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Emission estimates for Norwegian cities

NBV_Emission Database v.0

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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 for local air quality modelling applications. 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 is the second part of the work carried out in 2015 in 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. This report describes and documents the available input data to estimate emissions, the emission database used as baseline in the NBV project (NBV_Emission_Database v.0) and the preliminary emission estimates.

This report will present NO_x and PM_{10} emission estimates for Bergen, Drammen, Grenland, Oslo, Trondheim and Stavanger. Emissions for Nedre Glomma domain, which includes Sarpsborg and Fredrikstad, are not included in this report and will be included in further reporting. Nedre Glomma model domain was not part of Bedre Byluft system when writing this report. The final part of the report emphasizes on the need for improvements towards an updated version of the emission database. The initial developments carried out in 2015 involves i) the traffic sector through the development of application to retrieve data; ii) the residential heating sector by updating emissions from wood burning; and iii) the shipping sector by updating emissions.

The work has been led by Susana López-Aparicio and carried out in close collaboration with Dam Thanh Vo. Thanks to Christoffer Stoll for the development of the application to retrieve traffic data and Rune Åvar Ødegård for the technical support. The work performed and the early version of the report benefited from comments, feedbacks and discussions with other work packages of the NBV project. Internal quality control at NILU has been carried out by the project leader, Leonor Tarrasón.

The NBV project is established and funded by the Norwegian Environmental Agency in cooperation with the Norwegian Public Road Administration, the Norwegian Directorate of Health and the Norwegian Institute of Public Health. Ministry of Climate and Environment.

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Summary

Preliminary Emission Estimates for Norwegian Cities and emission improvements

This report presents preliminary emission estimates for 6 Norwegian Cities included in the NBV project and general improvements of emissions carried out to date. Correct emissions in space and time resolution is essential for dispersion calculations. This applies to both horizontal and height above ground.

As starting point, we collected all available emission data currently used under the Improved City Air forecasting system (Bedre byluft, 2013; Ødegaard et al., 2013). This emission data for the different model domains has been uploaded to the NBV database and it constitutes the call NBV Emission Database v.0. This is the first time that the Bedre Byluft emission data has been systematically documented. It is also the first time when the estimated emissions have been analysed by sectors and their contributions to total urban emissions have been calculated.

We have carried out emission estimates of NO_x and PM_{10} for Bergen, Drammen, Grenland, Oslo, Trondheim and Stavanger based on the NBV Emission Database v.0. $PM_{2.5}$ emissions will be included in further reporting of the NBV project. We assume that $PM_{2.5}$ emissions are quite similar to PM_{10} exhaust emissions, even though some road wear particles belong to the fine fraction ($PM_{2.5}$). The results are evaluated as total emissions and the contribution from each sector to total urban emissions are calculated. The current emission data and their sources have been documented. The documentation highlighted that some emission data are over a decade old, and there is not consistency on the years.

Based on the documentation and the contribution to total emissions in the urban area, we identified wood burning and shipping as two sources that need special attention, and therefore they are prioritized in this study. In addition, an application has been developed to retrieve data from the National Road database. This will contribute to the development of an automatic system for retrieving input data for traffic emission estimates in different cities and agglomerations as part of the NBV-project.

This report finalizes with a summary of the work carried out to update the two sectors previously identified; wood burning and shipping emissions. We describe the methodology used for such updates and the results obtained. The comparison between updated and earlier emissions (NBV_Emission_Database v.0) shows significant differences for most of the 7 selected Norwegian cities.

This work has been essential for the identification of gaps and needs for improvement on the emissions databases for the seven selected Norwegian Cities and paves the work towards the elaboration of NBV_Emission_Database_v.1, the final aimed result of this project.

Emission estimates for Norwegian cities NBV_Emission Database v.0

1 Introduction

The purpose of the NBV project is to increase the use and quality of model estimates of local air quality. A common methodology will therefore be developed meeting the requirements of current legislation. One of the main products from the NBV project is to develop updated emission inventories. This will be essential input for further activities as part of the NBV project, such as detailed studies of the pollution levels in seven Norwegian cities / urban areas (i.e. Oslo, Bergen, Stavanger, Trondheim, Drammen, Sarpsborg / Fredrikstad and Grenland) as part of the work under WP4 (Urban areas).

The main goal of the work package "Emissions" (WP2) of the NBV project is to develop high quality emission inventories that can be used as common input for air quality dispersion models. Therefore, the inventory and the methods used need to be validated, documented and available.

The production of emission data for the 7 selected Norwegian cities and agglomerations will satisfy the following requirements:

- The emission data will have space (including the height above the ground) and time resolution suitable for dispersion and 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 flexible way that allows future updates.

The first phase of the work in WP2 "Emissions" consisted of a description of the feasible methods to estimate emissions, existing practises to improve emission estimates, and the identification of the source of input data. The first phase was summarized in the report "Methods for estimating air pollutant emissions, PART 1: Review and source of input data" (López-Aparicio et al., 2015a).

Based on the work described in López-Aparicio et al., 2015a, we decided as starting point of our study to use the existing emission database in the Better City Air forecasting system (Bedre byluft, 2013; Ødegaard et al., 2013). This database is referred to in this report as NBV_Emission_Database v.0. A first step was to document the origin of the data, as data source (e.g. Statistics Norway, Statens Vegvesen, NILU), the year, and subsequent potential updates based on both documented proxies and / or expert opinion. We have used the documentation to identify and prioritize the sectors that need to be updated based on the year of reference and supported by knowledge regarding their contribution to total urban emissions. Thereafter we have estimated emissions based on the NBV_Emission_Database v.0, and identified the partial contribution from each sector.

We finish the report presenting a set of development and improvements carried out over different sectors (i.e. traffic, residential heating and shipping) towards a future updated emission database (what will be called NBV_Emission_Database v.1). The sectors to be updated are selected based on the findings from the documentation of the NBV_Emission_Database v.0, and the preliminary results from the emission estimates. Traffic is a main contributor to both NO_x and PM_{10}, domestic wood burning is a main contributor to PM_{10} emissions, and shipping is a main contributor to NO_x emissions.

The development and improvements carried out in our study include:

- Traffic emissions: development of an application to retrieve traffic data from the National Road Database (NVDB).
- Residential heating: update of wood burning emissions from residential heating based on updated activity data (i.e. wood consumption in 2013).
- Shipping: update of shipping emissions representing 2013 activity data through processing available emissions based on the maritime automatic identification system (AIS).

2 Input data

2.1 Geographic information

The urban areas of interest in the NBV project are Bergen, Drammen, Fredrikstad / Sarpsborg, Grenland, Oslo, Trondheim and Stavanger. However, the geographical domain considered in our study extends beyond the city area and it includes several other municipalities and agglomerations. Table 1 summarizes the seven model domains and the municipalities (part of) included in each domain. Figures in Appendix A show the geographical position of the seven gridded (1 km) model domain, and the municipalities included in each case.

Table 1: Municipalities included in the seven model domains.

NBV City / Areas	Municipalities	Figures in Appendix A
Bergen	Askøy, Bergen, Fjell	Figure 11
Drammen	Drammen, Lier, Nedre Eiker	Figure 12
Fredrikstad / Sarpsborg	Sarpsborg, Fredrikstad	Figure 13
Grenland	Skien, Porsgrunn, Bamble	Figure 14
Oslo	Asker, Bærum, Enebakk, Lørenskog, Nesodden, Oppegård, Oslo, Rælingen, Skedsmo, Ski	Figure 15
Stavanger	Randaberg, Sandnes, Sola, Stavanger	Figure 16
Trondheim	Trondheim	Figure 17

2.2 Documentation of baseline input data

The starting point of this study is the currently available 2012 emission inventories as part of the Improved City Air (Bedre Byluft) forecasting system (Bedre Byluft, 2013; Ødegaard et al., 2013) for Bergen, Drammen, Grenland, Stavanger and Trondheim. For Oslo, we will use the emission inventory prepared for the study regarding new action plans for Oslo and Bærum municipalities (Høiskar et al., 2014) as they represent more updated activity data (2013). Fredrikstad / Sarpborg was not part of Bedre Byluft system when writing this report. Emissions in this case have been estimated in the updating processes (wood burning and shipping sectors) summarized at the end of this report.

The origin of the NBV_Emission_Database v.0 is documented in Table 2, and Table 4, each corresponding to different sectors. In the documentation, we identify either the origin of the input data to estimate emissions (i.e. line sources) or directly the origin of the emissions (i.e. area sources). We have identified the reference year and the data source when available. Table 2, Table 3 and Table 4 show the information for each Norwegian urban area, and for the different emissions sectors.

In the case of traffic emissions (Table 2), the information makes reference to the activity data (i.e. amount of traffic at specific road links), whereas for area and point sources the information represents directly emissions.

Line sources are updated accordingly to the reference year of the emission inventory, whereas the information about area and point sources is relatively outdated and has been adjusted to the reference year based on expert opinion. For instance, Table 2 shows that wood burning emissions in Oslo in 2013 is SSB/NILU

(1998/2002/2013), meaning that the basic data is from Statistics Norway (SSB) from 1998, has been updated accordingly to 2002 activity data and expert opinion in 2013. More information about emissions in Oslo can be found in Høiskar et al., (2014). It is noteworthy to highlight that the emission sectors in the inventory for Drammen are different than for the other locations. Emissions from area sources are obtained through downscaling methods based on top-down emission inventory combined with land use data.

Table 2: Origin of input data in the NBV_Emission_Database v.0., and year of reference. SVV: provided by Statens vegvesen. SSB: provided by Statistics Norway. The input data is activity (e.g. traffic) or directly emissions (i.e. wood burning, shipping, off-road mobile combustion, non-wood heating, commercial heating, airports and industry). §: the urban area was not part of Bedre Byluft when writing this report. ¥: the sector is not included in the inventory. Empty cell: it is not applicable.

Urban Area	On-road Traffic	Wood Burning	Shipping and Port (Railway*)
Emission Type	*Line*	*Area*	*Area*
Bergen	SVV (2012)	SSB (2003)	SSB (1995/1998)
Drammen	SVV (2012)	NILU (2012 ↓)	¥
Fredrikstad / Sarpsborg	§	§	§
Grenland	SVV (2012)	SSB/SFT*/ NILU (1998)	¥
Oslo	SVV/Sweco (2013)	SSB/NILU (1998/2002/2013)	NILU (2013)
Stavanger	SVV (2012)	SSB (1998)	SSB (1995/1998)
Trondheim	SVV (2012)	SSB (2005)	SSB (2005)

Table 3: (continuation from Table 2, for additional sectors)

Urban Area	Off-road mobile combustion	Non-Wood Heating	Commercial Heating	Airport
Emission Source	*Area*	*Area*	*Area*	*Area*
Bergen	SSB (1995/1998)	SSB (1995/1998)	SSB (1995/1998)	SSB (1995/1998)
Drammen	NILU (2012↓)	¥	¥	
Fredrikstad / Sapsborg	§	§	§	
Grenland	¥	¥	¥	
Oslo	SSB/NILU (1995/2013)	SSB/NILU (1995/2013)	SSB/NILU (1995/2013)	
Stavanger	SSB (1995/1998)	SSB (1995/1998)	SSB (1995/1998)	SSB (1995/1998)
Trondheim	SSB (2005)	SSB (2005)	SSB (2005)	

Table 4: (continuation from Table 2 and 3, for industry sector)

Urban Area	Industry	Industry
Emission Source	*Area*	*Point*
Bergen	SSB (1995/1998)	
Drammen	NILU (2012↓)	
Fredrikstad / Sapsborg	§	§a
Grenland		SFT
Oslo		NILU (2013)
Stavanger	SSB (1995/1998)	
Trondheim	SSB (2005)	

From this evaluation and documentation process it is possible to establish that there is not consistency regarding the reference years nor the sectors considered. For instance, the year of reference for the on-road traffic represent the year of the emission database, whereas the other sources can be a decade old. Regarding sectors, some sectors such as shipping are missed in some model domains such as Grenland, Drammen, and Sarpsborg / Frederikstad.

