Norsk institutt for luftforskning
Norwegian Institute for Air Research

Air quality in 7 Norwegian municipalities in 2015

Summary report for NBV results

Leonor Tarrasón, Gabriela Sousa Santos, Dam Vo Thanh, Paul David Hamer, Matthias Vogt, Susana López-Aparicio, Håvard Vika Røen and Britt Ann K. Høiskar

NILU report 15/2018

NILU report 15/2018	ISBN: 978-82-425-2933-6 ISSN: 2464-3327	CLASSIFICATION: A – Unclassified (open report)
DATE 6.11.2018	SIGNATURE OF RESPONSIBLE PERSON Kari Nygaard, adm.dir. (sign)	NUMBER OF PAGES 50
TITLE Air quality in 7 Norwegian municipalities in 2015 Summary report for NBV results		PROJECT LEADER Leonor Tarrasón NILU PROJECT NO. O-114092
AUTHOR(S) Leonor Tarrasón, Gabriela Sousa Santos, Dam Vo Thanh, Paul David Hamer, Matthias Vogt, Susana López-Aparicio, Håvard Vika Røen and Britt Ann Høiskar		QUALITY CONTROLLER Britt Ann K. Høiskar
REPORT PREPARED FOR Miljødirektoratet, Grensesvingen 7, 0661 Oslo		CONTRACT REF. 840-91743 Isabella Kasin, Miljødirektoratet

ABSTRACT

This report documents the methodology used to compile air quality information for the year 2015 in seven Norwegian municipality areas under the first phase of development of the Norwegian Air Quality Planning Tool, also called "Nasjonalt Beregningsverktøy" or NBV. It follows a similar structure to and complements the final report entitled "Air quality in 7 Norwegian municipalities in 2015 – Summary report for NBV results" (NILU rapport 21/2017) where information on air quality in the seven main city areas in Norway was presented.

This report constitutes a user guide for the NBV-services, available at http://www.luftkvalitet-nbv.no, in municipal areas. It provides recommendations on how to best use each product for air quality planning purposes and explains the main strengths and limitations of the results. The NBV air quality data for municipalities is subject to larger uncertainties than the data available for the main Norwegian city areas and this has to be taken into consideration when analyzing the results.

NORWEGIAN TITLE

Luftkvalitet i syv norske tettsteder i 2015 – status rapport for Nasjonalt Beregningsverktøy (NBV)

KEYWORDS

Air quality	Local and Urban pollution	Modelling results

ABSTRACT (in Norwegian)

Denne rapporten dokumenterer metodene som ble brukt for å samle inn og utarbeide informasjon om luftkvalitet for 2015 i syv norske tettsteder under første fase av utviklingen av det norske planleggingsverktøyet for luftkvalitet, også kalt "Nasjonalt Beregningsverktøy" eller NBV. Rapporten utfyller sluttrapporten "Luftkvalitet i 7 norske byer i 2015 - Evalueringsrapport for NBV-resultater" (NILU rapport 21/2017) og følger en lignende struktur.

Rapporten gir brukerveiledning for NBV-tjenestene som er tilgjengelige for tettsteder på http://www.luftkvalitet-nbv.no. Den beskriver også kort hvordan de ulike produktene bør brukes og peker på mulige anvendelser og begrensninger. NBV-luftkvalitetsdata for kommuner og tettsteder er mer usikre enn de dataene som er tilgjengelige for de viktigste norske byområdene, og dette må tas i betraktning ved analyse av resultatene.

PUBLICATION TYPE: Digital document (pdf)	COVER PICTURE: Source: NILU

NILU's ISO Certifications: NS-EN ISO 9001 and NS-EN ISO 14001. NILU's Accreditation: NS-EN ISO/IEC 17025.

Preface

The Norwegian Air Quality Planning Tool (NBV) has been developed as a collaboration between the Norwegian Institute for Air Research (NILU) and the Norwegian Meteorological Institute (MET) under the direction of the Norwegian Environment Agency in cooperation with the Norwegian Public Roads Administration, the Norwegian Institute of Public Health and the Norwegian Directorate of Health. Work began in 2014 on behalf of the Ministry of Climate and Environment, the Ministry of Transport and Communications and the Ministry of Health and Care Services and its first phase was completed in 2017.

This report documents the methodology used to compile air quality information for the year 2015 in seven Norwegian municipality areas. It follows a similar structure to and complements the final report entitled "Air quality in 7 Norwegian municipalities in 2015 - Summary report for NBV results" (NILU rapport OR 21/2017) where information on air quality at the seven main city areas in Norway was presented. It constitutes a user guide for the NBV web-portal, available at http://www.luftkvalitet-nbv.no, with respect to the data products for the 7 municipality areas: Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana and Moss. The report explains how the available air quality data from these seven municipalities is subject to larger uncertainties than the data included in the NBV-web-portal for the 7 main city areas in Norway (Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger).

The authors are thankful to Christoffer Stoll for the development of the application to retrieve traffic data and to Morgan Kjølerbakken and Rune Åvar Ødegård for their support when defining the technical architecture of the system. We are also thankful to Randi Nordby Henriksen for her invaluable help in the elaboration of this report. Thanks are also due to the members of the Scientific Committee of the project, in particular Isabella Kasin, Pål Rosland and Sigmund Guttu for their comments, feedback and discussions and to the members of the Better City Air (Bedre Byluft) Forum for their guidance and support throughout the project.

Contents

Sammendrag

Denne rapporten presenterer beregnede luftkvalitetsdata og relevante inngangsdata for 2015 for syv (7) norske kommuner. Arbeidet er en del av utviklingen av det nasjonale beregningsverktøyet for luftkvalitet, «Nasjonalt beregningsverktøy» eller NBV. De syv kommunene det er foretatt beregninger for er Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana og Moss.

Beregningene som er omtalt her, er tilgjengelige på nettsidene til Nasjonalt beregningsverktøy på http://www.luftkvalitet-nbv.no. Nettsidene gir åpen tilgang til beregnede luftkvalitetsdata og relevante inngangsdata for nitrogendioksid (NO_2) og partikler (både PM_{10} og $PM_{2.5}$). Produktene som er tilgjengelige for de syv kommunene er de samme som tidligere ble utviklet for syv (7) norske byer, nemlig Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim og Stavanger.

I utviklingen av Nasjonalt beregningsverktøy er det lagt vekt på å benytte en felles metodikk for beregning og sammenstilling av meteorologiske data, utslippsdata og luftkvalitetsdata. Dette er for å sikre at resultater fra ulike deler av landet er sammenlignbare. Likevel finnes det noen forskjeller mellom beregningene for kommunene i forhold til de beregningene som er foretatt for de syv norske byene. I utslippsberegninger for de syv kommunene har det, på grunn av mangelfulle inngangsdata, vært nødvendig å gjøre en del antagelser som ikke ble gjort for de syv byene. I tillegg har de meteorologiske dataene som er benyttet i disse beregningene, lavere romlig oppløsning enn de som ble benyttet i beregningene for de syv byene. I motsetning til i de syv byene, har flere av kommunene ikke måledata som kan benyttes til å validere luftkvalitetsberegningene. Alle disse faktorene har påvirket kvaliteten på resultatene for de syv kommunene.

De meteorologiske feltene som brukes i beregningene for de syv byene har en høyere romlig oppløsning enn de meteorologiske feltene som brukes i beregningene for de syv kommunene. Meteorologiske data for de syv kommunene er opprinnelig tilgjengelige med en oppløsning på 2.5x2.5 km fra AROME-MetCoOp-systemet, mens de meteorologiske dataene for de syv byene var tilgjengelige med en oppløsning på 1x1km gjennom Bedre Byluft prosjektet. Likevel utføres luftkvalitetsberegningene i NBV for de syv kommunene med meteorologiske inngangsdata med samme finoppløsning på 1x1km. Dette skyldes at met.no har et system for å nedskalere de opprinnelige 2.5x2.5km-dataene til enten 1km eller til geografiske koordinater. De nedskalerte dataene er imidlertid ikke alltid av samme kvalitet som de dynamisk beregnede meteorologiske data. Dette må tas med i vurderingen av usikkerheten i de resulterende luftkvalitetsberegninger, selv om tester gjort under NBV-prosjektet viser at denne forskjellen kan være liten.

Det er også forskjeller mellom utslippsberegningene for de syv kommunene og de syv byene. Selv om metodene som brukes til å beregne utslippene stort sett er like, er ikke alle inngangsdata tilgjengelige for de syv kommunene i samme grad som for de syv byene. Dette er spesielt tilfelle for beregning av trafikkutslipp. For svært mange kommunale/lokale veier mangler det informasjon om trafikkvolum og bilparksammensetning, og det var nødvendig å gjøre antagelser om disse verdiene i utslippsberegningene. Dette bidrar til å øke usikkerheten i trafikkutslippene for de syv kommunene. Det ble også gjort antagelser om tidsvariasjonen av vegstøvutslipp og om den romlige fordelingen av vedfyringsutslipp. Sammenligning med tilgjengelige observasjoner indikerer at usikkerhetene i utslippene har

en innvirkning på luftkvalitetsberegningene, selv om det er viktig å påpeke at resultatene for 2015 i kommunene viser tilstrekkelig kvalitet. For å forbedre kvaliteten på luftkvalitetsberegningene, bør det fremover fokuseres på å få bedre estimater på utslipp fra de viktigste kildene. Økt samhandling med lokale myndigheter for å få bedre data på trafikkvolum og bilparksammensetning på lokale veier, implementering av NORTRIP-tilnærmingen for beregning av veistøvutslipp og beregning av vedfyringsutslipp ved bruk av MetVed-metoden vil gi betydelige forbedringer av utslippsestimatene. I tillegg er det viktig å få bedre informasjon om utslipp fra sektorer som vi i dag har lite kunnskap om, for eksempel utslipp fra off-road, jordbruk og bygg- og anleggsvirksomhet.

Valideringen av luftkvalitetsberegningene for 2015 som er utført her, er avhengig av tilgangen til overvåkingsdata. I 2015 var det vesentlig mer overvåkningsdata tilgjengelig i de syv norske byene enn i de syv kommunene. Flere av de syv kommunene hadde dessverre ingen målinger i 2015, mens det alltid var minst en eller to målestasjoner i hver av de syv byene. Mangelen på måledata begrenser muligheten for evaluering av beregningsresultatene. Likevel, der hvor observasjoner er tilgjengelige, viser valideringen god tidsmessig korrelasjon mellom beregninger og måledata, og resultatene er sammenlignbare med beregningene for byområdene. Valideringen viser også at det generelt er høyere systematiske forskjeller mellom beregninger og måledata for kommunene enn for byområdene. Dette skyldes større usikkerhet i de utslippsdataene som brukes som input. Til tross for disse begrensningene, viser sammenligningen med eksisterende observasjoner pålitelige beregninger i kommunenes områder. Det er kommet flere målestasjoner i disse områdene siden 2015, og dette, sammen med de initiativene som allerede er på gang for forbedring av utslippsdataene, vil kunne bidra til en enda bedre karakterisering av luftkvalitetsnivåene i disse områdene.

Executive Summary

This report presents air quality data and information for the year 2015 in seven Norwegian municipality areas as developed under the first phase of the Norwegian Air Quality Planning Tool, also called "Nasjonalt Beregningsverktøy" or NBV. The seven (7) municipalities are: Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana and Moss.

The air quality information referred to here are available on-line at the NBV-portal at http://www.luftkvalitet-nbv.no. The NBV web-portal provides open access to data and information on air quality and relevant input-data for nitrogen dioxide (NO_2) and particulate matter (both PM_{10} and $PM_{2.5}$). The available NBV-products are the same that have been developed for the seven (7) main Norwegian cities (Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger).

Despite the efforts to compile meteorological data, emission data and air quality data following a common methodological approach that guarantees the comparability of the data across Norway, there are still limitations on the data availability in cities versus in different municipalities. This affects the overall quality of the air quality results and hampers their validation. Differences in the data availability involve: meteorological input data, basic emission information and observations from monitoring stations. These differences affect the quality of the results and imposes higher uncertainty to the air quality calculations in the municipality areas.

The meteorological fields used for the main cities have originally a higher spatial resolution than the meteorological fields used for the municipalities. Meteorological data in the seven municipalities are available with a resolution of 2.5x2.5km from the AROME-MetCoOp system while meteorological data in the cities were available with a resolution of 1x1km from the Better City Air (Bedre Byluft) forecasting chain. Still, the air quality calculations in NBV are all carried out using meteorological input with the same fine resolution of 1x1km. This is because the meteorological office (MET) provides a system to downscale the original 2.5x2.5km data to either 1km or to geographical coordinates. However, downscaled data are not always of the same quality as dynamically calculated meteorological data. This needs to be considered when evaluating the uncertainty of the resulting air quality calculations, although initial tests carried out during the NBV project suggest that the impact of this difference may be small.

There are also differences between the emission calculations for the seven municipalities and for the cities. Although the methodologies used to calculate emissions are similar, the basic input data is not always available for the seven municipalities to the same extent as it was for the seven cities. This is especially the case for traffic emissions, where information on traffic volume and vehicle fleet composition is not available for all municipal roads, so that assumptions on these values were made. Such assumptions add to the uncertainty of the traffic emission data from the seven municipalities. Different assumptions were also made for the temporal variation of road dust emissions and for the spatial distribution of residential combustion sources. Initial comparison with available observations indicates that the uncertainties in the emission data have a visible impact in the air quality calculations, although the current air quality results in municipalities areas are of good quality. To improve the air quality estimates it is important to focus on the improvement of the main emission sources. Increased interaction with local authorities to improve the information on

traffic volume and vehicle fleet composition on local roads, the on-going implementation of the NORTRIP approach to calculate road dust emissions and the evaluation of residential heating emissions through the MetVed methodology, are all identified as relevant ways to improve the NBV air quality calculations. In addition, it is important to compile better information on sectors currently poorly or not included in the inventories, such as emissions from off-road, agriculture and construction and renovation activities.

The validation of the NBV air quality calculations for 2015 carried out here was limited by the access to monitoring data. In 2015, there were no operating monitoring stations at roughly half of the municipalities involved here, while there were always at least one or two monitoring stations in each city area domain. The lack of monitoring data hampers the evaluation of the results and their representativeness. Still, where observations are available, the validation shows good temporal correlation in the municipality results, comparable to the temporal correlations from the city areas. The validation also shows generally higher bias in the NBV municipality results than those in city areas, due to higher uncertainties in the emission data used as input. Despite these limitations, the comparison with existing observations shows reliable NBV-calculations in municipality areas. It is recognized that the number of operating monitoring stations in municipality areas has increased since 2015 and that this development, in addition to the on-going initiatives to improve emission data at municipality level, will contribute to an even better characterisation of the air quality levels in these areas.

Air quality in 7 Norwegian municipalities in 2015

Summary report for NBV results

1 Introduction

The Norwegian Air Quality Planning Tool (Nasjonalt beregningsverktøyet, NBV) is a web-service developed to support local air quality planning, solving tasks related to existing regulations. It provides a common methodological and information platform for local air quality modelling applications. The web-service is addressed to local and regional environmental authorities, air quality experts and consulting companies. It is intended to help them meet the requirements of current air quality legislation, to support local air quality planning and facilitate the improvement of air quality where people live.

The NBV tool and web-portal responds to the 2015 Judgement of the Court from the EFTA Surveillance Authority that pointed out to a significant drawback in Norwegian air quality management practices, namely, the lack of a systematic approach to the elaboration of plans and programs to control air pollution. Different factors contributed to the lack of a systematic approach to the elaboration of plans and programs in Norway, but one important reason had been the lack of available input air quality information. This involves in particular, input data such as emissions and meteorology, necessary to evaluate the air quality situation in Norwegian cities. These input data form the basis to calculate the effect of abatement measures. For this reason, work to support the creation of the Norwegian Air Quality Planning tool has precisely focussed on the compilation of meteorological and emission data in a consistent way throughout Norway.

The NBV web portal contains open access to data and information on air quality and relevant input data for the year 2015. Information on nitrogen dioxide (NO_2) and particulate matter (both PM_{10} and $PM_{2.5}$) is available at seven main Norwegian cities (Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger) and seven municipality areas (Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana and Moss).

This report focuses on the seven municipality areas. Despite the efforts to compile meteorological data, emission data and air quality data following a common methodological approach that guarantees the comparability of the data across Norway, there are limitations on the data availability in cities versus different municipalities. This report documents how meteorological and emission input data currently available in municipality areas are different from the data available at main city areas. It also explains how these differences affect the quality of the results and imposes higher uncertainty to the air quality calculations in municipality areas.

In chapter 2, the methodologies used to compile meteorology, emissions and air quality data in municipality areas are documented. Chapter 3 includes a first validation of the results somewhat hampered by the limited availability of air quality observations in municipality areas. Chapter 4 presents the different NBV air quality products and provides recommendations on how best to use them for assessment and planning purposes in municipality areas. Finally, in Chapter 5, conclusions and recommendations for the future are presented.

Methodology used in NBV for municipality areas

A short description of the methods used for calculating the input meteorological data, input emissions and air pollution dispersion results in the seven municipality areas is presented in this chapter. There is a special focus to describe how these methodologies differ from those used to compile data in the main city areas that are at the core of the Norwegian Air Quality Planning Tool (NBV) and were documented in Tarrasón et al. (2017).

1.1 Meteorological fields

As explained in Tarrasón et al. (2017), the meteorological data for the NBV system is produced by the meteorological model AROME (Application of Research to Operations at MEsoscale), coupled to the surface model SURFEX (Surface Externalisée, in French), a surface modelling platform developed by Météo-France in cooperation with the scientific community.. AROME is a high resolution model which was developed in the second half of the 2000s in Météo-France with the aim to improve local forecasts. The development was done for a chosen horizontal grid of 2.5km, which allows to explicitly resolve deep convection systems by the model dynamics (Seity et al., 2011). In this way, improvements were possible on forecasting especially dangerous convective phenomena (thunderstorms, flood risk, heavy precipitation) and low-level conditions (wind, temperature, ground state, fog, heat islands, etc.), as documented in Bouttier and Roulet (2008). The model was declared valid for operational use in December 2008. AROME forecasts showed better physical realism than the previous forecasting system. This physical realism was attributed to its mesoscale physics-dynamics and data assimilation scheme (Seity et al., 2011). The need to forecast the localization and intensity of high-impact meteorological events has pushed horizontal resolution to even finer scales of up to 1 km (Amodei et al., 2015).

The AROME-MetCoOp system is run operationally by the Norwegian Meteorological Institute (MET) and their partner meteorological institutes to produce meteorological forecasts at 2.5km resolution for all of Norway.

In addition, MET ran until 2016 the three regions that cover the largest cities, for the Better City Air (Bedre Byluft) forecasts system at 1 km resolution. The meteorological forecast data was operationally generated and regularly validated, but it was not operationally stored. When necessary, MET carried out a re-analysis of the data to store meteorological fields for a specific year. As part of the Norwegian Air Quality Planning Tool project (NBV), instead of re-analysis routines, an operational system was put in place so that the operational forecast data in 1x1km could be archived and processed by MET, securing the completeness of the data. This was necessary to allow easy access to relevant meteorological input as requested by air quality applications.

