Norsk institutt for luftforskning
Norwegian Institute for Air Research

OR 10/2015

Methods for estimating air pollutant emissions

PART 1: Review and source of input data

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Scientific report

Preface

This report is part of the development of a National Modelling System for local air quality (the "Nasjonalt Beregningsverktøy" or NBV project). The main purpose of the NBV project is to provide a common methodological and information platform. The system is addressed to local and regional authorities and is intended to help them meet the requirements of current air quality legislation.

This report summarises the work carried out in 2014 as part of WP2 "Emissions" of the NBV project. The aim of WP2 is to develop a common method for the preparation and update of emission sources in Norway for its use as input data in the National Modelling System, NBV. The work focussed on the methods to estimate emissions and identified the main information sources of the needed input data for emissions. In this report we differentiate methods or input data suitable for WP4 (Norwegian cities) and / or WP5 (Agglomerations and Industrial areas), as these two work packages follow different modelling approaches, with different requirements on emission data. Four pollution sources are identified as the main contributors to air quality problems in Norway; traffic, wood burning, shipping and activities within port areas, and industries.

This report presents the most common methods to determine emissions and includes recommendations for future improvement of the emission calculations. The main purpose of the report is to identify the most relevant sources of emission information and the emission input data requirements necessary for modelling air quality in Norwegian cities and agglomerations.

The work in this report has been led by Susana López-Aparicio and carried out in close collaboration with Matthias Vogt and Dam Thanh Vo. The work performed and the early version of the report benefited from comments, feedbacks and discussions with other work packages of the NBV project, especially from discussions with Ingrid Sundvor, Dag Tønnesen and Leonor Tarrasón. Internal quality control at NILU has been carried out by Cristina Guerreiro and the project leader, Leonor Tarrasón. An early version of the report benefited from the comments from Isabella Kasin, Sigmund Guttu and Nina Holmengen from the Norwegian Environmental Agency.

The NBV project is supported by the Ministry of Climate and Environment through the Norwegian Environmental Agency, the Norwegian Public Road Administration, The Norwegian Directorate of Health and the Norwegian Institute of Public Health.

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List of Abbreviations

ADT	Average Daily Traffic
AIS	Automatic Identification System
AOD	Annual Operating Distance
AOT	Annual Operating Time
AE	Auxiliary Engine
AF	Activity Factor
AirQUIS	Air QUality Information System
B(a)P	Benzo(a)Pyrene
CHE	Cargo Handling Equipment
CLC	CORINE Land Cover
ECCAD	Emission of atmospheric Compounds and Compilation of Ancillary Data
EDGAR	Emission Database for Global Atmospheric Research
EF	Emission Factor
EMEP	European Monitoring and Evaluation Programme
FS	Fuel Sales
HBEFA	The Handbook Emission Factors for Road Transport
HDV	Heavy Duty Vehicle
HP	Engine Power (Hourse Power)
HV	Harbour Vessels
IMO	International Maritime Organization
LDV	Light Duty Vehicle
LF	Load Factor
MACC	Monitoring Atmospheric Composition and Climate
MDV	Medium Duty Vehicle
ME	Main Engine
MF	Monthly Factors
NBV	“Nasjonalt Beregningsvektøy”
NVDB	“Nasjonal vegdatabank”
OFV	“Opplysningsrådet for Veitrafikken AS”
OGV	Oceangoing Vessels
PAH	Polycyclic Aromatic Hydrocarbons
RETRO	REanalysis of the TROpospheric chemical composition
TV	Time Variation
VEH	Vehicles
VHT	Vehicle Hours Travelled
VKT	Vehicle Kilometre Travelled
VOC	Volatile Organic Compounds
WC	Wood Consumption

Methods for estimating air pollutant emissions

PART 1: Review and source of input data

1 Introduction

The purpose of the NBV project is to increase the use and quality of model estimates by local and regional authorities. A common methodology will therefore be developed meeting the requirements of current legislation. The main products from the NBV project distinguish between the state of air quality in cities and in agglomerations. There will be detailed studies of the pollution levels in 1) seven Norwegian cities/urban areas (i.e. Oslo, Bergen, Stavanger, Trondheim, Drammen, Sarpsborg/Fredrikstad and Grenland) using dispersion model estimates with 1x1km resolutionas part of the work under WP4 (Urban areas) , and 2) in 54 selected Norwegian agglomerations/towns and industrial areas where the estimations will be carried out following a simplified method, as part of the work under WP5 (Agglomerations and industrial areas). Regarding compounds, the scope of the work is on NO_x, NO_2, PM_{10} and $PM_{2.5}$ as main pollutants. Emission estimates and modelling activities targeting other compounds such as PAH, VOCs, CO_2 are, although highly relevant, beyond the scope of the NBV project.

Emission inventories are an essential component for the understanding of air quality and climate change issues from local, regional to global scales (Parrish, 2006). Within the NBV project, emissions constitute an work package itself, Work Package 2 (WP2), as emission data for Norwegian cities and agglomerations are essential input for the dispersion model and the simplified method. A guiding principle for the work under WP 2 of the NBV project is to estimate emissions according to bottom-up approaches as their results are considered more reliable (Coelho et al., 2014). Therefore, these methods will be prioritized and top-down approaches will only be used when data for bottom-up are not available.

The main goal of the work package WP2 on emissions is to develop a common method for the preparation and update of input data needed to estimate emissions and subsequently pollution dispersion. The production of emission data for Norwegian cities and towns will satisfy the following requirements:

- The emission data will have space and time resolution suitable for air quality analysis;
- Emission data will be of documented quality and accessible through open web applications;
- The access to the emission data as well as the production system will be developed in a way that allows future updates.

The first phase of the work in WP2 “Emissions” and summarized in this report has consisted of 1) describing feasible methods to estimate emissions, 2) describing methods for future updates for improving emissions estimates (best practises), 3) identifying the source of needed input data and 4) listing the input data requirements for the NBV project. This has been carried out for the four most relevant pollution sources; 1) On-road transport; 2) Wood burning; 3) Shipping and Port authorities; and 4) Industries (point sources).

Part of the work will continue beyond this report, especially regarding the source and access to input data. This is based on ongoing communication with relevant institutions such as The Norwegian Public Road Administration, Statistics Norway and the Norwegian Environmental Agency, and further work is foreseen for 2015.

2 Emissions estimates for traffic

This chapter focuses on emissions from on road transport. On-road transport sector is one of the prominent sources of emissions to air.
For on-road transport we have to distinguish between three groups of emissions:

- Exhaust (tail-pipe) emissions from the vehicle's engine as it is driven;
- Non-exhaust emissions;

For exhaust emissions, the main focus will be on compounds like particulate matter (PM_{10}, $PM_{2.5}$) and nitrogen oxides (NO_2, NO_x). For the non-exhaust emissions, in particular break-and-tire wear and re-suspended road dust, the main compounds which will be addressed are PM_{10} and $PM_{2.5}$.

The general methods designed for estimating emissions from on-road traffic are either bottom-up or top-down approaches. The bottom-up approach allocates traffic flow for each road link, while the top-down approach guarantees that estimated total kilometres driven in the study area, and corresponding fuel consumption, are in agreement with total consumption of fuel in the area over the same period. In general emissions are estimated using the following equation:

$$E = \left(EF_{abcde} * Activity_{abcdef}\right) + Cold \qquad 1$$

Where total emissions from road transport (*E)* are estimated as a function of the emission factors (EF) as mass per unit of activity rate (e.g. fuel consumed or distance travelled), extra emissions due to cold starts (*Cold*). Activity and therefore emissions will differ between type of fuel (*a*; petrol, diesel, liquefied petroleum gas – LPG, etc), vehicle type (*b*;e.g. light-duty vehicle, heavy duty vehicle, bus), emission control (*c*; Euro class), road type or vehicle speed (*d*), road gradient (*e*) and vehicle age (*f*).

2.1 Models for traffic emissions

2.1.1 Exhaust Emissions

Emission models have a double purpose in function of the scale on which they work. They can predict emissions at regional or national level, permitting to obtain emission inventories at these levels or they can predict the effects on emissions produced by changes in the design or operation of urban transportation systems at a very local level. It can be distinguished between two main approaches, 1) the average speed approach and 2) the instantaneous speed approach.

The average speed approach is the commonly used method to estimate emissions from road traffic. This approach is based on aggregated emission information for various driving patterns, whereby the driving patterns are represented by their average speeds alone. The information is put together according to vehicle technology, capacity class and model year and a speed dependent emission function is derived. This means that in addition to vehicle type, the average speed of the vehicle is the only influential parameter used to estimate emission rates. This restricts the approach to regional and national emission estimates.

