehicle category affects the production of CO_2 emissions
- Effects of vehicle age (total mileage) - relevant for PC, LDV and CO, NO_x and VOC pollutants. In most cases, vehicles with Euro 1 standard have a negative impact on the emission factors and those with higher ones a positive impact. The resulting overall impact depends on fleet composition in individual years under review.

2.3.7 Output data

The program allows to export data in common formats (e.g. xls, xlsx or csv). Excel formats are in the form of a PivotTable, so it is possible to selectively export sums for selected technologies, Euro standards and fuels.

Fuel consumption

Fuel consumption is calculated for all 447 categories of vehicles. The output unit is TJ. Fuel consumption is calculated according to the COPERT methodology and is further normalized by the total fuel consumption from the energy statistics. Normalized fuel consumption is then divided according to the methodology into different categories of vehicles and, accordingly, emission estimates from these categories are adjusted.

Emissions of pollutants from combustion processes

The unit of output is "kg" or "t" according to the size of the emission. Below are descriptions of the different types of emissions for which the values are exported:

- "Hot" emissions (relevant for all pollutants) – depend on the number of vehicles, the distance travelled, the technology, the Euro standard and the average cruising speed.
- "Cold" emissions (relevant for all pollutants) – depend on the number of vehicles, the distance travelled, the technology, the Euro standard and the average cruising speed, on the ambient temperature and the average length of one ride.
- Emissions of pollutants from tanks – these emissions depend primarily on the Reid vapour pressure and on the ethanol content of the fuel. Other factors are the design parameters of the vehicle such as the tank size, the quantity and quality of activated carbon in the canister absorbing vapour from the tank and the cleaning strategy applied to the vehicle. Last but not least, evaporation from the tank depends on the structure of the vehicle's activity i.e. its standing time, the distance travelled and also the ambient temperature.
- Emissions from air conditioning (relevant for all pollutants) – The correction factor increases the fuel consumption to take into account the increase in emissions due to the use of air conditioning in cars.
- Effect of lubricant oil consumption – The correction factor to calculate the increase in CO_2 emissions due to the consumption of lubricating oils. The factor is a function of the distanced travelled. The percentage of lubricating oil consumption relative to fuel consumption is around 0.1% for PC, 0.3% for HDV and from 5 to 50% for motorcycles. The total contribution of combustion of lubricating oils is 0.2 to 0.3% of CO_2 emissions.
- Non combustion emissions (relevant for PM) – COPERT implements emission factors only for tyre and brake wear. These emissions depend on the vehicle category, the speed, the vehicle load and, in the case of HDV, also on the number of axles. The calculation of emissions from road abrasion is not currently included.

Groups of pollutants according to the degree of detail of the methodology used for the emission estimates and the accuracy of their calculation:

- Group 1 – pollutants with very detailed calculation methodology based on specific emission factors depending on combustion technology (CO, NO_x, NO, NO_2, VOC, CH_4, N_2O, NH_3, PM)
- Group 2 – pollutants estimated using fuel-related emission factors, that is, depending on the consumption (CO_2, SO_2, heavy metals)
- Group 3 – pollutants with less sophisticated calculation methodology due to current data deficiency (PAH, PCDD, PCDF)
- Group 4 – pollutants derived as a proportion of total NMVOC emissions (alkanes, alkenes, alkynes, aldehydes, ketones, cycloalkanes, aromatic hydrocarbons)

COPERT program, in line with the IPCC methodology, only calculates CO_2 emissions from fossil fuels, because biofuel emissions are addressed separately within the AFOLU (Agriculture, Forestry and Other Land Use) sector.

2.3.8 Types of outputs

COPERT outputs are predominantly used for the calculation of national greenhouse gas and other pollutant emissions under CLRTAP and Regulation No 525/2013/EC of the European Parliament and of the Council on a mechanism for monitoring and reporting greenhouse gas emissions and for providing further information at Member State and Union level on climate change and repealing Decision No 280/2004/EC.

In addition, COPERT outputs (mainly through EFs) can be applied at regional level for individual regions and smaller territorial units.

According to its authors, COPERT program can also be used for:

- environmental impact assessment of the air pollution;
- projection of energy consumption, production of CO_2 and other pollutants;
- assessment of new plans to build a transport network;
- emissions assessment from corporate car fleet and
- optimization of heavy duty truck loading (HDT).

COPERT street level was developed to calculate emissions from road transport in a specific part of the road. It is based on the COPERT software but brings a whole new approach to the level of calculations. COPERT street level can calculate emissions on a single street or on a full city street network. It requires the well accessible set of input data to produce results. Emissions can then be displayed on a GIS map to improve visualization. It is designed to work alongside traffic analysis tools in order to facilitate a wide range of input datasets (www.emisia.com). The differences of this software compared to COPERT are summarized in table 4.

Table 4 Scope and comparison of COPERT 5 and COPERT street level (source: www.emisia.com)

	copert	copert street level
Minimum temporal level	Year	Hour
Minimum spatial level	City	Small road
GIS visualization	No	Yes
Emissions covered	Regulated and Non Regulated pollutants, GHG	CO, CO2, NOx, PM, VOC
Energy consumption calculation	Yes	No
Automated scenario execution	No	Yes
Advanced input data	No	Yes

2.3.9 Vehicle categories and fuel type

Outputs are generated separately for all vehicle categories (i.e. 447 categories), see Table 1 to Table 3. If we only consider the relationship of vehicle types to fuel, we are only interested in Table 1. COPERT therefore distinguishes 11 types of propulsion and 5 types of fuel (diesel, biodiesel, petrol, LPG and CNG).

2.4 Country specific emission models

Several counties use their own country-specific model to calculate emissions. This subchapter describes some of the country-specific emission models used in several countries. For each model, a short general description is provided, including a reference where more information on the model can be found. Whenever an emission model also calculates emissions to surface waters, this is described in more detail.

2.4.1 The Netherlands

In the Netherlands, a technology specific model is used to calculate the emissions from road transport. Necessary input data include the amount of vehicle kilometres per vehicle type, fuel type, weight class, emission control technology (different Euro standards and engine and exhaust gas technology) and operating conditions (urban, rural and highways driving, including degree of congestion). Emission factors are derived from measurements (under test conditions and from real-world driving). Pollutants that are calculated are NOx, PM, CO, NMVOC, NH3, PAH and metals.

This model is developed to calculate national emissions, but it could also be used to calculate the emission for one specific road. The type of asphalt on highways in the Netherlands (porous asphalt) is not very common in Europe, and therefore the applicability of emission factors needs to be checked when this is used for other countries as well.

A more detailed model description and the emission factors can be found in Klein et al. (2017).

Emissions to surface waters in the Netherlands

Total wear factors are presented in Table 5. This includes the total wear of tyres, brakes and roads (both the atmospheric emissions and the part that end up on the roads).

Table 5 Total wear factors used in the Netherlands to calculate the emissions from tyre wear, brake wear and road wear (mg TSP/vkm), from Klein, et al. (2017). These emission factors include both the atmospheric emissions and the part that end up on the roads.