The meteorological data available for NBV covers three years: 2010, 2015 and 2016. For 2010, reanalysis of the 3D meteorological fields have been carried out and validation results are documented in Denby and Süld (2016). The meteorological data for 2015 and 2016 is no longer a re-analysis but has been directly archived from the forecast chain. This has the advantage that meteorological data is available for use very short after the actual period is completed.

The meteorological data compiled under NBV consists of 3D spatial meteorological parameter fields with 1 hour resolution covering a full year. These meteorological fields include all the parameters necessary as input for air quality dispersion model calculations, in particular those required by the EPISODE model used as basis for NBV air quality results. These meteorological data are freely available through the NBV web portal or directly through METs THREDDS data distribution server. The 3D meteorological data cover the whole of Norway. They are available as monthly files, with 1h temporal resolution and different spatial resolution, as explained below:

- **For the 7 NBV cities**: Meteorological data in the seven main cities are available with a resolution of 1x1km from the Better City Air (Bedre Byluft) forecast chain. This high resolution meteorological data is available for the years 2010, 2015 and 2016. The high resolution 1x1km meteorology data for 2015 form the basis for the main cities air quality results available for the same year at NBV. It consist of a) 3D meteorological parameters including temperature, wind, humidity, turbulent kinetic energy and pressure and b) 2D near surface parameters including, among others, precipitation, cloud cover, pressure, surface momentum fluxes, surface turbulent energy fluxes, short and long wave radiation fluxes, boundary layer height, surface temperature and surface water content.
- **For the 7 NBV municipalities**: Meteorological data in the seven municipalities are available with a resolution of 2.5x2.5km from the AROME-MetCoOp system. These meteorological data are available for the years 2010, 2015 and 2016 for the whole of Norway. The 2.5x2.5km resolution meteorology data for 2015 form the basis for the air quality results at the seven municipalities available for the same year at NBV. However, for the air quality model calculations, these meteorological data have been dynamically downscaled to 1x1km resolution using statistical methods developed by MET, so that the meteorological input data used to produce air quality results have the same 1x1km resolution as for main city areas. These downscaled meteorological data consist of the same 3D and 2D parameters as listed above for main cities. The downscaled data covers 23 different municipalities in 10 different domains and can be downloaded from the THREDDS data server at MET (http://thredds.met.no)
- **For any geographical point**: With the downscaling capability developed by MET, the operational meteorological 2.5x2.5km resolution data from the AROME-MetCoOp system is interpolated to any given geographical point over the whole of Norway. Such downscaled data is then provided through the NBV web portal or directly through METs THREDDS data distribution server. However, these data include only 2D surface parameters and are available only as point timeseries.

The meteorological fields used for seven municipalities are downscaled from the original 2.5x2.5km data. It is often argued that downscaled data are not always of the same quality of dynamically calculated meteorological data. For this reason, a comparison between the dynamic meteorology results at 2.5 and 1 km was carried out in Denby and Süld (2016), as part of the NBV project. The report provides an initial analysis of the meteorological models ability to describe inversion situations, important for air quality applications. The results show that both meteorological model resolutions provide satisfactory predictions for wind, temperature and precipitation. For the period under study, there was no significant statistical difference between the meteorological results in 1 and 2.5km resolution, when compared to measurement stations. The impact of these different meteorological input data in the air quality simulations for selected urban areas was also analysed as part of the NBV project, as documented in Tarrasón et al., 2017. Based on these initial results, it was justified to streamline the Bedre Byluft and NBV production lines by using solely 2.5km AROME-METCoOp data in the future. Eventually, the 2.5km operational meteorological data can be downscaled to 1km resolution, when necessary for air quality runs. In this way, better synergies with the operational Bedre Byluft system are secured. But for fine scale resolution applications, the use of downscaled data can impose higher uncertainty in the final results. The validity of the meteorological model results would need to be validated in each case with observations, as recommended in Tarrasón et al (2018).

1.2 Emission data

The emission data compiled for the seven municipality areas follows as far as possible the methodology developed to compile NBV_V1 emissions for the seven city areas. The methods used for the compilation of municipality emissions are those recommended by López-Aparicio et al. (2017) after carrying out a comparison of the NBV_V0 inventory with other emission inventories in the framework of FAIRMODE (Thunis et al., 2016). This inventory benchmarking work provided useful recommendations to guide the development of the NBV_V1 inventory and is the basis for the compilation of emission data both in cities and in municipality areas, where data is available.

Where bottom-up input data for emissions is not available, the NBV-V1 inventory for municipality areas relies on the downscaling emission inventory developed under the NordicWelfair project (http://projects.au.dk/nordicwelfair/). The NordicWelfair (NWA) project has the overall aim to further understand the link between air pollution levels and chemical composition, and to investigate and assess the effects of air pollution on the distribution of related health impacts, socio-economics and welfare in the Nordic countries. NILU is a partner in NordicWelfair (NWA) and has compiled a high resolution emission inventory based on top-down approaches. The inventory covers the whole of Norway with a spatial resolution of 1kmx1km. It is based on national data compiled at county level from Statistics Norway (SSB) and uses downscaling spatial methods to re-locate the county emission data in high resolution. First results for the year 2012 were made available to the NBV project by the time when the compilation of emissions for municipality areas was initiated. NBV favours bottom-up inventory approaches so the data from the NWA inventory has been used only in the sectors where bottom-up data is otherwise missing or non-available. In particular, it has been used as basis for the determination of emissions in the "residential heating" and "other" sectors.

An important difference between the NBV_V1 inventory for cities and for municipalities is the basic year used for the emission calculations. Both inventories are build up around 2015, but they do not use consistently the same year of emissions for all sectors. This is due to differences in the availability of updated emission data. At the time of the compilation of the NBV_V1 emission inventory for city areas, in 2015, the most recent emission information data was from 2013. Therefore, the NBV_V1 inventory for city areas consistently compiled information for the year 2013 across all sectors. By the time of compilation of the NBV_V1 inventory for municipalities, more data for 2015 was available and was therefore used, when possible, in the inventory.

Differences also arise from the availability of key input data to produce the emission estimates, independently of the year of the update. These data are identified below. The bottom-up methodology used to compile emissions in NBV_V1 is more often constrained by lack of data in the seven Norwegian municipalities than in the seven cities.

1.2.1 Traffic

For exhaust emissions from traffic, the emission compilation at the seven municipalities follows a bottom-up approach, similar to the one documented in detail in López-Aparicio and Vo Thanh (2015). The basic traffic volume data originates from the National Roads Database (NVDB). However, information on the traffic volume per road link are only available at NVDB for some roads in municipality areas. Generally, national and county roads have better coverage than municipal roads. The information coverage is very low: in NVDB there is no available traffic volume data for over 90% of all road links in each municipality area. Where traffic volume data is available, we have used the yearly averaged daily traffic volume (ÅDT) data for the year 2015. Where traffic volume data is not available, we have made an estimate for the yearly averaged daily traffic volume according to the speed-limit of the roads. The assumption is based on the fact that roads with high speed limit are usually frequented by a higher number of vehicles. We have assumed larger traffic volumes in Brumunddal, Gjøvik Lillehammer and Moss, than in Halden, Harstad and Mo i Rana, as indicated in Table 2.1. We also made assumptions on the vehicle fleet composition, since these information was not available for all the municipality areas. We have used the same vehicle fleet composition as in Oslo, recognizing that this probably implies an underestimation of the actual emissions because of the higher proportion of new low-emitting vehicles in Oslo and the lower contribution of heavy duty traffic in the calculations.

While in for the city inventories we assumed a weekly, daily and hourly temporal variability of the exhaust traffic emission, for the municipality estimates we have used the daily and hourly variation of Oslo for all municipalities and a generally flat weekly variation throughout the year. It is expected that assigning a refined temporal profile to the exhaust emissions will improve the temporal correlation of the air quality results.

Table 2.1. Estimated traffic volume at different municipal roads, for three different standard speed limits classes, expressed as averaged Annual Daily Traffic (ADT). Units: [number of cars.day^{-1}.roadlink^{-1}]

Speed limit at Road link	Brumunddal	Gjøvik	Halden	Harstad	Lillehammer	Mo i Rana	Moss
70-80 km/h	1300	1300	750	750	1300	750	1000
50-60 km/h	1300	1300	500	500	1300	500	750
30-40 km/h	1300	1300	250	200	1300	200	500

It is recommended to establish a dialog with local authorities in order to check and improve the given exhaust traffic emission assumptions. This is especially important with respect to traffic volume and vehicle composition, but also relevant with respect to the temporal variation of the traffic emissions.

For non-exhaust emissions from traffic, emissions of PM_{10} and $PM_{2.5}$ due to resuspension from the road surface are calculated based on a parameterisation from Tønnesen (2000). This relates the emission of particulate matter to the percentage of studded tyres use, the percentage of heavy duty traffic, the traffic speed, the traffic volume and the road wetness (precipitation). The percentage use of studded tyres was available from the Norwegian State Roads Administration for the year 2015, but only for certain municipalities[1]. For the other municipalities, we have assumed that the percentage studded tyre use in Halden and Moss is 20%, the same as in Fredrikstad/Sarpsborg and that it is 85% in Harstad and Mo i Rana, based on the usage in Tromsø, since these municipalities have similar winter weather conditions. The parametrization is applied for yearly values and no temporal variation has been assumed for these emissions. It is recognized that road dust emissions are very weather dependent and tend to be larger in spring and autumn. These effects are not considered in the present emission calculations. A better approach to calculate road dust emissions and re-suspension is with the help of the NORTRIP model (Denby et al., 2013) that is currently implemented in Bedre Byluft, NBV and uEMEP. This parametrization takes into account actual meteorological conditions and it is expected to reproduce better both the extent and temporal evolution of road dust emissions. We assume that the PM_{10} and $PM_{2.5}$ non-exhaust emission estimates will be improved if the implementation of NORTRIP is done for all areas in Norway.

1.2.2 Residential heating

Residential heating emissions for 2012 from the NordicWelfair (NWA) inventory are used to derive the emission values from this sector in all seven municipalities in the NBV_V1 inventory. This NWA inventory has a detailed spatial allocation of wood burning emissions that makes it a good candidate for applications such as NBV. Wood burning emissions were identified as the largest single source of uncertainty in the NBV results in city areas (Tarrasón et al., 2017). López-Aparicio et al. (2017) reported on important discrepancies in $PM_{2.5}$ emissions from residential wood burning from different inventories and concluded that these discrepancies are associated with the assumptions made for the allocation of these emissions. This findings guided the selection of the NWA inventory as basis for the NBV_V1 inventory in municipality areas, because special attention was given to the allocation of the residential heating emissions.

The NWA inventory is based on wood combustion activity data compiled at county level by Statistics Norway (SSB). The county emission data is then re-located in high spatial resolution (1kmx1km) using information on the dwelling number and the dwelling type as proxies for the spatial distribution. Two types of dwelling types are distinguished: apartments and houses. For all the municipalities, 70% of the wood consumption is allocated in house locations and 30% in apartment locations. Despite the improved system for allocating wood burning emissions, similar problems to those reported in city areas where found for the municipality areas, so that, again, residential heating emissions were adjusted down to meet available observations of $PM_{2.5}$. We use an averaged scaling of a factor of 2 for all municipalities with respect to NWA inventory values. The scaling factor is determined from indirect validation and by identifying the bias towards observations. Figure 2.1 shows a

[1] http://luftkvalitet.info/Theme.aspx?ThemeID=13dc725e-fd54-4e78-ad48-64735a844e32

comparison in five cities of the NBV_V1 inventory (both adjusted and unadjusted with the scaling factor of 2) with the NWA emissions for 2014 and the emissions derived from the MetVed project (López-Aparicio et al., in prep.). The MetVed project was designed to better understand wood burning emissions in Norway and identify the reasons behind the systematic biases reported for these emissions. The methodology developed in MetVed builds on a process oriented approach to residential heating emissions. Figure 2.1 shows that both the NVB_V1 (unadjusted) and the NWA inventories provide significantly larger $PM_{2.5}$ emissions than the NBV_V1 (adjusted) and the MetVed inventories. It also shows that the NBV_V1 (adjusted) and the MetVed inventories give similar results. The figure provides an indication that the prescribed adjustment of NBV_V1 may be explained by the emission process approach developed in MetVed. It also brings further trust in the MetVed methodology since we know that the NBV_V1 (unadjusted) inventory overestimates the $PM_{2.5}$ concentrations in air when validated with observation through a dispersion model, while the NBV_V1 (adjusted) shows good agreement with observations.

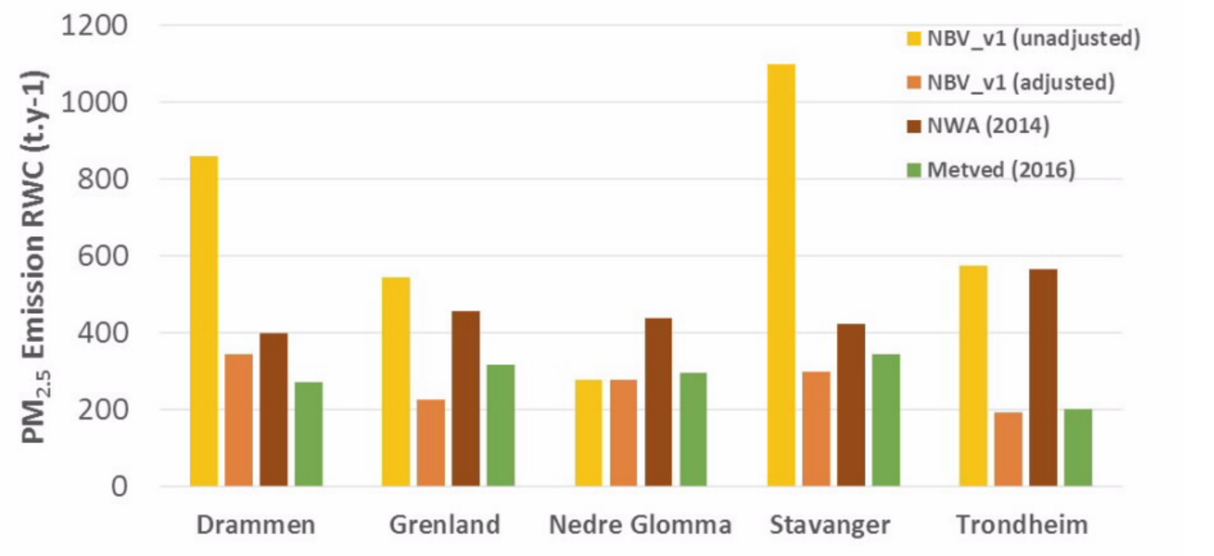


Figure 2.1: Comparison of annual emission estimates of PM2.5 emissions from residential wood combustion (RWC) from different inventories in five Norwegian cities. The inventories are NBV_V1 both adjusted and unadjusted, NWA- Nordic WelfAir project and MetVed (López-Aparicio et al., in prep.). Units: [t.y-1]

The MetVed methodology uses a downscaling method approach and builds on bottom-up principles to derive a wood burning potential for each grid based on the housing type, size and heating technology, energy demand and outdoor temperature of each grid. The emission model builds on the combination of several databases with information at high level of detail. The databases include information on dwelling number and dwelling type at 250m resolution, energy consumption statistics per residential energy commodity and type of dwelling at municipality level, fireplace and stoves locations as point sources (derived from the Norwegian Fire Department databases), and geo-localised information about dwellings, the type they belong to and the available technology for residential heating. The different datasets are combined and the dependencies between the different variables is analysed in order to define a wood burning potential at a 250m grid. The MetVed model includes estimates of the time variation for residential wood combustion based on the heating degree concept combined with time variation from consumer statistics, and the vertical distribution based on the wood consumption shared in apartment buildings versus houses (López-Aparicio et al., in prep). This on-going work is expected to contribute to further improvements of the emission estimates from the residential heating sector. For the time being, it helps build trust on the current NBV_V1 estimates for the seven municipalities.

1.2.3 Shipping

Following the recommendations by López-Aparicio and Vo Thanh (2015), emission from the shipping sector have been compiled from the AIS service hosted by the Norwegian Coastal Administration. The 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 AIS system is a powerful tool that provides real time information and supports a reliable system to estimate emissions from shipping. Shipping emissions are the dominant source of NO_x in Moss and are also significant in Harstad, Halden and Mo i Rana. The NBV_V1 shipping sector estimates use the 2016 updated AIS data (to avoid the errors identified with the 2015 and reported in Tarrason et al., 2017).

1.2.4 Industry

Emissions from land-based industrial sources are reported every year under the European Pollutant Release and Transfer Regulation (E-PRTR) that establishes an integrated pollutant release and transfer register at EU level in the form of a publicly accessible electronic database. The Norwegian PRTR website[2] provides updated information on industrial emissions, including releases per facility. We have used 2015 data from the Norwegian PRTR register to compile the annual industrial emission from all seven municipalities. These data are introduced in the NBV_V1 inventory as point sources. Industrial emissions are dominating in Mo i Rana, but are also significant in Halden, Brumunddal, and Moss and to a lesser degree in Gjøvik.

1.2.5 Other sources

The NordicWelfair (NWA) inventory for Norway was used as basis for the determination of "Other sources" in the NBV-V1 emission estimates for the seven municipality areas. The emissions included in "Other sources" for municipality areas are a) emissions from agricultural activities, including husbandry and b) emission from off-road activities, including also mobile sources and machinery from agriculture and forestry activities. The NWA results for 2012 were available in 1x1km in a different grid from the one used in the NBV calculations, so that the data was re-gridded to obtain the NBV-V1 emission estimates.

[2] https://www.norskeutslipp.no/en/Components/Emission/Nitrogen-oxides/?ComponentType=utslipp&ComponentPageID=159&SectorID=600

Currently, emissions from construction sites are not included the NBV_V1 estimates, not even as part of this bulk group “Other sources”. It is recognized that this constitutes a potentially important gap and contributes to the uncertainty of the PM_{10} and $PM_{2.5}$ emission estimates. Cooperation with local authorities on the establishment of new methods to determine these type of sources is recommended in order to fill existing emission gaps.

1.2.6 NBV_V1 annual estimates

The resulting annual emission values are presented in Table 2.2 for NOx, Table 2.3. for PM_{10} and Table 2.4 for $PM_{2.5}$ emissions. The contribution from industrial sources dominates the NOx emissions from Mo i Rana, while shipping emissions are dominant in Moss. Otherwise, traffic emissions are the largest single contributor to NOx emissions in most municipality areas, as expected. It is interesting to note that the contribution of off-road and agricultural sources in most municipality areas is significantly higher than it was for the city emissions.