By means of *the instantaneous speed approach*, emissions are measured continuously at the exhaust during chassis dynamometer tests and stored at a particular time interval (usually every second). The operational condition of the vehicle is recorded simultaneously with the emission rate. In this way it is possible to generate emission functions by assigning exactly defined emission values to particular operational conditions. The emission function for each pollutant can be defined as a two-dimensional matrix as said above. All instantaneous emission data are put into one cell of the emission matrix, according to the velocity and acceleration of the measured vehicle at that time. The emission function is the arithmetic mean of all emission quantities in each cell of the emission matrix. Once such an emission matrix exists for a vehicle, it should be possible to calculate the emission amounts for any driving pattern that is defined as series of modal value-pairs of speed and acceleration. This method uses another variable in addition to speed, the acceleration rate (or the product speed-acceleration), to describe in more detail the vehicle's operations.

2.1.2 Non-exhaust emission model

For the NVB project, it is proposed to use the NORTRIP model to determine non-exhaust road traffic induced particle emissions. This is a process based emission model that predicts non-exhaust emissions on an hourly / daily basis with good accuracy. The basic emission processes determined by the model are direct emissions due to road wear, direct emissions due to other wear sources and indirect emissions (suspension) of road dust either mechanically by vehicle wheels or by vehicle or wind induced turbulence. A detailed description can be found in Denby and Sundvor (2012).

2.2 Input data and source

2.2.1 General Input data

A detailed analysis of the variables influencing emissions is developed by André et al. (1999). The following list gives the main variables for the input data of emissions models, including information on the vehicles, mechanical and operating conditions and the meteorology for a given emission year, as follows:

- number of vehicles per hour and weekday on a road link (i.e. link volume);
- vehicle mix; percentage of e.g. trucks, buses, other heavy vehicles and light vehicles;
- vehicle age;
- vehicle technology, engine size, and presence of catalytic converters;
- vehicle average speed (for the average speed approach models). In this case geographical location is important because there are different driving cycles for urban, rural and motorway situations, and also inside urban category different types of road and driving conditions can be found;
- vehicle speed-time (acceleration/deceleration) profiles (modal models);
- vehicle kilometre travelled (VKT) and vehicle hours travelled (VHT);
- average trip length by purpose;
- ambient temperature and humidity.

When cold start emissions are included, the following information is needed:

- engine temperature at start;
- average speed in the transient phase;
- parking conditions (duration and location);
- use of heating system;
- wind speed.

In the optimal case the distribution of listed data should be also known: distribution of length trips, parking duration, temperature (the starts are distributed in different period of the day), etc., and for most of the activity data (traffic volume, speed… etc) temporal scale should be fine-grained and not annual based.

2.2.2 Input data for non-exhaust emissions

The basic input parameters for the non-exhaust emission are listed as follows

- *Meta data* (Road and building configuration, street direction, surface albedo)
- *Meteorological data*
- *Road wear and suspension parameters* (Traffic flow, HDV share, studded tyre share, sign posted speed)
- *Road moisture*
- *Concentration data* (Street level and background concentrations of NOx for converting the PM emissions to PM concentrations)

2.2.3 Emission factors for on-road transport

Different sources or databases for EF exist. Appendix A shows those commonly used in house for emissions estimates and subsequent dispersion in Norwegian cities, and the comparison with the EF suggested by The Handbook Emission Factors for Road Transport (HBEFA) for Norway. In the NBV project, emissions factors will go through different updating processes.

In this chapter the following databases, which are the most commonly used and accepted for urban air quality studies, will be described:

- The European EMEP/EEA air pollutant emission inventory guidebook;
- The Computer Programme to calculate Emissions from Road Transport version 4 (COPERT 4);
- The HandBook Emission FActors for road transport (HBEFA).

The European EMEP/EEA air pollutant emission inventory guidebook provides guidance on estimating emissions from both anthropogenic and natural emission sources. The guidebook includes methodologies and EF for estimating emissions for each pollutant sector. For each source, emissions can be estimated at different levels of complexity, classified as Tier 1, Tier 2 and Tier 3 methods. Tier 1 is a simple method using default EFs, which assume an average process description as well as a linear relation between the intensity of the process and the resulting emissions. Going from Tier 1 to a Tier 2, the default EFs and activity factors (AFs) should be replaced by country-specific or technology-specific EFs. Tier 2 methods are more complex and reduce the level of uncertainty. Finally, a Tier 3 method is the method that uses the latest scientific knowledge in more sophisticated approaches and models, with a greater disaggregation of AFs and EFs than Tier 2.

The Computer Programme to calculate Emissions from Road Transport version 4 (COPERT 4) is a software tool used to calculate air pollutant (CO, NO_2 NO_X, VOC, PM, NH_3, SO_x, heavy metals) and greenhouse gas (CO_2, N_2O, CH_4) emissions from road transport produced by different vehicle categories (i.e. passenger cars, light commercial vehicles, heavy duty trucks, busses, motorcycles, and mopeds) (Ntziachristos et al., 2009). The model estimates exhaust emissions (i.e. hot and cold-start) and non-exhaust PM emissions from tyre and break wear) using speed-dependent EFs derived from a binomial regression analysis applied to a large dataset of vehicle measurements classified by vehicle type. Compared to other road transport models (e.g. HBEFA, 2010) COPERT 4 is widely used among the European countries and its performance has been tested in several studies (e.g. Kioutsioukis et al., 2010; Borge et al., 2012).

The HandBook Emission FActors for road transport (HBEFA, 2010) provides emission factors per traffic activity and at different levels:

- By type of emission: "hot" emissions, cold start excess emissions,
- By vehicle category: passenger cars, light duty vehicles, heavy duty vehicles, buses, coaches and motorcycles.
- By year and implicitly by varying fleet compositions in the different countries (1990-2030 / 2035 – depending on the country),
- By pollutants.

The "hot" EF are given for several traffic situations and differentiated factors are provided for different road gradient classes (0%, 2%, 4%, 6%). Also weighted average values (distributions over several traffic situations and gradient classes) are calculated.

The cold start emissions are based on typical temperature distributions and behavioural parameters, such as trip length distributions, parking time distributions. The output is either weighted emission factors (per vehicle category), or as emission factors per concept (e.g. conventional passenger cars, passenger cars with catalysts, diesel passenger cars etc.), or as emission factors per fuel type (petrol, diesel) or as emission factors per sub-segment (e.g. passenger cars with engine size <1.4 l Euro-4 etc.).

2.2.4 Input data and source for the NBV project

Currently emissions and the subsequent air dispersion are modelled by means of the AirQUIS management system. Traffic emission are considered in this system as line sources. The input data to estimate emissions from line sources is provided based on an Excel template. The template contains information regarding road class identification (e.g. European, regional, state, municipal, tunnels), vehicle class distribution, road nodes (ID, geographical coordinates), static road data (e.g. length, width, road gradients), and dynamic traffic data (e.g. annual daily traffic, flow speed). One of the purpose of the NBV project is to develop an automatic system where the data is feed into the system and therefore into the emission model to allow future updates.

A possibility for automatic implementation is coupling the national road database from the Norwegian Public Road Administration (NVDB 2014; Figure 1) to the NBV system. Figure 1 shows as example the information currently available to the public for the areas around Sarpsborg and Fredrikstad. By searching for the amount of traffic (i.e. “Traffikmengde”), the roads with available information at the selected zoom appear highlighted as green (Figure 1), and by selecting a road link we get access to information such as the average daily traffic (ADT) and the time validity period.

Based on communication with the road administration, we may be able to get access to the raw data behind the NVDB database. The database includes information such as type of road (e.g. regional, municipal), width, length and gradient, amount of traffic (ADT) and the percentage of heavy duty vehicle. During writing this report, internal discussion at NILU are ongoing to evaluate the development of a code to retrieve the needed data and coupled to the NBV project. Additional meetings with the technical responsible of the NVDB are foreseen.

Vehicle class distribution is not available in the NVDB database and currently the information if obtained from hard documents provided by “Opplysningsrådet for Veitrafikken AS” (OFV). This information is essential to determine emissions, and its automatic implementation for the NBV project needs to be further discussed.

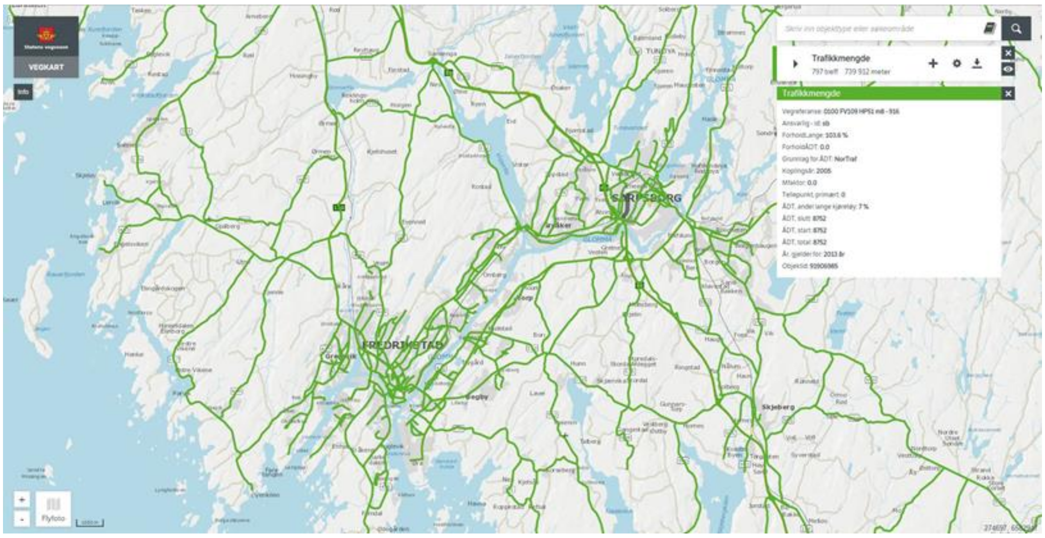


Figure 1: Option of NVDB database available to the public. Highlighted as green appear the roads with available information regarding amount of traffic at the selected zoom.