	Passenger cars	Motor-cycles	Mopeds	Delivery Vans	Lorries	Road tractors	Busses
Urban roads							
Particles from tyres	132	60	13	159	850	658	415
Particles from brake linings	21	8	0	23	69	63	52
Particles from asphalt roads	180	74	50	180	922	922	922
Rural roads							
Particles from tyres	85	39	9	102	546	423	267
Particles from brake linings	6	2	0	7	21	19	16
Particles from asphalt roads	116	48	32	116	592	592	592
Highways							
Particles from tyres	104	47	10	125	668	517	326
Particles from brake linings	3	1	0	4	11	10	8
Particles from asphalt roads	141	58	39	141	724	724	724

Part of the total wear ends up in the atmosphere, and part ends up on the road surface, soil and in surface water. The emission model in the Netherlands assumes the following percentages for emissions released to these compartments:

- Tyre wear: Atmosphere: 5%
  Soil/surface water: 95%
- Brake wear: Atmosphere: 49%
  Soil/surface water: 20%
  Remaining on the vehicle: 31% (removed from the vehicle when the vehicle is washed)

- Road surface wear: Atmosphere: 5%
  Soil/surface water: 95%

Porous asphalt is used on highways in the Netherlands, and this affects the amount of pollutants that could be emitted to soil and surface water. Particles and other pollutants are trapped in the porous asphalt and removed by cleaning the asphalt. It is expected that the amount of particulate matter and PAH is reduced with a factor of 20 and 2.5 respectively. In 2015, approximately 90% of the highways in the Netherlands were paved with porous asphalt. For particulate matter, this results in an emission correction factor of (1-0.9) + (0.9/20) = 0.1 + 0.045 = 0.145. This means that as a result of 90% porous asphalt on highways, it is assumed that only 14.5% of the particles on the road surface can be transported to soil and surface waters. From all of the emissions that are transported of the road, it is assumed that 10% will end up in surface waters (Deltares and TNO, 2008a,b,c).

The resulting emission factors to soil and surface water together are presented in Table 6.

Table 6 Emission factor to soil and surface water from tyre, brake and road wear for different vehicle types, in mg TSP/vkm. Data for the year 2015, based Klein et al. (2017). For the Netherlands, it is assumed that 10% of the emissions in this table will end up in surface water, while the remaining 90% will end up in the soil.

	Passenger cars	**Motor-cycles**	**Mopeds**	**Delivery Vans**	**Lorries**	**Road tractors**	**Busses**
Urban roads							
Particles from tyres	125.40	57.00	12.35	151.05	807.50	625.10	394.25
Particles from brake linings	4.20	1.60	0.00	4.60	13.80	12.60	10.40
Particles from asphalt roads	171.00	70.30	47.50	171.00	875.90	875.90	875.90
Rural roads							
Particles from tyres	80.75	37.05	8.55	96.90	518.70	401.85	253.65
Particles from brake linings	1.20	0.40	0.00	1.40	4.20	3.80	3.20
Particles from asphalt roads	110.20	45.60	30.40	110.20	562.40	562.40	562.40
Highways							
Particles from tyres	14.33	6.47	1.38	17.22	92.02	71.22	44.91
Particles from brake linings	0.09	0.03	0.00	0.12	0.32	0.29	0.23
Particles from asphalt roads	19.42	7.99	5.37	19.42	99.73	99.73	99.73

2.4.2 The CDV emission model (Czech Republic)

The CDV (Transport research centre) emission model is based on two basic methodologies namely (i) the Methodology for the determination of emissions of air pollutants from traffic (Dufek, et al., 2002) and (ii) the Determination of the emission flow from road transport for the monitoring, evaluation and management of air quality (Dufek, et al., 2008). The basis for the emission model is the 2002 methodology (Dufek, et al., 2002). The model was then supplemented and expanded in 2008 with lessons learned from the new methodology (Dufek, et al., 2008). Over the following years, the model has been retrofitted and improved on the basis of UNFCCC and individual review requirements. CDV emission model deals with road transportation, railways, aviation, national navigation and off - road mobile sources.

Inputs to the CDV emission model are activity data in the form of fuel consumption, emission factors related to the fuel and mode of transport (in case of road transport - vehicle category).

The input data into the emission model is fuel consumption supplied annually by the Czech Statistical Office. Individual consumption is allocated to each vehicle category on the basis of the following criteria:

- average dynamic vehicle fleet composition calculated every 5 years (2000-2010, 2016) within the National Census;
- static vehicle fleet composition from the Central registry of road vehicles administrated by Ministry of Transport (MoT) and
- average fuel consumption by vehicle category.

Based on the share of total transport performance in the individual regions of the Czech Republic, the consumption within the vehicle categories is divided among the individual regions, where the emissions of pollutants are subsequently calculated. Emissions from individual regions are then used for yearbooks and periodical statistical documents of the Ministries of the Environment (MoE) and Transportation. The results are consumptions for a total of 21 road transport categories (see Table 7) and 10 non-road categories (see Table 8) in all 13 regions of the Czech Republic and the capital city of Prague.

Table 7 Road transport activity data of the CDV emission model

No	Category	AD Unit
1	Motorcycles – Petrol	kt
2	Motorcycles – Bioethanol	kt
3	PC and LDV, conventional - Petrol	kt
4	PC and LDV, conventional, meeting limits of EURO 1 or EURO 2 - Petrol	kt
5	PC and LDV, conventional, meeting limits of EURO 3 and higher - Petrol	kt
6	PC and LDV, conventional - Diesel	kt
7	PC and LDV, conventional, meeting limits of EURO 1 or EURO 2 - Diesel	kt
8	PC and LDV, conventional, meeting limits of EURO 3 and higher - Diesel	kt
9	PC and LDV – LPG	kt
10	PC and LDV – CNG	kt
11	PC and LDV – Biodiesel	kt
12	PC and LDV – Bioethanol	kt
13	HDV - Diesel, conventional or meeting limits of EURO 0	kt
14	HDV - Diesel, meeting limits of EURO 1 nebo EURO 2	kt
15	HDV - Diesel, meeting limits of EURO 3 and higher	kt
16	HDV - CNG	kt
17	HDV - Biodiesel	kt
18	Buses, meeting limits of EURO 2 and lower	kt
19	Buses, meeting limits of EURO 3 and higher	kt
20	Buses - CNG	kt
21	Buses - Biodiesel	kt

Table 8 Activity data categories of other transport modes of the CDV emission model

No	Category	AD Unit
1	Rail transport - Diesel	kt
2	National Navigation - Diesel	kt
3	Domestic Aviation - Aviation gasoline	kt
4	Domestic Aviation - Jet kerosene	kt
5	International Aviation - Aviation gasoline	kt
6	International Aviation - Jet kerosene	kt
7	Commercial and institutional mobile sources	kt
8	Household and gardening mobile sources	kt
9	Agriculture, Forestry and Fishing off-road vehicles and other machinery	kt
10	Other mobile sources including military, land based and recreational boats	kt

In the Czech Republic there are currently no detailed data on the transport performance of individual categories of vehicles. Only data on total transport performance is available, so the calculation of emissions is based on fuel consumption. All emission factors (EFs) in the CDV emission model are therefore in g/kg and not in g/km as is customary.