Table 2.2: NBV_V1 emissions for NOx compiled for seven municipalities. Units: [tons/year]

NOX sector emissions	Brumunddal	Gjøvik	Halden	Harstad	Lillehammer	Mo i Rana	Moss
Industry	109	1	122	0	0	1458	19
Traffic	962	261	283	85	375	99	989
Domestic Heating	0	0	0	0	0	0	0
Shipping	0	0	38	136	0	60	1202
Other (incl. off road)	239	27	98	23	77	59	212
TOTAL	**1310**	**288**	**541**	**244**	**452**	**1677**	**2422**

Table 2.3.: NBV-V1 emissions for PM_{10} compiled for seven municipalities. Units: [tons/year]

PM_{10} sector emissions	Brumunddal	Gjøvik	Halden	Harstad	Lillehammer	Mo i Rana	Moss
Industry	4	2	0	0	0	260	0
Traffic	603	153	157	61	219	103	535
Domestic Heating	576	157	97	51	193	50	243
Shipping	0	0	1	7	0	2	77
Other (incl. off road)	13	3	4	3	5	3	12
TOTAL	**1196**	**313**	**260**	**121**	**418**	**420**	**868**

Table 2.4.: NBV_V1 emissions for $PM_{2.5}$ compiled for seven municipalities Units: [tons/year]

$PM_{2.5}$ sector emissions	Brumunddal	Gjøvik	Halden	Harstad	Lillehammer	Mo i Rana	Moss
Industry	4	2	0	0	0	26	0
Traffic	88	25	20	9	39	10	69
Domestic Heating	576	157	97	51	193	50	243
Shipping	0	0	1	7	0	2	77
Other (incl. off road)	13	3	4	3	5	3	12
TOTAL	**681**	**186**	**123**	**69**	**237**	**92**	**402**

Traffic, residential heating and “other” sources dominate the emissions of particulate matter. As expected, traffic is the main contributing sector for PM_{10} while residential heating is the main contributing sector for $PM_{2.5}$ emissions. Comparison between the emissions of PM_{10} and $PM_{2.5}$ from traffic in all municipality areas shows that the coarse fraction dominates the traffic emissions and is an indication of the extent of emissions from the re-suspension of road-dust. The comparison between the emissions of PM_{10} and $PM_{2.5}$ for residential heating shows that the fine fraction dominates the residential heating emissions. In fact, there is no coarse fraction contribution in the emission from that sector in our NBV_V1 estimates.

1.3 The EPISODE dispersion model

EPISODE is the core of the NBV system. This same air quality dispersion model has been used for the calculations at the seven municipalities as it was used for the seven cities. The model has been developed at the Norwegian Institute for Air Research (NILU) for air quality studies at the local scale. It has been the basis for the air quality forecast in the Better City Air program and has been routinely validated with observations as part of the program operations for the last twenty years. Moreover, it is an important tool for regulatory and policy in air quality in Norway and has been used regularly to support the elaboration of plans and programs to reduce air pollution. In the latest years, the EPISODE model was successfully used for planning purposes in Drammen (Wergeland et al., 2017), Bergen (Høiskar et al. 2017), Oslo and Bærum (Høiskar et al., 2016; Høiskar et al., 2014), Stavanger (Denby et al., 2013) and Fredrikstad (Weydahl et al., in prep).

The EPISODE model results have been benchmarked against other European model results within the framework of FAIRMODE. The results are documented in Janssen et al. (2017) and show results comparable with those of state-of-art models used in Europe for air policy applications.

The EPISODE model consists of an Eulerian 3D grid model with embedded sub-grid Gaussian and Lagrangian models, which take care of the dispersion from different type of sources (point, line, and area sources) (Slørdal et al., 2003). The Eulerian part of the model consists of a numerical solution of the atmospheric mass conservation equation of the pollutant species in a three-dimensional Eulerian grid. The Lagrangian part consists of separate sub-grid models for line and point sources. The line source model is an integrated Gaussian type model, while the point source model is a Gaussian puff trajectory model. Point sources are for example stack emissions from industry. Line sources are typically emissions from traffic. Area sources are emissions dispersed in space as for example the emissions from residential heating.

The model is typically used to calculate air pollution concentrations in cities and local areas from multiple emission sources such as road traffic, shipping, residential heating and industry. The model calculates hourly average concentrations as gridded values and in a set of irregularly placed receptor points. The output of the model in hourly frequency is used for calculating long-term average concentrations and other statistical parameters. Traditionally EPISODE has been applied for the calculation of airborne species such as SO_2, CO, NO_X[3], NO_2, PM_{10} and $PM_{2.5}$. Calculations of NO_2 are based on a simplifying assumption of photochemical equilibrium between NO, NO_2 and O_3 for each time step. For urban scale applications, the mode does not include neither dry nor wet deposition processes.

In order to make maps of air quality, concentrations must be modelled throughout the model domain. The model simulations are carried out in 1x1km using the EPISODE model

[3] $NO_X = NO_2 + NO$

and in addition we have used receptor point simulations to better resolve the Gaussian dispersion of line sources so that the final resolution of the maps is 100x100m. In order to create maps at 100 m resolution, the model domain is populated with a large number of receptor points. These receptor points are placed with higher density near roads, out to the extent of the road link influence distance (400 m), the distance to which the line source model is applied. Outside of this region receptor points are placed every 500 m in a regular grid as these sample only from the grid model. The EPISODE model calculates concentrations at the receptor points by adding line source and grid model concentrations.

2 Evaluation of 2015 results with available observations

The validation of air quality levels for nitrogen dioxide (NO_2) and particulate matter (both PM_{10} and $PM_{2.5}$) in comparison with observations is an essential way to understand the validity not only of the model results but also of the emissions used as input to the calculations. However, the evaluation of the air quality results at Norwegian municipalities was far more challenging than it was for city areas because of the lack of monitoring data.

There were only a very limited number of monitoring stations actively compiling air quality data in 2015 in the municipality areas under consideration. For NO_2, there were only three active stations in 2015: one in Gjøvik (Minnesundvegen) and two in Lillehammer (Bankplassen and Lillehammer barnehage). Halden had measured NO_2 concentrations at the Oskleva station earlier in 2010 and 2011, but the measurements were not active in 2015. In addition, at Vangsveien station in Hamar, there were measurements of NO_2 for the last six months of 2015, but not for the full year. For $PM_{2.5}$, the situation was not better. There were only four active stations in 2015 measuring $PM_{2.5}$ concentrations: the same three in Gjøvik and in Lillehammer as for NO_2, and the Vangsveien station in Hamar. For PM_{10}, there were a total of five stations, the same ones as for $PM_{2.5}$ in Gjøvik, Lillehammer and Hamar and an additional one in Rana, namely the Moheia station in Mo i Rana.

It is worth mentioning that the number of monitoring stations increased in 2016 and it is much improved at present. In Halden, at the Vaterland station, there are regular measurements of PM_{10} and $PM_{2.5}$ since December 2017. In Harstad, regular measurements of NO_2, PM_{10} and $PM_{2.5}$ were initiated in January 2018 at Seljestad. In Moss, measurements of PM_{10} and $PM_{2.5}$ were re-established again in 2016 after a break of 4 years, at the Kransen station. And in Hamar, the measurements of NO_2 initiated at Vangsveien station in July 2015 have continued ever since.

Tables 3.1., 3.2. and 3.3. show summary statistics for the validation of model results with observations for respectively NO_2, PM_{10} and $PM_{2.5}$. Validation results at available measurement stations in 2015 are presented by municipality area, that is, Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana and Moss, and per measurement station in each area. Detailed results of the comparison with observations are documented in Appendix A and have served as basis for the analysis summarized below. The statistics and validation values provided in Appendix A and the summary tables are relevant for air quality planning and reporting purposes. This is particularly the case for the correlation coefficient R^2 that is calculated with either hourly or daily frequency to quantify the temporal correlation of the pollution levels, thus providing a measure to what extent the modelled values are able to reproduce the observations during episodes of air pollution. When the correlation coefficient R^2 is calculated for annual means, it quantifies the spatial correlation, which is the ability of the modelled results to reproduce differences between pollution regimes. The spatial correlation is determined to a large extent by the position of the stations and thus the design of the monitoring network. Since most of the stations considered here are placed in urban areas or close to sources, the limited monitoring network represents very similar pollution regimes. Given the existing monitoring network in the seven municipalities, spatial correlation values will only reflect the limitations of this sparse network and are therefore not presented here.

The lack of monitoring data hampers the validation of the modelling results and consequently adds to the uncertainty of the air quality results in this seven municipality areas. We have carried out different types of comparisons with observations, namely, we have compared to observations from one year with model calculation from another year and we have also compared model results in one municipality with observations in another. Such comparisons are only meaningful to assess that the modelled pollution values fall into a reasonable level range. Results from such comparisons are not shown here but demonstrate that the model calculations presented in NBV are consistent with each other provide a reasonable first estimate of the pollution levels in 2015 also in areas without observations. In the following, only results from direct comparison with available observations are presented.

2.1 NO_2

The evaluation of the model results for NO_2 in municipality areas shows a generally good temporal correlation coefficient with available observations. Temporal correlation coefficients for hourly data over the whole year vary between 0.5 and 0.6, which is somewhat better than the results for Norwegian cities. However, this is not the case for the bias and the root-mean square error. The modelled results for the municipality areas underestimate the observed NO_2 values in most available stations by almost 39% while the average fractional bias for the Norwegian cities was 0.5%, a considerably better result. The large negative bias in municipality areas might be taken as an indication that the assumptions on traffic volume and traffic fleet may have been too conservative.

Table 3.1: Summary evaluation results for annual mean value of NO_2 for all municipality domains with monitoring stations in 2015. Units: [µg.m^{-3}]

Domain	**AQ Station - NO_2**	**Emission version**	**Obs mean**	**Model mean**	**Bias**	**RMSE**	**R^2**	**Frequency**
Brumunddal	No station active for the whole year 2015	NBV_V1	-	-	-	-	-	-
Gjøvik	Minnesundvegen	NBV_V1	24,49	18,06	-6,43	19,14	0,52	hourly
Halden	No station active in 2015	NBV_V1	-	-	-	-	-	-
Harstad	No station active in 2015	NBV_V1	-	-	-	-	-	-
Lillehammer	Bankplassen	NBV_V1	32,66	19,48	-13,18	21,50	0,67	hourly
Lillehammer	Lillehammer barnehage	NBV_V1	18,22	8,59	-9,63	16,67	0,61	hourly
Mo i Rana	No station active in 2015	NBV_V1	-	-	-	-	-	-
Moss	No station active in 2015	NBV_V1	-	-	-	-	-	-

The sources affecting NO_2 concentrations are primarily traffic emissions, but there can also be contributions from industrial NO_x emissions, off-road sector and/or from shipping emissions. Of these sources, traffic emissions from municipality roads are subject to the highest uncertainty because of the assumptions made on traffic volume and fleet composition to fill the gaps of official information. Otherwise, the good temporal correlation with observations indicates that the initial effort made to compile high resolution emission data has resulted in a reasonable first emission estimate for this component.

2.2 PM_{10}

Table 3.2 summarises the results from the evaluation of the modelled PM_{10} concentrations with available observations at the seven municipalities. The comparison with observations shows very low temporal correlation coefficients, much lower than in the results for the seven cities. In addition, the results show that the NBV model calculations underestimate the observed PM_{10} levels with negative bias. While in average over all stations in the seven Norwegian cities in NBV, the fractional bias for PM_{10} was of -16%, the average bias in the Norwegian municipalities is larger and reaches up to -26%. These results are consistent with the treatment of road dust and re-suspension emissions in this version of NBV, an emission source that generally contributes to increase the mass of coarse particles. This would also explain why the PM_{10} concentration levels are generally underestimated, despite the fact that $PM_{2.5}$ concentrations are more generally overestimated (see Table 3.3). As it is shown in Appendix A, PM_{10} values are generally underestimated in spring and autumn, when the contribution of road dust emissions is generally larger. The parametrisation of road dust in this NBV version is based on the system available in AirQUIS and developed by Tønnesen (2000). This parametrisation affects only yearly values, by adding a resuspension contribution to PM_{10} emissions based on information on the percentage of studded tyres, the traffic volume, the share of heavy traffic, traffic speed, and the road wetness (based on precipitation rates per year). In the current inventory, the temporal distribution of the PM_{10} emissions does not distinguish between re-suspension and other traffic sources, so that the effects of spring and autumn re-suspension are not taken into account. In city areas, we made a distinction in the temporal distribution of these two sources. This can explain why the PM_{10} temporal correlation was better in the city areas than in the municipalities. A new parametrization of road dust emissions and re-suspension is currently implemented in Bedre Byluft. This parametrization takes into account actual meteorological conditions and it is expected to reproduce better the temporal evolution of road dust emissions. It is based on the NORTRIP approach, developed at NILU (Denby et al., 2013) and only implemented in Oslo for the purposes of NVB. So, the expectation is that the PM_{10} estimates can be improved in the future following the implementation of NORTRIP for all areas in Norway.

Another reason why the temporal correlation in municipality areas is lower than in city areas is the larger contribution from off-road and agricultural sources, where no temporal profile is assumed. The negative bias can also indicate that there are missing sources in the inventory, like, for instance, emissions from the construction sector. Further attention should be given in the future to these “other” sources in order to improve the PM_{10} pollution estimates.

2.3 $PM_{2.5}$

The evaluation of the modelled $PM_{2.5}$ concentrations with available observations is summarised in Table 3.3. The results of the comparison shows temporal correlations generally around 0.5, calculated on the basis of daily values. This temporal correlation for the stations available at municipalities is similar to the average temporal correlation in Norwegian cities available at NBV. As indicated in Table 3.3, $PM_{2.5}$ concentrations were overestimated by the model, but with overestimation levels similar to those found in most city area stations, except for the Vansgveien station in Hamar where the model overestimation is considerably larger. The averaged fractional bias for $PM_{2.5}$ in Norwegian cities is very small (-1%) and although the averaged fractional bias for the municipality areas is larger (18%), this result is driven by one single station (in Hamar). For the other stations, the fractional bias is still small and comparable to the results in city areas. This good result is achieved because the NBV_V1 emission estimates include a factor correction of the residential wood burning emissions.

Air concentrations of $PM_{2.5}$ are determined to a significant extent by residential heating emissions although background concentrations and traffic and industrial emission play also a significant role. In order to explain the current observations of $PM_{2.5}$, residential emissions from wood burning derived from national statistics data and certified Norwegian emission factors need to be adjusted. Interestingly, new insights on wood burning emissions from the MetVed project have shown that the adjustment of emissions proposed by NBV can be justified by a more accurate spatial distribution of the emissions (López-Aparicio et al., in prep.). The use of the MetVed emission estimates for the whole of Norway is expected to result in an improvement of the $PM_{2.5}$ modelled concentration values.

Results from this validation chapter need to be considered when evaluating the products available at the NBV portal and presented in detail in the next chapter.

The observed air pollution annual mean levels for NO_2, PM_{10} and $PM_{2.5}$ at the seven municipalities are generally lower that for the seven city areas, although there are individual differences depending on the positioning of the stations. However, the averaged observed values for the seven municipalities are considerably less representative of the air pollution situation in these areas than for the seven Norwegian cities in NBV. This is because we had at least one or two stations operating in each city, while monitoring network for the seven municipalities is considerably more sparse. The monitoring network in the seven municipalities has improved in coverage since 2015. This is a positive and welcomed development because an accurate representation of the status of air quality levels in Norway relies on the improvement of the spatial and temporal coverage of its air pollution monitoring network.

Table 3.2: Summary evaluation results for annual values PM_{10} for all municipality domains with monitoring stations in 2015. Units: [µg.m^{-3}]

Domain	AQ Station – PM_{10}	Emission version	Obs mean	Model mean	Bias	RMSE	R^2	Frequency
Brumunddal	Vangsveien in Hamar	NBV_V1	20,38	18,39	-1,99	25,27	0,19	daily
Gjøvik	Minnesundvegen	NBV_V1	18,74	16,70	-2,04	21,43	0,20	daily
Halden	No station active in 2015	NBV_V1	-	-	-	-	-	-
Harstad	No station active in 2015	NBV_V1	-	-	-	-	-	-
Lillehammer	Bankplassen	NBV_V1	21,10	15,10	-6,00	29,72	0,15	daily
Lillehammer	Lillehammer barnehage	NBV_V1	15,30	10,36	-4,94	20,40	0,21	
Mo i Rana	Moheia	NBV_V1	19,43	13,24	-6,19	16,90	0,24	daily
Moss	No station active in 2015	NBV_V1	-	-	-	-	-	-

Table 3.3: Summary evaluation results for annual values of $PM_{2.5}$ for all municipality domains with monitoring stations in 2015. Units: [µg.m^{-3}]

Domain	AQ Station - $PM_{2.5}$	Emission version	Obs mean	Model mean	Bias	RMSE	R^2	Frequency
Brumunddal	Vangsveien in Hamar	NBV_V1	7,48	12,08	4,6	8,66	0,51	daily
Gjøvik	Minnesundvegen	NBV_V1	7,07	8,74	1,67	5,42	0,52	daily
Halden	No station active in 2015	NBV_V1	-	-	-	-	-	-
Harstad	No station active in 2015	NBV_V1	-	-	-	-	-	-
Lillehammer	Bankplassen	NBV_V1	7,52	9,77	2,25	7,09	0,55	daily
Lillehammer	Lillehammer barnehage	NBV_V1	6,68	7,94	1,26	6,55	0,52	daily
Mo i Rana	No station active in 2015	NBV_V1	-	-	-	-	-	-
Moss	No station active in 2015	NBV_V1	-	-	-	-	-	-

3 NBV air quality products in Norwegian municipalities

The air quality products developed in the Norwegian planning tool are the same for the seven municipalities as for the seven cities, namely:

1) Air pollution indicator maps
2) Air quality zones
3) Exposure calculations
4) Emission data
5) Main contributors to pollution
6) Data downloads

All products are available at the NBV portal at http://www.luftkvalitet-nbv.no. They are based on calculations carried out with the EPISODE air pollution model. As explained in chapter 2, the air quality calculations use background data from the Copernicus Atmosphere Monitoring Service at https://atmosphere.copernicus.eu/ documented in Marecal et al., (2015). They rely on meteorological data for the year 2015 operationally calculated by the AROME-MetCoOp system with a spatial resolution of 2.5x2.5km and downscaled to 1x1km and on emission input data, NBV_V1, developed as part of NBV with a common methodology for all municipalities. The spatial resolution of the mapping results is 100x100m.

Results are provided for nitrogen dioxide (NO_2) and particulate matter (both $PM_{2.5}$ and PM_{10}). These pollutants have been selected as they are priority components of air pollution in cities and are regulated under the European Air Quality Directive 2008/50/EC and Norwegian law (Forurensningsforskriften, chapter 7). All indicators chosen in NBV and further explained in the next subsections follow the Norwegian air pollution regulations for the protection of human health. Table 4.1. shows the limit value established by the current regulation, while Table 4.2 shows the current upper threshold values. While exceedance of the limit values over permitted values implies non-compliance with air pollution regulations, exceedance of the upper threshold values triggers the need for the elaboration of air quality plans and evaluation of possible control actions.