3 Emission estimates

We have estimated emissions with AirQUIS and the NBV_Emission Database v.0. Emissions are divided in three types: i) "area" emission sources; ii) "line" emission sources; and iii) "point" emission sources, the latest one less significant in most of the urban areas. The AirQUIS emission model deals with these emission types in different ways and produces emission files in gridded format from the summing up of emissions already provided as such (i.e. area sources) and those provided by direct modelling (i.e. line sources).

3.1 Area emission sources

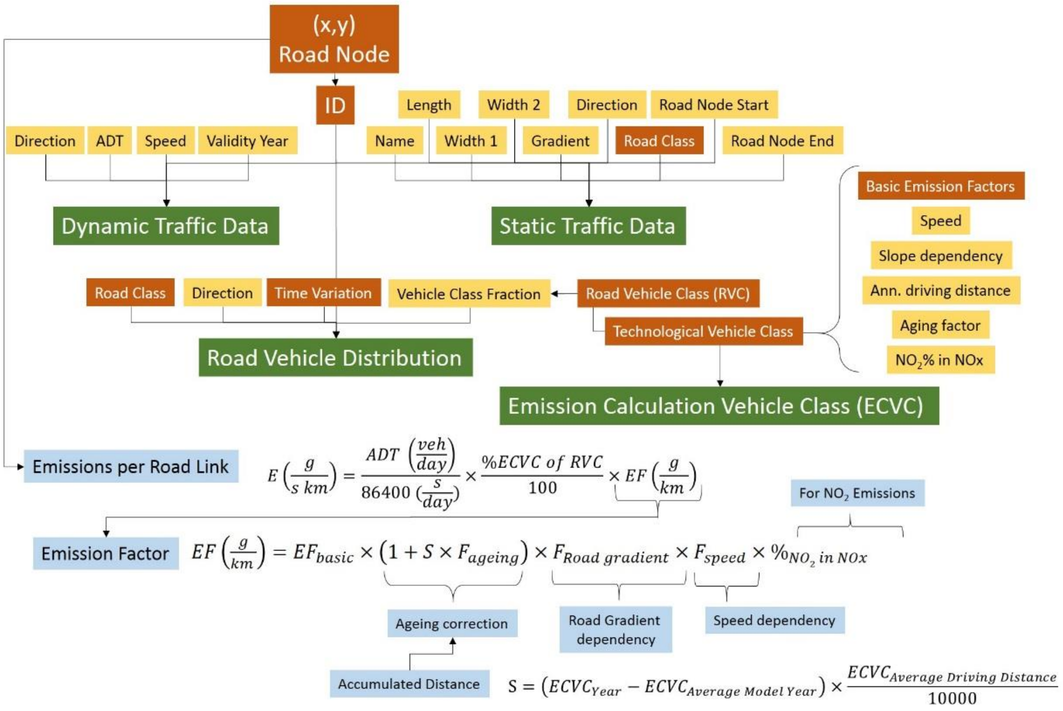
In the AirQUIS emission model, area sources are associated with residential heating, shipping and port activities, off-road mobile combustion and in some cases industry and airport emissions (Table 2, Table 3, Table 4). Emissions from area sources are provided in administrative areas (e.g. districts), polygons or directly in gridded format. Most of the emissions from area sources were originally provided by Statistics Norway a decade ago (Table 2, Table 3, Table 4), others have been produced by NILU based on downscaling methods (e.g. Drammen) or as results of comprehensive studies based on bottom-up approaches (e.g. shipping and port activities in Oslo; López-Aparicio et al., 2015b).

3.2 Line emission sources

Lines sources are exclusively related to on-road traffic emissions. The AirQUIS emission model calculates on-road traffic emissions from relevant input data. Figure 1 provides a schematic overview of the AirQUIS line source model. It shows the input data needed to model exhaust traffic emissions and how the different variables are related. The input data in AirQUIS is divided in "Dynamic Traffic Data", "Static Traffic Data", and "Road Vehicle Distribution" as main groups, to finally calculate exhaust emissions. The "Static Traffic Data" makes reference to the physical characteristics of the road network (e.g. width, length, gradient), the "Dynamic Traffic Data" refers to the amount of traffic (e.g. average daily traffic, ADT), whereas the "Road Vehicle Distribution" makes reference to the type of vehicle. The type of vehicle includes two levels of detail, i) the vehicle class (e.g. light duty vehicle, heavy duty vehicle, buses), and ii) the technological aspects (e.g. Euro class). For each road link (ID) the ADT, the fraction of heavy duty vehicle (HDV), the road type (e.g. highway, municipal, tunnel) and the road width is provided. The model computes emissions according to the mathematical expression also indicated in Figure 1.

3.3 Point emission sources

Point sources are mainly industries, refereeing to individual plants and / or emission outlet. For industrial emissions, we need information on the stack(s) (physical and geographical parameters), cleaning devices and their efficiency, industrial processes, and emissions for each of the processes. In our study, industrial emissions are accounted as point sources for Grenland (2012; Bedre Byluft, 2013) and Oslo (2013). For the other model domains, industrial emissions are included as area sources.



$$E\left(\frac{g}{s\ km}\right) = \frac{ADT\left(\frac{veh}{day}\right)}{86400\left(\frac{s}{day}\right)} \times \frac{\%ECVC\ of\ RVC}{100} \times EF\left(\frac{g}{km}\right)$$

$$EF\left(\frac{g}{km}\right) = EF_{basic} \times \left(1 + S \times F_{ageing}\right) \times F_{Road\ gradient} \times F_{speed} \times \%_{NO_2\ in\ NOx}$$

$$S = \left(ECVC_{Year} - ECVC_{Average\ Model\ Year}\right) \times \frac{ECVC_{Average\ Driving\ Distance}}{10000}$$

Figure 1: Scheme representing the modelling system to estimate exhaust traffic emissions in AirQUIS.

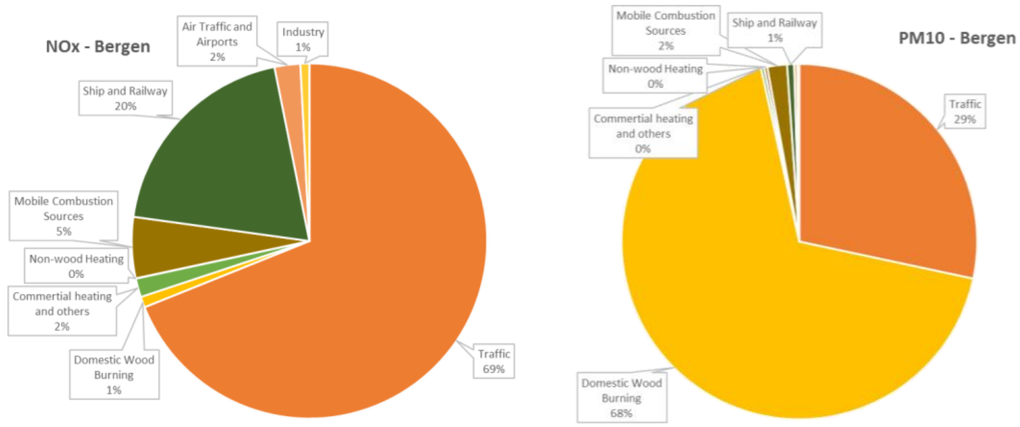
4 Results

In this chapter, we summarize the preliminary emission estimates as totals and contribution from each sector for the Norwegian cities.

4.1 Bergen

In this study, as Bergen we refer to the domain represented in Figure 11 in Appendix A, which covers part of Askøy, Bergen and Fjell municipalities. Figure 2 shows NO_x and PM_{10} emission estimates for the urban area of Bergen (2012) as well as the distribution per sectors.

NO_x emissions are calculated to be about 2 142 tonnes per year. Traffic is the main source contributing with around 69% of the total emissions, followed by emissions from shipping and railway, which contributes around 20% of the total NO_x emissions. PM_{10} emissions in Bergen are calculated to be about 801 tonnes in 2012 and the main contributor is domestic wood burning (65%; Figure 2), followed by on-road traffic emissions, which include both exhaust and non-exhaust (27%; Figure 2).



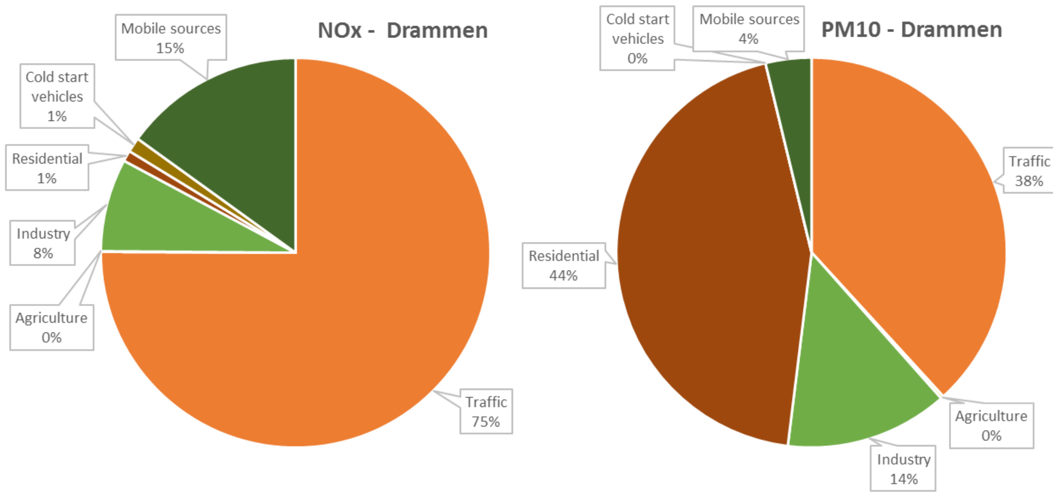
	NO_x (tonn/y)	PM_{10} (tonn/y)
Traffic	1 477	217
Domestic Wood Burning	21	522
Commercial Heating and others	37	2
Non-wood Heating	1	2
Mobile Combustion Sources	119	14
Ship and Railway	421	5
Air Traffic and Airport	50	2
Industry	18	1
TOTAL	2142	766

Figure 2: Emissions of NO_x (top left) and PM_{10} (top right) in Bergen (2012) distributed per sectors. Decimals (table at the bottom) are rounded up or down to the nearest tenth.