2.3 Best practise - Recommendations

In this section, best practises currently used in European cities to acquire emission input data are described. Some of the methods in this overview, such as the information acquisition from license plates, may be affected by data protection laws in Norway. In order to guarantee the protection of personal information, this type of methods should be developed in such a way that the data, once retrieved, is uncoupled from personal information, guaranteeing therefore the anonymity. The methods presented below are divided in four different categories based on the type of data collected. The best practice methods for emission data acquisition are organised with respect to: 1) vehicle characteristics (e.g. class, age, fuel type); 2) vehicle speed; 3) vehicle operation mode; and 4) emission factors.

Data collection on vehicle characteristics; as the emission rates vary according to the characteristics of a vehicle, in particular the size and weight of the vehicle, the type of fuel used and the age. So, the information required on vehicle mix is:

- the class
- the age and mileage accumulation rate
- the fuel type used
- the usage levels (i.e. vehicle kilometres travelled, vehicle hours travelled)
- the air-conditioning use.

The source for this type of information is usually national/area statistics, counts/surveys and in some cases traffic models. Traffic counts do not give the vehicle classifications required and are not usually located on minor roads. There is also little information on temporal or seasonal variation in vehicle characteristics on the roads. New smart traffic systems with surveillance cameras connected with supercomputers could be solution to get the information needed. Since 2008 these smart traffic systems are operated in cities like Milan. Traffic cameras first detect the licence plate, use image recognition technique coupled with a supercomputer, which has the information on car registration, and then give the fractions of the total mileage, vehicle class, fuel type, age and in the optimum case also the vehicle speed.

Data collection on vehicle speed; this is a crucial parameter as emission rates vary strongly with the vehicle speed. Vehicle speed is usually given as the output from a transport demand model as average speed on a specific link or based on the speed limit of the road. In reality, these speeds vary by time and even by lane. So, there is the need to take the final assignment of volume and recalculate speeds more accurately. In fact, most of the travel speed estimation methods do not include the effect of traffic congestion on upstream locations. With the exception of micro-scale traffic simulation models, none of the methods adequately assesses the build-up and dissipation of vehicle queues over time and space. Nevertheless traffic simulation models are extremely data and runtime intensive.

To overcome this high uncertainty, a dense setup of traffic stations would allow high resolution digital road map with traffic flow information. One of the best examples for this might be Barcelona, with approximately 3 000 traffic stations within the city getting high resolution temporal profiles of traffic volume and speed.

Data collection for vehicle operation mode; vehicle operational mode is an important determinant of emissions, and the most common independent variable in this respect is vehicle speed**.** The operating modes of a vehicle can be broadly classified in two categories: engine warming-up phase and thermally stabilised modes. This data is usually not available. Some transport models target the issue by implementing trip motives with start and end time. With the trip end data the assessment of the hot soak evaporative emissions is possible. The requirements of emission models are time of day, trip purpose, duration and vehicle type. This information is used to determine the total number of vehicle trips, the number of hot and cold starts and their spatial allocation, the trip length taken as the time from the origin to the destination, the diurnal evaporative emissions.

As this information is usually not available, cold and evaporative emissions are usually included in the emission factors provided by several software tools for emission estimation (e.g. COPERT, HBEFA).

Data collection - Emission Factors; EF for each vehicle and road type are needed. These can come from COPERT IV, HBEFA or EEA emission guidebook. Those EFs are based upon measurements made on a dynamometer in the laboratory, which in most cases are not representative of real driving conditions, such as signalized corridors. There is a rising concern within the scientific community that EFs should be resulting from measurements taken under real world driving conditions, including effects of road grades, roadway design, traffic signal timing, traffic conditions, weather conditions, etc. to give more representative information of real world emissions than the predictions of computer models.

A keypoint is the use of EFs from COPERT/HBEFA for the euro 5/euro 6 for diesel cars. Kousoulidou et al., (2012) showed that in the case of NO_x emissions, emission levels of Euro 5 diesel passenger cars are consistently higher in urban, rural, and highway driving compared to the corresponding COPERT emission factor. This shows that there is an important need for on-road emissions estimates to predict the impact of vehicle emissions on air quality and introduction of green zones.

Data collection – Input parameters for NORTRIP. The basic input parameters to determine the non-exhaust emissions are described in the previous section. In addition there are several parameters which improves model results significantly. Those parameters include road wear and suspension parameters (e.g Pavement properties (especially if studded tyres are used). measured vehicle speed.), road moisture measurements, PM_{10} and $PM_{2.5}$ measurement data for validation, activity data (dust binding, road salting and sanding activities) and mass balance data (road dust layer and salt loading concentrations in surface water and drainage water). In addition to those proven parameters, data on road surface temperature, wind speed at street level, salt content of road dust layer, cleaning and salting activities, splash and spray data and cleaning activities and ploughing activities might improve the model results significantly (Denby and Sundvor, 2012).

The recommendation is to investigate ways to include these type of information to the NBV modelling system. It is recognised that there are limitations on what is practically functional information to make available in the next two years but actions should be initiated to ensure the future availability of these type of input data.

3 Emission estimates for wood burning

Wood burning from domestic heating is one of the main contributors to air pollution in urban areas. The incomplete combustion of wood produces several types of compounds that are considered harmful such as fine particle matter, polycyclic aromatic hydrocarbon (PAH), including benzo(a)pyrene (BaP), and different types of VOC.

In Norway around 64% of the housing are equipped for combustion of wood, and around 60% use them. The main factors needed to estimate emissions from wood burning are:

- Wood consumption per technology (i.e. type of stove);
- Emission factors per technology;

Additionally spatial distribution and time variation are relevant to place emissions in space and time.

3.1 Wood burning emissions method

The simplest method for estimating emissions from wood burning is based on the wood consumption and on the different types of technologies such as newer clean burning stoves, older stoves and open fireplace. Total emissions for specific pollutants and type of technologies can therefore be calculated based on the equation:

$$E_i = \sum_j WC \; x \; EF_{i,j} \qquad 2$$

where, *i* is the pollutant of interest, *j* is the type of technology (i.e. new stoves, old stoves or open fireplace), *WC* is the activity level expressed as wood consumption (kg/year) and $EF_{i,j}$ is the emission factor specific to the pollutant (*i*) and the type of technology or stove (*j*).

3.2 Input data and source

The main input data for the NVB project to estimate emissions from wood burning are 1) wood consumption per technology or type of stove; 2) emission factors per stove type (Appendix A); 3) Spatial distribution and 4) Time variation.

The information concerning wood consumption per type of technology and regionally distributed is available from Statistics Norway (SSB; Statistikkbanken) and the data is based on questionnaires. Wood consumption data is available since 2005, and the latest year available at the time of writing this report is 2012. The information is available at regional scale as theoretical energy content (TWh), useful energy (TWh) and as amount of wood (tonnes) (Figure 2). Information regarding wood consumption discriminates between open fireplaces, old closed ovens (produced before 1998) and new closed ovens (produced after 1998). Time activity data is available per week of the year and hour. However, this data is only available for Oslo, Trondheim, Bergen and Drammen, and in addition the information is not updated to current wood consumptions.

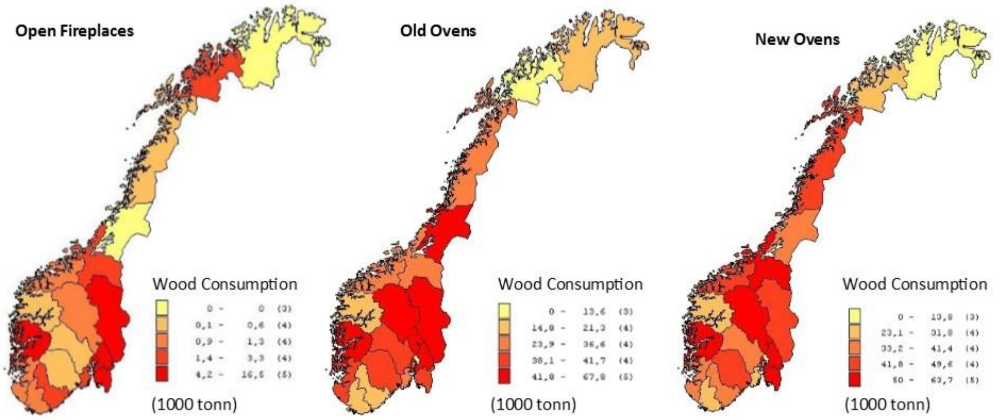


Figure 2: Regional wood consumption in Norway distributed per type of technology for 2012. Source: Statistic Norway and Norwegian Mapping Authority.