Table 4.1. Limit values according to current Norwegian legislation.

Pollutant	Averaging time	Limit value	Allowed number of exceedances per calendar year
Nitrogen dioxide (NO_2) - Yearly mean limit value	1 year	40 $\mu g.m^{-3}$ NO_2	0
Nitrogen dioxide (NO_2) – Hourly mean value	1 hour	200 $\mu g.m^{-3}$ NO_2	18
Particulate matter (PM_{10}) – Yearly mean value	1 year	25 $\mu g.m^{-3}$ PM_{10}	0
Particulate matter (PM_{10}) – Daily mean value	1 day	50 $\mu g.m^{-3}$ PM_{10}	30
Particulate matter ($PM_{2.5}$) – Yearly mean value	1 year	15 $\mu g.m^{-3}$ $PM_{2.5}$	0

Table 4.2 Upper threshold values according to current Norwegian legislation that trigger need for plans and programs

Pollutant	Averaging	Upper threshold	Allowed number

	time	value	of exceedances per calendar year
Nitrogen dioxide (NO_2) - Yearly mean value	1 year	32 µg.m^{-3} NO_2	0
Nitrogen dioxide (NO_2) – Hourly mean value	1 hour	140 µg.m^{-3} NO_2	18
Particulate matter (PM_{10}) – Yearly mean value	1 year	22 µg.m^{-3} PM_{10}	0
Particulate matter (PM_{10}) – Daily mean value	1 day	35 µg.m^{-3} PM_{10}	30
Particulate matter ($PM_{2.5}$) – Yearly mean value	1 year	12 µg.m^{-3} $PM_{2.5}$	0

3.1 Air pollution indicator maps

The air quality indicator maps in the Norwegian planning tool are provided both as yearly mean values and as short term values. For the short term indicator maps, the values presented are those of the 19th highest hourly mean values over the calendar year for NO_2 and for PM_{10}, are those of the 31st highest daily mean values. With this choice of indicators, the maps provide a good way to quickly evaluate the status of air quality in an area. All maps show calculated concentrations for 2015 in µg .m^{-3}.

The color scale in the air pollution indicator maps reflects the current limit values and upper threshold limits. In all maps, red zones indicate areas above allowed limit values, while the orange zones indicate areas with values above the upper threshold values but below limit values. The persistent existence of orange areas in an area will trigger the need for elaboration of plans and programs to control air quality.

When used for planning purposes, it is important to consider that the current indicator maps are valid for the year 2015 and are not representative for other years. For long-term planning purposes, indicator maps for additional years need to be compiled. It is generally recommended to use averages of at least 3 to 5 meteorological years for planning applications.

The maps are valid down to a resolution of 100x100m and for surface level and do not resolve details beyond that horizontal scale because the model set-up does not allow for further detail.

As documented in chapter 2, these maps are based on modelled values and are subject to both systematic and random errors in comparison with observations. These errors are known through regular validation and can be accounted for. Ideally a combination of measured and modelled values, preferably through the use of data fusion or data assimilation techniques could be used for compliance applications.

The data from the indicator maps should always be complemented with information on the model performance against observations, as we have done here. The comparison with available observations carried out in chapter 3 indicate that the current maps constitute a reliable first estimate of the air pollution levels at the seven municipalities. We can however expect higher NO_2 and PM_{10} levels than those provided in the 2015 maps, because the model results tend to underestimate the available observations for these two components. For $PM_{2.5}$, the NBV estimates for the municipalities areas were generally higher than the available observations, meaning that the identified areas with no exceedances of limit values are probably correct.

3.2 Air quality zone maps

Air quality zones are calculated according to the national regulations provided in the T-1520 Guidelines for air quality treatment in area planning. The T-1520 guidelines provide advice on how air quality should be handled in area planning. They are part of the national "Planning and Building Regulations" and help ensure that the use of land and building areas is as beneficial as possible for the individual and for society, facilitating good living environments and promoting the health of the population.

The T-1520 guidelines specify how air quality zones are to be determined. The air quality zones provided by the Norwegian Air Quality Planning Tool are based on model calculations alone. They identify and define red and yellow zones based on the modelled concentrations of NO_2 and PM_{10}. In areas defined as Yellow Zones, the municipality should exercise caution in allowing the construction of buildings for use with a purpose that can be sensitive to air pollution, such as hospitals or kindergartens. The municipality should exercise caution in allowing the establishment of new activities and substantial expansion of existing activities if it causes a significant increase in air pollution. Areas defined as Red Zones, are not suitable for residential use that is sensitive to air pollution due to the high air pollution levels expected in that areas. Red zones are also not suitable for the establishment of new business or substantial expansion of existing activities if it causes a significant increase in air pollution.

The concentration indicators chosen for the elaboration of the air quality zones are provided in Table 4.3. As it can be seen from direct comparison of the values in Table 4.3 with the values in Tables 4.1. and 4.2., the red zone delimitation for long-term planning is more restrictive than the compliance with daily limit values with respect to PM_{10} concentrations in terms of the number of exceedances allowed. The delimitation of the yellow zones is more stringent than the upper threshold value (the value that triggers the need for elaboration of plans and programs) with respect to PM_{10} concentrations, in term of the number of exceedances allowed. However, for NO_2 concentrations, it is not obvious which of the two indicators is more restrictive, in some cases it is the winter mean value of 40 $\mu g.m^{-3}$ NO_2 as requested in the air quality zone determination in other places it can be the yearly mean upper threshold value of 32 $\mu g.m^{-3}$ NO_2.

It is the responsibility of the municipality to produce their own air quality zone maps or to declare which map that is valid.The air quality zone maps developed under NBV are meant only as reference to allow an expert comparison of the air quality zones in different municipalities and cities across Norway.

Table 4.3. Criteria for the determination of air quality zones in Norwegian legislation

Component	Yellow Zone	Red Zone
PM_{10} concentrations	Daily mean values above 35 µg.m^{-3} PM_{10} allowed a maximum of 7 days per calendar year	Daily mean values above 50 µg.m^{-3} PM_{10} allowed a maximum of 7 days per calendar year
NO_2 concentrations	Winter mean values above 40 µg.m^{-3} NO_2 not allowed Winter mean values defined for the period from 1st November to 30rd April	Yearly mean values above 40 µg.m^{-3} NO_2 not allowed

The information in the air quality zone maps can be used down to a resolution of 100x100m and for surface level. However, the air quality zone maps do not resolve details beyond that horizontal scale. Caution is advised when interpreting the limit between red, yellow and open zones beyond the model spatial resolution as this has important consequences for planning applications.

Given the existing year-to-year meteorological variability and the fact that emissions also vary from place to place in the different years, high variability is expected in air quality zones calculated from one year to another. It is recommended that local environmental authorities elaborate their air quality zone maps based on a combination of modelled results (for example from NBV) and observations, and that they take into account the meteorological variability by combining results of 3-5 different years. Further guidance on how to deal with meteorological variability on the elaboration of air quality zones is necessary in Norway under the T-1520 Guidelines (see also recommendations from Tarrasón et al., 2018)

In Figure 4.1., the 2015 NBV air quality zone maps calculated with a common methodology for all seven municipalities are provided. Because the air quality zones are calculated with modelled data that underestimates the observed NO_2 and PM_{10} levels, we can expect that the current 2015 air quality zones are a conservative estimate of the extent of red and yellow zones. Note especially that the lack of red air quality zones in Halden and Harstad may be a spurious effect due to the uncertainties in the input emission data. Unfortunately, there were no observations in 2015 to evaluate the validity of the results.

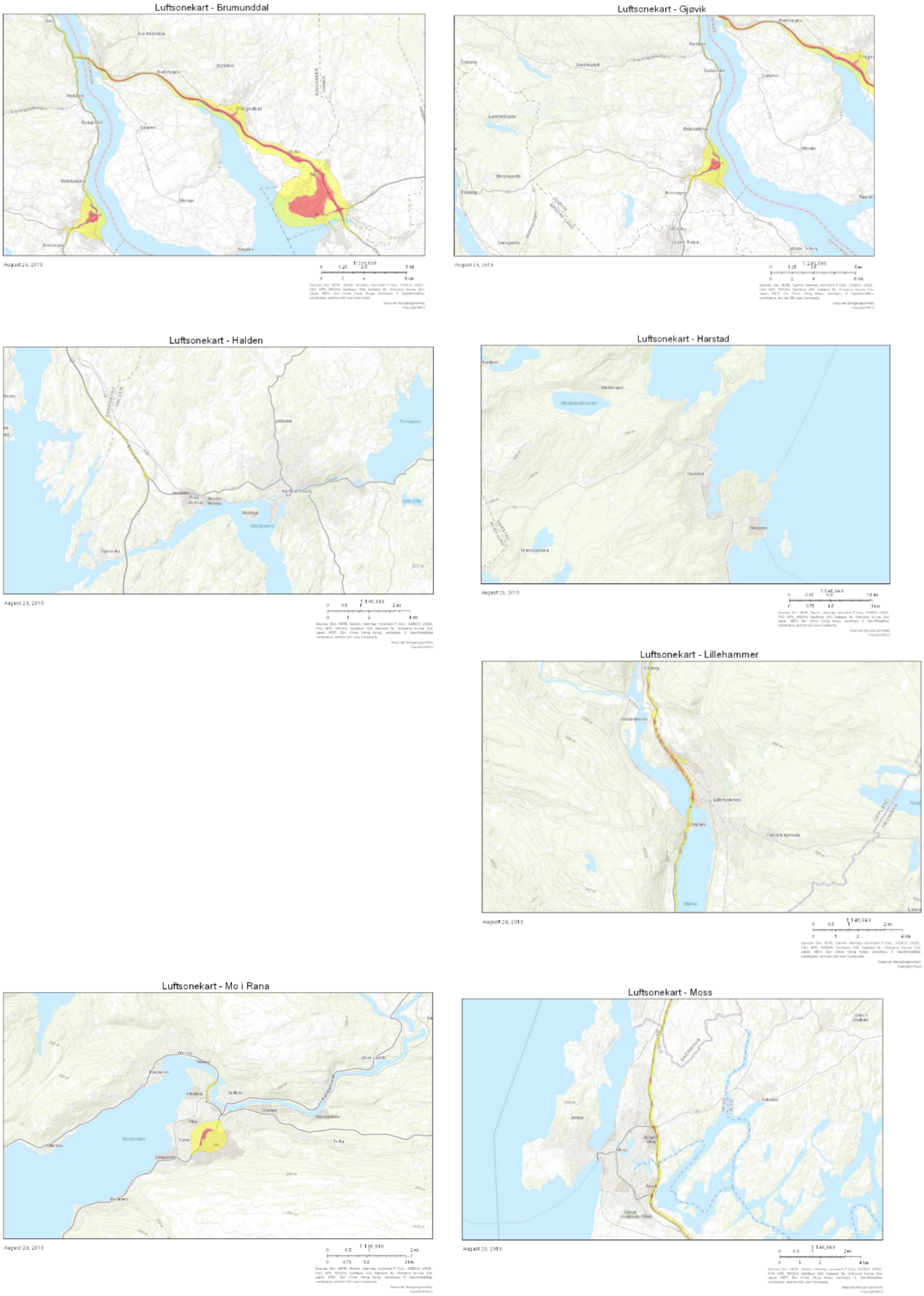


Figure 4.1. Air quality zones as derived by NBV system in 2015 for the seven municipalities.

3.3 Exposure calculations

The effect of air pollution on people's health is generally provided on the basis of population exposure indicators. In the Norwegian Air Quality Planning Tool, the health exposure indicator is defined as the number of people living inside an area where air quality levels exceed the regulatory short and long-term limit values established under Norwegian legislation and listed in Table 4.1.

Exposure numbers have been calculated on the basis of where people live, using the high-resolution NO_2, PM_{10} and $PM_{2.5}$ concentration maps in 100x100m grids. Population data was obtained from Statistics Norway and provides the number of people living in each building in the different domain areas by 1st January 2016. The population data was aggregated to the same 100x100m resolution as the concentration maps. The health exposure numbers for each domain were calculated by identifying the number of people living in an area where modelled air concentration were above the regulatory short and long-term limit.

The exposure numbers in NBV are indicators for how many people within a municipality or region live in areas where air pollution reaches levels that may affect their health. But they are not an estimation of individual exposure. How much pollution an individual is exposed to will depend on where people are staying at any time and can vary widely from individual to individual. This type of individual exposure is not currently provided by NBV.

For planning purposes, the numbers can be used to identify and prioritize measures that aim at reducing the levels of pollution in areas where people are likely to be exposed to high pollution levels. The exposure numbers may also be used to rank and evaluate the effect of different measures against each other.

It is important to note that year-to-year meteorological variability causes large differences in the air pollution levels and that population exposure is a very sensitive indicator. Large differences in population exposure can be expected from just small air quality concentration changes so that year-to-year variability will affect significantly the population exposure estimates. Therefore, it is recommended to take into account this meteorological variability by combining results of 3-5 different years.

For the meteorological conditions of 2015 and with the current NBV-V1 emission estimates, there are no significant levels of population exposure in any of the seven municipalities. Still, one should keep in mind that NBV modelled estimates underestimate the pollution levels of NO_2 and PM_{10}, so that the actual exposure may be higher than calculated. It is important to gather further information on monitoring and emission data at municipality level to determine the levels of exposure with higher accuracy.

3.4 Emission data

Information on emissions for each municipality is provided in the NBV website in three different ways as emission maps, pies and tables.

- The emission data maps show the spatial distribution of annual emissions of the various components (NOx, PM_{10} and $PM_{2.5}$) in tons per year. Total emissions are displayed as grid values with a horizontal resolution of 1 x 1km. In addition, the spatial distribution of emissions from traffic are displayed in separate maps as lines sources. Emissions from other sources than traffic are all displayed in a common map, named under the common name 'Other'. These emissions are shown as grid emissions with 1x1 km resolution and include residential heating, shipping, industrial, agriculture and off-road emissions, where applicable.

- The emission tables show the annual emission per sector and component in tons per year, where emissions from the different activity sectors are specified in the relevant categories and the term "other sources" in these tables should not be confused with the aggregated information denominated as "Other" in the emission maps. "Other sources" refer to off-road and agriculture emission for the seven municipalities.
- The emission pies show the percentage contribution of each emission sector to the total annual emissions. The information provided in the pies is consistent with the information provided in the tables and the term "other sources" correspond to those identified in the tables for emissions.

The information on the horizontal spatial distribution of the emissions provided in the NBV emission maps allows direct validation of the data by local experts. It is also useful information for local scale planning applications (such as under T-1520) as it allows to identify the main sources in the neighborhood of a specific planning area. Used in combination with the information on air concentration dispersion patterns from the air pollution indicator maps, these data can help determining how different emissions will affect air quality in the planning area. They are also the basis for the evaluation of main contributors to pollution as presented in section 4.5. In the download section, gridded emission data can be retrieved.

The NBV_V1 emission data set is a first valuable estimate for the emission data in the seven municipalities. However, there is room for improvement. Emissions vary significantly from place to place and local understanding of the emission is required to secure reliable air quality assessments and to facilitate the implementation of efficient control strategies. The data is valid for 2015 and it is recommended to update these emission estimates at least evry second year.

The validation work of the emission data carried out through comparison of derived air concentrations with observations shows that there are limitations in certain activity sectors. In particular, NOx emissions from traffic are probably underestimated in the current NBV_V1 estimates. This is related to the lack of information on traffic volume and vehicle fleet composition in municipal roads that are currently not included in the National Roads Database (NVDB). The traffic emission estimates can be improved in cooperation with local authorities by gathering local information and carrying out traffic activity counting campaigns. The traffic sector emissions for PM_{10} are also shown to be underestimated in the validation with observations, in particular in relation with road dust non-exhaust emissions. The on-going implementation of the NORTRIP approach to calculate road dust emissions is expected to contribute to improve these estimates. For $PM_{2.5}$ emissions, the comparison with observations shows that the NBV_V1 estimates are probably overestimated. Improvements are also underway with the on-going calculation of residential heating emissions with the MetVed methodology (López-Aparicio et al., in prep.). All these initiatives are relevant ways to improve the current NBV_V1 emission estimates.

3.5 Main contributors to pollution

The contribution of different emission sources to air pollution concentrations of NO_2, PM_{10} and $PM_{2.5}$ is presented in percentage maps at the NBV website. The maps provide information about how much the different emission sectors contribute in percentage to the total air concentrations. The percentage calculations are presented for annual mean concentrations. The emission sectors considered are traffic, shipping, residential heating, industry and "other", which includes off-road and agricultural emissions. In addition to the contribution from specific emission sectors, information is also provided as to how important is the contribution of background concentrations to the air pollution levels in the modelled domain. Background concentrations are introduced as boundary conditions in the calculations and can be interpreted as the concentrations in air originating from outside the city or the municipality domain.

The contribution of different sources vary considerable from municipality to municipality, for the different components. The background air contribution to pollution levels is significant for all components and is generally larger for $PM_{2.5}$ than for PM_{10} and, while it is generally smaller for NO_2, it is still significant also for this component. Otherwise, NO_2 concentrations are dominated by traffic, off-road and shipping emissions where applicable, except in Mo i Rana, where the influence of industrial emissions is dominating. For PM_{10}, the background contribution dominates in municipality areas, followed by traffic, shipping and residential heating sources. However, this dominance of the background contribution may be related to the recognized underestimation of road dust emissions in the current estimates. The $PM_{2.5}$ concentrations in municipality areas are dominated also by the background component, followed by residential heating and to lesser degree by traffic and shipping sources.

The contributions of different sources in municipality areas apply to the year (2015) and for the emissions in NBV-V1 for which they are calculated. These contributions will change somewhat under different meteorological conditions and more significantly if the emissions from one or more sector change. The relative contributions apply also only for annual air pollution values. For other indicators, such as highest values over threshold limits, the contributions of different sources may differ. For planning applications, in order to make these contribution calculations more robust, it is recommended to use an average of the source contributions for at least 3 to 5 years.

The relative contributions from the different sources to annual pollution levels in the city domains constitute important information for planning applications. Such information is politically highly relevant because it identifies which sources should be targeted in different areas when planning future control scenarios. This is a first step toward the elaboration of future scenarios and it can be used in combination with the emission maps in NBV to support emission planning.

3.6 Data downloads

Three types of data are available for download at the NBV website: a) meteorological data, b) emission data and c) air concentration data. These data are mainly intended for air pollution dispersion applications for assessment, forecasting and planning purposes. The data can be used as input or boundary conditions and the different versions and years available provide a good basis for sensitivity expert analysis. All data is downloadable from the NBV website, either in the form of graphs and shapefiles or directly as data files. The data files are available in a set of standard formats. These involve NETCDF format for meteorological and air concentration data, CSV for meteorological coordinate data and ASCII files for emission gridded data. In addition, mapping information is available as PDF or as SHAPE files. These standard formats were identified as the most relevant ones by different users.