For the emission model, a database of emission factors has been used. The database contains and statistically evaluates the measured values both in the Czech Republic and abroad, depending on the type and age of the vehicles, the fuel used, the speed and the driving mode and other factors.
The database ensures that the calculated emission values are a function of values detected by direct measurements. Emission factors are defined for:

- combustion processes and
- automotive tyre, break wear and road abrasion

All emission factors are expressed as g/kg of combusted fuel. For automotive tyre, break wear and road abrasion, the original EFs of the EMEP/EEA Guidebook (EMEP/EEA, 2016) reported in g/km were converted using the average consumption (according to IPCC, 2006) for the vehicle category per g/kg of fuel. The CDV emission model includes only "Hot EFs". Cold start effects and other effects, such as evaporation from tanks, use air conditioning, lubricating oil or vehicle aging effect, are not included in the model.

Table 9 presents the EF method used for the given pollutant in road transport. The abbreviation CS stands for "country specific" and is taken from the national database of EFs, which is data from the Czech emission measurements (mostly obtained from the Motor Vehicle Research Institute - TÜV UVMV).

The Tier methods are based on the EMEP/EEA Guidebook (EMEP/EEA, 2016) and IPCC (IPCC, 2006) methodologies and indicate the level of sophistication of a particular emission factor. Tier 1 has the lowest accuracy and is representative of the most aggregated data. Tier 3 has the highest precision with great detail.

The abbreviation NR indicates "Not relevant" and N/A that the current methodology does not include the EF.

Table 9 Used Tiers for EFs

Pollutant	Combustion - road transport	Tyre wear	Break wear	Road wear
CO_2	Tier 1	NR	NR	NR
CH_4	Tier 2	NR	NR	NR
N_2o	Tier 1	NR	NR	NR
NO_x	CS	NR	NR	NR
NMVOC	CS	NR	NR	NR
SO_2	CS	NR	NR	NR
NH_3	CS	NR	NR	NR
$PM_{2.5}$	CS	Tier 2	Tier 2	Tier 2
PM_{10}	CS	Tier 2	Tier 2	Tier 2
TSP	CS	Tier 2	Tier 2	Tier 2
BC	CS	Tier 1	Tier 1	N/A
CO	CS	NR	NR	NR
Pb	CS	Tier 2	Tier 2	Tier 2
Other heavy metals	Tier 1	Tier 2	Tier 2	Tier 2
PAHs	Tier 1	Tier 2	Tier 2	N/A
POPs	Tier 2	N/A	N/A	N/A

Outputs of the CDV emission model are emissions from road and non-road transport in tonnes per year, and for the pollutants concerned, according to the defined categories. Outputs for the Czech Republic are exported every year to special tables according Annex I of Guidelines for reporting emissions and projections data under the Convention on Long-range Transboundary Air Pollution for the reporting of transport emissions.

In addition, outputs are used for regional statistics within national periodicals, mainly for:

- annual update of the Czech Transport Yearbook, issued by the Ministry of Transport
- updating of the emission data for the publication of the “Study on the development of transport from an environmental point of view in the Czech Republic for the year ..." published every year since 1993
- updating the emission data provided within the interdepartmental data transmission (MoE, MoT, CENIA ...), which is necessary to process statistical publications such as the Report on the Environment in the Czech Republic, Statistical Yearbook of the Czech Republic, Regional Yearbooks etc.

2.4.3 MEFA model (Czech Republic)

MEFA is the emission modelling tool developed by private company ATEM s.r.o. from the Czech Republic within the financial support of Technology agency of the Czech Republic (TACR) as the project No. TA01020491 “Development of application environment for implementation of MEFA methodology update”.

Data about traffic for the calculation of fleet composition (EURO 0 - 6) according to the known dynamic tracking data (e.g. traffic aggregation in the area under consideration or ATEM study: "Evaluation of dynamic fleet composition on the Czech Republic's communication network in terms of its emission parameters in 2015") are the first input data set. Another input file is traffic flow data, which includes the transport intensity of selected vehicle categories (up to 12 categories). The traffic model uses traffic flow rates and traffic fluency in the modelled sections. Using spatial analysis in the GIS environment, the slopes of the communication are assigned to sections. Data can also be directionally routed.

For calculations, the MEFA emission model allows the user to specify additional refinements such as climate data or truckloads. MEFA includes emission factors for primary emissions of 13 pollutants. The model considers cold start emissions for parked vehicle departures, brake and tyre wear, and resuspension according to US EPA AP-42 methodology. Emission factors for the relevant pollutant are further divided according to several criteria, which are the categories of used fuel (automotive gasoline, diesel fuel, LPG, CNG) and met the emission standard (conventional drive - EURO 0, EURO 1-6). The emission model thus prepared allows a detailed spatial assessment of transport emissions and accurate comparison of current and prospective status.

MEFA is suitable for detailed modelling of intersections, parameters such as congestion length, delay at junction and speed of vehicles before and behind the junction.

When creating an emission model, two basic variables can be calculated:

• Production of emissions (kg/section/day)

• Emission flow (kg/km/day or g/m/s)

MEFA 13 can be used is the most suitable model for local solutions. (Šebor, et al., 2010)

2.4.4 HBEFA

Several other countries have their own country-specific emission model. Some of them are based on the HBEFA (Handbook of Emission Factors for Road Transport). HBEFA was already introduced in subchapter 2.3.2 however it is used in some countries as a separate model for emission calculations.

HBEFA was originally developed on behalf of the Environmental Protection Agencies of Germany, Switzerland and Austria. In the meantime, further countries (Sweden, Norway, France) as well as the JRC (European Research Center of the European Commission) are supporting HBEFA (Keller, et al., 2017). This model is the result of a multi-year research project to determine emission parameters for all emission categories of road vehicles in both countries. The research is constantly updated and implemented under the auspices of the German Environmental Protection Agency (UBA) and the Swiss Environmental, Forest and Landscape Protection Agency (FOEFL). The results are handled in the form of a comprehensive database of emission factors "Handbook of Emission Factors". The results of the research, produced in the form of the emission database, make it possible to evaluate the production of emissions from automotive transport at several levels - from the regional scale (using average emission factors) to the assessment of individual buildings.

HBEFA provides emission factors, i.e. the specific emission in g/km for all current vehicle categories (PC, LDV, HDV, buses and motor cycles), each divided into different categories, for a wide variety of traffic situations. Factors for the following components are provided CO, HC, NOx, PM, several components of HC (CH4, NMHC, benzene, toluene, xylene), fuel consumption (gasoline, diesel), CO2, NH3 and N2O, PN and PM.

2.5 Conclusion

This chapter provided a description of several emission models used in Europe, of which COPERT is the most often used. The structure of the different models is similar to each other, but differences occur in the necessary detail of the input data and the output data.

COPERT, EMEP/EEA Guidebook and HBEFA are appropriate to apply for other countries in Europe, although the appropriateness of the emission factors needs to be reviewed when an emission model is used in another country.

3 Dispersion and deposition models

3.1 Introduction

Several air quality models are used to assess air quality against air quality standards and limit values or develop and test policy and action plans for air quality improvement at scales from street level (hotspots) to urban areas as well as rural road networks including e.g. ADMS Urban and some national ones. However, to assess the air quality in connection with possible runoff contamination, more specific applications should be used if available. The dispersion and deposition of particulate matter depends on particle sizes, meteorological circumstances and land use.

Subchapter 3.2 provides a description of several air quality models for fine particulates (PM10). Numerical models to describe particle dispersion in the vicinity of roads (including vehicles movement and velocity of air masses) will be assessed.