3.2.1 Temporal variation

Residential heating and therefore wood burning is very much associated with seasonal variations, so monthly wood consumption need to be constructed, and the data is needed with a time variation of week, weekday and hour. The monthly wood burning emission can be obtained by multiplying the annual average emissions with a monthly factor (MF) estimated as:

$$MF_n = \frac{WC_n}{WC} \qquad 3$$

Where, n is the month (n = 1 - 12), WC_n is the wood consumption in the month *n* and *WC* is the total wood consumption in a year.

In Norway, information regarding temporal variation is available for wood consumption for residential heating distributed per weeks, days and hours of the day (Table 1). However, the information in only available for Oslo (Finstad et al. 2004a), Trondheim (Finstad et al. 2004b), Bergen (Finstad et al. 2004b) and Drammen (Aasestad 2010) and based on surveys carried out in 2002, 2003, 2003 and 2006/2007, respectively.

Table 1: Time variation of wood burning consumption in Oslo (Finstad et al. 2004a), Trondheim (Finstad et al. 2004b), Bergen (Finstad et al. 2004b) and Drammen (Aasestad 2010), for temperature conditions below -5°C and expressed as percentage.

	Oslo 2002			Trondheim 2003	Bergen 2003	Drammen (2006/2007)
	Weekday	Saturday	Sunday			
6:00-10:00	7	18.3	18.9	17.8	13.4	19.6
10:00-14:00	3.9	17.3	19.3	19.9	13.9	11.5
14:00-18:00	34.5	43.5	46.2	72.9	69.4	56.2
18:00-00:00	85	84.6	80.9	82.5	79.1	80.4
00:00-06:00	0.8	0.9	0.9	1.3	0.8	1.6

3.2.2 Spatial distribution

Wood consumption data is needed at national, regional and city levels. In the case of urban areas (i.e. Oslo/Bærum, Stavanger/Sandnes, Drammen, Bergen, Trondheim, Sarpsborg/Fredrikstad, Grenland) the data is needed spatially distributed on urban districts and as gridded data (1x1km). The reason for this is the substantial differences inside urban areas regarding residential heating and the use of wood burning. For instance, the study carried out in Oslo by Statistics Norway based on a survey in 2002 (Finstad et al., 2004) established that the neighbourhoods Sagene-Torshov and Uranienborg-Majorstua were the highest contributors to wood burning emissions.

In the case of wood burning emissions in towns ("tettsted" in Norwegian), the information is needed for applications in WP5 (Agglomerations and Industrial areas) of NBV project. In this case, wood consumption can be extracted from the activity data at regional level based on populations, as a top-down approach. Accordingly, if a town has 10% of the regional population, then 10% of the total emission at regional level from wood burning could be allocated to this town, consequently 10% of the regional wood consumption will be assigned to this town.

3.2. Best practise

The use of a potentially unrepresentative EF could result in underestimates of air quality assessments and of the emission reductions required to meet air quality objectives. Emissions are usually calculated for each wood burning scenario by multiplying the quantity of wood used by the appropriate EF for that scenario. One possibility to obtain better emission estimates is by adjusting the existing EFs by real life measurements. Vertical flux measurements is an example of method that could be used, and by which we could improve the information (e.g. CO_2, $PM_{2.5}$). With vertical flux measurements, concentration over time and along a vertical profile is measured. These measurements would provide real-time information on wood consumption in small geographical areas (e.g. districts) which then could be extrapolated to a larger grid.

Moreover, residential heating has been identified as an important source of PM_{10}, $PM_{2.5}$, PAHs (including BaP) and CO in many cities/districts in Norway. However, other contaminants, including those classified as air toxics, are not targeted from residential wood heating. Therefore, it is important to ensure that emission estimates are robust and that residential wood combustion and its associated impacts on air quality are fully understood. This leads to address more focus on the PM size fraction of below 1 µm (PM_1), as over 90% of the particle number within the $PM_{2.5}$ fraction in wood burning is actually PM_1. In addition to that, the chemical composition needs to be addressed conceding the health effects of emitted PAHs and possible carcinogenic compounds in the organic fraction. The latter (PM size fraction and chemical composition) could be addressed using atmospheric mass spectrometry fluxes to determine the inorganic/organic composition of particles in various size classes.

3.3. Recommendations

To estimate emissions from wood burning within the NBV project the following data is needed:

- Wood consumption data per technology (i.e. fireplace, old oven, new oven) and distributed per district (“bydel” in Norwegian) for Oslo, Trondheim, Bergen, Stavanger, Drammen, Sarpsborg/Fredikstad, and Grenland. However, wood consumption data is available at regional (“fylke” in Norwegian) levels (Figure 2).

  Action: we are in communication with Statistic Norway to discuss the possibility of getting access to the raw data from the yearly questionnaires from where the updated regional activity is estimated. This will be used to update the available information regarding distribution of wood consumption within the selected Norwegian cities. Moreover, potential near future cooperation between Statistic Norway and Norwegian Environment Agency may contribute to new data and their accessibility.

- Time activity data is needed for the seven Norwegian cities (WP4) as consumption per week and hour of the day. This information is available for Oslo (Finstad et al. 2004a), Trondheim/Bergen (Finstad et al. 2004b) and Drammen (Aasestad 2010), based on surveys carried out in 2002, 2003 and 2006/2007, respectively.

  Action: we are in communication with Statistic Norway to evaluate the possibility of updating this information.

- The emission factors recommended by today for wood burning and distributed per type of technology are shown in Appendix A and are estimated by SINTEF (2013). These EFs could be updated under potential future development regarding estimation of wood burning EF under real world conditions.

4. Emission estimates for shipping and port activities

This chapter focuses on emissions related to activities within port areas, including emissions from shipping and land activities. As emissions from land activity we understand those from traffic (i.e. light, medium and heavy duty vehicle) and those from cargo handling equipment (e.g. crane, forklift, tractor), both occurring within the port area. As previously commented, within the NBV project, the modelling tools will be carried out 1) in seven Norwegian cities (WP4); and 2) in agglomerations and industrial areas (WP5). In this chapter different methods will be described and evaluated to estimate shipping emissions for the two different geographical context and their suitability for the NBV project.

4.2. Methods for emission estimates in port areas

4.2.1. Ship call activity method

The ship call activity method is a bottom-up approach based on the information regarding arrival and departure of the vessels visiting the port. This method is very accurate, although it demands significant amount of data and therefore resources to determine emissions. The main input data is the activity log of the port, with information about the arrivals/departures and the identification number of each individual vessels. To estimate emissions, the methodology published by US EPA (2009) can be used, which takes into account the engine power (HP) and load factors (LF).

Vessels operating in the port area are first divided between harbour vessels or oceangoing vessels. Harbour vessels (HV) are those that spend most of the time within the harbour, and include domestic ferries, excursion boats, fishing boats, tugboats, recreational, supply and work boats. Emissions for harbour vessels are then estimated based on the annual operating time (AOT; Equation 4) of each specific vessels. The AOT can be available from the port authority, public transport authority, responsible of managing public transport, or operators. If this information is not available, average AOT for HV groups is available (e.g. US EPA, 2009). Regarding the engine, information about the engine power can be obtained through the operator webpage (e.g. in the case of tourist excursion boats) or from databases such as the world shipping register.

$$E_{i,HV} = \sum EF_{i,HV} * LF_{HV} * AOT_{HV} * HP_{HV} \qquad 4$$

Emissions from oceangoing vessels (OGV) are distributed in emissions according to operational mode, such as cruising ("at sea"; Equation 5), manoeuvring (Equation 6) and at berth (Equation 7). Emissions factors for each pollutant (*i*), operational mode and type of OGV or HV are shown in Table 14 in Appendix A.