4 Conclusions

Results from the air pollution status in 2015 in seven municipality areas in Norway (Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana and Moss) have been compiled here and are openly available via the NBV web-portal at http://www.luftkvalitet-nbv.no.

The air quality products for Norwegian municipalities are the same that were developed for the seven city areas. As far as possible, the same methodologies have been used as those reported in Tarrasón et al. (2017). The same dispersion model has been used for the air pollution calculations. The model is the EPISODE-model, developed at NILU and widely validated during its 20 years operation under the Better City Air (Bedre Byluft) program. EPISODE has also been regularly tested for policy applications at local scale and has demonstrated ability to support the elaboration of plans and programs to reduce air pollution in Norwegian cities and municipalities. The same background concentrations were also used, namely air pollution data from the Copernicus Atmosphere Monitoring Service. However, the meteorological and emission input data currently available in municipality areas are methodologically different from the data available at main city areas.

The meteorological fields used for the main cities have originally a higher spatial resolution than the meteorological fields used for the seven municipalities. This needs to be considered when evaluating the uncertainty of the resulting air quality calculations, although initial tests carried out during the NBV project suggest that the impact of this difference may be small.

More significant are the differences between the emission calculations. While the methodologies used to calculate emissions are similar to those reported in López-Aparicio et al. (2017) for Norwegian cities, the basic input data is not always available for the seven municipalities. Differences arise mainly from the lack of detailed data necessary to calculate local emissions and the need to make assumptions instead. Such assumptions add to the uncertainty of the emission data from the seven municipalities. They involve, in particular, assumptions on traffic volume and vehicle fleet composition at municipal road level, assumptions on the extent and temporal variation of road dust emissions and assumptions on the spatial distribution of residential combustion sources. Emissions from construction sites are currently missing in the NBV_V1 estimates and such gaps contribute also to the uncertainty of the emission estimates. Other sectors, such as shipping and industry, have better data coverage and availability, so that the current NBV-approach for these sectors provides reasonable emission estimates, comparable for the whole of Norway. The comparison with available observations indicates that uncertainties in the emission data have a significant impact in the air quality calculations.

Differences in the data availability also involve observations from monitoring stations. About half of the municipalities represented lacked operating monitoring stations in 2015, while there were always at least one or two monitoring stations in each city area domain. This affects the validation of the air quality results and hampers the representativeness of the conclusions. Still, the comparison with existing observations shows reliable NBV-calculations in municipality areas. Where observations are available, the validation shows generally good temporal correlation in the municipality results, with levels comparable to the temporal correlations in city areas. This is the case for $PM_{2.5}$ and also for NO_2 (with correlations up to

0.5-0.6 average values), but not for PM_{10}. For PM_{10}, average temporal correlation levels are considerably lower in municipality areas, urging for a revision the temporal assumptions and the treatment of road dust emissions. The validation also shows generally higher bias in the NBV municipality results than those in city areas, due to higher uncertainties in the emission data used as input. Increased interaction with local authorities to improve the information on traffic volume and vehicle fleet composition in local roads, the on-going implementation of the NORTRIP approach to calculate road dust emissions and the evaluation of residential heating emissions through the MetVed methodology, are all identified as relevant ways to improve the NBV air quality calculations and are already underway. Emission data can also be improved with regular yearly updates. The emission work in NBV has pointed out the significance of year-to-year emission variability in particular for the residential heating sector, and for shipping emissions. Industrial emission can also vary significantly from one year to the other, when plants revise their activities, or either open or close. Therefore, it is recommended to continue the effort initiated under the NBV-project by updating emission data at least every two years, aiming at building a robust update system to allow for regular yearly emission estimates. Additional efforts should also be addressed to cover identified emission gaps in sectors currently poorly or not included in the inventories, such as emissions from agriculture, off-road and construction sources.

The air quality results show generally lower averaged levels in municipality areas than in city areas. As a consequence, the calculated air quality zones in the municipality areas have a reduced extension of yellow zones and significantly lower area of red zones. Because the air quality zones are calculated with modelled data that underestimates the observed NO_2 and PM_{10} levels, it is possible that the current 2015-extension of the air quality zones is somewhat optimistic. For instance, the lack of red air quality zones in Halden and Harstad may be a consequence of the inherent uncertainties in the input emission data, but unfortunately, there were no observations in 2015 to determine the validity of these results. It is recognized however, that the number of operating monitoring stations in municipality areas has increased since 2015 and that stations are now operating in both Halden and Harstad. This will facilitate a better characterisation of the air quality levels in these areas.

An interesting result in comparison with the seven cities, is that there is no population exposed to air quality over threshold values in any of these seven municipalities for 2015. Still, one should keep in mind that NBV-modelled estimates underestimate the pollution levels of NO_2 and PM_{10}, so that the actual exposure to these pollutants may be higher than calculated. It is important to keep gathering further information on monitoring and emission data at municipality level to determine the levels of exposure with higher accuracy.

The contribution of different sources vary considerable from municipality to municipality, for the different components. The background air contribution to pollution levels is significant for all components and is generally larger for $PM_{2.5}$ than for PM_{10}, and generally smaller for NO_2. Otherwise, NO_2-concentrations are dominated by traffic emissions and shipping emissions where applicable, except in Mo i Rana, where the influence of industrial emissions is dominating. For PM_{10}, the background contribution dominates in municipality areas, followed by traffic, shipping and residential heating sources. However, this dominance of the background contribution may be related to the recognized underestimation of emissions in the current estimates. The $PM_{2.5}$-concentrations in municipality areas are also dominated by the background component, followed by residential heating and to lesser degree by traffic and shipping sources.

The results presented here are valid for 2015, and extrapolations to other years are not advisable. It is generally recommended that for policy relevant analysis, 3-yearly or 5-yearly averaged data is used instead of data for only one specific meteorological year. The work carried out under NBV shows the importance of continuous dialog with local authorities to gather further information on monitoring and emission data at municipality level. This is to secure higher accuracy in the evaluation of air quality levels and associated air quality indicators.

5 References

Amodei, M., Sanchez, I., & Stein, J. (2015). Verification of the French operational high-resolution model AROME with the regional Brier probability score. *Meteorological Applications*, *22*, 731-745.

Bouttier, F. & Roulet, B. (2008). AROME, the new high resolution model of Météo-France. In The European Forecaster Newsletter, no. 13, pp. 27-30. http://www.euroforecaster.org/newsletter13/full.pdf

Denby, B. R., Sundvor, I., Johansson, C., Pirjola, L., Ketzel, M., Norman, M., Kupiainen, K., Gustafsson, M., Blomqvist, G., & G. Omstedt (2013). A coupled road dust and surface moisture model to predict non-exhaust road traffic induced particle emissions (NORTRIP). Part 1: Road dust loading and suspension modelling. *Atmospheric Environment*, *77*, 283-300. doi:10.1016/j.atmosenv.2013.04.069

Denby B.R., Sundvor, I., Schneider, P., & Vo Thanh, D. (2014) *Air quality maps of NO_2 and PM_{10} for the region including Stavanger, Sandnes, Randaberg and Sola (Nord-Jæren). Documentation of methodology* (NILU TR, 01/2014). Kjeller: NILU

Denby, B. R. & Süld, J. K. (2016). *NBV report on meteorological data for 2015. Deliverable 6, Work package 3* (Met Report, 2016). Oslo: Norwegian Meteorological Institute.http://www.luftkvalitet-nbv.no/Shared/pdf/NBV_MET_report_2016_v3.pdf

Haug, T. W., Solli, H., Høiskar, B. A. H., Sundvor, I., & Johnsrud, M. (2017). *Tiltaksutredning for lokal luftkvalitet, Drammen kommune* (UA Rapport, 90/2017). Oslo: Urbanet Analyse.

Høiskar, B.A.K., Sundvor, I., & Strand, A. (2014). *Tiltaksutredning for luftkvalitet i Oslo og Bærum 2015-2020* (NILU OR, 49/2014). Kjeller: NILU

Høiskar, B. A. K., Sundvor, I., & Vogt, M. (2016). *Effekt av lavutslippssoner på luftkvaliteten i Oslo - Utslipps- og spredningsberegninger* (NILU rapport, 22/2016). Kjeller: NILU.

Høiskar, B. A. H., Sundvor, I., Johnsrud, M., Haug, T. W., & Solli, H. (2017) *Tiltaksutredning for lokal luftkvalitet i Bergen* (NILU rapport 15/2017) Kjeller: NILU.

Janssen, S, Guerreiro, C., Viane, P., Georgieva, E., Thunis, P., Cuvelier, K., Trimpeneers, E., Wesseling, J., Montero, A., Miranda, A., Stocker, J., Rørdam Olesen, H., Sousa Santos, G., Vincent, K., Carnevale, C., Stortini, M., Bonafè, G., Minguzzi, E., Malherbe, L., Meleux, F., Stidworthy, A., Maiheu, B., & Deserti, M. (2017). *Guidance Document on Modelling Quality Objectives and Benchmarking – FAIRMODE WG1.* http://fairmode.jrc.ec.europa.eu/document/fairmode/WG1/Guidance_MQO_Bench_vs2.1.pdf

López-Aparicio, S., Guevara, M., Thunis, P., Cuvelier, K., & Tarrasón, L. (2017). Assessment of discrepancies between bottom-up and regional emission inventories in Norwegian urban areas. *Atmospheric Environment*, *154*, 285-296. doi:10.1016/j.atmosenv.2017.02.004

López-Aparicio, S. & Vo, D.T. (2015). *Emission estimates for Norwegian cities. NBV_Emission Database v.0* (NILU OR, 35/2015). Kjeller: NILU.

López-Aparicio, S., Grythe H., & Vogt, M. (2018). *Model development for high-resolution emissions from residential wood combustion.* (NILU report in preparation for the Norwegian Environment Agency).

Marécal, V., Peuch, V.-H., Andersson, C., Andersson, S., Arteta, J., Beekmann, M., Benedictow, A., Bergström, R., Bessagnet, B., Cansado, A., Chéroux, F., Colette, A., Coman, A., Curier, R. L., Denier van der Gon, H. A. C., Drouin, A., Elbern, H., Emili, E., Engelen, R. J., Eskes, H. J., Foret, G., Friese, E., Gauss, M., Giannaros, C., Guth, J., Joly, M., Jaumouillé, E., Josse, B., Kadygrov, N., Kaiser, J. W., Krajsek, K., Kuenen, J., Kumar, U., Liora, N., López, E., Malherbe, L., Martinez, I., Melas, D., Meleux, F., Menut, L., Moinat, P., Morales, T., Parmentier, J., Piacentini, A., Plu, M., Poupkou, A., Queguiner, S., Robertson, L., Rouïl, L., Schaap, M., Segers, A., Sofiev, M., Tarrasón, L., Thomas, M., Timmermans, R., Valdebenito, Á., van Velthoven, P., van Versendaal, R., Vira, J., & Ung, A. (2015). A regional air quality forecasting system over Europe: the MACC-II daily ensemble production. *Geoscientific Model Development*, *8*, 2777-2813, doi:10.5194/gmd-8-2777-2015

Seity, Y., Brousseau, P., Malardel, S., Hello, G., Bénard, P., Bouttier, F., Lac, C., & Masson, V. (2011). The AROME-France Convective-Scale Operational Model. *Monthly Weather Review*, *139,* 976-991.

Slørdal, L. H., Walker, S.-E., & Solberg, S. (2003). *The Urban Air Dispersion Model EPISODE applied in AirQUIS$_{2003}$. Technical Description* (NILU TR, 12/2003). Kjeller: NILU.

Tarrasón, L., Sousa Santos, G., Thanh, D.V., Vogt, M. López-Aparicio, S., Denby, B., Tønnesen, D., Sundvor, I., Vika Røen, H., & Høiskar, B. A. K. (2017). *Air quality in Norwegian cities in 2015 – Evaluation Report for NBV Main Results* (NILU report, 21/2017). Kjeller: NILU. http://luftkvalitet-nbv.no/Shared/pdf/NBV-Luftkvalitet_AP4_D4_Final.pdf

Tarrasón, L., Høiskar, B. A. K., Guerreiro, C., Berge, E., & Selvig, E. (2018). *Kvalitetskrav knyttet til luftkvalitetsberegninger i norsk regelverk - Status og anbefalinger til videre prosess* (NILU rapport, 7/2018). Kjeller: NILU. http://hdl.handle.net/11250/2502926

Tønnesen, D. & Slørdal, L.H. (2000). *Bakgrunnsverdier for VLUFT bestemt med AirQUIS-EPISODE* (NILU OR, 40/2000). Kjeller: NILU.

Thunis, P., Degraeuwe, B., Cuvelier, K., Guevara, M., Tarrasón, L., & Clappier, A. (2016). A novel approach to screen and compare emission inventories. *Air Quality, Atmosphere & Health*, *9,* doi:10.1007/s11869-016-0402-7

Weydahl, T., Grythe, H., Høiskar, B. A. K., Svorstøl, E. T., & Haug, T. W. (2018). *Tiltaksutredning for lokal luftkvalitet i Sarpsborg og Fredrikstad.* (NILU report in preparation).

Appendix A

Validation with observations

Brumunddal - Vangsveien station in Hamar

PM_{10}

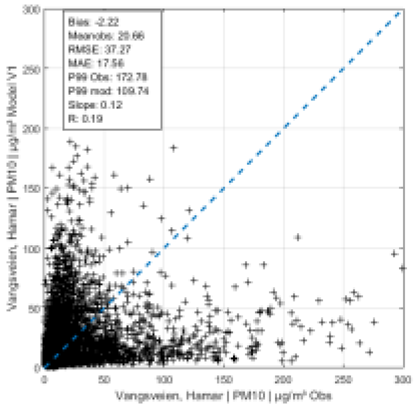


Figure A1: Scatterplot of modelled vs observed hourly values of PM_{10} in Vangsveien, Hamar. Units: [µg.m^{-3}]

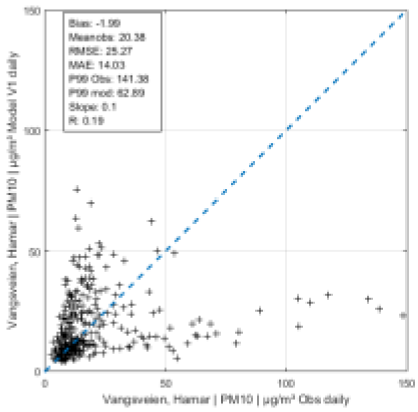


Figure A2: Scatterplot of modelled vs observed daily values of PM_{10} in Vangsveien, Hamar. Units: [µg.m^{-3}]

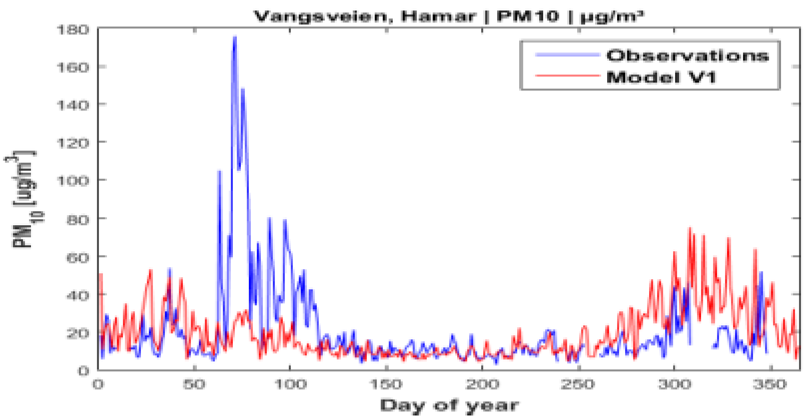


Figure A3: Timeseries with daily PM_{10} in Vangsveien, Hamar. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Brumunddal - Vangsveien station in Hamar

$PM_{2.5}$

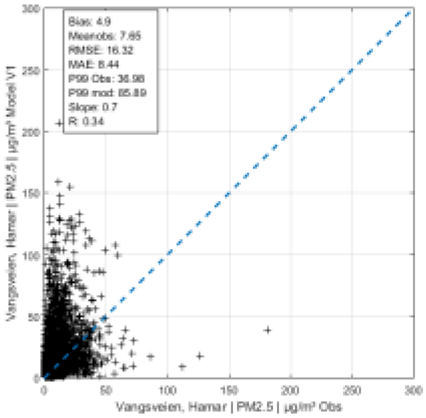


Figure A4: Scatterplot of modelled vs observed hourly values of $PM_{2.5}$ in Vangsveien, Hamar. Units: [µg.m^{-3}]

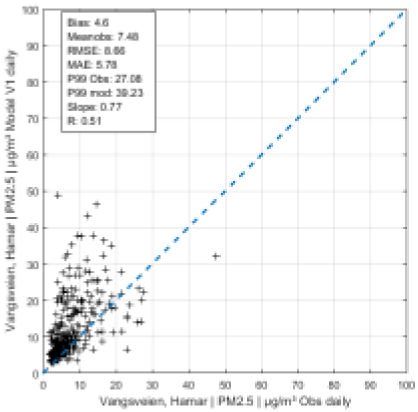


Figure A5: Scatterplot of modelled vs observed daily values of $PM_{2.5}$ in Vangsveien, Hamar. Units: [µg.m^{-3}]

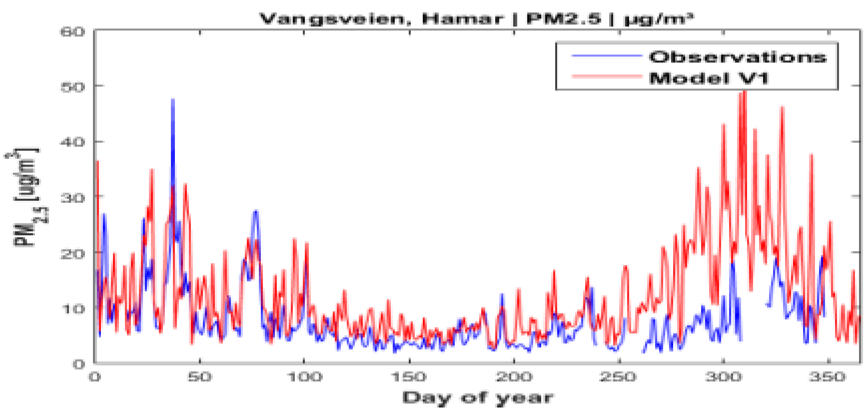


Figure A6: Timeseries with daily PM_{10} in Vangsveien, Hamar. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Gjøvik – Minnesundvegen station