Subchapter 3.3 provides an example calculation of deposition in the vicinity of a road. With a Gaussian plume model, combined with deposition velocity, it is possible to calculate the dispersion of large particles from road transport and possible deposition distances. Deposition distances could be relevant if a vulnerable water body is located within deposition distance from the road.

3.2 Dispersion of particulate matter smaller than 10 µm (PM10)

Several modelling tools can be used for air quality assessment. Some of them were developed directly for this purpose while others were developed to solve different issues but may also be used for air quality modelling. This chapter describes the most common used (ADMS – urban) and two examples of country specific models and one example of different type of modelling tool.

3.2.1 ADMS – urban

ADMS-Urban (Mc Hugh, et al., 1997), the most comprehensive version of the Atmospheric Dispersion Modelling System (ADMS), is the PC-based advanced Gaussian model of dispersion in the atmosphere of pollutants (PM and gases) released from industrial, domestic and road sources in urban areas (CERC, 2013). It models these using point, line area, volume and grid source models. It is designed for the range from the simplest scenarios to the most complex urban scenarios.

Input data consist of meteorological data, detailed traffic information (including emissions) and geographical characteristics (point, line and area sources).

ADMS-Urban has number of distinctive features:

- Advanced dispersion model in which the boundary layer is characterised by height of boundary layer and Monin-Obukhov length. Length scale is dependent on the friction velocity and the heat flux at the surface. The "local" Gaussian type model is nested within trajectory model, so the areas greater than 50 x 50 km may be considered.
- It is possible to set up to 3000 road sources (each with up to 50 vertices).
- An integrated street canyon model represented by WinOSPM model.
- Boundary layer is calculated from variety input data: e.g. wind speed and cloud cover or wind speed, surface heat flux and boundary layer height. Meteorological data may be raw hourly values or statistically analysed.
- ADMS-Urban improves accuracy by using non-Gaussian vertical profile of concentration in convective conditions. This helps to avoid to high surface concentrations near the source.
- Realistic calculation of flow and dispersion over complex terrain and around buildings.

ADMS-Urban uses an advanced Gaussian approach with a normal Gaussian distribution in stable and neutral conditions, whilst the vertical dispersion is approximated by two different Gaussian distributions in a convective boundary layer. Road sources are simplified in model. The roads have a constant width and buildings have a flat roof and a constant height on both sides of the street. The new ADMS-Urban advanced street canyon module, which allows for a wide variety of canyon geometries with smooth transitions of concentrations between open and built-up areas, is available now (Hood et al. 2014). This is based on the Danish model Operational Street Pollution Model OSPM (see subchapter 3.2.2). ADMS –Urban doesn't allow to model crossroads. This model is widely used for urban areas (Righi, et al., 2009). Its relatively short processing time is the main advantage compared to more sophisticated models (Connan, et al. 2013).

3.2.2 Operational Street Pollution Model (OSPM)

Dispersion in a canyon is represented by the Operational Street Pollution Model OSPM (Berkowicz, et al., 2008; Hertel and Berkowicz, 1989; Hertel et al.,1990). This is a widely used and often validated model (Pu and Yang, 2014; Ketzel, et al., 2012; Elbir, et al., 2011). If there is a wind component normal to the canyon, a vortex on the lee-side is parameterized. The extend of the recirculation zone depends on the wind-speed and direction above the canyon. Receptor points situated at the lee-side of the buildings receive contributions from all traffic emissions within the recirculation region. Receptor points downwind of the street receive contributions from the traffic emissions outside of the recirculation zone only (Hirtl and Baumann-Stanzer, 2007).

Input data in the OSPM model includes meteorological data, detailed traffic information and knowledge of the geometrical configuration of the street canyon. The model calculates concentrations of NO2, CO and PM, and can be used for other gases as well. It has been applied or validated in many locations in Europe (Kakosimos, et al., 2010).

More information on this model is available via:

http://envs.au.dk/en/knowledge/air/models/ospm/

3.2.3 SYMOS'97

Stationary Sources Modelling System (SYMOS'97) was developed by Czech Hydro-meteorological Institute in 1997. This model is required by the Czech Ministry of Environment for air quality assessment. It is a regional Gaussian long-term dispersion model based on the application of the statistical theory of turbulent diffusion formulated by Sutton, which predicts atmospheric concentrations of harmful substances within a distance up to 100 km from sources (Bubnik, et al., 2013). The model allows fast forecasting of pollutants dispersion from point, area and line sources.

Input data for modelling of road sources are:

- Information about road sources (coordinates, altitude, operational characteristics).
- Meteorological characteristics which are classified into five stability classes according to the classification of Bubnik and Koldovsky (1974). Each stability class is divided into three wind speed classes with average wind speeds of 1.7, 5.0 and 11 m/s.
- Terrain data (ASCII format with elevation of grid points).
- Emission data (emission rates in g/m/s).
- Output grid points data (coordinates, elevation, and elevation above terrain level)

With the help of SYMOS'97, it is possible to:

- calculate concentrations of gaseous pollutants and from point, line and area sources (yearly averages, maximum hourly concentrations in certain meteorological conditions and maximum hourly concentrations regardless meteorological conditions)
- calculate the contamination from a number of sources and identify the characteristics of pollution in a network of reference points;
- calculate the duration of exceedance of limit concentrations.

The model allows to estimate only the dispersion of pollutants under inversions and calm wind conditions, and has a poor incorporation of the physicochemical properties of modelled substance. The main constraint for modelling of traffic pollution in urban areas is that concentrations are computed above the roof level without the influence of buildings or street canyon settings (Methodological guidance for dispersion studies, 2013). In general, results of the model are underestimated especially in case of nitrogen oxides (Keder, 2002). On the other hand, the model does not limit the number of input emission sources or receptors (Sanka, et al., 2014).

For hourly average calculations, the SYMOS' 97 module for hourly data was used (Benesova, 2013). Hourly module of SYMOS'97 uses hourly meteorological data instead of wind rose, which is used by common version. The main constraint is that the module doesn't integrate daily traffic fluctuation data. It is necessary to calculate emission rates separately for part of the time series corresponding to peak hours and non-peak hours. But still, this is not a very precise way to estimate the variability of daily traffic. This module is still under development and hourly traffic will be included in the next steps of the development process.

3.2.4 NNM

The New National Model (in Dutch: *Nieuw National Model – NNM)* was developed in 1998 in the Netherlands to calculate atmospheric concentrations. There was already an old national model available, but the results of this model showed differences between calculations and measurements of high emission sources. The new national model was developed in 1998. The local dispersion is modelled with the Gaussian Plume dispersion functions. The concentration is calculated hourly and for each hour, data is needed on meteorology, background concentrations and characteristics of the emission sources (emissions, location, height, etc).

There are three models in the Netherlands that are based on the NNM calculation method:

- Geomilieu
- PLUIM-PLUS
- ISL3a

In general, NNM is developed to calculate concentrations from point sources and area sources. The first model in the list can also be used to calculate concentrations resulting from traffic.

Input data in the NNM model includes meteorological data for a period of time, detailed traffic information (including emissions) and roughness of the surrounding area. The model calculates concentrations of NOx, PM and several other pollutants.