4.2 Drammen

Drammen domain includes Drammen and Nedre Eiker municipalities, and part of the Lier municipality as indicated in Figure 12 in Appendix A. Figure 3 shows NO_x and PM_{10} emission estimates for Drammen (2012), and the contribution per sectors.

Emissions in Drammen are mainly due to on-road traffic, mobile sources, residential, and industry. NO_x emissions in Drammen reach about 1 465 tonnes per year, and on-road traffic is the main source. On-road traffic contributes with around 75% of total NO_x emissions, followed by emissions from (off-road) mobile sources. PM_{10} emissions from Drammen reach about 777 tonnes per year, and residential combustion is the main contributor of total PM_{10} emissions. As previously indicated, emissions from area sources (i.e. mobile sources, cold start vehicles, residential, industry, agriculture) in Drammen are downscaled estimates.



	NO_X (tonn/y)	PM_{10} (tonn/y)
Traffic	1 100	297
Agriculture	0.7	2
Industry	113	105
Residential	13	344
Cold start vehicles	18	0
Mobile sources	220	29
TOTAL	1 465	777

Figure 3: Emissions of NO_x (top left) and PM_{10} (top right) in Drammen (2012) distributed per sectors. Decimals (table at the bottom) are rounded up or down to the nearest tenth.

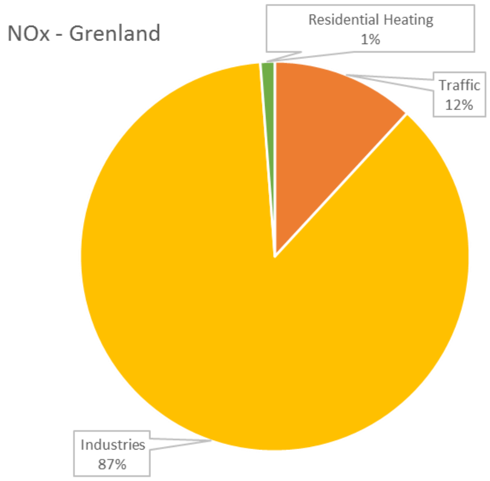
4.3 Fredrikstad / Sarpsborg

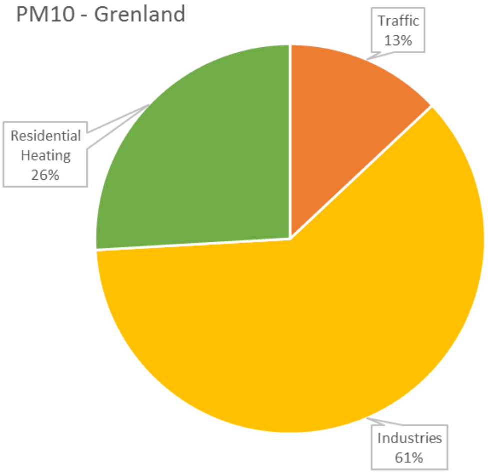
Information on emission data from Fredrikstad / Sarpsborg is currently under review. A similar analysis to the other cities will be available in further steps of the project.

4.4 Grenland

Three sectors are available in the emission inventory of Grenland (Figure 14); on-road traffic, industries and residential heating. Emissions from each sector are shown in Figure 4.

Industrial emissions are the main contributor of both total NO_x and PM_{10} emissions in Grenland, with about 87% and 61%, respectively. Regarding PM_{10} emissions, residential heating contributes with around 26% of total PM_{10} emissions.





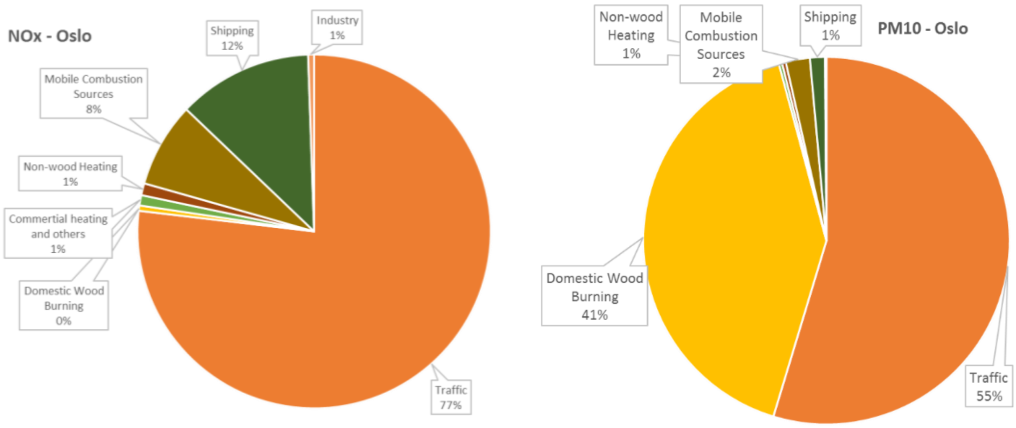
	NO_x (tonn/y)	PM_{10} (tonn/y)
Traffic	602	192
Industry	4 414*	903
Residential Heating	61	383
TOTAL	5 077	1 479

*Figure 4: Emissions of NO_x (top left) and PM_{10} (top right) in Grenland (2012) distributed per sectors. *NO_x industrial emissions estimated based on the assumption that NO_2 emissions (available data) constitute 10% of NO_x emissions. Decimals (table at the bottom) are rounded up or down to the nearest tenth.*

4.5 Oslo

The Oslo domain includes parts of 10 municipalities, which are represented in Figure 15, in Appendix A. Figure 5 shows NO_x and PM_{10} emission from Oslo (2013) based on the available information from the study regarding new action plans for Oslo and Bærum municipalities (Høiskar et al., 2014).

NO_x emissions in Oslo domain are calculated to be 8 237 tonnes in 2013. On-road traffic is the main contributor, and its share is around 75% of the total emissions, followed by emissions from shipping and activities in the port that reach 12% of total NO_x emissions (Figure 5). PM_{10} emissions from Oslo domain are calculated to be about 1 860 tonnes in 2013, and domestic wood burning, on-road traffic and (off-road) mobile combustion sources are the main contributors, with a share of approximately 30%.



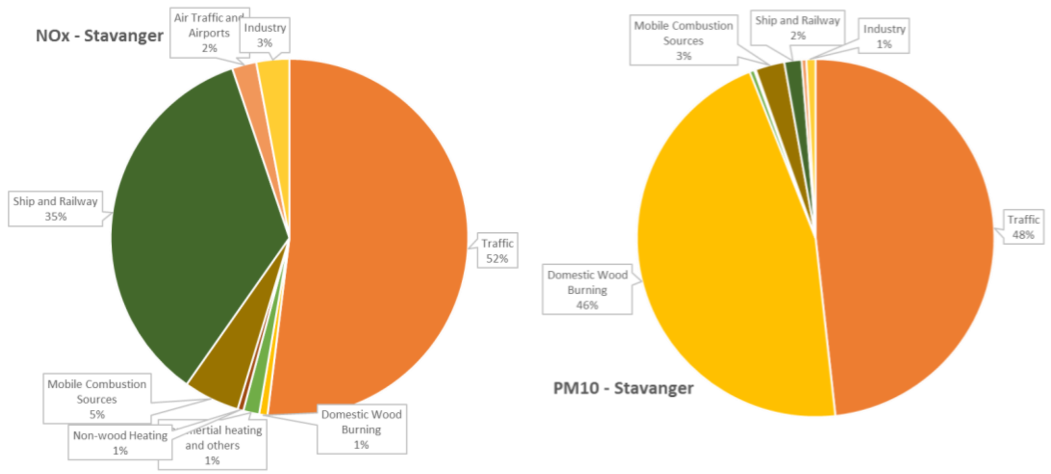
	NO_x (tonn/y)	PM_{10} (tonn/y)
Traffic	4 730	728
Domestic Wood Burning	30	548
Commercial Heating and others	58	4
Non-wood Heating	67	4
Mobile Combustion Sources	476	28
Ship and Port activities	759	18
Air Traffic and Airport	-	-
Industry	33	2
TOTAL	6 153	1 331

Figure 5: Emissions of NO_x (top left) and PM_{10} (top right) in Oslo (2013) distributed per sectors. Decimals (table at the bottom) are rounded up or down to the nearest tenth. Modified after Høiskar et al., 2014

4.6 Stavanger

NO_x and PM_{10} emission estimates from Stavanger (2012) are shown in Figure 6. These emissions correspond to the geographical domain shown in Figure 16 in Appendix A, covering part of the municipalities of Randaberg, Sandnes, Stavanger and Sola.

NO_x emissions in the Stavanger model domain are calculated to be 2 619 tonnes in 2012 (Figure 6), and traffic (52%) and ship and railway (35%) are the main contributors. PM_{10} emissions from the Stavanger model domain are estimated to be 613 tonnes in 2012, and the main contributors (Figure 6) are residential wood burning (46%) and traffic (48%).



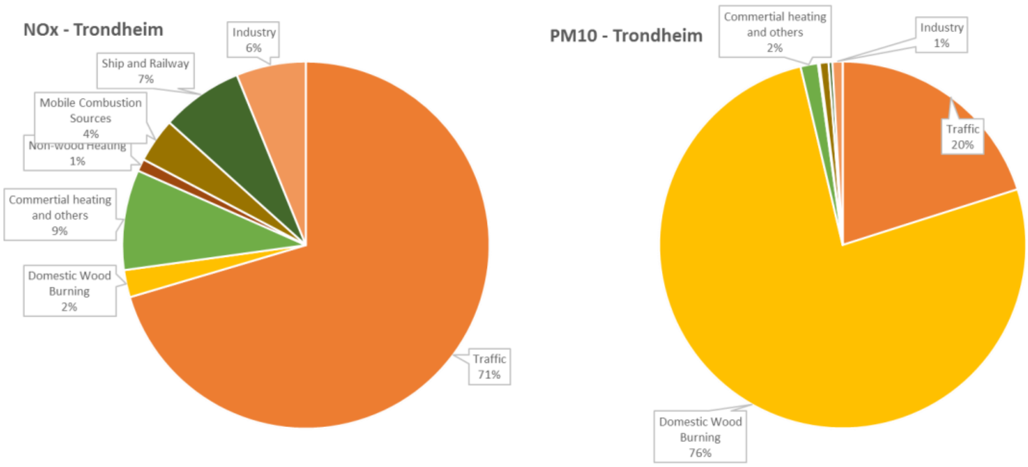
	NO_x (tonn/y)	PM_{10} (tonn/y)
Traffic	1 361	296
Domestic Wood Burning	20	280
Commercial heating and others	38	3
Non-wood Heating	14	1
Mobile Combustion Sources	133	16
Ship and Railway	918	10
Air Traffic and Airports	58	3
Industry	78	5
TOTAL	2 619	613

Figure 6: Emissions of NO_x (top left) and PM_{10} (top right) in Stavanger (2012) distributed per sectors. Decimals (table at the bottom) are rounded up or down to the nearest tenth.

4.7 Trondheim

NO_x and PM_{10} emission estimates for Trondheim (2012) and the contribution per sector are shown in Figure 7. Emissions in Trondheim urban area correspond to the geographical domain shown in Figure 17, refereeing to part of the municipality of Trondheim.