NO_2

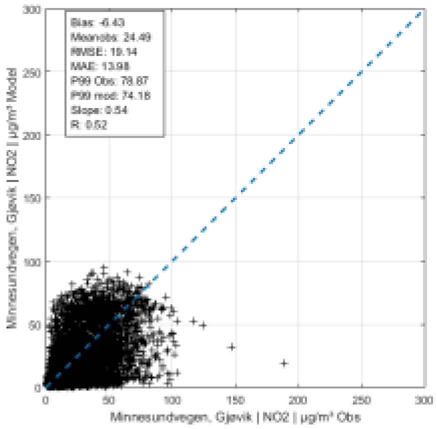


Figure A7: Scatterplot of modelled vs observed hourly values of NO_2 in Minnesundvegen, Gjøvik. Units: [µg.m^{-3}]

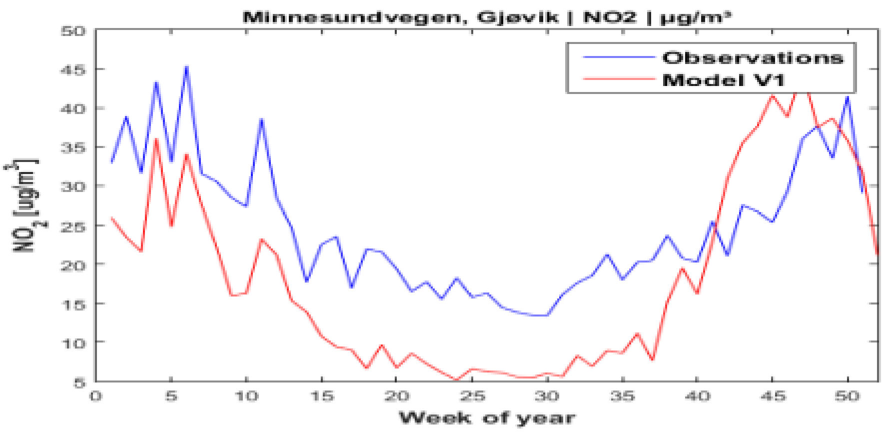


Figure A8: Timeseries with weekly NO_2 concentrations in Minnesundvegen, Gjøvik. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

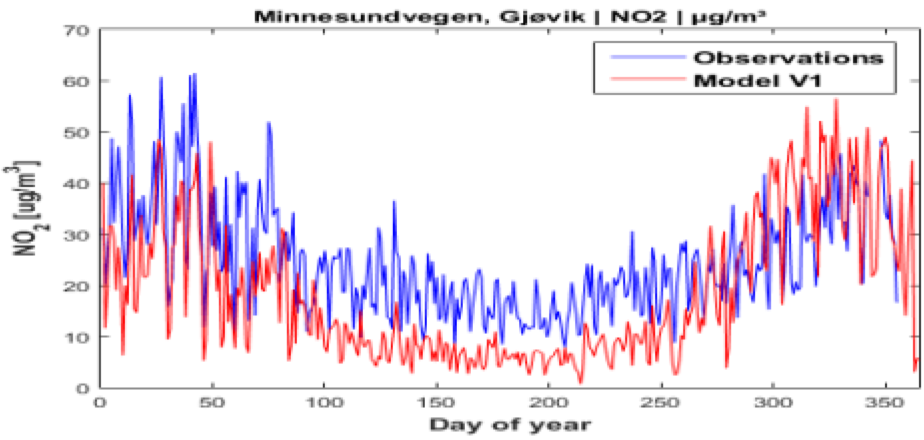


Figure A9: Timeseries with daily NO_2 concentrations in Minnesundvegen, Gjøvik. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Gjøvik – Minnesundvegen station

PM_{10}

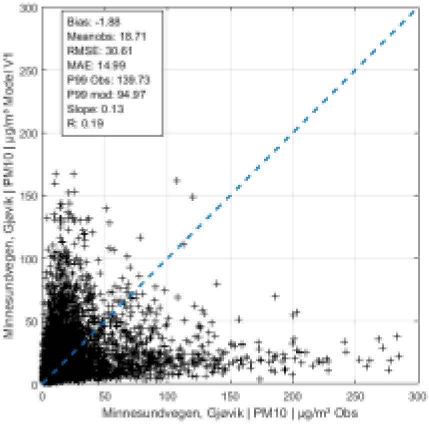


Figure A10: Scatterplot of modelled vs observed hourly values of PM_{10} in Minnesundvegen, Gjøvik. Units: [µg.m^{-3}]

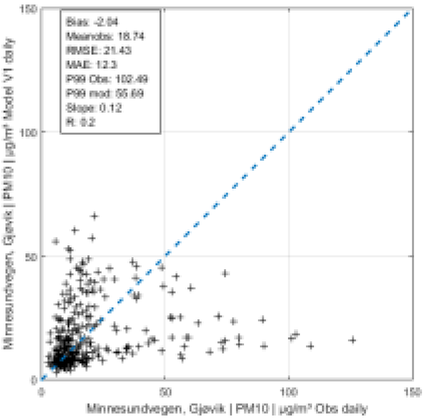


Figure A11: Scatterplot of modelled vs observed daily values of PM_{10} in Minnesundvegen, Gjøvik. Units: [µg.m^{-3}]

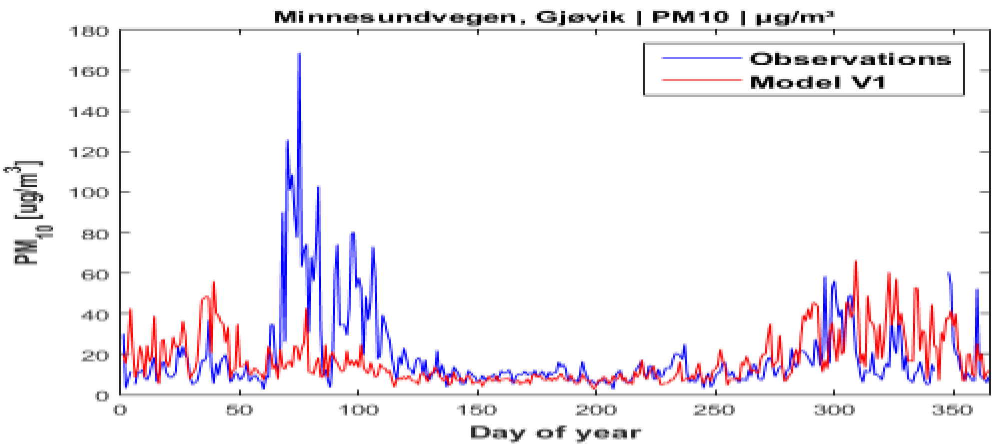


Figure A12: Timeseries with daily PM_{10} concentrations in Minnesundvegen, Gjøvik. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Gjøvik – Minnesundvegen station

$PM_{2.5}$

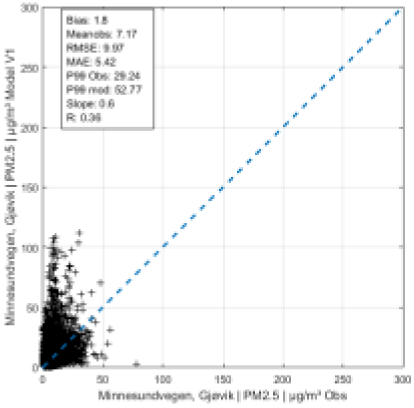


Figure A13: Scatterplot of modelled vs observed hourly values of $PM_{2.5}$ in Minnesundvegen, Gjøvik. Units: [$\mu g.m^{-3}$]

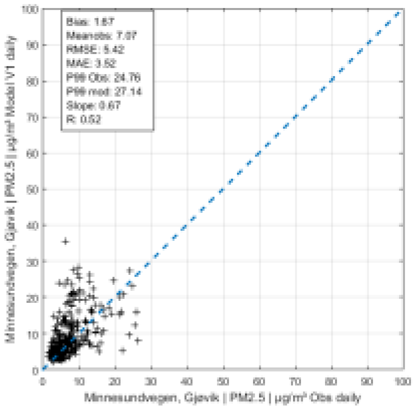


Figure A14: Scatterplot of modelled vs observed daily values of $PM_{2.5}$ in Minnesundvegen, Gjøvik. Units: [$\mu g.m^{-3}$]

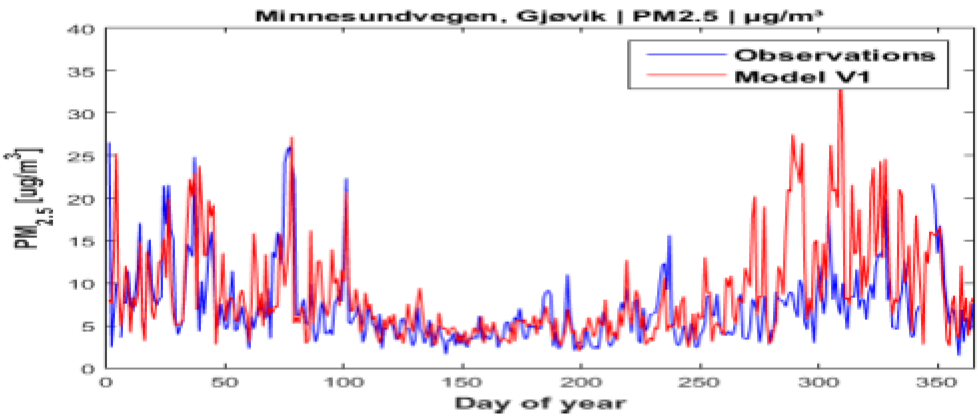


Figure A15: Timeseries with daily $PM_{2.5}$ concentrations in Minnesundvegen, Gjøvik. Modelled values for 2015 are given in red and observations in blue. Units: [$\mu g.m^{-3}$]

Lillehammer – Bankplassen and Barnehage stations

NO_2 -Bankplassen

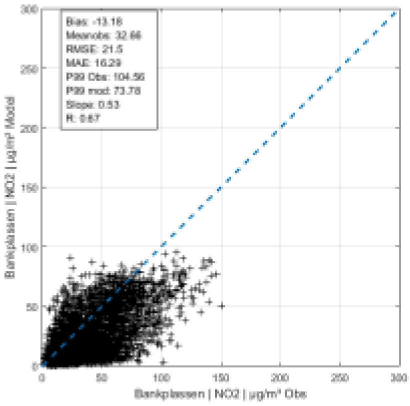


Figure A16: Scatterplot of modelled vs observed hourly values of NO_2 in Bankplassen, Lillehammer. Units: [µg.m^{-3}]

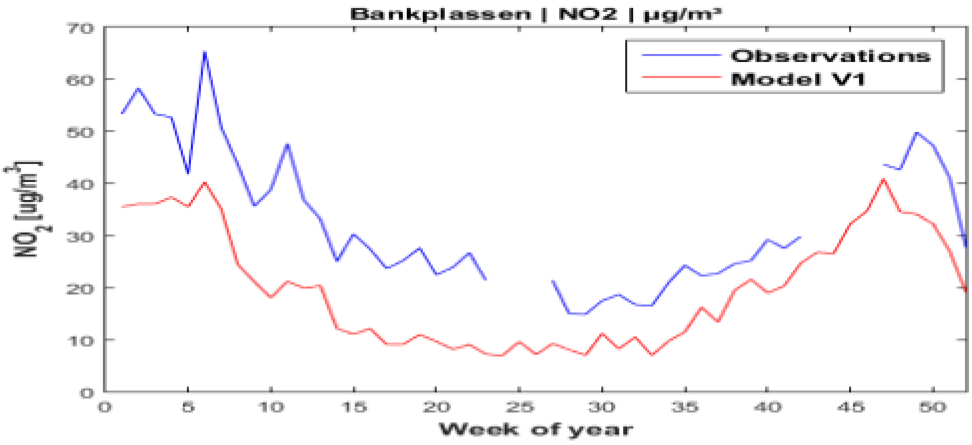


Figure A17: Timeseries with weekly NO_2 concentrations in Bankplassen, Lillehammer. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

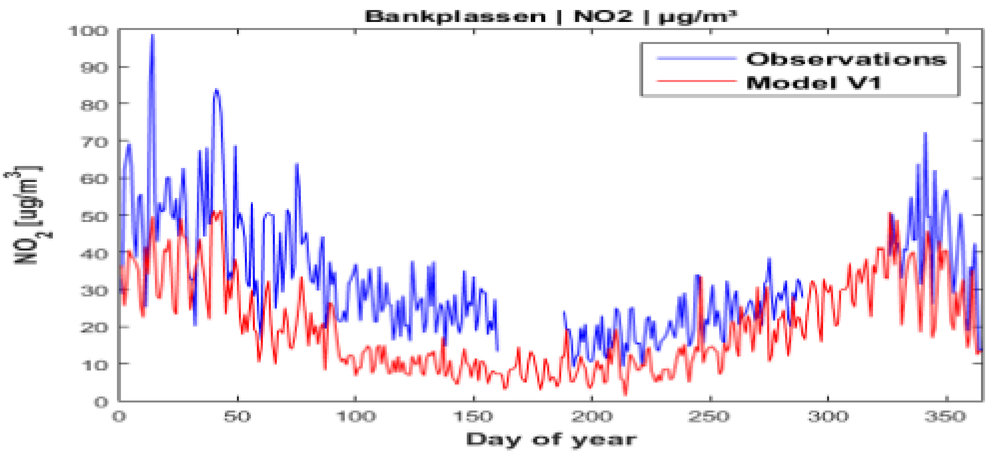


Figure A18: Timeseries with daily NO_2 concentrations in Bankplassen, Lillehammer. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Lillehammer – Bankplassen and Barnehage stations

NO_2 – Lillehammer barnehage

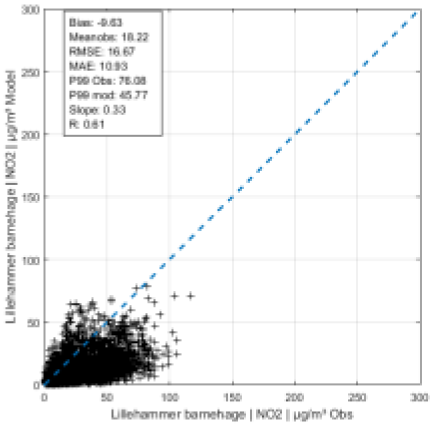


Figure A19: Scatterplot of modelled vs observed hourly values of NO_2 in Lillehammer barnehage station. Units: [µg.m^{-3}]

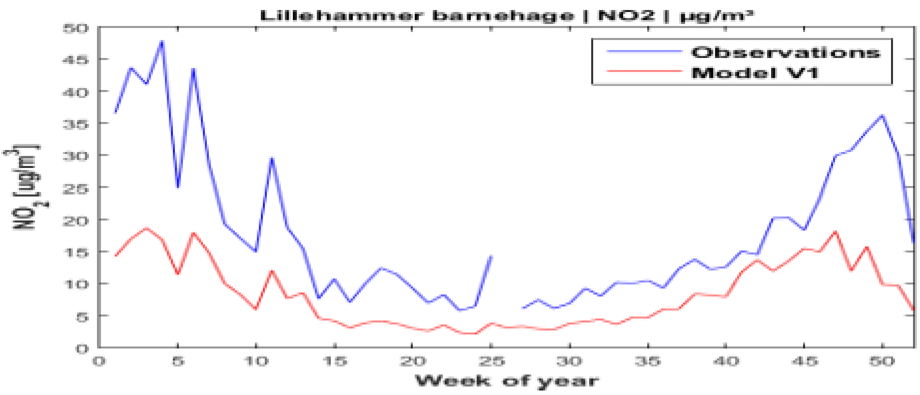


Figure A20: Timeseries with weekly NO_2 concentrations in Lillehammer barnehage station. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

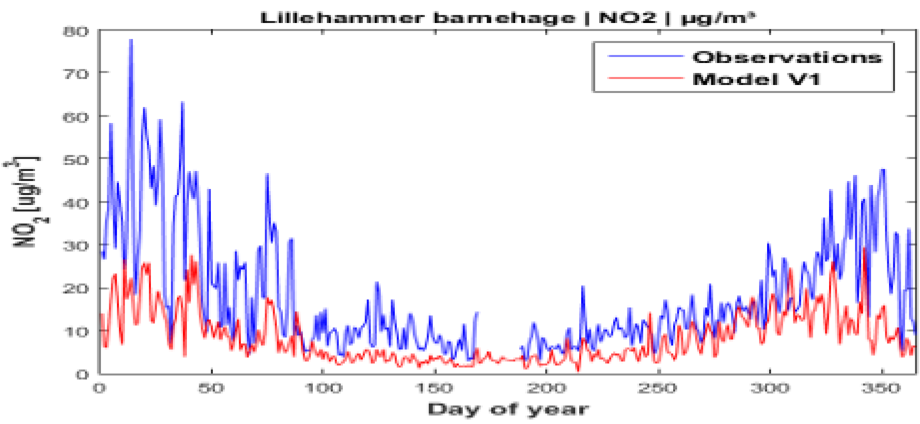


Figure A21: Timeseries with daily NO_2 concentrations in Lillehammer barnehage station. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Lillehammer – Bankplassen and Barnehage stations

PM_{10} - Bankplassen

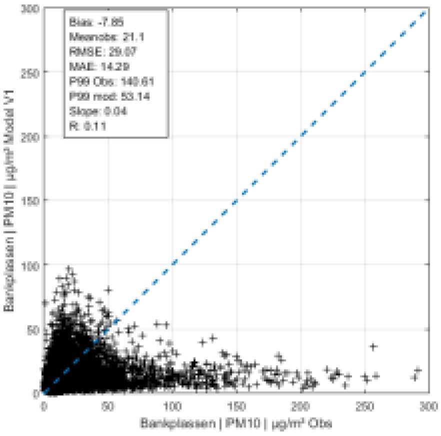


Figure A22: Scatterplot of modelled vs observed hourly values of PM_{10} in Bankplassen, Lillehammer. Units: [µg.m^{-3}]

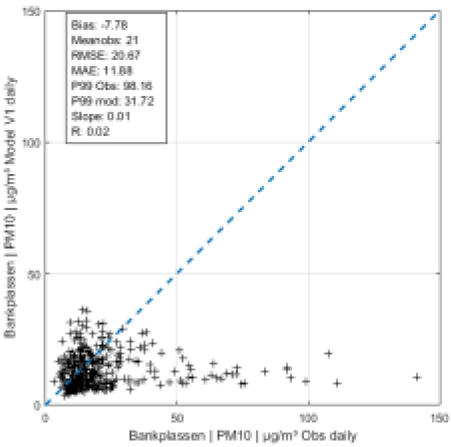


Figure A23: Scatterplot of modelled vs observed daily values of PM_{10} in Bankplassen, Lillehammer. Units: [µg.m^{-3}]