Emissions are estimated as a function of the engine (i.e. horsepower) of the different type of vessels and their load factor under different operational modes. The load factors can be estimated for OGV in cruise mode based on the speed, if the information is available. Otherwise, load factors for the different type of vessels can be obtained from other sources (e.g. US EPA, 2009). The information regarding the main (ME) and auxiliary engine (AE) for the main groups of vessels (e.g. container vessels, ferries, tourist cruises) is also available in US EPA (2009) or in scientific publications. An alternative is using specific data for each individual vessels based on the International Maritime Organization number (IMO) and retrieve them from databases such as the world shipping register (World Shipping Register, 2014).

$$E_{i,OGV"at\ sea"} = \sum EF_{i,OGV"at\ sea"} * LF_{OGV,"at\ sea"} * 2 * t_{OGV,"at\ sea"} * HP_{OGV,ME} \quad 5$$

$$E_{i,OGV"man."} = \sum EF_{i,OGV"man."} * LF_{OGV,"man."} * (t_{OGV,"man.IN"} + t_{OGV,"man.OUT"}) * HP_{OGV,ME} \quad 6$$

$$E_{i,OGV"at\ berth"} = \sum EF_{i,OGV"at\ berth"} * LF_{OGV,"at\ berth"} * t_{OGV,"at\ berth"} * HP_{OGV,AE} \quad 7$$

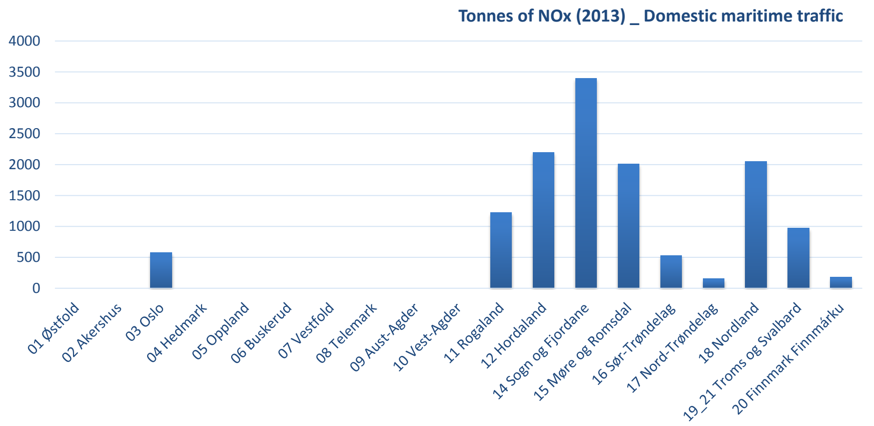
4.2.2. Marine fuel sale method

A more simple method than the one previously described is the top-down approach based on fuel sales. This method can be suitable for emissions estimates of towns and as part of the simplified method to be developed in WP5. Examples of towns from WP5 with intensive maritime traffic are Narvik, Tromsø and Kristiansand, among others. The method is a simple approach based on maritime fuel sales and a generic EF (ENTEC, 2005) for the type of marine fuel;

$$E_{i,f} = FS\ x\ EF_{i,f} \quad 8$$

Emission of the pollutant *i* from the type of fuel *f* (e.g. residual oil, distillate fuel or marine diesel oil, liquefied natural gas, LNG), is estimated by the product of the fuel sales (*FS*; ktonne) and the general EF for the pollutant *i* and type of fuel (EF_{if}; g/ktonne of fuel sales). This method assumes responsibility for emissions from the region that possess the maritime fuel before it is purchase by the vessels, hence it is sensitive to the relative price of the fuel. This method has additionally several disadvantages, such as the lack of information regarding the location of the emissions. However, as it was previously pointed it out (ENTEC, 2005), it is worthwhile to look further into this method.

Regarding input data, updated data (i.e. from 2005 to 2013) on sales of petroleum products is available from Statistics Norway (SSB, 2014). Sales are distributed per region, type of industry (e.g. domestic shipping, international shipping), and type of petroleum product (e.g. marine gas oil, heavy oil). This information will allow to estimate emissions from domestic and international shipping separately. Figure 3 shows as example NO_x emission estimates at national and regional level for 2013 and distributed as domestic and international maritime traffic. As previously stated, the uncertainties of this method are especially regarding the location of the emissions. For instance, NO_x emissions in Buskerud are zero as there are no register of maritime fuel sales in this region (Figure 3). However, the port of Drammen is located in this region. Comparing emissions for Oslo region based on the maritime fuel sale (≈1033 tonnes) with available results based on the ship call activity method (≈700 tonnes), we see that the maritime fuel sale may overestimate results or that emissions are misplaced. Emissions in Buskerud are zero according to the maritime fuel sale (Figure 3), we can assume that the fuel sales for the port of Drammen are misplaced in Oslo region, explaining the higher values.



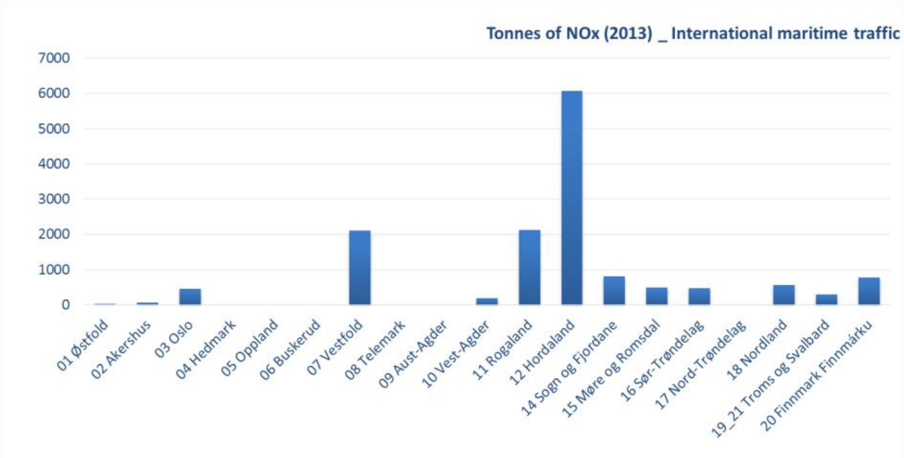


Figure 3: NO_x emission estimates (2013) for domestic maritime traffic (top) and international maritime traffic (bottom) at regional level estimated based on the marine fuel sale method.

4.2.3. The Automatic Identification System (AIS)

An automatic tracking identification system (AIS) was introduced by the UN's International Maritime Organisation (IMO) in order to increase the safety of ships and the environment, and to improve traffic monitoring and maritime traffic services. The information is received by nearby vessels, satellite or AIS land bases. The AIS system is a very relevant tool as it provides real time information regarding vessel position, course, speed, identification, among other variables. This method has been used to estimate emissions from shipping (e.g. Winther et al., 2014) and it is a promising method to be applied in the NBV project. However, we still need additional research to evaluate the information regarding input data acquisition, processing and emissions estimates. In addition, this method cannot be used to determine emissions from land activities within the port.

4.2.4. Emission from activities in the port

Activities in the port area which can be included in emission inventories from ports are those associated with handling the cargo and the traffic (light duty vehicle, medium duty vehicle, and heavy duty vehicle) that occurs in the areas that belongs to the port. Among cargo handling equipment we may distinguish between emissions from terminal tractors, forklifts, cranes, etc.

For cargo handling equipment (CHE; Equation 9) and vehicles operating within the port area, the AOT and the annual operating distance (AOD; Equation 10) of each type of equipment or vehicle, respectively, is needed. This information can be provided by the port authority and/or by the operators in charge of handling the cargo.

$$E_{i,CHE} = \sum EF_{i,CHE} * LF_{CHE} * AOT_{CHE} * HP_{CHE} \quad 9$$

$$E_{i,VEH} = \sum EF_{i,VEH} * AOD_{VEH} \quad 10$$

4.3. Input data and source

Table 2 shows a summary of the needed data to estimate emissions from the shipping sectors according to the methods described before; 1) the ship call activity data method, 2) the marine fuel sales and 3) the automatic identification system (AIS). The amount of data required for the ship call activity method is bigger than for the other methods. The method based in the tracking AIS require data which may be provided by the Norwegian Coastal Administration. However, further research is needed to validate this information.

Table 2: Summary of the needed input data per emission estimate method and source of this data. AOT: Annual operating time of harbour vessels and cargo handling equipment. AOD: annual operating distance of vehicles within the port. Emission factors are included in Appendix A.

<table>
<tr><th>Methods</th><th>Input data</th><th>Source</th></tr>
<tr><td rowspan="4">Ship Call Activity</td><td>Engine power (main / auxiliary)</td><td>▪ World shipping register (http://www.world-ships.com/)
▪ Operators (e.g. excursion boats)</td></tr>
<tr><td>Load factors</td><td>▪ US EPA (2009)
▪ At cruising; estimated based on speed</td></tr>
<tr><td>AOT</td><td>▪ Port authorities
▪ Public transport authorities
▪ Cargo operators
▪ US EPA (2009)</td></tr>
<tr><td>AOD</td><td>▪ Port authorities
▪ Operators</td></tr>
<tr><td>Marine fuel sales</td><td>Fuel sales</td><td>▪ StatBank (http://www.ssb.no)</td></tr>
<tr><td>AIS</td><td>Sample AIS data</td><td>▪ Norwegian Coastal Administration (work in progress)</td></tr>
</table>

4.4. Recommendations

All methods have advantages and disadvantages, so Table 3 summarised the suitability of each method for the purpose of WP4 and WP5, dealing with air pollution determination. The ship call activity method is the most accurate, and therefore suitable to estimate emissions of the seven cities within the WP4 (Table 3). However, this method requires a big amount of data and therefore resources. The method based on marine fuel sale has several disadvantages such as the lack of information regarding the location of the emissions, but it may be accurate enough to estimate emissions for the towns and industrial areas in WP5. The needed data is in addition easily accessible (Table 2). A promising method for both applications is the one based on the tracking AIS vessel position, speed and fuel consumption, but it needs further research and development.