NO_x emissions are calculated to be 1 102 tonnes in 2012, and on-road traffic is the main contributors with around 71% of total NO_x emissions. PM_{10} emissions in Trondheim reached 830 tonnes in 2012 and, domestic wood burning for residential heating and on-road traffic (exhaust and non-exhaust) are the main contributor, with 76% and 20% of total PM_{10} emissions.



	NO_x (tonn/y)	PM_{10} (tonn/y)
Traffic	776	167
Domestic Wood Burning	26	633
Commercial heating and others	97	13
Non-wood Heating	12	1
Mobile Combustion Sources	43	6
Ship and Railway	80	3
Industry	68	7
TOTAL	1 102	830

Figure 7: Emissions of NO_x (top left) and PM_{10} (top right) in Trondheim (2012) distributed per sectors. Decimals (Table at the bottom) are rounded up or down to the nearest tenth.

5 Improvement – Updating emissions

This chapter presents the improvements and updates currently carried out towards an updated emission database (hereafter named as NBV_Emission_Database_v1). The updates and improvements are over different sectors. These sectors are prioritized based on 1) their importance as contributor of total NO_x and/or PM_{10} emissions and 2) the fact that the sector is outdated in the NBV_Emission_Database_v0 (Bedre Byluft forecasting system).

We have carried out the following developments and updates:

- *On-road traffic emission*; it is the biggest contributor to NO_x and PM_{10} emissions in most of the urban areas (except Grenland industrial area). Therefore emissions from on-road sector need to be always updated representing the year of reference. In order to facilitate regular updates of activity on-road traffic information, we have developed an application to retrieve traffic data from the national road database (NVDB; Chapter 5.1).
- *Residential heating (wood burning)*; it is one of the biggest contributors to PM in urban areas along with on-road traffic resuspension. The documentation of the NBV_Emission_Database_v0 indicated residential heating (wood burning) as a sector which is outdated and requires new updated. Part of the work carried out this year has been updating wood burning emissions from residential heating based on the most recent activity data (wood consumption in 2013; Chapter 5.2).
- Shipping; it is a significant contributor of NO_x total emission in urban areas with near and intense port activity. Activity data regarding shipping activities were highlighted at the beginning of this report as outdated. Part of the work carried out this year was to update shipping emissions representing 2013 activity data. This was supported by available emissions (i.e. NO_x and $PM_{10} \approx PM_{2.5}$) based on the maritime automatic identification system (AIS).

5.1 Automatic retrieval of traffic data

One of the advantages of the NBV project is to develop an automatic system for necessary input data to feed the AirQUIS emission model and allow efficient future updates. López-Aparicio et al., (2015a) pointed out as a possibility for automatic implementation of on-road traffic data a system that connect with the national road database from the Norwegian Public Road Administration (NVDB 2014). Following this recommendation, an application has been developed to get access to the national road database and retrieve traffic data within selected areas (Figure 8). The application allows to retrieve data such as the geographical position of the road network, the annual average daily traffic (AADT), the percentage of light/heavy duty vehicles, and physical characteristics of the road (e.g. length). The application has also been developed to upload files (e.g. shape, geojson) representing point, lines or areas. This combined information is thereafter stored in a database for later use.

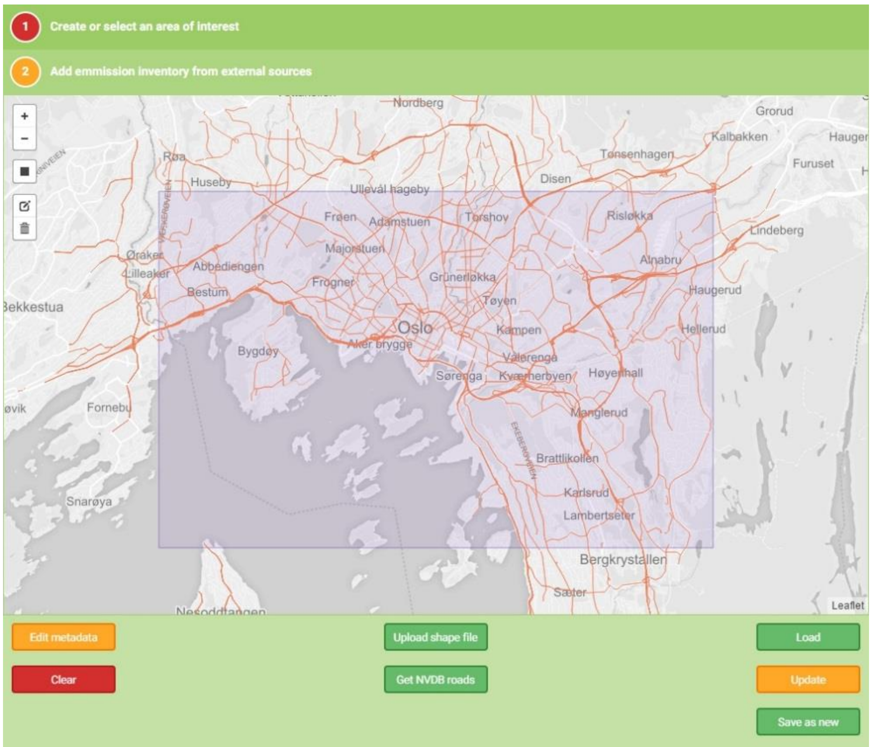


Figure 8: Screenshot of the application developed to connect and retrieve data from the national road database (NVDB).

5.2 Updated wood burning emissions

Wood burning emissions in the 7 Norwegian cities are calculated based on geoprocessing and proxies that take into account:

- Wood consumption in 2013 distributed per region ("Fylke") and technology (i.e. open fireplace, old closed ovens, new closed ovens).
- Dwelling density in 2011 distributed per district ("Grunnkrets")
- PM emission factors for wood stove firing in Norway (SINTEF, 2013)

Figure 9 shows as example PM emissions from wood burning in Stavanger model domain (1 km space resolution) and obtained through geoprocessing. The input data for the geoprocessing is wood consumption per type of technology at regional level. Then this data is distributed at higher space resolution using dwelling density available at district level. PM emissions from wood burning in 2013 has been estimated for the seven Norwegian cities and the results are visualized in Appendix B.

Table 5 shows total $PM_{2.5}$ emissions from residential wood burning for the seven Norwegian cities, and the comparison with the wood burning emissions in the NBV_Emission_Database v.0 based on Bedre Byluft forecasting system. The updated emissions are named NBV_Emission_Database v.1 in Table 5, as they will constitute part of a new updated emission database of the NBV project.

Differences are significant for most of the selected cities and therefore we need to further evaluate this update. In Oslo and Bergen, the new estimates are about 200% and 43% higher than the outdated wood burning emissions. However, updated wood burning emissions for Trondheim seem to be similar to the emissions available in the NBV_Emission_Database_v.0 (Bedre Byluft).

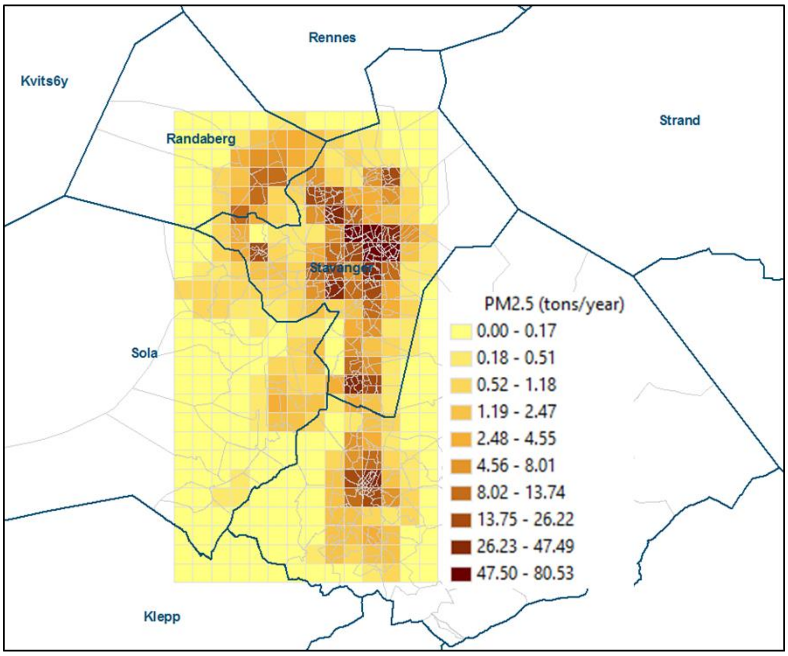


Figure 9: Example of PM emissions from wood burning for residential heating in Stavanger urban environment.

*Table 5: Comparison of total PM emissions from residential wood burning. NBV_Emission Database v.0 based on Better Air Quality city forecasting system (Bedre Byluft, 2013; Ødegaard et al., 2013) and updated emissions (NBV_Emission Database v.1). Decimals are rounded up or down to the nearest tenth. n.a.: not available. *Results for a provisional model domain. $Represents residential heating in general.*

Units: tonn/y	NBV_Emission Database v.0	NBV_Emission Database v.1
	PM Emissions from Wood Burning	
Bergen	522	847
Drammen	344$	1 722
Fredrikstad / Sarpsborg	n.a.	283*
Grenland	383$	545
Oslo	548	1 623
Stavanger	280	1 101
Trondheim	633	575

5.3 Update shipping emissions

An automatic tracking identification system (AIS) was introduced by the UN's International Maritime Organisation (IMO) in vessels 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 powerful tool that 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).

In Norway, emissions from shipping based on AIS are available through The Norwegian Coastal Administration (NCA). NILU has contacted the NCA, organized Skype meetings, and keep frequent email communication. As a result we have been granted access to emissions from shipping in whole Norway for 2013. Emissions are available in space as emission points with a time resolution of six minutes. The information has been geo-processed at NILU, and emissions in the areas of interest (Appendix A) has been extracted. Figure 10 shows as example the extracted shipping emissions in the model domain areas for Bergen and Stavanger urban environments, and represented as gridded emissions at 1x1 km resolution. The visualization allows to identify hot stops such as the port areas, where higher emissions occur.