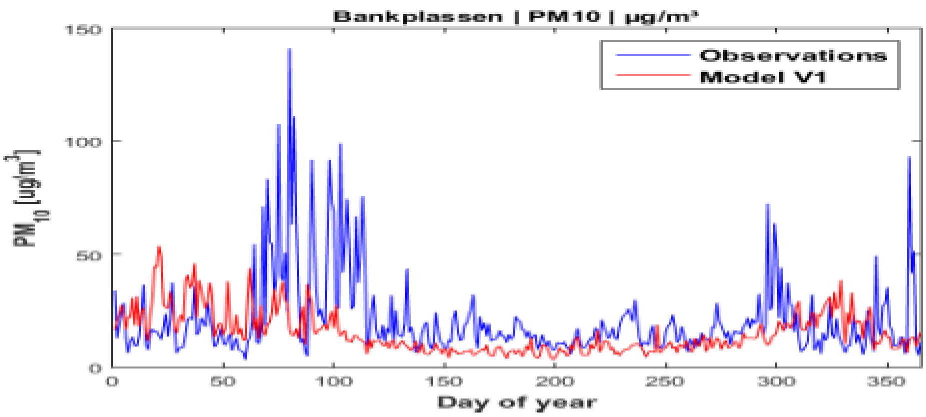


Figure A24: Timeseries with daily PM_{10} concentrations in Bankplassen, Lillehammer. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Lillehammer – Bankplassen and Barnehage stations

PM_{10} – Lillehammer barnehage

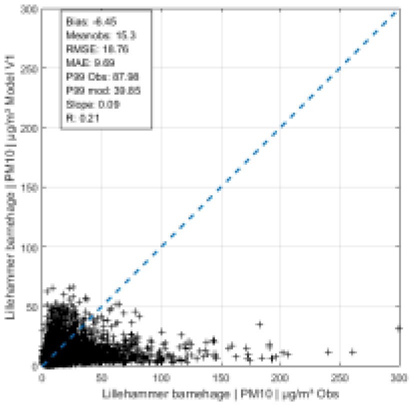


Figure A25: Scatterplot of modelled vs observed hourly values of PM_{10} in Lillehammer barnehage station. Units: [µg.m^{-3}]

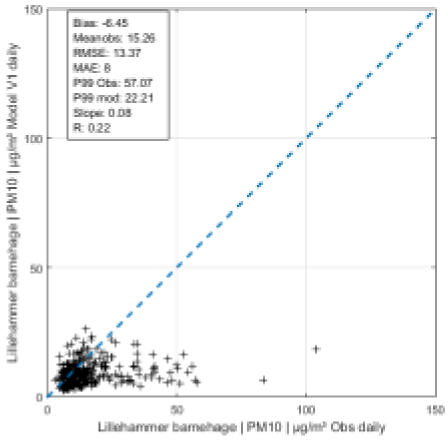


Figure A26: Scatterplot of modelled vs observed daily values of PM_{10} in Lillehammer barnehage station. Units: [µg.m^{-3}]

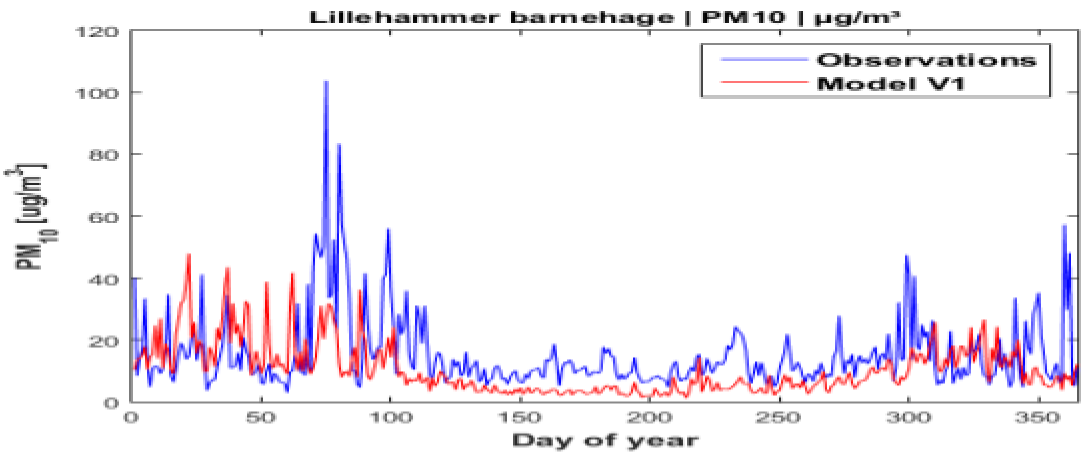


Figure A27: Timeseries with daily PM_{10} concentrations in Lillehammer barnehage station. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Lillehammer – Bankplassen and Barnehage stations

$PM_{2.5}$ - Bankplassen

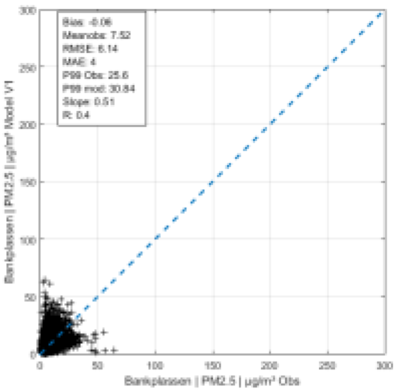


Figure A28: Scatterplot of modelled vs observed hourly values of $PM_{2.5}$ in Bankplassen, Lillehammer. Units: [µg.m^{-3}]

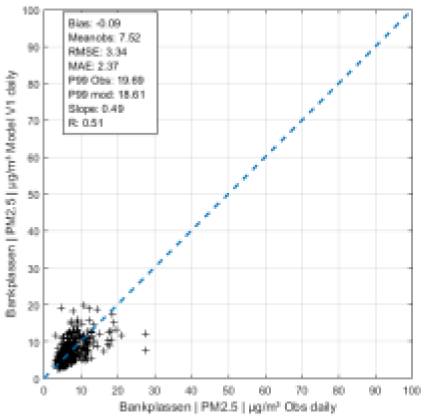


Figure A29: Scatterplot of modelled vs observed daily values of $PM_{2.5}$ in Bankplassen, Lillehammer. Units: [µg.m^{-3}]

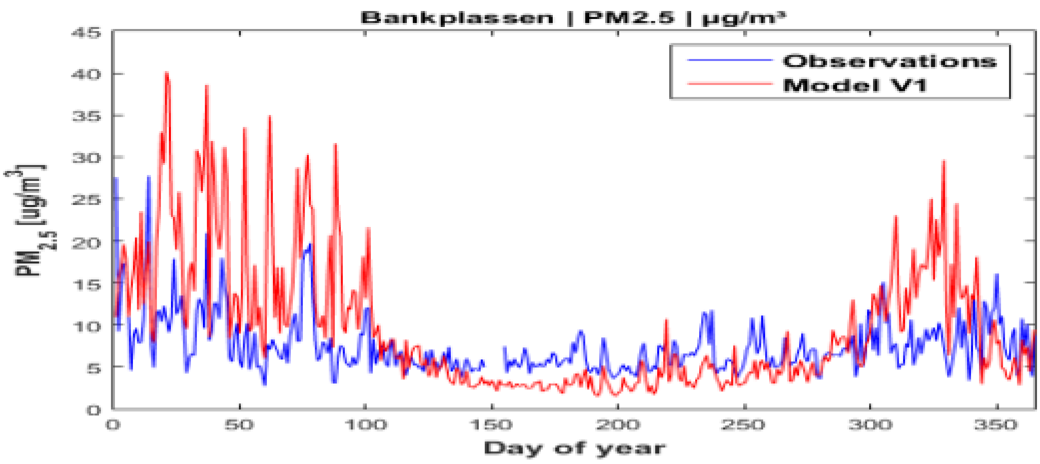


Figure A30: Timeseries with daily $PM_{2.5}$ concentrations in Bankplassen, Lillehammer. *Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]*

Lillehammer – Bankplassen and Barnehage stations

$PM_{2.5}$ – Lillehammer barnehage

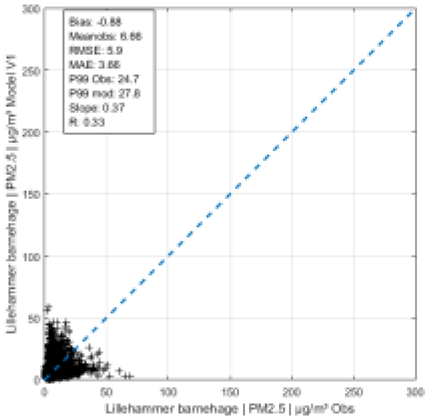


Figure A31: Scatterplot of modelled vs observed hourly values of $PM_{2.5}$ in Lillehammer barnehage station. Units: [µg.m^{-3}]

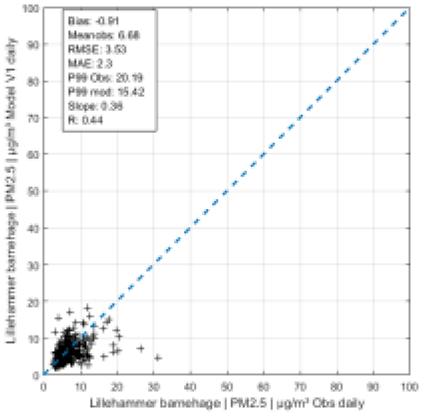


Figure A32: Scatterplot of modelled vs observed daily values of $PM_{2.5}$ in Lillehammer barnehage station. Units: [µg.m^{-3}]

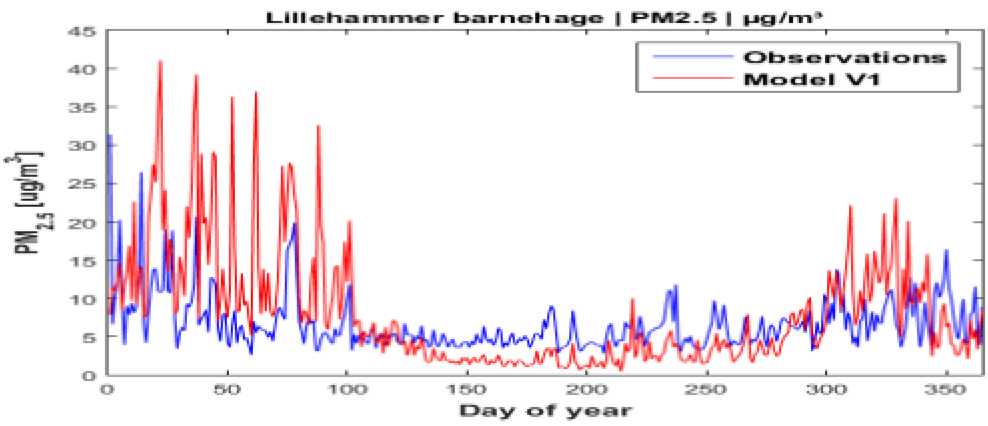


Figure A33: Timeseries with daily $PM_{2.5}$ concentrations in Lillehammer barnehage station. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Mo i Rana – Moheia station

PM_{10}

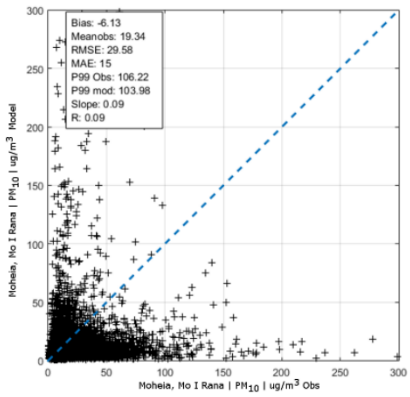


Figure A34: Scatterplot of modelled vs observed hourly values of PM_{10} in Moheia, Mo i Rana. Units: [µg.m^{-3}]

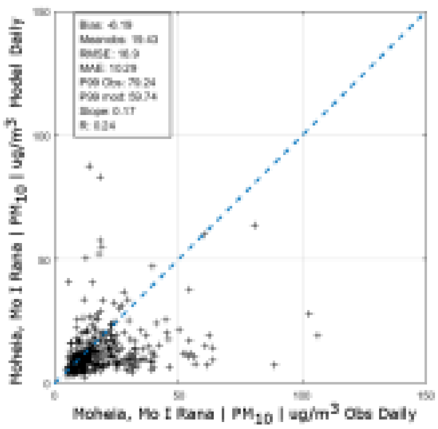


Figure A35: Scatterplot of modelled vs observed daily values of PM_{10} in Moheia, Mo i Rana. Units: [µg.m^{-3}]

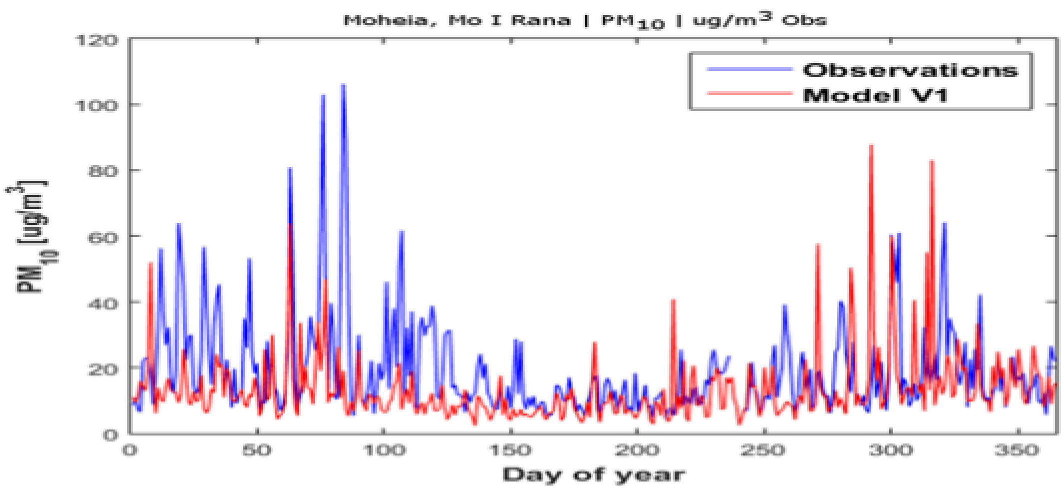


Figure A36: Timeseries with daily PM_{10} in Moheia, Mo i Rana. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

NILU – Norsk institutt for luftforskning

NILU – Norwegian Institute for Air Research is an independent, non-profit institution established in 1969. Through its research NILU increases the understanding of climate change, of the composition of the atmosphere, of air quality and of hazardous substances. Based on its research, NILU markets integrated services and products within analysing, monitoring and consulting. NILU is concerned with increasing public awareness about climate change and environmental pollution.

NILU's values: *Integrity - Competence - Benefit to society*

NILU's vision: *Research for a clean atmosphere*

NILU – Norwegian Institute for Air Research

P.O. Box 100, NO-2027 KJELLER, Norway

E-mail: nilu@nilu.no

http://www.nilu.no

ISBN: 978-82-425-2933-6
ISSN: 2464-3327

Norsk institutt for luftforskning
Norwegian Institute for Air Research

Norsk institutt for luftforskning
Norwegian Institute for Air Research

Air quality in 7 Norwegian municipalities in 2015

Summary report for NBV results

Leonor Tarrasón, Gabriela Sousa Santos, Dam Vo Thanh, Paul David Hamer, Matthias Vogt, Susana López-Aparicio, Håvard Vika Røen and Britt Ann K. Høiskar

NILU report 15/2018

NILU report 15/2018	ISBN: 978-82-425-2933-6 ISSN: 2464-3327	CLASSIFICATION: A – Unclassified (open report)
DATE 6.11.2018	SIGNATURE OF RESPONSIBLE PERSON Kari Nygaard, adm.dir. (sign)	NUMBER OF PAGES 50
TITLE Air quality in 7 Norwegian municipalities in 2015 Summary report for NBV results		PROJECT LEADER Leonor Tarrasón NILU PROJECT NO. O-114092
AUTHOR(S) Leonor Tarrasón, Gabriela Sousa Santos, Dam Vo Thanh, Paul David Hamer, Matthias Vogt, Susana López-Aparicio, Håvard Vika Røen and Britt Ann Høiskar		QUALITY CONTROLLER Britt Ann K. Høiskar
REPORT PREPARED FOR Miljødirektoratet, Grensesvingen 7, 0661 Oslo		CONTRACT REF. 840-91743 Isabella Kasin, Miljødirektoratet

ABSTRACT

This report documents the methodology used to compile air quality information for the year 2015 in seven Norwegian municipality areas under the first phase of development of the Norwegian Air Quality Planning Tool, also called "Nasjonalt Beregningsverktøy" or NBV. It follows a similar structure to and complements the final report entitled "Air quality in 7 Norwegian municipalities in 2015 – Summary report for NBV results" (NILU rapport 21/2017) where information on air quality in the seven main city areas in Norway was presented.

This report constitutes a user guide for the NBV-services, available at http://www.luftkvalitet-nbv.no, in municipal areas. It provides recommendations on how to best use each product for air quality planning purposes and explains the main strengths and limitations of the results. The NBV air quality data for municipalities is subject to larger uncertainties than the data available for the main Norwegian city areas and this has to be taken into consideration when analyzing the results.

NORWEGIAN TITLE

Luftkvalitet i syv norske tettsteder i 2015 – status rapport for Nasjonalt Beregningsverktøy (NBV)

KEYWORDS

Air quality	Local and Urban pollution	Modelling results

ABSTRACT (in Norwegian)

Denne rapporten dokumenterer metodene som ble brukt for å samle inn og utarbeide informasjon om luftkvalitet for 2015 i syv norske tettsteder under første fase av utviklingen av det norske planleggingsverktøyet for luftkvalitet, også kalt "Nasjonalt Beregningsverktøy" eller NBV. Rapporten utfyller sluttrapporten "Luftkvalitet i 7 norske byer i 2015 - Evalueringsrapport for NBV-resultater" (NILU rapport 21/2017) og følger en lignende struktur.

Rapporten gir brukerveiledning for NBV-tjenestene som er tilgjengelige for tettsteder på http://www.luftkvalitet-nbv.no. Den beskriver også kort hvordan de ulike produktene bør brukes og peker på mulige anvendelser og begrensninger. NBV-luftkvalitetsdata for kommuner og tettsteder er mer usikre enn de dataene som er tilgjengelige for de viktigste norske byområdene, og dette må tas i betraktning ved analyse av resultatene.

PUBLICATION TYPE: Digital document (pdf)	COVER PICTURE: Source: NILU

NILU's ISO Certifications: NS-EN ISO 9001 and NS-EN ISO 14001. NILU's Accreditation: NS-EN ISO/IEC 17025.

Preface

The Norwegian Air Quality Planning Tool (NBV) has been developed as a collaboration between the Norwegian Institute for Air Research (NILU) and the Norwegian Meteorological Institute (MET) under the direction of the Norwegian Environment Agency in cooperation with the Norwegian Public Roads Administration, the Norwegian Institute of Public Health and the Norwegian Directorate of Health. Work began in 2014 on behalf of the Ministry of Climate and Environment, the Ministry of Transport and Communications and the Ministry of Health and Care Services and its first phase was completed in 2017.