3.2.5 Computational fluid dynamics

Computational fluid dynamics (CFD) is a field of fluid mechanics that uses numerical analysis and data structures to solve and analyse problems that involve fluid flows. Calculations simulate the interaction of liquids and gases with surfaces defined by boundary conditions. It produces quantitative predictions of fluid-flow phenomena based on the conservation laws (conservation of mass, momentum, and energy) governing fluid motion (Hu, 2012).This method was developed mainly for engine operation modelling, however it can be used as a suitable modelling tool for detail calculation of pollutants dispersion in small settlements because it allows calculation of complex 3D concentration fields of pollutants on the basis of the real geometry (see Figure 2). This method allows inclusion of a detailed description of the geometry of an area and the dispersion of pollutants on computed 3D air velocity field. Input data into this model include when calculating vehicle emission are the geometry of the area, vehicles emission factors and air velocity characteristics (wind speed and direction, motion direction of vehicles). This method is based on a numerical approach to the system of differential equations (Euler method) accurately describing air flow and transport of gaseous pollutants and small suspended particles.. The accuracy of the calculated air velocity field depends on the quality of the assigned geometry of an area and assigned boundary conditions. When dealing with urban areas the calculation can include detailed geometry of individual buildings. The information on the concentration of pollutants is collected in nodal points of the model network on the basis of balance equations for conservation of matter, energy and momentum, which describe the transfer between individual volume elements of the numerical model (Pospisil et al., 2014).

The created detailed mathematical model always represents only a part of the real area. The size of the model itself is limited by the amount of time for processing and by the used hardware. The limitations due to the limited model size lead to the use of corresponding boundary conditions which accurately substitute the influence of the surroundings. The air mass in the model moves above the terrain described by the corresponding parametric roughness. The terrain has an impact on the original velocity profile in relation to specific local conditions (Pospisil et al., 2014.

The output of this model results in concentration maps of defined area as shown in Figure 2.

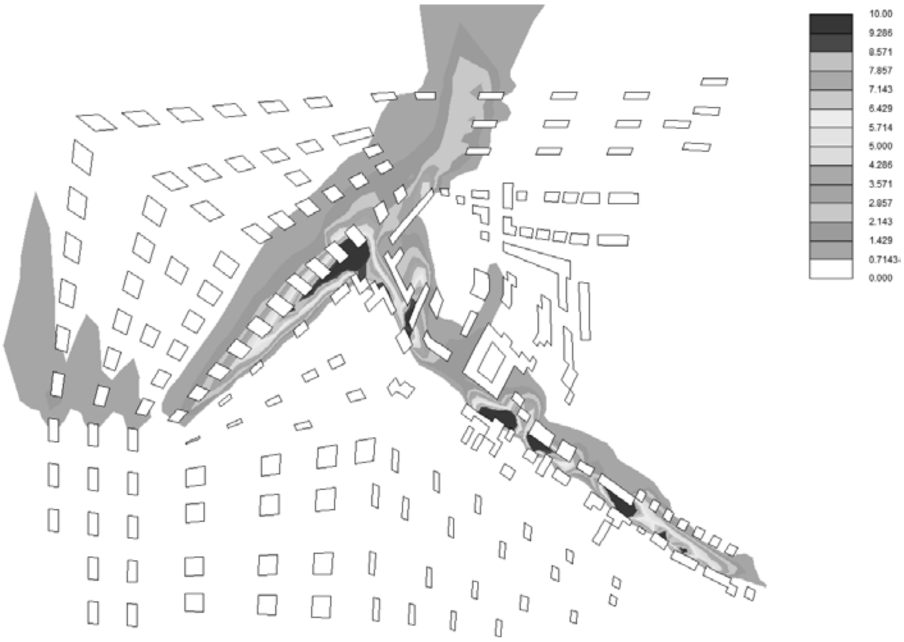

Figure 2 Example of calculated concentration field of vehicles emissions (Pospisil et al., 2014)

3.3 Deposition of particulate matter

3.3.1 Introduction

Atmospheric emissions of particulate matter are transported from the road and deposited in the vicinity of the road. The downward transport of pollution from the atmosphere to the surface is a physical process, depending on pollutant concentration, atmospheric circumstances and pollutant characteristics such as size, density and solubility in water.

This subchapter contains an example calculation of the deposition of particulate matter in the vicinity of a road. The Dutch air quality model “Nieuw Nationaal Model” (in English: new national model) is used to calculate the dispersion and deposition of atmospheric pollutants. The local dispersion and downward transport are modelled with the Gaussian Plume dispersion functions.

This model can also be used to estimate the downward transport of emissions from a road.

Exhaust emissions are not included in this example, because the size of these particles is relatively small and these particles will remain in the atmosphere for longer periods. Therefore, this example will focus on particles released by tyre, brake and road wear. The wear from the road surface, tyres, and brakes results in atmospheric emissions of particulate matter. This results in an increase of atmospheric particle concentration near the road. Due to gravity, Brownian motion and precipitation (see 3.3.2), the particulates are transported downward. The transport is proportional to the concentration, so near the road the downward transport is increased as well. A brief explanation of this model type is given in 3.3.2.

3.3.2 Local scale modelling: Gaussian Plume modelling

The local dispersion and downward transport are modelled with the Gaussian Plume dispersion formulation (van Ham and Pulles, 1998). The concentration is calculated with:

$$C = \frac{Q}{2\pi \cdot \sigma_x \cdot \sigma_y \cdot u} e^{-\frac{y^2}{2\sigma_y^2}} \cdot \left(e^{\frac{-(z-h)^2}{2\sigma_z^2}} - e^{\frac{-(z+h)^2}{2\sigma_z^2}} \right)$$

In which:

C	Concentration
Q	emission (kg)
U	wind velocity
y	y horizontal distance from the plume axis
z	z vertical distance from the plume axis
σ	3-dimensional turbulent diffusion

The downward transport of particles results from three different process: dry deposition, wet deposition and sedimentation. All of these processes are included in the Gaussian model. In brief; dry deposition is the dominant process for small the very small particles and gas molecules. This process results from Brownian motion, which becomes more important the smaller the particles are. For the larger particles, sedimentation becomes more important. This process results from gravity and increases strongly for larger and more dense particles. Wet deposition results from collision of rain or snow droplets with particles. This process is more important for larger particles and increases with the rain intensity. The model is described by van Ham and Pulles (1998).

3.3.3 Example

This subchapter shows an example of the use of this model to estimate the downward transport of wear emission in the vicinity of a road. The calculations have been performed for a theoretical highway with two lanes and an emergency lane, used by 30 000 vehicles per day. Since this study focusses on the larger particles that are expected to deposit near the road, this example will focus on particles released by tyre, brake and road wear. Exhaust emissions are not included in this example, because they are relatively small and will remain in the atmosphere for longer periods.

The input data consist of emissions and meteorological characteristics.

<u>Input data</u>

Only non-exhaust emissions are included in this example and these emissions were estimated by means of emission factors that are presented in the EMEP/EEA air pollutant handbook (EMEP/EEA, 2016). It has to be stressed that in this handbook only airborne emissions are presented. A large fraction of non-exhaust emissions of road traffic however consists of non-airborne particles (>> 10 µm). Because of their size, these particles are deposited on or very near the impermeable road surface.

Table 10 Atmospheric emission factors of tyre wear and brake wear and road surface wear (gram/vehicle.km). Data from EMEP/EEA, 2016.