Table 3: Summary of the suitability of the methods to estimate emissions from shipping activities for the purpose of WP4 and WP5 in the NBV project, and require data.

Methods	WP4 (Norwegian Cities)	WP5 Towns and industries	Data
Ship Call Activity	√		Logging system from Port authorities, load factors, operational time, horsepower engine, EFs
Marine Fuel Sale		√	Marine fuel sales, EFs
AIS	√	√	Work going on

A compromise solution is to apply a simplified method based on the ship call activity bottom up approach. The main difference is that instead of using information from the individual vessels regarding engine and time in operation (cruising, manoeuvring and at berth), we use averages for each vessel group (e.g. container vessel, ferries) based on information available in house and suggested in US EPA (2009). For this simplified method, a table has been developed to gather the needed information from the Port authorities in Oslo, Trondheim, Bergen, Stavanger, Drammen, Sarpsborg/Fredikstad regarding oceangoing vessels (Table 4). Similar tables would be used for harbour vessels (Table 5), cargo handling equipment (Table 5) and traffic (Table 6).

Table 4: Example of table to be provided to the ports authorities to gather information concerning the number of calls of different oceangoing vessels in the port and the approximately average time at cruising (from a selected geographical point), manoeuvring and berth.

OGV type	#Calls	$t_{cruising}$ (h)	$t_{manoeuvring}$ (h)	$t_{at\ berth}$ (h)
Bulk Carrier				
Container Ship				
Cruise Ship				
Ferries (International)				
General Cargo				
Ro-Ro				
Oil / Chemical Tankers				

Table 5: Example of table to be provided to the port authorities to gather the information regarding harbour vessels and cargo handling equipment operating in the harbour and annual operating time.

Harbour vessel type	#	Annual Operating time (h)	Type of CHE	#	Annual Operating time (h)
Excursion boats			Crane		
Ferries (Domestic)			Forklift		
Fishing boats			Reach Stackers		
Supply vessels			Tractors		
Tug – Push boats					
Work boats					
Others					

Table 6: Example of table to be provided to the port authorities to gather information regarding amount of traffic (light, medium and heavy duty vehicle) and annual operating distance within the port area.

Type of Vehicle	#	Annual operating distance
LDV		
MDV		
HDV		

5. Emission estimates for industry

In this chapter we describe the general method to estimate emissions from industry, focussing on industrial point sources, the needed data and potential source of the input data.

5.2. Industrial emissions methods

The simplest way to estimate emissions from industrial sources is based on activity expresses as energy input or fuel consumption;

$$E_i = Activity \ x \ EF_i \qquad 10$$

For industrial sources, emission represents the sum of emissions for all processes that are emitting through the stack(s). For each process then activity (i.e. fuel or consumption, production output) or directly emission data is needed. When consumption or production data is available, emissions are calculated by multiplying with the corresponding EF for that process. In the case of existing technological devices to reduce emissions, this aspects must be considered in the calculation. Accordingly, emissions are estimated following the equation:

$$Q = Q_p * \left(\frac{100 - \%reductionfromcleaningdevice}{100} \right) \qquad 11$$

where
Q = Emission
Q_p = Emission from process

Industrial emissions are obviously not constant with time, so total emissions need to be adjusted to time variations. Time dependency factors are important for each individual industrial source, as for other pollution sources such as traffic and areas sources. Accordingly emissions will be distributed following the equation 12;

$$E = E*TV_{hour}*24*TV_{day}*7*TV_{week}*52$$

Where emissions (E) are distributed based on time variation per hour (TV_{hour}), day (TV_{day}) and per week (TV_{week}).

5.3. Input data and source

In Norway, total emissions from industry are estimated by Statistics Norway, in collaboration with the Norwegian Environmental Agency, and are available through The Norwegian Pollutant Release and Transfer Register (“Norske Utslipp”, 2014). The inventory includes emissions for different components (e.g. CO_2, CH_4, NO_x, Dioxins, SO_2) based on the figures reported by the companies to the authorities. In the case industries are not subject to reporting obligations, emissions are estimated based on activity data. Therefore, information regarding total emissions per year is available for most of the industries in Norway. However, other needed data (e.g. geographical and physical information about the stacks) have to be collected from other sources. Table 7 summarizes the most relevant data needed to evaluate emissions and subsequently estimate pollution levels associated with industrial sources.

Table 7: Summary of the input data required for evaluation of emissions from industrial sources.

No.	Name	Definition	Type of data	Source of data
1	Source sectors	Classifying air pollution industrial sources.	• Bricks production • Smelting • Power plants (coal + natural gas) • Cement production • Steel furnace • Glass furnace • Paper production • Plastic • Food processing, Noodle, Vegetable oil • Beverage • Furniture • Textile, dye • Tobacco • Pesticide	
2	Owner and Plant register	Administrative information	Name, address, contact information	
3	Stack data	The physical and geographical information of each stack within an industry	coordinate, stack height, diameter, gas temperature, gas velocity, gas flow rate, height and width of buildings around the stack	
4	Cleaning device	Cleaning device and it's efficiency used by industry processes	Specific components reduction efficiencies and which stack it is connected to	
5	Process data	Consumption amount of a certain fuel or the direct emission amount for each process	amount of all type of fuels consumption and/or emission from the process	
6	Process emission factor	Emission factors are ratios that relate emission of pollution to an activity at a plant such as amount of fuel used. Process emission factors for each fuel-component	emission factor component, emission factor value	

5.4. Recommendations

As described, total emissions of different compounds from Norwegian industries is yearly available in the Norwegian Pollutant Release and Transfer Register ("Norske Utslipp", 2014). However, other data (Table 7) need to be retrieved from other sources. Communication with the Norwegian Environmental Agency, and the responsible of industrial emissions, indicated us that the data is not available in national registers. Consequently, we need to address this issues, directly with the industries or with the municipalities. A possibility of getting this data is to prepare a simplified version of Table 7 and distribute it to the municipalities where main industrial sources are located, and especially in those urban areas relevant for the objective of the NBV project.

6. Downscaling methodology and its applications

6.2. The top-down method

Emissions from area sources over a region of interest can be produced by spatially downscaling data from existing global emission inventories (Figure 4). The disaggregation at the sub-grid cell level is assisted by the use of spatially detailed land cover information derived from multispectral satellite data using classification techniques.

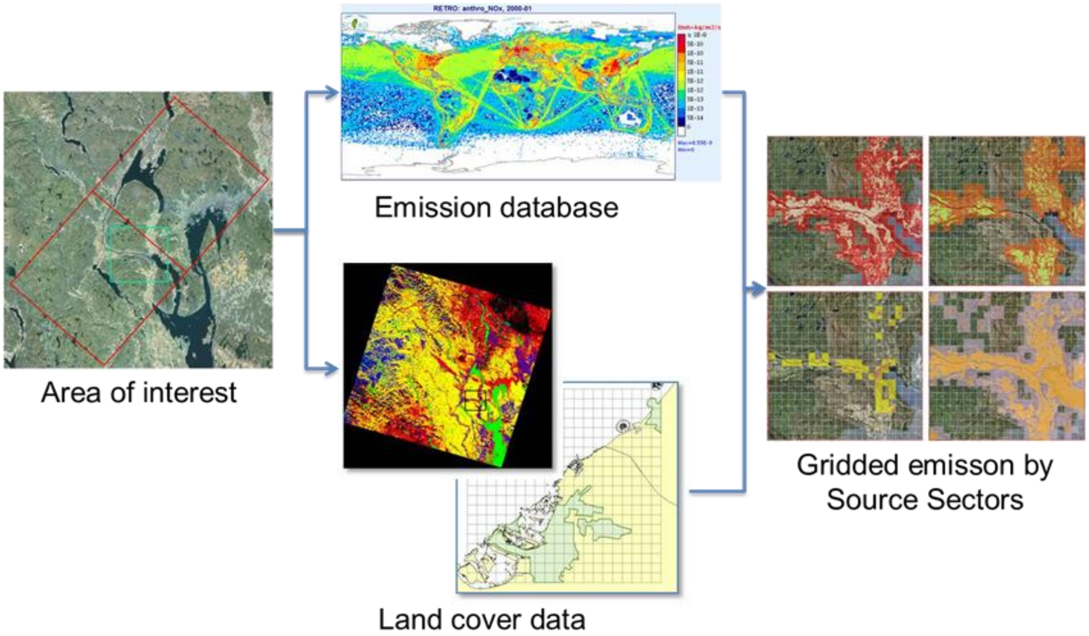


Figure 4: Concept diagram of downscaling methodology to estimate emissions from area sources.