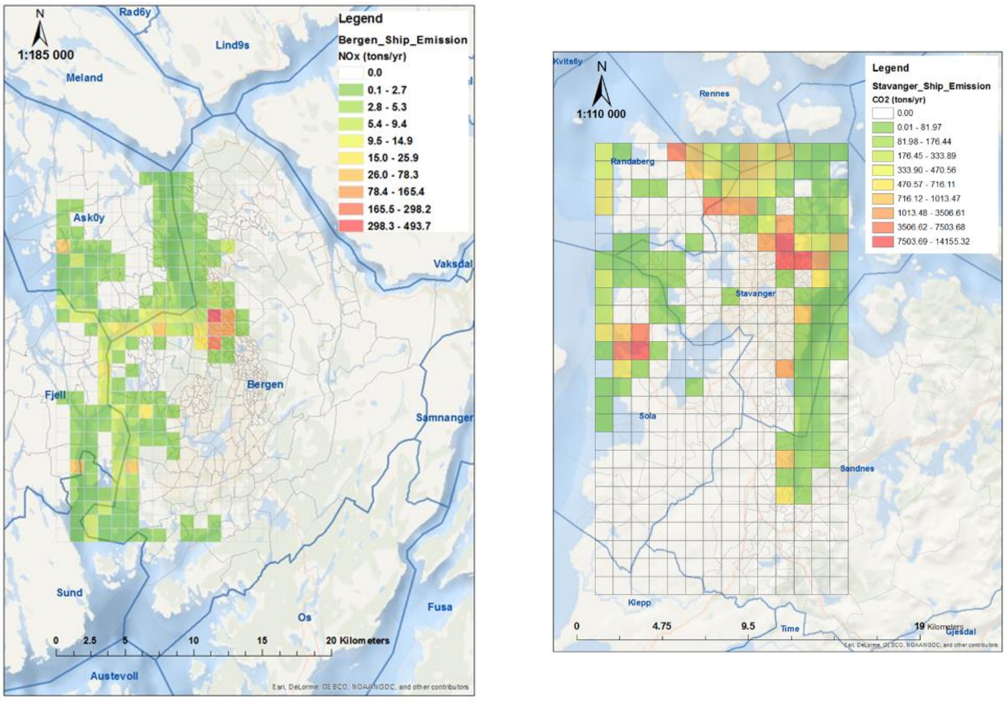


Figure 10: Examples of NO_X shipping emissions obtained from AIS. Bergen (left) and Stavanger (right) urban areas.

Emissions from shipping in the NBV_Emission_Database v.0 are originally provided by Statistic Norway and they are more than a decade old for most of the Norwegian urban areas (Table 2). In addition, Statistics Norway reported shipping emissions along with emission from railway (e.g. Bergen, Stavanger) as one unique emission sector. Table 6 shows for comparison total shipping emissions in the areas of interest available in the NBV_Emission_Database v.0 and obtained from the AIS

(Appendix C) for the year 2013. For urban environments such as Bergen and Stavanger, the comparison reveal that the updated shipping emissions are much higher than those considered in Bedre Byluft forecasting system. In addition, shipping emissions in Grenland and Drammen were not included in the respective inventory. Therefore, this update is a step forward, and specially for Grenland where shipping could be a significant sector.

The validity of the shipping emissions from AIS has been tested in detail for the city of Oslo (López-Aparicio et al., 2015b). The study for the port of Oslo represent emissions in 2013 from the port, including shipping and land activities and emissions are estimated through a bottom up approach. These results are similar to those based on the AIS

Table 6: Comparison of total NO_X and PM emissions from shipping. NBV_Emission Database v.0 based on Better Air Quality city forecasting system (Bedre Byluft, 2013; Ødegaard et al., 2013) and results obtained from AIS for 2013 (NBV_Emission Database v.1). §: the urban area was not part of Bedre Byluft forecasting system when writing this report. ¥: the sector was not included in the inventory (Bedre Byluft).

Units: tonn/y	NBV_Emission Database v.0		NBV_Emission Database v.1	
	Emissions from Shipping*			
	NOx	PM	NOx (2013)	PM (2013)
Bergen	421	5	1 982	59
Drammen	¥	¥	67	2
Fredrikstad / Sarpsborg	§	§	77	2
Grenland	¥	¥	386	11
Oslo	759	18	675	32
Stavanger	918	10	1 438	41
Trondheim	80	3	210	7

6 Conclusions

This study shows the importance of documentation processes. We identified inconsistencies regarding the reference years and the sectors considered for each domain. This information along with the emission estimates and the sectorial contributing, is essential to identify and prioritize which sectors in the emission inventories need to be regularly updated.

Our study started with the available emission inventories for Bergen, Drammen, Grenland, Stavanger and Trondheim as part of the Bedre Byluft forecasting system, and Oslo from Høiskar et al., (2014). These emissions inventories were named NBV_Emission_Database v.0. and used as starting point. The documentation of the input data (i.e. activity and direct emissions) highlighted the need for updates, and especially for two sectors; i) wood burning for residential heating and ii) shipping.

Emissions estimated based on the NBV_Emission_Database v.0 pointed out that; i) on-road traffic is a main contributor of total NO_x and PM_{10} (exhaust and non-exhaust); ii) wood burning for residential heating is one of the biggest contributors to PM_{10}; and iii) shipping emissions are important contributors to NO_x emissions for nearby urban areas.

Development work has been carried out over two sectors, wood burning and shipping. The comparison between updated emissions and those in the NBV_Emission_Database v.0 shows significant differences for most of the Norwegian urban environments (e.g. Bergen, Stavanger), but not significant for others (e.g. Trondheim). In some cases emissions sectors were absent (shipping) or aggregated (residential heating) in the NBV_Emission_Database v.0, such is the case for Drammen and Grenland. The updates allow to complete these emission inventories. The updates will be incorporated in a near future in a new database, namely NBV_Emission_Database v.1. These emissions will be evaluated through dispersion modelling activities and the comparison of the outputs with measurement data. Moreover, there is the need for user involvement (e.g. Municipalities) to discuss the work carried out as part of the NBV project, exchange of expertise and local knowledge, and discuss possible available input data to improve emissions.

In conclusion the documentation of the NBV_Emission_Database v.0 shows significant inconsistencies on 1) the reference years, 2) sectors included in the inventory and 3) methods used to estimate emissions. Alternatively, the NBV_Emission_Database v.1 better represents current situation, as it is consistent regarding the methods used to estimate emissions, and completes the identified gaps (e.g. shipping was missing in some domains). Our study highlight the importance of updating regularly emissions inventories.

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Appendix A

The seven geographical domains

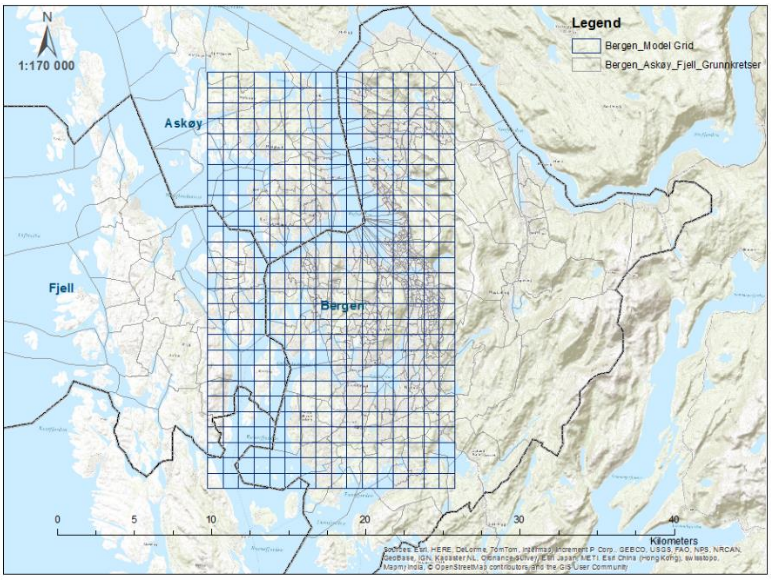

Figure 11: Bergen model domain (1 km grid).

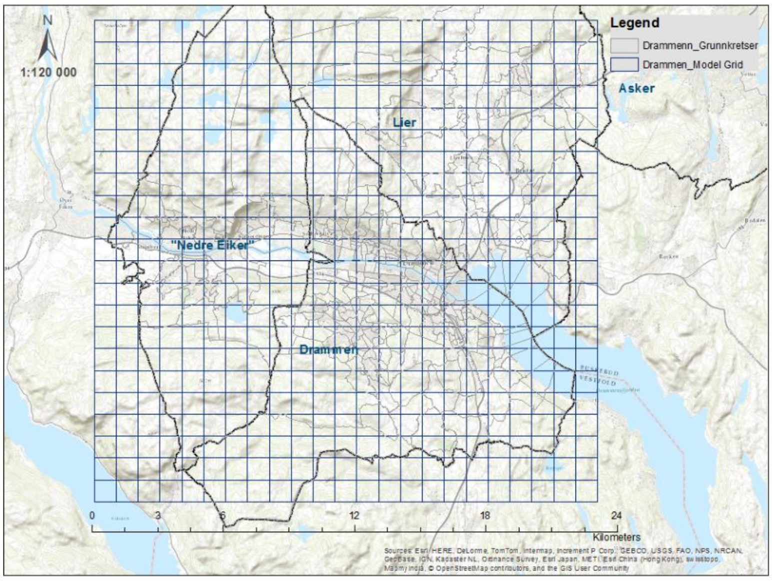

Figure 12: Drammen model domain (1 km grid)

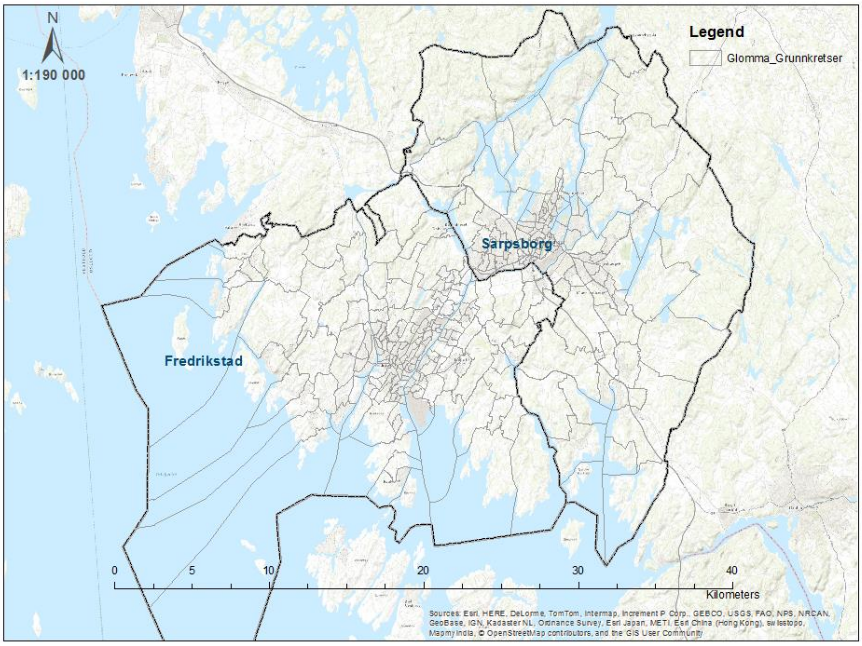

Figure 13: Fredrikstad – Sarpsborg model domain (1 km grid).