	Tyre and brake wear			**Road surface wear**			**Share of total vehicle km**
Vehicle group	**TSP**	**PM10**	**PM2.5**	**TSP**	**PM10**	**PM2.5**	
Passenger cars	0.0182	0.0138	0.0074	0.015	0.0075	0.0041	75%
Light duty trucks	0.0286	0.0216	0.0117	0.015	0.0075	0.0041	14%
Heavy duty vehicles	0.0777	0.059	0.0316	0.076	0.038	0.0205	10%
Two wheelers	0.0083	0.0064	0.0034	0.006	0.003	0.0016	1%
Weighted average	0.025507	0.019338	0.010382	0.02101	0.010505	0.005715	

Next to estimation of airborne emissions by means of the EMEP/EEA handbook an estimation was prepared of non-airborne emissions. Based on data on total wear and release to the atmosphere in the EMEP/EEA Guidebook (2016), it was estimated that 50% of brake wear and 90% of tyre wear consist of non-airborne emission and is deposited on road-surface (see subchapter 2.2.2).

The environmental pathways of redistribution of non-airborne emissions depend on the distribution mechanism. Only a fraction of these emissions is transported by the run-off mechanism by wet precipitation. The POLMIT-model (POLMIT, 2002) estimates 35% to be transported by run-off.

The other fraction of 65% probably is re-emitted by air in other sizes than the original primary emissions. By our knowledge there is no research available wherein these sizes of resuspended particles are investigated. Therefore, percentages and size bins have been assumed in order to be able to calculate the distribution patterns of re-emissions along a road with moderate traffic intensity. For resuspension via air, it is assumed that 50% of the particles are smaller than 30 micrometer (PM30) and 25% of the particles are smaller than 10 micrometer (PM10). For resuspension via splash and spray, it is assumed that 30% of the particles are smaller than 30 micrometer (PM30) and 10% of the particles are smaller than 10 micrometer (PM10). These values are used for a road with regular asphalt, while on road with open asphalt redistribution by air probably is avoided by the greatest part.

Table 11 Estimation of total non-airborne emission factors and resuspension emission factors (g/vehicle.km) of non-exhaust emissions

	Total non-airborne emission factors (TSP)				Resuspension emission factors		
Source	**Share**	**Tyre**	**Brake**	**Total**	**PM100**	**PM30**	**PM10**
Resuspension via air	40%	0.0538	0.0042	0.0580	0.0580	0.0290	0.0145
Resuspension via splash and spray	25%	0.0336	0.0026	0.0362	0.0362	0.0109	0.0036
Runoff	35%	0.0470	0.0037	0.0507	-	-	-
Total		0.1344	0.0106	0.1450	0.0942	0.0399	0.0181

The model needs data on total emissions from a road. These have been calculated with the emission factors in Table 10 and Table 11, combined with a traffic intensity of 30 000 vehicles per day. The emissions for this road are presented in Table 12.

The emissions from tyre and brake wear, surface wear, resuspension to air and resuspension via splash and spray (during rain) are distinguished. The emissions of resuspension via splash and spray are only taken into account in the air quality model during wet circumstances.

Table 12 Emission factors (g/veh.km) and yearly emissions (g/km road/year) for a road with 30 000 vehicles per day.

	Emission factors (g/veh.km)				Yearly emissions (g/km road/year)			
Source	**<PM25**	**PM25-PM10**	**PM10-PM30**	**PM30-PM100**	**<PM25**	**PM25-PM10**	**PM10-PM30**	**PM30-PM100**
Tyre and brake wear	0.0104	0.0090	0.0062	0	312	270	186	0
Surface wear	0.0057	0.0048	0.0105	0	171	144	315	0
Resuspension via air	0	0.0145	0.0145	0.0290	0	435	435	870
Resuspension via splash and spray	0	0.0036	0.0072	0.0254	0	108	216	762

The resulting deposition and sedimentation was modelled at various distances from the middle of the road, starting from the edge of the road and ending at 200 m distance. The distance from the middle of the road to the edge is 16m (2 driving lanes, an emergency lane and half of the middle bank). Meteorological circumstances such as wind speed and precipitation intensity are of influence on deposition. This is taken into account by the model and for this example, the meteorological circumstances for 1 year in the Netherlands are used.

Result of the dispersion and deposition calculation

The emissions shown in Table 12 were applied in the Gaussian dispersion model and resulted in a year-round hourly time series of wet – and dry deposition. The weighted average of the deposition is shown in Figure 3.

Resuspension via air is responsible for the largest amount of emissions and also has the largest contribution to the total deposition. However, resuspension via splash and spray is responsible for the second largest amount of emissions, but it has the smallest contribution to the total deposition. This results from the limited number of time with rain. During dry circumstances, the emission from resuspension via splash and spray is zero. The contribution from surface and tyre and break wear is about equal, as expected from Table 12.

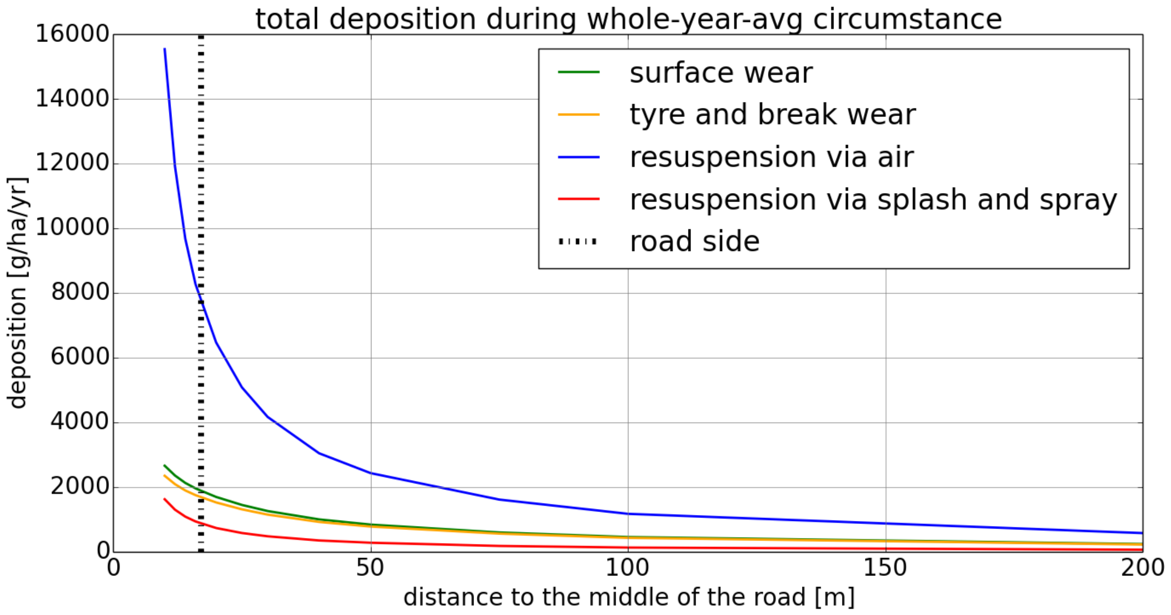

Figure 3 Weighted average deposition [g/ha/year] versus the distance to the middle of the road. The road side is assumed to be 16m from the middle of the road.