Recently updated Europe-wide or global emission inventories are used depending on the individual suitability to obtain regional emission data of main pollutants such as $PM_{2.5}$, PM_{10}, NO_x and NO_2. Examples of such emission inventories are:

- The European Monitoring and Evaluation Programme (EMEP);
- D-EMIS, based on datasets gathered from different MACC sub-projects (MACC, 2014), as well as from publicly available inventories.
- The REanalysis of the TROpospheric chemical composition over the past 40 years data sets (RETRO);
- The Emission Database for Global Atmospheric Research (EDGAR) version 4.2 (EC/JRC, 2009).

The information at coarse-resolution is then downscaled to higher spatial resolution using land cover data derived from different platforms. Land cover information for the downscaling process is obtained from Mapping Authorities, CORINE Land Cover (CLC) a seamless European land cover vector database or simply using Google Earth Mapping. Depending on the available information regarding land cover databases, the land cover classes will vary. The primary classes are urban/built-up area, agricultural area, natural vegetation, and water surfaces.

Geoprocessing, which combines land cover layers and global scale gridded emissions, is handled by Geographic Information System (GIS) tools to distribute emissions according to emission source sectors, spatial positions and population density information. All regional emissions of NO_x, NO_2, PM_{10} and $PM_{2.5}$ are subsequently imported into the emission database as part of the input data for the air dispersion calculation.

6.3. Input data and its source

Most of the global or regional emission data is available online. The portal for Emission of atmospheric Compounds and compilation of Ancillary Data (ECCAD, 2014) compiles the information regarding available databases for a wide variety of compounds and sectors (e.g. aviation, transportation, energy, solvents).

For the aim of the NBV, available emission databases such as EMEP or MACC can be the most suitable. For the land cover data, CORINE database is available from the Norwegian Forest and Landscape institute.

6.4. Recommendations

The main purpose of applying downscaling methodology is to retrieve emission information from sectors others than those already covered by the bottom-up approach, for instance waste, agriculture, construction sites, among others.

The contribution of those sector is rather small and the accuracy of the method is questionable. A priori and within the work in the NBV project, we can recommend the downscaling method for emission retrievals of towns and industrial areas, object of study of WP5, and as part of the simplified method. The downscaling method may not be recommendable to estimate emissions from sectors in the seven Norwegian cities (WP4). The extend of the application of this method within the NBV project will be further evaluated during the implementation of the project.

7 Data source and information requirements for the NBV project

Table 15 in Appendix B shows an overview of sources of needed input data to establish emissions from 1) traffic, 2) wood burning, 3) shipping emissions and activities in port areas; and 4) industrial emissions. Apart from the source of information, it is indicated the availability (yes, no, maybe), the spatial and temporal data resolution, the need for update, among other features.

One of the aims of the NBV project is to develop a tool that allows automatic input data flow. This can be achieved by coupling the NBV system with existing databases, such as the NVDB database with information about traffic amount distributed in the road network. The feasibility of implementing the input data flow automatically is additionally indicated in the table with a colour code. We highlight as green a feasible automatic implementation, as yellow a probable automatic data flow, and as red improbable automatic implementation.

8 Summary and Recommendations

This study summarises existing methods to estimate emissions, best practises for future improvement and input data requirement for the NBV project. One of the objectives is to determine the source of needed input data for estimating emissions, with both space and time resolution suitable for the evaluation of local air quality in Norwegian cities and towns. Emissions methods are divided according to the main four pollution sources, as emissions from 1) on-road traffic, 2) wood burning, 3) shipping and port activities and 4) industries. In addition, evaluation, recommendations and requirements are described within the scope of the NBV project.

The main findings from this study are:

- ***On-road traffic emissions;*** the most relevant input data is the road network with the amount of traffic, vehicle distribution and composition. The most suitable source of data, which in addition is appropriate for automatic data acquisition, is the available National Road database (NVDB). Based on communication with the technical responsible at the Public Road Administration, we can have access to the data and need to develop a code to retrieve the needed information. An internal evaluation process is ongoing in-house regarding code development for the data retrieval. Vehicle class distribution is, however, not available in the NVDB database, but available from OFV. Vehicle class distribution is essential to determine emissions, and its automatic implementation for the NBV project needs to be further discussed and evaluated.

  As part of this report it is also emphasized the need of implementing state of the art techniques for real (near-real) time acquisition of traffic information (e.g. vehicle characteristics, speed, driving patterns) for future implementation and improvement.

- ***Wood burning emissions;*** The most crucial input data is wood consumption data distributed per type of technology (i.e. fireplaces, old/new closed ovens). The data is required at district level ("bydel"), in the case of the seven Norwegian cities (WP4), or at regional scale in the case of agglomerations and industrial area applications (WP5). Yearly updated data is available at regional level, but it is not at district level ("bydel"). Similarly, there is not updated information regarding time activity. Currently, we are in communication with Statistic Norway and the Norwegian Environmental Agency to evaluate how we could update the needed data and get access to it. A preliminary suggestion is getting access to the raw data from where regional information is estimated. We foresee progress at the beginning of 2015.

- ***Shipping and Port authorities;*** Three different methods have been described and evaluated regarding the aim of the NBV project. The ship call activity method is the most accurate but it also requires significant amount of input data and therefore resources. The marine fuel method is rather uncertain but suitable for estimating emissions from shipping activities in agglomerations and industrial areas as part of the WP5. The method based on the automatic tracking identification system is the most promising, especially for automatic applications. However, the method needs further research and development. A suggested alternative is to develop a simplified version of the ship call activity data, based on average characteristics of vessels groups instead of individual vessels. This method would require 1) development of a code for implementation in the NBV; and 2) input data from the port authorities (e.g. number of ferries, number of container vessels).

- ***Industries;*** annual total emissions from industrial point sources are available at the Norwegian Pollutant and Transfer Register ("Norske Utslipp, 2014"). However, the data needed such as time activity and geographical/physical characteristics of the stack(s) are not a priori available. We need to evaluate the data availability directly with the municipalities or the industries. We foresee progress at the beginning of 2015.

- ***The Other method*** that is described in this report is the downscaling approach based on the use of a regional and global emission database and land cover data. This method is applied to estimate area emissions from sources which were not considered in the bottom-up approach. The downscaling method is rather uncertain, although it may be accurate enough for estimating relevant area emissions for the agglomerations and industrial area application in WP5.

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Appendix A

Emission Factors Information Source

Emissions factors for on-road traffic

Table 8: Emission factors (PM and NO_x) for passenger cars recommended by HBEFA (2010) and those currently implemented in the air quality management system, AIRQUIS. P: petrol; D: Diesel.

Source	HBEFA_PM	AIRQUIS_PM	HBEFA_NO_x	AIRQUIS_NO_x
Passenger cars Unit = (g veh km^{-1})				
PC-P-Euro-0	3.36E-03	3.73E-03	1.06	0.92
PC-P-Euro-1	2.84E-03	3.40E-03	0.82	0.70
PC-P-Euro-2	3.52E-03	4.20E-03	0.52	0.49
PC-P-Euro-3	1.67E-03	1.94E-03	0.10	0.09
PC-P-Euro-4	9.30E-04	6.60E-04	0.09	0.07
PC-P-Euro-5	6.30E-04	5.60E-04	0.07	0.07
PC-P-Euro-6	4.80E-04	7.20E-04	0.07	0.06
PC-D-Euro-0	1.77E-01	1.23E-01	0.82	0.72
PC-D-Euro-1	1.57E-01	1.13E-01	0.77	0.66
PC-D-Euro-2	1.12E-01	8.04E-02	0.82	0.71
PC-D-Euro-3	4.46E-02	3.73E-02	0.91	0.71
PC-D-Euro-4	2.14E-02	1.73E-02	0.69	0.52
PC-D-Euro-5	2.03E-03	1.66E-03	0.69	0.52
PC-D-Euro-6	2.04E-03	1.66E-03	0.24	0.19

Table 9: Emission factors (PM and NO_x) for light duty vehicles recommended by HBEFA (2010) and currently implemented in the air quality management system, AIRQUIS. D: Diesel.

Source	HBEFA_PM	AIRQUIS_PM	HBEFA_NO_x	AIRQUIS_NO_x
Light duty Vehicles				
Unit = (g veh km^{-1})				
LCV-D-Euro-0	3.85E-01	3.33E-01	1.47	1.41
LCV-D-Euro-1	1.89E-01	1.65E-01	1.32	1.26
LCV-D-Euro-2	1.23E-01	1.07E-01	1.17	1.13
LCV-D-Euro-3	5.25E-02	4.87E-02	1.01	1.02
LCV-D-Euro-4	3.58E-02	2.92E-02	0.71	0.66
LCV-D-Euro-5	2.43E-03	2.14E-03	0.65	0.62
LCV-D-Euro-6		1.89E-03		0.22

Table 10: Emission factors (PM and NOx) for heavy duty vehicles recommended by HBEFA (2010) and currently implemented in the air quality management system, AIRQUIS. D: Diesel.