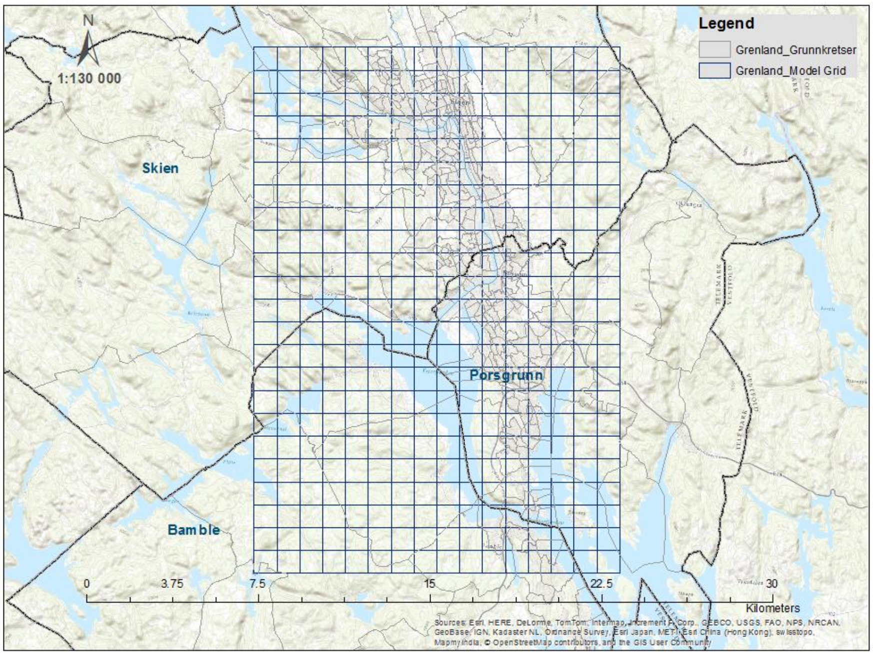

Figure 14: Grenland model domain (1 km grid).

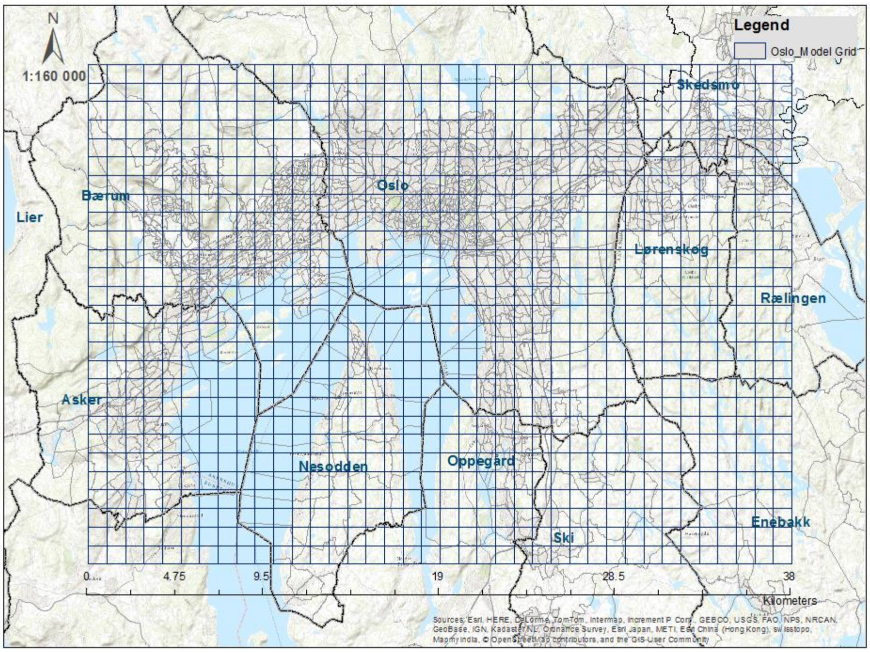

Figure 15: Oslo model domain (1 km grid).

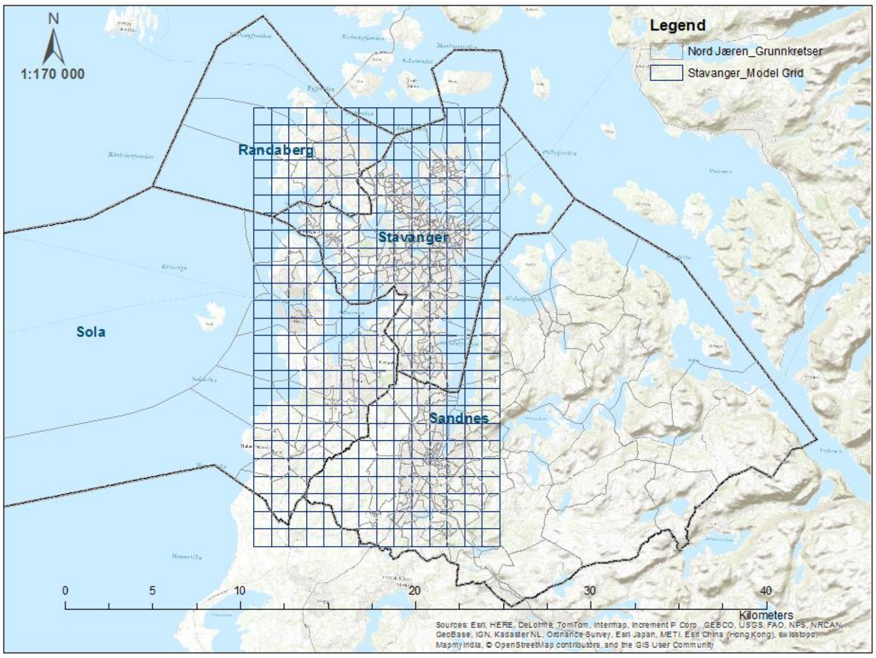

Figure 16: Stavanger model domain (1 km grid).

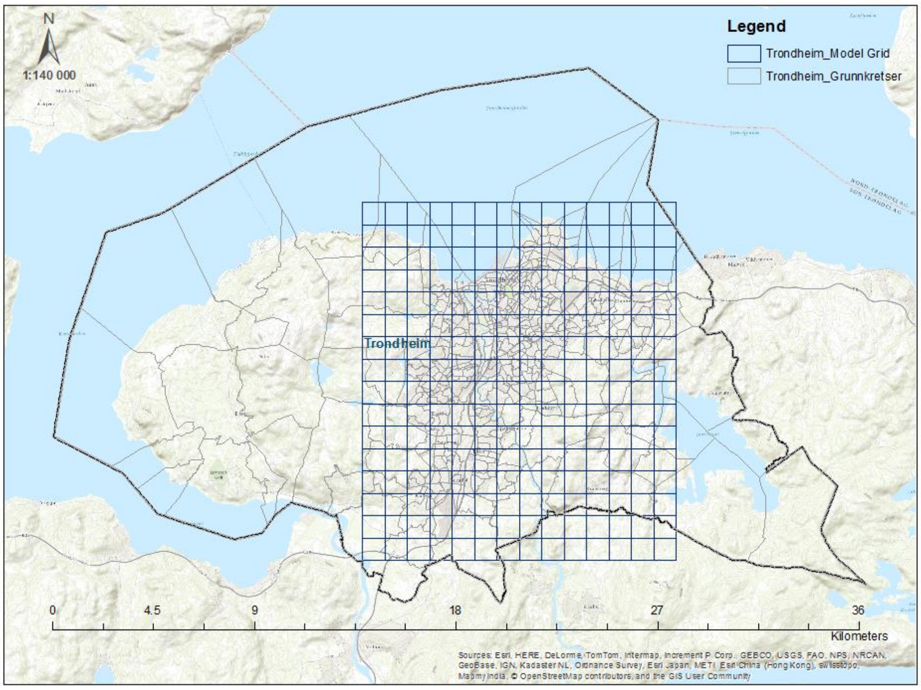

Figure 17: Trondheim model domain (1 km grid).

Appendix B

Updated PM Wood Burning Emissions from Residential Heating in the 7 Norwegian Cities

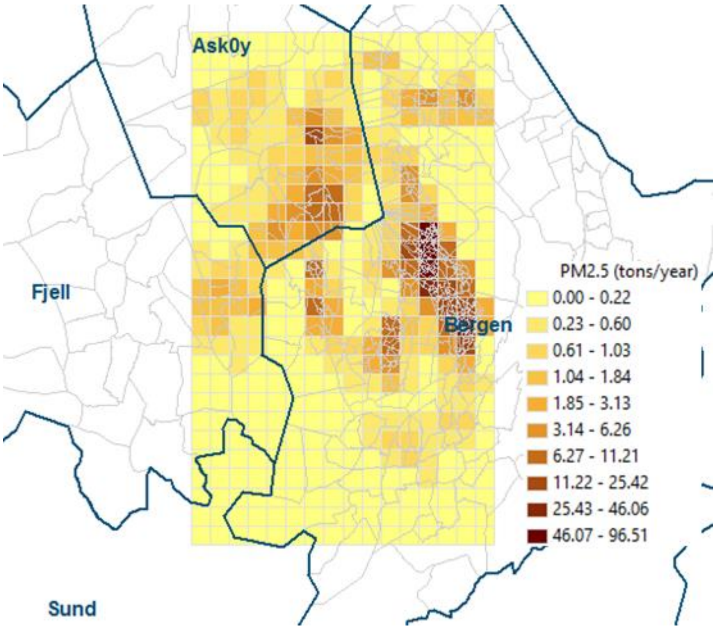

Figure 18: PM emissions from wood burning for domestic heating in Bergen model domain (1 km grid).

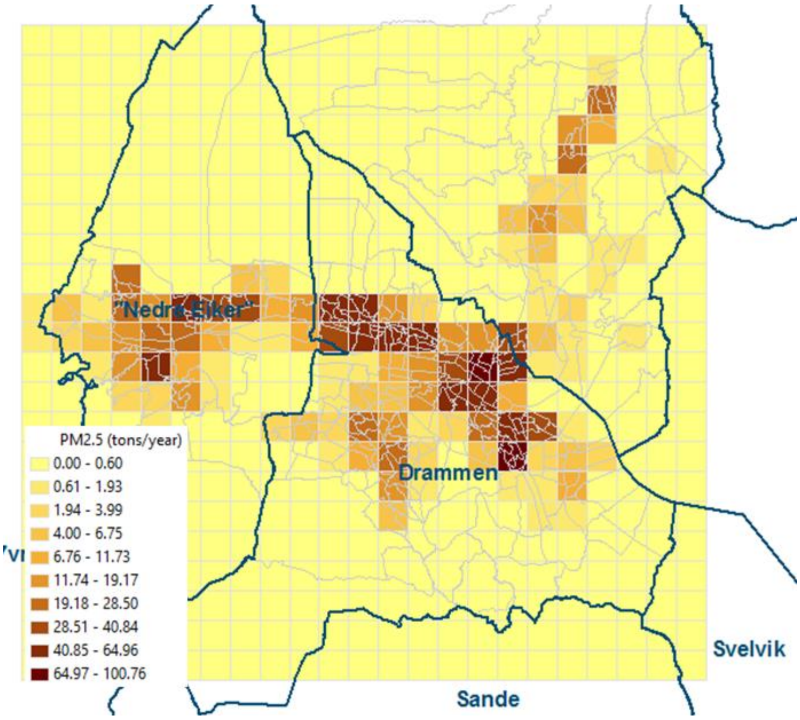

Figure 19: PM emissions from wood burning for domestic heating in Drammen (1 km grid)