The total deposition in Figure 3 shows the average deposition (during the modelled year). The deposition depends on weather circumstances. Figure 4 shows examples of deposition during dry and rainy circumstances, during circumstances with low or high wind. Also the openness of the surrounding area (e.g. open meadow or trees next to the road) influences the deposition pattern, but this is not included in this example. Figure 4 shows that deposition distance increases during high wind circumstances and that it also shows that the total deposition increases during rainy circumstances (as a result of splash and spray).

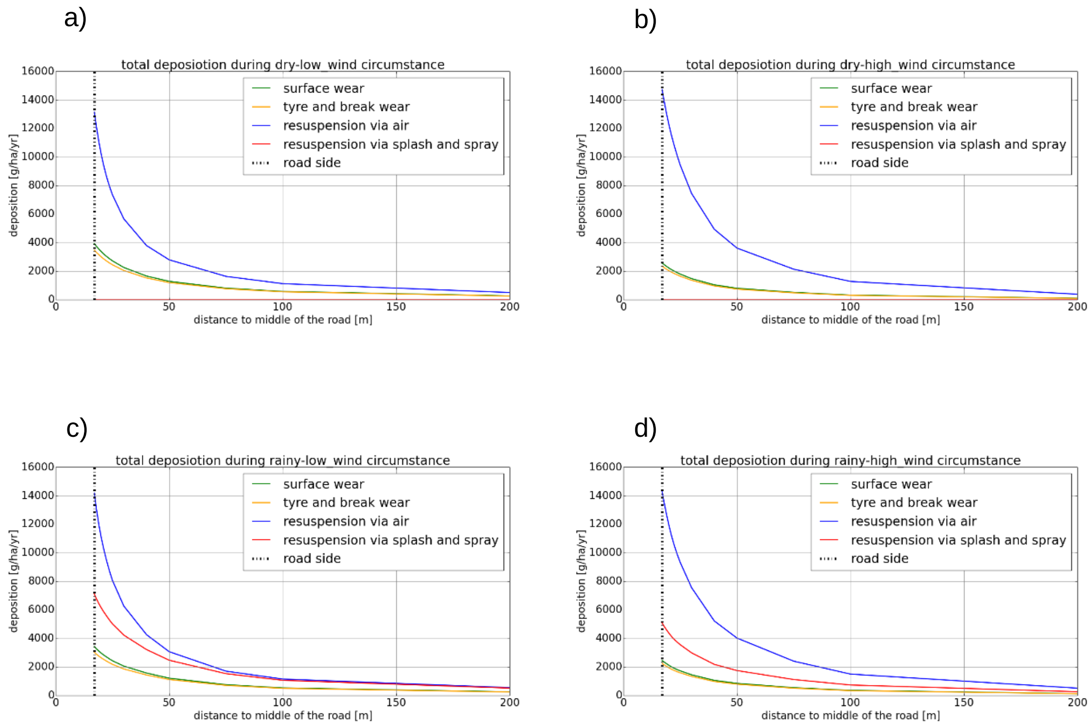

Figure 4 Deposition [g/ha/year] versus the distance to the middle of the road. The road side is assumed to be 16m from the middle of the road. Figures a and b show the deposition during dry circumstances (with low wind in figure a and high wind in figure b), while figure c and d show the deposition in rainy circumstances (with low wind in figure c and high wind in figure d)

3.3.4 Conclusion

Since the majority of the road related particles could be transported from the road via atmospheric processes, it is expected that a large part of the pollutants that enter a surface water body, will be transported to that surface water body via dispersion and deposition. With this air quality model, it is possible to calculate the deposition of road related particles on a nearby surface water body.

4 Conclusions

A large variety in regional and national scale models for emissions and air quality calculations is available.

Emission models are based on detailed traffic characteristics and emission factors. The emission factors depend on national and local circumstances (type of vehicles, type of roads, speed limits, braking and steering, etc), and therefore an average country-specific emission factor is not necessarily useful for other countries. Instead each country need to calculate emissions using detailed local traffic characteristics as input data (although the same model could be used).

Air quality models are based on physical processes and need data on meteorology, detailed traffic information (including emissions) and geographical characteristics. The basic calculations included in air quality models are similar and could be applicable for other sites in Europe, but some models are specifically designed for one country only.

The emission and air quality models described in this deliverable are more advanced than most runoff models. Runoff models are often regression models, which are developed for a specific region, while air quality models are based on physical atmospheric processes.

Recommendations to improve models to calculate the potential load of pollutants in surface waters:

- Emission models:
  - For calculating the pollutant load in surface waters, the emission model should mainly focus on tyre, brake and road wear. Particles released by tyre, brake and road wear are relatively large and will be deposited on or near the road, while exhaust emissions are relatively small and will remain in the atmosphere for longer periods. Some emission models contain data to calculate emissions to soil and water.
  - The amount of emissions is influenced by vehicle type (weight, euro class, type of fuel, etc), road type (asphalt type, maximum speed, etc), steering and braking (degree of congestion, bends, crossings, driving behaviour, etc). Atmospheric emission models take (most of) these variables into account to calculate emissions. This type of variables could be included in runoff models as well to improve the estimation of emissions from traffic. Especially the factors relevant for tyre, brake and road wear (weight, asphalt type, maximum speed, congestion, bends, driving behaviour) will influence the calculated emissions and including these in the runoff calculations may increase the correlation between actual runoff and modelled runoff.
- Air quality models:

- A potential large part (>50%) of the pollutants could be transported to the road side environment via drift and spray at specific conditions. Deposition of particles in the road side environment can be calculated, but to include deposition in air quality models would be very difficult.

5 Acknowledgement

The research presented in this report/paper/deliverable was carried out as part of the CEDR Transnational Road Research Programme Call 2016. The funding for the research was provided by the national road administrations of Austria, Finland, Germany, Ireland, Norway, Netherlands and Sweden.

6 References

Benesova, N., 2013. SYMOS' 97 – Module for hourly calculation. CHMI. Praha. 13 pp.

Berkowicz R., et al., 2008. Evaluation and application of OSPM for traffic pollution assessment for a large number of street locations. Environmental Modelling & Software 23. p. 296 – 303.

Best, J. H. de, Vergouwen, A. A., & Schipper, P. N. M., 2002. Afstroming en verwaaiing bij provinciale wegen - literatuur overzicht Grontmij Advies & Techniek bv; Energieonderzoek Centrum Nederland (ECN).,

Boller, M., 2006. Bankette bestehender Strassen - Untersuchung der Versickerung von Strassenabwasser über Strassenrandstreifen an einer bestehenden Strasse. Schlussbericht, eawag, Berner Fachhochschule, GSA, ASTRA, BUWAL.

Boulter P. G., McCrae I. S., 2009. ARTEMIS: Assessment and Reliability of Transport Emission Models and Inventory Systems final report. TRL. 348p. Available at: https://trl.co.uk/reports/PPR350

Bubnik, J., Keder, J., Macoun, J., Manak, J., 2013. SYMOS'97-Stationary Sources. Modeling System - Reference Manual actualization of methodology from 1998 (In Czech). CHMI, Prague.

Bubnik, J., Koldovsky, M., 1974. Weather classification focused in air pollution. In: Böhm, B., et al. (Eds.), Air Pollution in Krusne Mts. HMÚ, Prague.