Source	HBEFA_PM	AIRQUIS_PM	HBEFA_NO_x	AIRQUIS_NO_x
Heavy duty Vehicles				
Unit = (g veh km^{-1})				
HGV-D-Euro-0	6.57E-01	5.18E-01	12.58	10.94
HGV-D-Euro-I	4.70E-01	3.58E-01	9.07	7.80
HGV-D-Euro-II	2.26E-01	1.87E-01	11.82	10.02
HGV-D-Euro-III	3.00E-01	2.25E-01	10.83	8.84
HGV-D-Euro-IV	7.15E-02	4.24E-02	9.45	7.43
HGV-D-Euro-V	6.44E-02	3.85E-02	6.95	5.34
HGV-D-Euro-VI	5.29E-03	3.99E-03	1.13	0.78

Table 11: Emission factors (PM and NOx) for buses recommended by HBEFA (2010) and currently implemented in the air quality management system, AIRQUIS. D: Diesel.

Source	HBEFA_PM	AIRQUIS_PM	HBEFA_NOx	AIRQUIS_NOx
Buses				
Unit = (g veh km^{-1})				
UBus-D-Euro-0	1.63E+00	7.40E-01	25.52	14.53
UBus-D-Euro-I	7.53E-01	3.70E-01	16.55	9.13
UBus-D-Euro-II	3.74E-01	1.86E-01	17.67	9.97
UBus-D-Euro-III	3.37E-01	1.96E-01	17.23	8.34
UBus-D-Euro-IV	8.19E-02	3.35E-02	13.28	7.39
UBus-D-Euro-V	9.73E-03	4.06E-03	10.85	5.94
UBus-D-Euro-VI	8.09E-03	4.61E-03	1.23	0.62
Gas Bus		7.00E-03		3.34

Emission Factors for wood burning

Table 12: $PM_{2.5}$ emission factors for wood burning according to different technologies, as open fireplace, new closed ovens and old close ovens.

Unit = (gkg^{-1})	SINTEF (normal)	SINTEF (media)
Open fireplace	17.3	17.3
Old oven	22.7	17.4
New oven	13.4	12.2

Emission Factors for shipping

Table 13: Emissions factors reported by Copper and Gustafson 2004 for different types of engines and marine fuels with different sulphur contents. Engine; SSD: slow speed diesel, MSD: medium speed diesel. Fuels; MDO: marine fuel oil, MGO: marine gas oil.

Engine	Fuel	bsfc	NO_x (g/kWh)	PM_{10} (g/kWh)	Sulphur %
SSD	MDO	185	17	0.45	1
	MGO	185	17	0.31	0.5
	MGO	185	17	0.19	0.1
MSD	MDO	203	13.2	0.47	1
	MGO	203	13.2	0.31	0.5
	MGO	203	13.2	0.19	0.1
	MDO	217	13.9	0.49	1
	MGO	217	13.9	0.32	0.5
	MGO	217	13.9	0.18	0.1

Table 14: Emission factors reported by European Commission and ENTEC (2005) for vessels under different operational modes.

	Cruising		Manoeuvring		At berth	
Units	g/kWh		g/kWh		g/kWh	
Types of vessels	NO_x	PM_{10}	NO_x	PM_{10}	NO_x	PM_{10}
Bulk carrier	17.9	n/a	14.3	2.3	13.8	1.5
Car carrier vessel	15.6	n/a	12.5	2.3	13	1.4
RO-RO	15.6	n/a	12.5	2.3	13	1.4
Charter boat	13.2	n/a	10.7	2.3	11.6	1.8
Chemical tankers	16.5	n/a	13.3	2.2	13.3	2.2
Combine cargo	17.9	n/a	14.3	2.3	13.8	1.5
Container Ship	17.5	n/a	14	2.3	13.7	1.5
Cruise ship	13.3	n/a	10.6	2.1	11.3	1.8
Dry bulk cargo	17.5	n/a	14	2.3	13.7	1.5
Ferry (domestic)	13.2	n/a	10.7	2.3	11.6	1.8
Ferry (International)	13.3	n/a	10.6	2.1	11.3	1.8
Fishing	13.9	n/a	13	1.1	13.4	0.8
General Cargo	16.3	n/a	13.1	2.3	13.3	1.5
Supply boats	14.2	n/a	11.4	2.4	11.8	2
Oil Tankers	14.9	n/a	12	2.3	12.1	2.2
Reefer ship	17.4	n/a	13.9	2.2	13.5	1.2
Tank Barge	14.9	n/a	12	2.3	12.1	2.2
Tugboat	13.7	n/a	11	2.3	11.8	1.8

Appendix B

Input Data

Table 15: Overview Input data

Emission Source	Input Data	Provider	Source	Availability	Format per today	Time Resolution	Space Resolution	Need for updating	Feasibility of automatic implementation
Traffic	Road network[1]	Statens vegvesen	Nasjonal Vegdatabank	Yes	Web / Excel	year	Line		
	Traffic density/amount[1]	Statens vegvesen	Nasjonal Vegdatabank	Yes	Web / Excel	year	Line		
	Vehicle fleet composition	OFV AS	Report	Yes	HC document	year			
Wood Burning	Wood Comsuption / technology	Statistisk sentrabyrå	Statistikkbanken	Yes	Excel	year (t/year)	Region (Fylke)	Yes	
	Time variation[2]	Statistisk sentrabyrå	Finstad et al., (2004a,b) A	Yes				Yes	
Industry	Total Emissions	Miljødirektoratet	Norske Utslipp	Yes	Excel/CSV	year (t/year)	Point	Yes	
	Total Emissions	Miljødirektoratet	PRTR - EC	Yes	Web	year (t/year)	Point	Yes	
	Stack height[3]			No				Yes	
	Number of stacks[3]			No				Yes	
	Time variation			No				Yes	
Shipping	Vessel Activity log	Port Authoritites		do not know	Excel	hours	Grid		
	Harbour vessel (HV) composition	Port Authoritites		do not know	Excel	year	Grid		
	Annual operating hours for HV	Port Authoritites		do not know	Excel	hour/year	Grid		
	Maritime Fuel Comsuption/Sales	Statistisk sentrabyrå		Yes	Excel	year/month	Region (Fylke)		
Land actitivy in the Port	Traffic density/amount	Port Authorities / Operators		do not know	Excel	year	Grid		
	Vehicle fleet composition/Type	Port Authorities / Operators		do not know	Excel	year	Grid		
	Annual distance	Port Authorities / Operators		do not know	Excel	year	Grid		
	Type of Cargo HE	Port Authorities / Operators		do not know	Excel	year	Grid		
	Cargo HE amount	Port Authorities / Operators		do not know	Excel	year	Grid		
	Annual operating hours	Port Authorities / Operators		do not know	Excel	year	Grid		

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P.O. Box 100, N-2027 Kjeller, Norway
Associated with CIENS and the Fram Centre
ISO certified according to NS-EN ISO 9001/ISO 14001

REPORT SERIES SCIENTIFIC REPORT	REPORT NO. OR 10/2015	ISBN: 978-82-425-2766-0 (print) 978-82-425-2767-7 (electronic) ISSN: 0807-7207	
DATE 1/6-15.	SIGN.	NO. OF PAGES 43	PRICE NOK 150.-
TITLE Methods for estimating air pollutant emissions PART 1: Review and source of input data		PROJECT LEADER) Susana Lòpez-ApariciSusana López-Aparicio, Matthias Vogt and Dam Thanh Vo NILU project no O-114092	
AUTHOR(S) Susana López-Aparicio, Matthias Vogt and Dam Thanh Vo		CLASSIFICATION * A CONTRACT REF.	
QUALITY CONTROLLER: Cristina Guerreiro			
REPORT PREPARED FOR Miljødirektoratet			

ABSTRACT
This report is part of the development of a National Modelling System for local air quality (the "Nasjonalt Beregningsverktøy" or NBV project). The work focussed on the methods to estimate emissions and identified the main information sources of the needed input data for emissions. This report presents the most common methods to determine emissions and includes recommendations for future improvement of the emission calculations. The main purpose of the report is to identify the most relevant sources of emission information and the emission input data requirements necessary for modelling air quality in Norwegian cities and agglomerations.

NORWEGIAN TITLE

KEYWORDS

Luftkvalitet	By- og trafikkforurensning	Modellering

ABSTRACT (in Norwegian)
Denne rapporten er en del av utviklingen av Nasjonalt Beregningsverktøy for lokal luftkvalitet (NBV prosjektet). Arbeidet ble fokusert på metoder for å estimere utslipp og identifisere hovedkildene til nødvendige data for utslipp. Denne rapporten presenterer de mest vanlige metodene for å fastslå utslipp og inkluderer anbefalinger for fremtidig forbedring av utslippsberegninger. Hovedformålet med rapporten er å identifisere de mest relevante kildene til utslippsinformasjon og nødvendig krav til utslippsdata for modellering av luftkvalitet i norske byer og tettsteder.

** Classification* | *A* | *Unclassified (can be ordered from NILU)*
B | *Restricted distribution*
C | *Classified (not to be distributed)*

REFERENCE: O-114092
DATE: May 2015
ISBN: 978-82-425-2766-0 (print)
978-82-425-2767-7 (electronic)