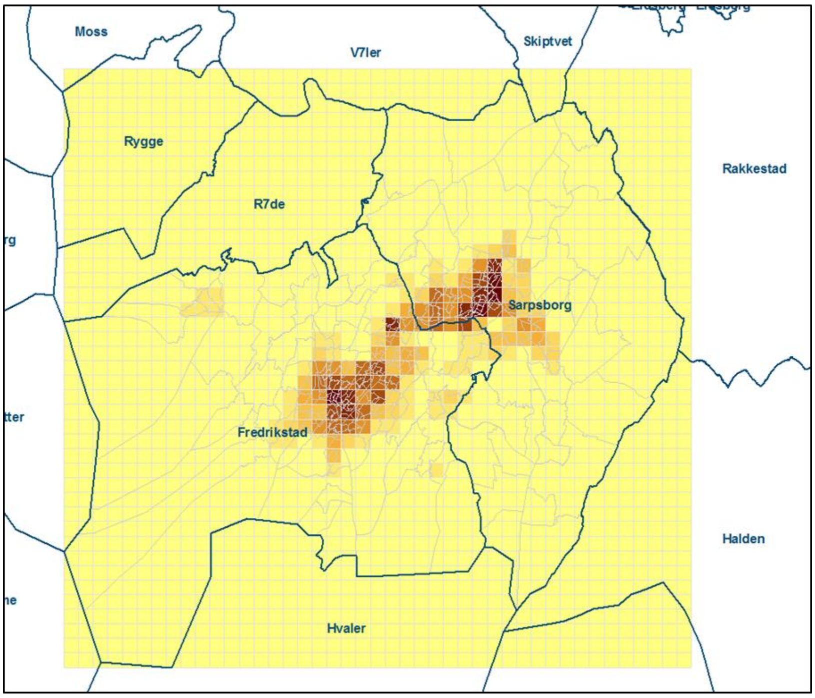

Figure 20: PM emissions from wood burning for domestic heating in Sarpsborg / Fredrikstad (1 km grid).

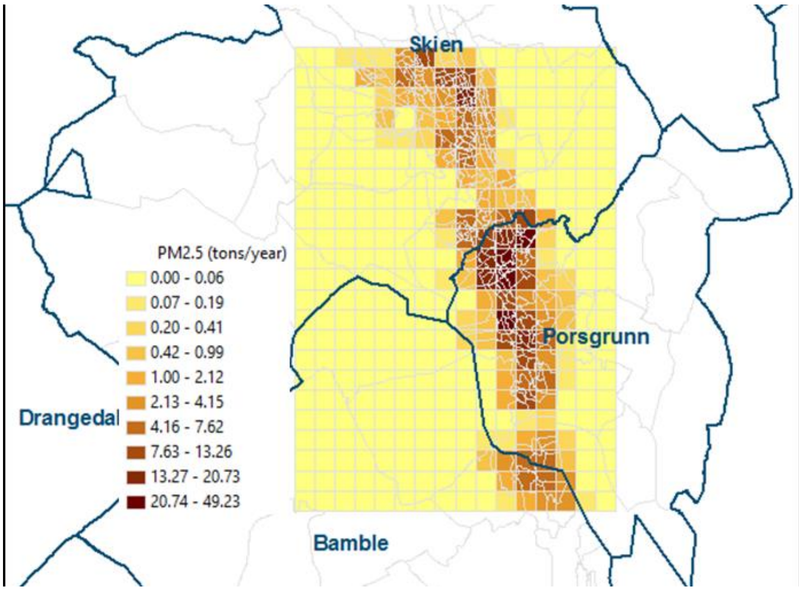

Figure 21: PM emissions from wood burning for domestic heating in Grenland (1 km grid).

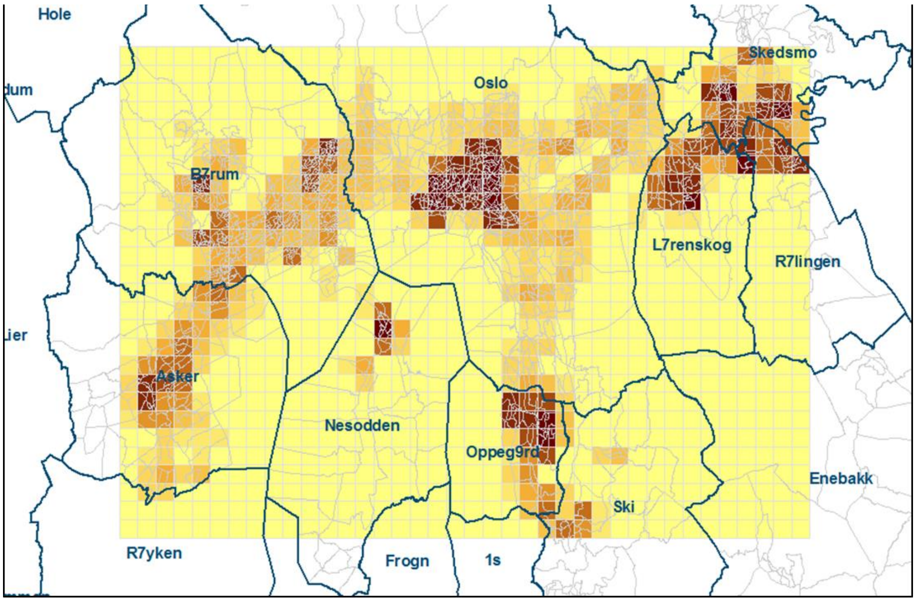

Figure 22: PM emissions from wood burning for domestic heating in Oslo model domain (1 km grid).

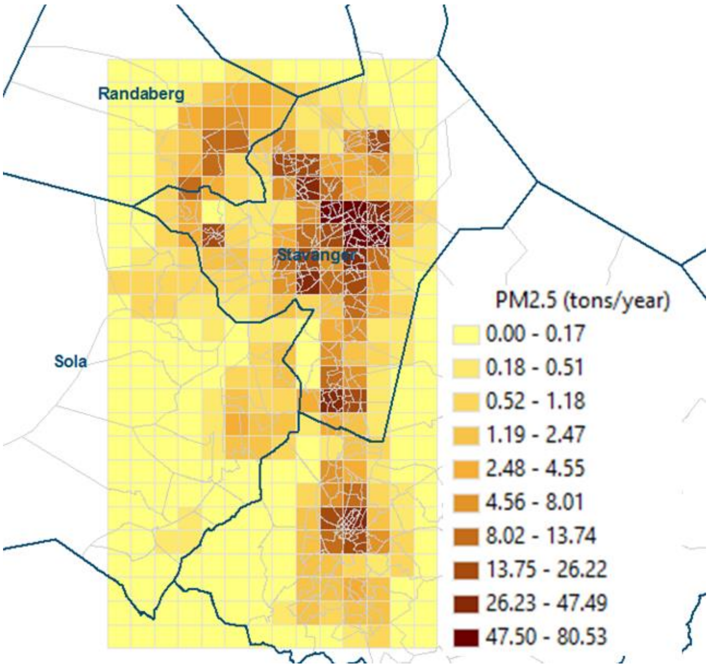

Figure 23: PM emissions from wood burning for domestic heating in Stavanger model domain (1 km grid).

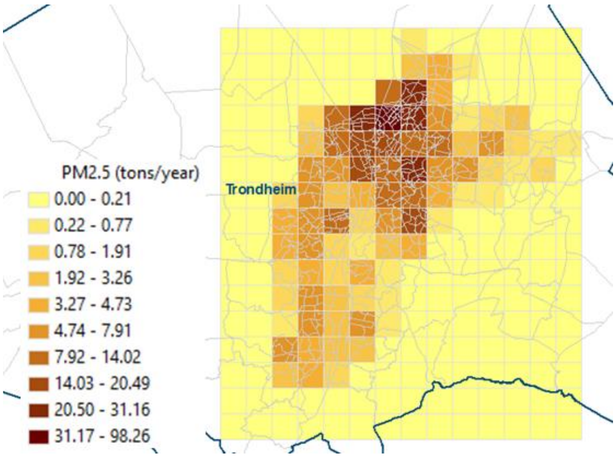

Figure 24: PM emissions from wood burning for domestic heating in Trondheim model domain (1 km grid).