CERC, 2013. ADMS-Urban 3.2. Urban Quality Air Management System. User Guide. Cambridge Environmental Research Consultants Ltd, Cambridge.

Connan O., et al., 2013. Comparison of RIMPUFF, HYSPLIT, ADMS atmospheric dispersion model outputs, using emergency response procedures, with 85Kr measurements made in the vicinity of nuclear reprocessing plant. . Atmospheric Environment 124. p. 266 - 277.

Folkeson L, Bækken T, Brenčič, M, Dawson A, Francois D, Kuřímská P, Leitão T, Ličbinský R, Vojtěšek M (2009) Sources and fate of water contaminants in roads. In: Dawson A (ed) Water in road structures, 5th edn. Springer, Netherlands, pp. 107–146

Deltares and TNO, 2008a. Road surface wear. Emission estimates for diffuse sources. Netherlands Emission Inventory. Available via: http://emissieregistratie.nl/erpubliek/documenten/Water/Factsheets/English/Road%20surface%20wear.pdf

Deltares and TNO, 2008b. Road traffic brake wear. Emission estimates for diffuse sources. Netherlands Emission Inventory. Available via: http://emissieregistratie.nl/erpubliek/documenten/Water/Factsheets/English/Road%20traffic%20brake%20wear.pdf

Deltares and TNO, 2008c. Road traffic tyre wear. Emission estimates for diffuse sources. Netherlands Emission Inventory. Available via: http://emissieregistratie.nl/erpubliek/documenten/Water/Factsheets/English/Road%20traffic%20tyre%20wear.pdf

Dufek, J., et al., 2002. Methodology for determination of emissions of air pollutants from transport (in Czech). CDV. Brno. 22p.

Dufek, J., et al., 2008. Determination of the emission flow from road transport for the monitoring, evaluation and management of air quality (in Czech). CDV. Brno. 34p.

Elbir T., et al., 2011. Comparison of predicted and observed PM10 concentrations in several urban street canyons. Air Quality, Atmosphere and Health 4. p.121 -131.

EMEP/EEA, 2016. EMEP/EEA air pollutant emission inventory guidebook 2016. European Environment Agency. Luxemburg.

Ham, J. van, and Pulles T., 1998. Het Nieuw Nationaal Model. TNO.

Hertel, O., Berkowicz, R., 1989. Modelling pollution from traffic in a street canyon. Evaluation of data and model development. DMU Luft A-129.

Hertel, O., Berkowicz, R., Larssen, S., 1990. The operational street pollution model (OSPM). 18th International Meeting of NATO/CCMS on Air Pollution Modelling and its Application, Vancouver, Canada, 1990, pp. 741–749.

Hirtl M., Baumann-Stanzer K., 2007. Evaluation of two dispersion models (ADMS-Roads and LASAT) applied to street canyons in Stockholm, London and Berlin. Atmospheric Environment 41. p. 5959–5971

Hood, Ch. et al., 2014. Urban canopy flow field and advanced street modelling in ADMS-urban 16th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes 8-11 September 2014, Varna. Bulgaria

Hu H. H. (2012) Computational fluid dynamics. In: Kundu, P. K., Cohen, I. R:, Dowling D. R. (eds) Fluid Mechanics, 5th Edition Elsevier Inc., USA, pp. 421 - 472

IPCC, 2006. IPCC Guidelines for national greenhouse gas inventories. IPCC. National Greenhouse Gas Inventories Programme. Iges. Japan.

JRC, 2006. Effects of gasoline vapour pressure and ethanol content on evaporative emissions from cars. Interim report. 14p. Available at: https://circabc.europa.eu/webdav/CircaBC/Climate%20action/fuel_quality/Library/jrc_report_annexes/ANNEX_1_EVAP%20programme%20results.pdf

Kakosimos, K.E., Hertel, O., Ketzel, M. & Berkowicz, R., 2010. Operational Street Pollution Model (OSPM) - A review of performed application and validation studies, and future prospects. Environmental Chemistry. 7. 485-503. DOI:10.1071/EN10070.

Keder, J., 2002. Report from solution of partial project DP2 in 2002 - The proposal of modelling tools for the objective assessment of the state and development of air pollution in accordance with the new Air pollution law and EU Directives. CHMU. Prague. 18 pp. (only in Czech)

Keller M., Wüthrich P., Notter B. Handbook emission factors for road transport 3.1 / 3.2 / 3.3, Quick reference. INFRAS, Bern, Switzerland, 2017, 31 pp

Ketzel, M., et al., 2012. Evaluation of the Street Pollution Model OSPM for Measurements at 12 Streets Stations Using a Newly Developed and Freely Available Evaluation Tool. Civil & Environmental Engineering. (http://dx.doi.org/10.4172/2165-784X.S1-004)

Klein, J., Molnár-in 't Veld, H., Geilenkirchen, G., Hulskotte, J., Ligterink, N., Dellaert, S., de Boer, R., 2017. Methods for calculating the emissions of transport in the Netherlands. Task Force on Trasportation of the Dutch Pollutant Release and Transfer Register. Available via http://emissieregistratie.nl/erpubliek/documenten/Lucht%20(Air)/Verkeer%20en%20Vervoer%20(Transport)/Methoderapporten%20Taakgroep%20Verkeer%20en%20Vervoer/Klein%20et%20al.%20(2017)%20Methods%20for%20calculating%20the%20emissions%20of%20transport%20in%20the%20Netherlands.%202017.pdf

Knorr, W. et al., 2004. Handbuch Emissionenfaktoren des Strassenverkehrs v. 2.1. INFRAS. Bern. Switzerland. 127p.

Mc Hugh, C.A., Carruthers, D.J., Edmunds, H.A., 1997. ADMSUrban: an air quality management system for traffic, domestic and industrial pollution. International Journal of Environment and Pollution 8 (306), 437–440.

Methodological guidance of department for air protection for processing of dispersion studies according §32 par. 1 letter. e) law n. 201/2012 law compilation., about air protection (only in Czech) 2013

POLMIT, 2002. Pollution from Roads and Vehicles and Dispersal to the Local Environment: Final Report and Handbook; Pollution of Groundwater and Soil by Road and Traffic Sources: dispersal mechanisms, pathways and mitigation measures, RO-97-SC.1027

Pu Y., Yang Ch., 2014. Estimating urban roadside emissions with an atmospheric dispersion model based on in-field measurements. Environmental Pollution 192. p. 300 – 307.

Righi S., Lucialli P., Pollini E., 2009. Statistical and diagnostic evaluation of the ADMS-Urban model compared with an urban air quality monitoring network. Atmospheric Environment 43. p. 3850–3857.

Samaras, Z. et al., 2005. Characteristics of Exhaust Particulate Emissions from Road Vehicles (PARTICULATES) European Commission. 114p.

Sanka, O., et al., 2014. Dispersion modelling of selected PAHs in urban air: A new approach combining dispersion model with GIS and passive air sampling, Atmospheric Environment, Issue 96, p. 88-95.

Šebor, G., et al., 2010. Comprehensive methodology for the assessment of pollutant emissions from road transport (in Czech). ATEM. Prague. 274p.

TRL, 1999. Methodology for calculating Transport Emissions and Energy Consumption. Project MEET. UK. 362p.