Appendix C

Updated Shipping Emissions for the 7 Norwegian Cities

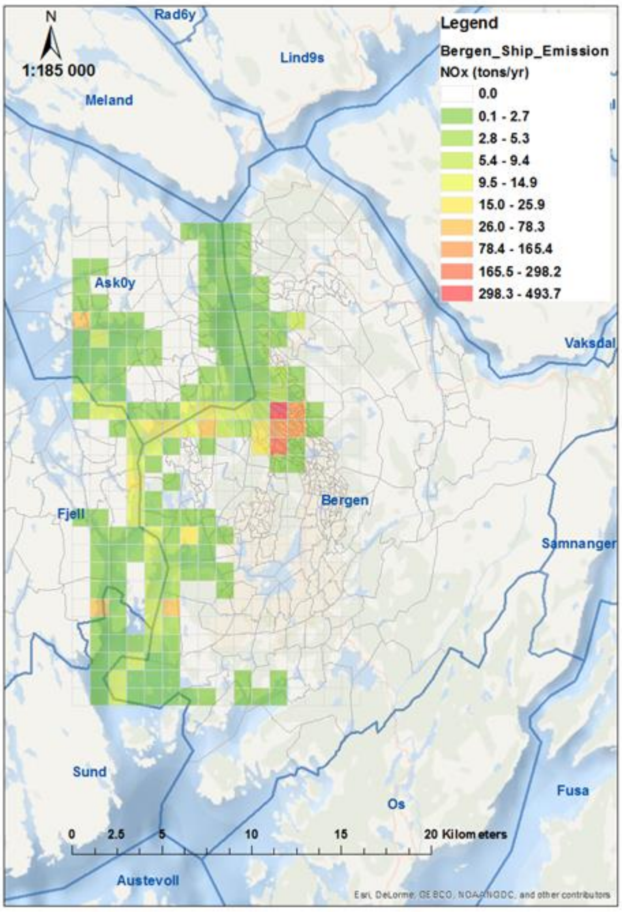

Figure 25: Updated shipping emissions in Bergen (2013) at 1 km resolution

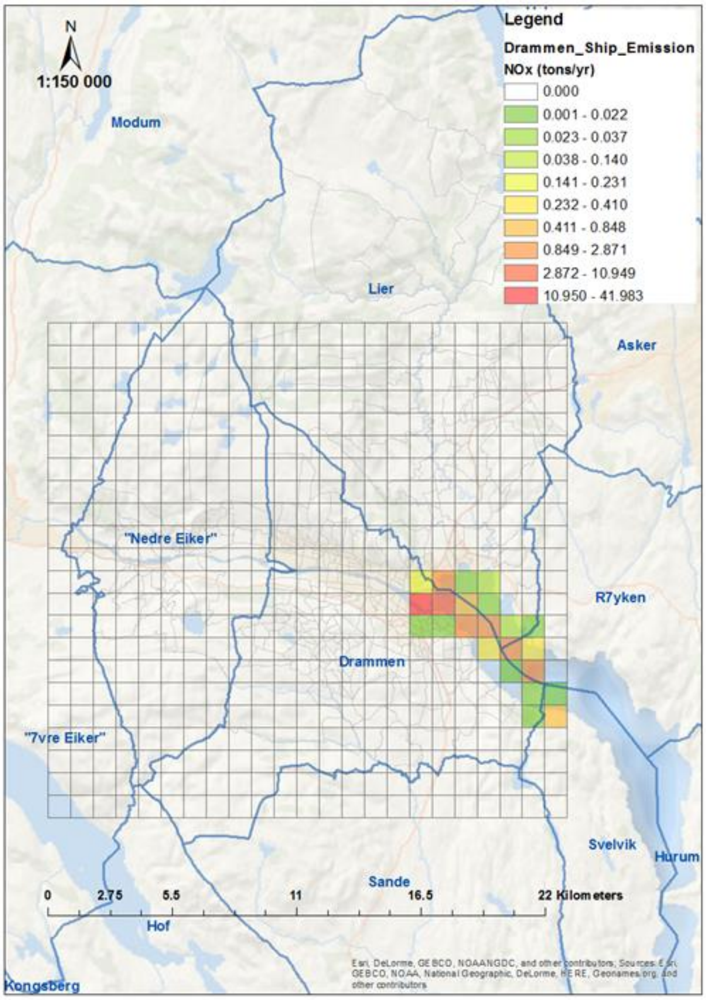

Figure 26: Updated shipping emissions in Drammen (2013) at 1 km resolution

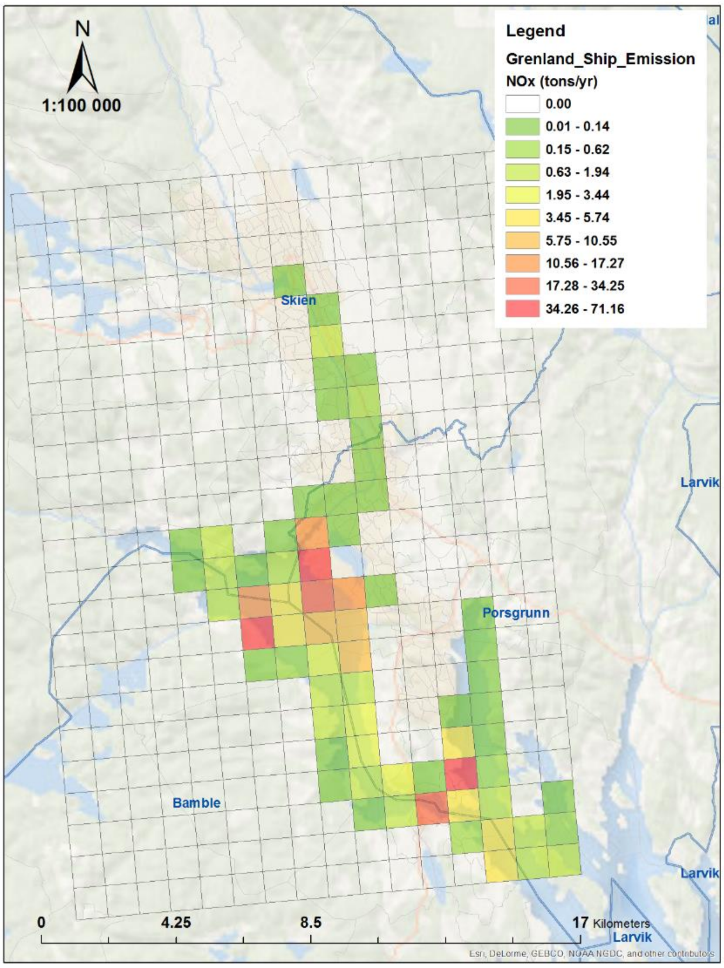

Figure 27: Updated shipping emissions in Grenland (2012) at 1 km resolution

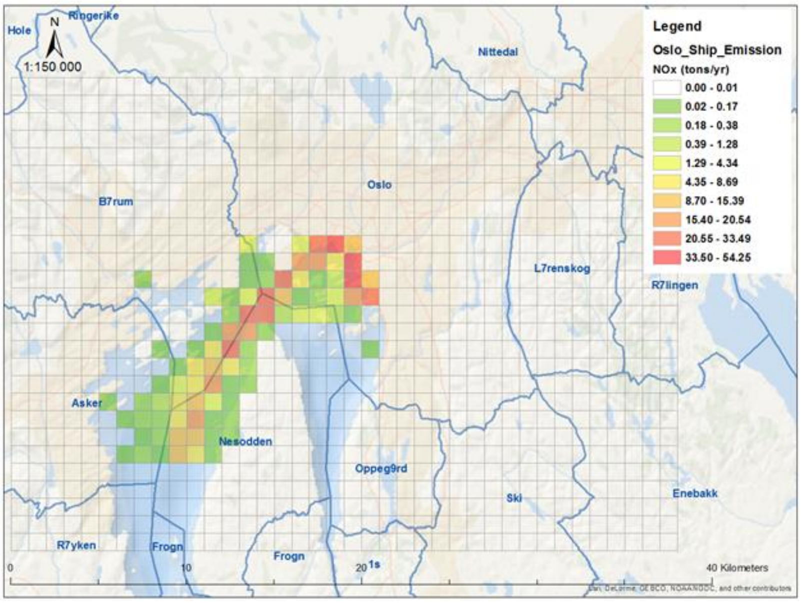

Figure 28: Updated shipping emissions in Oslo (2013) at 1 km resolution

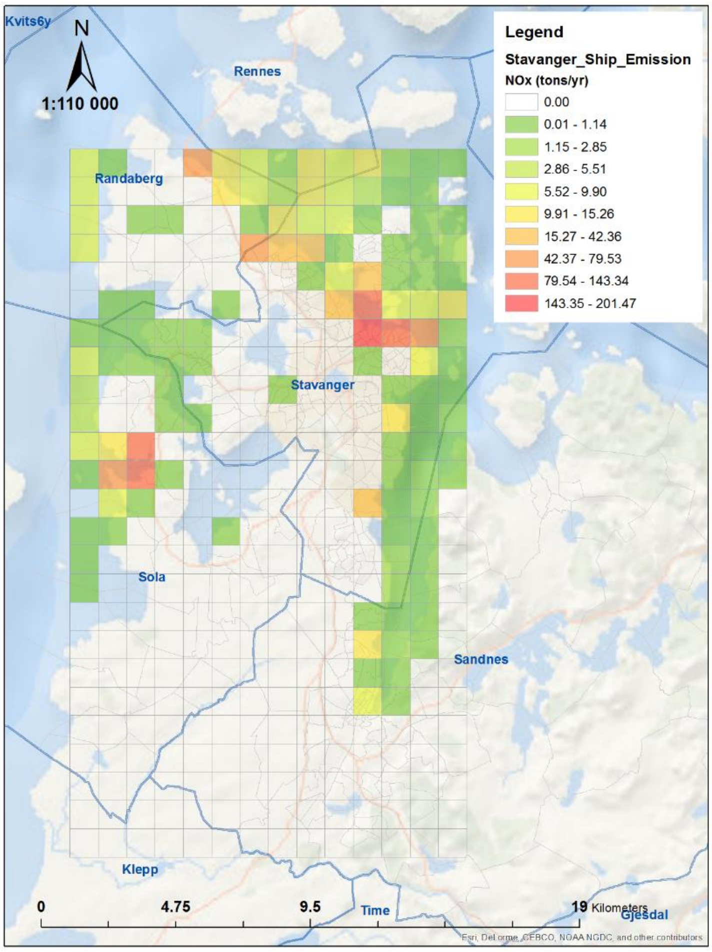

Figure 29: Updated shipping emissions in Stavanger (2012) at 1 km resolution.

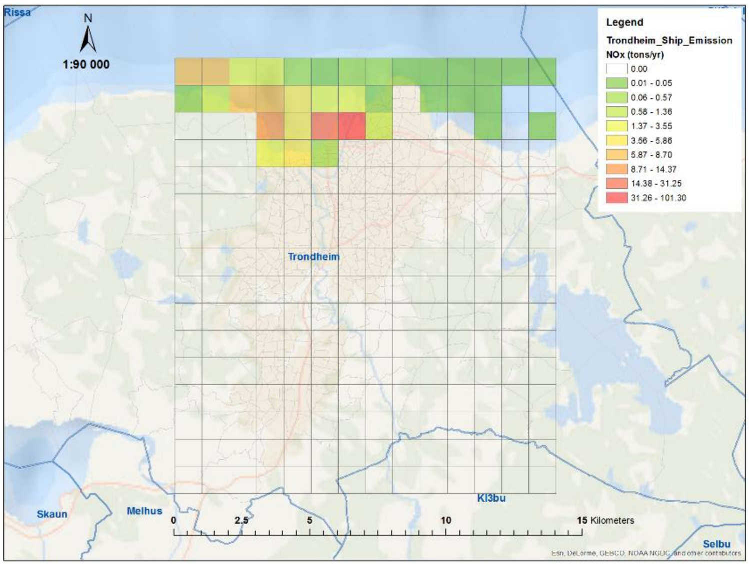

Figure 30: Updated shipping emissions in Trondheim (2012) at 1 km resolution.

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ABSTRACT
This report is part of the development of a National Modelling System for local air quality ("Nasjonalt Beregningsverktøy" or NBV project). We describe and document the emission database used as baseline in the NBV project (i.e. NBV_Emission_Database v.0) and the preliminary emission estimates. This report presents NO_x and PM_{10} emission estimates for Bergen, Drammen, Grenland, Oslo, Trondheim and Stavanger, and the breakdown among sectors. The report emphasizes on the need for update emissions. The developments carried out in 2015 and described in this report involves i) the traffic sector through the development of application to retrieve data; ii) the residential heating sector by updating emissions from wood burning; and iii) the update of shipping emissions. The updated emissions will constitute the NBV_Emission_Database v.1, which better represents current situation, is consistent regarding the methods used to estimate emissions, and completes identified gaps. Our study highlight the importance of updating regularly emissions inventories.

NORWEGIAN TITLE

Utslippsestimater i norske byer. NBV_Utslipp Database v.0

KEYWORDS		
By- og trafikkforurensning	Luftkvalitet	Utslippskontroll

ABSTRACT (in Norwegian)
Denne rapporten er en del av et nasjonalt modelleringssystem for lokal luftkvalitet ("Nasjonalt Beregningsverktøy" eller NBV prosjektet). Vi beskriver og dokumenterer utslippsdatabasen som er brukt som baseline i NBV prosjektet (dvs. NBV Utslipp Database v.0) og utslippsberegningene. Denne rapporten presenterer NO_X og PM_{10} utslippsestimater for Bergen, Drammen, Grenland, Oslo, Trondheim og Stavanger, og fordelingen mellom sektorene. Rapporten understreker behovet for oppdatering av utslippsdata. Utviklingen er gjennomført i 2015 og er beskrevet i denne rapporten, og innebærer i) trafikksektoren gjennom utvikling av en applikasjon for å hente data; ii) husholdningssektoren ved å oppdatere utslipp fra vedfyring; og iii) oppdatering av skipsutslipp. De oppdaterte utslippene er NBV_Utlipp_Database v.1, som bedre representerer dagens situasjon, er i overensstemmelse med metodene som brukes for å beregne utslipp og fullfører identifiseringen av huller.

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

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