This report documents the methodology used to compile air quality information for the year 2015 in seven Norwegian municipality areas. It follows a similar structure to and complements the final report entitled "Air quality in 7 Norwegian municipalities in 2015 - Summary report for NBV results" (NILU rapport OR 21/2017) where information on air quality at the seven main city areas in Norway was presented. It constitutes a user guide for the NBV web-portal, available at http://www.luftkvalitet-nbv.no, with respect to the data products for the 7 municipality areas: Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana and Moss. The report explains how the available air quality data from these seven municipalities is subject to larger uncertainties than the data included in the NBV-web-portal for the 7 main city areas in Norway (Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger).

The authors are thankful to Christoffer Stoll for the development of the application to retrieve traffic data and to Morgan Kjølerbakken and Rune Åvar Ødegård for their support when defining the technical architecture of the system. We are also thankful to Randi Nordby Henriksen for her invaluable help in the elaboration of this report. Thanks are also due to the members of the Scientific Committee of the project, in particular Isabella Kasin, Pål Rosland and Sigmund Guttu for their comments, feedback and discussions and to the members of the Better City Air (Bedre Byluft) Forum for their guidance and support throughout the project.

Contents

Sammendrag

Denne rapporten presenterer beregnede luftkvalitetsdata og relevante inngangsdata for 2015 for syv (7) norske kommuner. Arbeidet er en del av utviklingen av det nasjonale beregningsverktøyet for luftkvalitet, «Nasjonalt beregningsverktøy» eller NBV. De syv kommunene det er foretatt beregninger for er Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana og Moss.

Beregningene som er omtalt her, er tilgjengelige på nettsidene til Nasjonalt beregningsverktøy på http://www.luftkvalitet-nbv.no. Nettsidene gir åpen tilgang til beregnede luftkvalitetsdata og relevante inngangsdata for nitrogendioksid (NO_2) og partikler (både PM_{10} og $PM_{2.5}$). Produktene som er tilgjengelige for de syv kommunene er de samme som tidligere ble utviklet for syv (7) norske byer, nemlig Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim og Stavanger.

I utviklingen av Nasjonalt beregningsverktøy er det lagt vekt på å benytte en felles metodikk for beregning og sammenstilling av meteorologiske data, utslippsdata og luftkvalitetsdata. Dette er for å sikre at resultater fra ulike deler av landet er sammenlignbare. Likevel finnes det noen forskjeller mellom beregningene for kommunene i forhold til de beregningene som er foretatt for de syv norske byene. I utslippsberegninger for de syv kommunene har det, på grunn av mangelfulle inngangsdata, vært nødvendig å gjøre en del antagelser som ikke ble gjort for de syv byene. I tillegg har de meteorologiske dataene som er benyttet i disse beregningene, lavere romlig oppløsning enn de som ble benyttet i beregningene for de syv byene. I motsetning til i de syv byene, har flere av kommunene ikke måledata som kan benyttes til å validere luftkvalitetsberegningene. Alle disse faktorene har påvirket kvaliteten på resultatene for de syv kommunene.

De meteorologiske feltene som brukes i beregningene for de syv byene har en høyere romlig oppløsning enn de meteorologiske feltene som brukes i beregningene for de syv kommunene. Meteorologiske data for de syv kommunene er opprinnelig tilgjengelige med en oppløsning på 2.5x2.5 km fra AROME-MetCoOp-systemet, mens de meteorologiske dataene for de syv byene var tilgjengelige med en oppløsning på 1x1km gjennom Bedre Byluft prosjektet. Likevel utføres luftkvalitetsberegningene i NBV for de syv kommunene med meteorologiske inngangsdata med samme finoppløsning på 1x1km. Dette skyldes at met.no har et system for å nedskalere de opprinnelige 2.5x2.5km-dataene til enten 1km eller til geografiske koordinater. De nedskalerte dataene er imidlertid ikke alltid av samme kvalitet som de dynamisk beregnede meteorologiske data. Dette må tas med i vurderingen av usikkerheten i de resulterende luftkvalitetsberegninger, selv om tester gjort under NBV-prosjektet viser at denne forskjellen kan være liten.

Det er også forskjeller mellom utslippsberegningene for de syv kommunene og de syv byene. Selv om metodene som brukes til å beregne utslippene stort sett er like, er ikke alle inngangsdata tilgjengelige for de syv kommunene i samme grad som for de syv byene. Dette er spesielt tilfelle for beregning av trafikkutslipp. For svært mange kommunale/lokale veier mangler det informasjon om trafikkvolum og bilparksammensetning, og det var nødvendig å gjøre antagelser om disse verdiene i utslippsberegningene. Dette bidrar til å øke usikkerheten i trafikkutslippene for de syv kommunene. Det ble også gjort antagelser om tidsvariasjonen av vegstøvutslipp og om den romlige fordelingen av vedfyringsutslipp. Sammenligning med tilgjengelige observasjoner indikerer at usikkerhetene i utslippene har en innvirkning på

luftkvalitetsberegningene, selv om det er viktig å påpeke at resultatene for 2015 i kommunene viser tilstrekkelig kvalitet. For å forbedre kvaliteten på luftkvalitetsberegningene, bør det fremover fokuseres på å få bedre estimater på utslipp fra de viktigste kildene. Økt samhandling med lokale myndigheter for å få bedre data på trafikkvolum og bilparksammensetning på lokale veier, implementering av NORTRIP-tilnærmingen for beregning av veistøvutslipp og beregning av vedfyringsutslipp ved bruk av MetVed-metoden vil gi betydelige forbedringer av utslippsestimatene. I tillegg er det viktig å få bedre informasjon om utslipp fra sektorer som vi i dag har lite kunnskap om, for eksempel utslipp fra off-road, jordbruk og bygg- og anleggsvirksomhet.

Valideringen av luftkvalitetsberegningene for 2015 som er utført her, er avhengig av tilgangen til overvåkingsdata. I 2015 var det vesentlig mer overvåkningsdata tilgjengelig i de syv norske byene enn i de syv kommunene. Flere av de syv kommunene hadde dessverre ingen målinger i 2015, mens det alltid var minst en eller to målestasjoner i hver av de syv byene. Mangelen på måledata begrenser muligheten for evaluering av beregningsresultatene. Likevel, der hvor observasjoner er tilgjengelige, viser valideringen god tidsmessig korrelasjon mellom beregninger og måledata, og resultatene er sammenlignbare med beregningene for byområdene. Valideringen viser også at det generelt er høyere systematiske forskjeller mellom beregninger og måledata for kommunene enn for byområdene. Dette skyldes større usikkerhet i de utslippsdataene som brukes som input. Til tross for disse begrensningene, viser sammenligningen med eksisterende observasjoner pålitelige beregninger i kommunenes områder. Det er kommet flere målestasjoner i disse områdene siden 2015, og dette, sammen med de initiativene som allerede er på gang for forbedring av utslippsdataene, vil kunne bidra til en enda bedre karakterisering av luftkvalitetsnivåene i disse områdene.

Executive Summary

This report presents air quality data and information for the year 2015 in seven Norwegian municipality areas as developed under the first phase of the Norwegian Air Quality Planning Tool, also called "Nasjonalt Beregningsverktøy" or NBV. The seven (7) municipalities are: Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana and Moss.

The air quality information referred to here are available on-line at the NBV-portal at http://www.luftkvalitet-nbv.no. The NBV web-portal provides open access to data and information on air quality and relevant input-data for nitrogen dioxide (NO_2) and particulate matter (both PM_{10} and $PM_{2.5}$). The available NBV-products are the same that have been developed for the seven (7) main Norwegian cities (Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger).

Despite the efforts to compile meteorological data, emission data and air quality data following a common methodological approach that guarantees the comparability of the data across Norway, there are still limitations on the data availability in cities versus in different municipalities. This affects the overall quality of the air quality results and hampers their validation. Differences in the data availability involve: meteorological input data, basic emission information and observations from monitoring stations. These differences affect the quality of the results and imposes higher uncertainty to the air quality calculations in the municipality areas.

The meteorological fields used for the main cities have originally a higher spatial resolution than the meteorological fields used for the municipalities. Meteorological data in the seven municipalities are available with a resolution of 2.5x2.5km from the AROME-MetCoOp system while meteorological data in the cities were available with a resolution of 1x1km from the Better City Air (Bedre Byluft) forecasting chain. Still, the air quality calculations in NBV are all carried out using meteorological input with the same fine resolution of 1x1km. This is because the meteorological office (MET) provides a system to downscale the original 2.5x2.5km data to either 1km or to geographical coordinates. However, downscaled data are not always of the same quality as dynamically calculated meteorological data. This needs to be considered when evaluating the uncertainty of the resulting air quality calculations, although initial tests carried out during the NBV project suggest that the impact of this difference may be small.

There are also differences between the emission calculations for the seven municipalities and for the cities. Although the methodologies used to calculate emissions are similar, the basic input data is not always available for the seven municipalities to the same extent as it was for the seven cities. This is especially the case for traffic emissions, where information on traffic volume and vehicle fleet composition is not available for all municipal roads, so that assumptions on these values were made. Such assumptions add to the uncertainty of the traffic emission data from the seven municipalities. Different assumptions were also made for the temporal variation of road dust emissions and for the spatial distribution of residential combustion sources. Initial comparison with available observations indicates that the uncertainties in the emission data have a visible impact in the air quality calculations, although the current air quality results in municipalities areas are of good quality. To improve the air quality estimates it is important to focus on the improvement of the main emission sources. Increased interaction with local authorities to improve the information on traffic volume and vehicle fleet composition on local roads, the on-going implementation of the NORTRIP

approach to calculate road dust emissions and the evaluation of residential heating emissions through the MetVed methodology, are all identified as relevant ways to improve the NBV air quality calculations. In addition, it is important to compile better information on sectors currently poorly or not included in the inventories, such as emissions from off-road, agriculture and construction and renovation activities.

The validation of the NBV air quality calculations for 2015 carried out here was limited by the access to monitoring data. In 2015, there were no operating monitoring stations at roughly half of the municipalities involved here, while there were always at least one or two monitoring stations in each city area domain. The lack of monitoring data hampers the evaluation of the results and their representativeness. Still, where observations are available, the validation shows good temporal correlation in the municipality results, comparable to the temporal correlations from the city areas. The validation also shows generally higher bias in the NBV municipality results than those in city areas, due to higher uncertainties in the emission data used as input. Despite these limitations, the comparison with existing observations shows reliable NBV-calculations in municipality areas. It is recognized that the number of operating monitoring stations in municipality areas has increased since 2015 and that this development, in addition to the on-going initiatives to improve emission data at municipality level, will contribute to an even better characterisation of the air quality levels in these areas.

Air quality in 7 Norwegian municipalities in 2015

Summary report for NBV results

1 Introduction

The Norwegian Air Quality Planning Tool (Nasjonalt beregningsverktøyet, NBV) is a web-service developed to support local air quality planning, solving tasks related to existing regulations. It provides a common methodological and information platform for local air quality modelling applications. The web-service is addressed to local and regional environmental authorities, air quality experts and consulting companies. It is intended to help them meet the requirements of current air quality legislation, to support local air quality planning and facilitate the improvement of air quality where people live.

The NBV tool and web-portal responds to the 2015 Judgement of the Court from the EFTA Surveillance Authority that pointed out to a significant drawback in Norwegian air quality management practices, namely, the lack of a systematic approach to the elaboration of plans and programs to control air pollution. Different factors contributed to the lack of a systematic approach to the elaboration of plans and programs in Norway, but one important reason had been the lack of available input air quality information. This involves in particular, input data such as emissions and meteorology, necessary to evaluate the air quality situation in Norwegian cities. These input data form the basis to calculate the effect of abatement measures. For this reason, work to support the creation of the Norwegian Air Quality Planning tool has precisely focussed on the compilation of meteorological and emission data in a consistent way throughout Norway.

The NBV web portal contains open access to data and information on air quality and relevant input data for the year 2015. Information on nitrogen dioxide (NO_2) and particulate matter (both PM_{10} and $PM_{2.5}$) is available at seven main Norwegian cities (Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger) and seven municipality areas (Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana and Moss).

This report focuses on the seven municipality areas. Despite the efforts to compile meteorological data, emission data and air quality data following a common methodological approach that guarantees the comparability of the data across Norway, there are limitations on the data availability in cities versus different municipalities. This report documents how meteorological and emission input data currently available in municipality areas are different from the data available at main city areas. It also explains how these differences affect the quality of the results and imposes higher uncertainty to the air quality calculations in municipality areas.

In chapter 2, the methodologies used to compile meteorology, emissions and air quality data in municipality areas are documented. Chapter 3 includes a first validation of the results somewhat hampered by the limited availability of air quality observations in municipality areas. Chapter 4 presents the different NBV air quality products and provides recommendations on how best to use them for assessment and planning purposes in municipality areas. Finally, in Chapter 5, conclusions and recommendations for the future are presented.

2 Methodology used in NBV for municipality areas

A short description of the methods used for calculating the input meteorological data, input emissions and air pollution dispersion results in the seven municipality areas is presented in this chapter. There is a special focus to describe how these methodologies differ from those used to compile data in the main city areas that are at the core of the Norwegian Air Quality Planning Tool (NBV) and were documented in Tarrasón et al. (2017).

2.1 Meteorological fields

As explained in Tarrasón et al. (2017), the meteorological data for the NBV system is produced by the meteorological model AROME (Application of Research to Operations at MEsoscale), coupled to the surface model SURFEX (Surface Externalisée, in French), a surface modelling platform developed by Météo-France in cooperation with the scientific community.. AROME is a high resolution model which was developed in the second half of the 2000s in Météo-France with the aim to improve local forecasts. The development was done for a chosen horizontal grid of 2.5km, which allows to explicitly resolve deep convection systems by the model dynamics (Seity et al., 2011). In this way, improvements were possible on forecasting especially dangerous convective phenomena (thunderstorms, flood risk, heavy precipitation) and low-level conditions (wind, temperature, ground state, fog, heat islands, etc.), as documented in Bouttier and Roulet (2008). The model was declared valid for operational use in December 2008. AROME forecasts showed better physical realism than the previous forecasting system. This physical realism was attributed to its mesoscale physics-dynamics and data assimilation scheme (Seity et al., 2011). The need to forecast the localization and intensity of high-impact meteorological events has pushed horizontal resolution to even finer scales of up to 1 km (Amodei et al., 2015).

The AROME-MetCoOp system is run operationally by the Norwegian Meteorological Institute (MET) and their partner meteorological institutes to produce meteorological forecasts at 2.5km resolution for all of Norway.

In addition, MET ran until 2016 the three regions that cover the largest cities, for the Better City Air (Bedre Byluft) forecasts system at 1 km resolution. The meteorological forecast data was operationally generated and regularly validated, but it was not operationally stored. When necessary, MET carried out a re-analysis of the data to store meteorological fields for a specific year. As part of the Norwegian Air Quality Planning Tool project (NBV), instead of re-analysis routines, an operational system was put in place so that the operational forecast data in 1x1km could be archived and processed by MET, securing the completeness of the data. This was necessary to allow easy access to relevant meteorological input as requested by air quality applications.

The meteorological data available for NBV covers three years: 2010, 2015 and 2016. For 2010, reanalysis of the 3D meteorological fields have been carried out and validation results are documented in Denby and Süld (2016). The meteorological data for 2015 and 2016 is no longer a re-analysis but has been directly archived from the forecast chain. This has the advantage that meteorological data is available for use very short after the actual period is completed.

The meteorological data compiled under NBV consists of 3D spatial meteorological parameter fields with 1 hour resolution covering a full year. These meteorological fields include all the parameters necessary as input for air quality dispersion model calculations, in particular those required by the EPISODE model used as basis for NBV air quality results. These meteorological data are freely available through the NBV web portal or directly through METs THREDDS data distribution server. The 3D meteorological data cover the whole of Norway. They are available as monthly files, with 1h temporal resolution and different spatial resolution, as explained below:

- **For the 7 NBV cities**: Meteorological data in the seven main cities are available with a resolution of 1x1km from the Better City Air (Bedre Byluft) forecast chain. This high resolution meteorological data is available for the years 2010, 2015 and 2016. The high resolution 1x1km meteorology data for 2015 form the basis for the main cities air quality results available for the same year at NBV. It consist of a) 3D meteorological parameters including temperature, wind, humidity, turbulent kinetic energy and pressure and b) 2D near surface parameters including, among others, precipitation, cloud cover, pressure, surface momentum fluxes, surface turbulent energy fluxes, short and long wave radiation fluxes, boundary layer height, surface temperature and surface water content.
- **For the 7 NBV municipalities**: Meteorological data in the seven municipalities are available with a resolution of 2.5x2.5km from the AROME-MetCoOp system. These meteorological data are available for the years 2010, 2015 and 2016 for the whole of Norway. The 2.5x2.5km resolution meteorology data for 2015 form the basis for the air quality results at the seven municipalities available for the same year at NBV. However, for the air quality model calculations, these meteorological data have been dynamically downscaled to 1x1km resolution using statistical methods developed by MET, so that the meteorological input data used to produce air quality results have the same 1x1km resolution as for main city areas. These downscaled meteorological data consist of the same 3D and 2D parameters as listed above for main cities. The downscaled data covers 23 different municipalities in 10 different domains and can be downloaded from the THREDDS data server at MET (http://thredds.met.no)
- **For any geographical point**: With the downscaling capability developed by MET, the operational meteorological 2.5x2.5km resolution data from the AROME-MetCoOp system is interpolated to any given geographical point over the whole of Norway. Such downscaled data is then provided through the NBV web portal or directly through METs THREDDS data distribution server. However, these data include only 2D surface parameters and are available only as point timeseries.

The meteorological fields used for seven municipalities are downscaled from the original 2.5x2.5km data. It is often argued that downscaled data are not always of the same quality of dynamically calculated meteorological data. For this reason, a comparison between the dynamic meteorology results at 2.5 and 1 km was carried out in Denby and Süld (2016), as part of the NBV project. The report provides an initial analysis of the meteorological models ability to describe inversion situations, important for air quality applications. The results show that both meteorological model resolutions provide satisfactory predictions for wind, temperature and precipitation. For the period under study, there was no significant statistical difference between the meteorological results in 1 and 2.5km resolution, when compared to measurement stations. The impact of these different meteorological input data in the air quality simulations for selected urban areas was also analysed as part of the NBV project, as documented in Tarrasón et al., 2017. Based on these initial results, it was justified to streamline the Bedre Byluft and NBV production lines by using solely 2.5km AROME-METCoOp data in the future. Eventually, the 2.5km operational meteorological data can be downscaled to 1km resolution, when necessary for air quality runs. In this way, better synergies with the operational Bedre Byluft system are secured. But for fine scale resolution applications, the use of downscaled data can impose higher uncertainty in the final results. The validity of the meteorological model results would need to be validated in each case with observations, as recommended in Tarrasón et al (2018).

2.2 Emission data

The emission data compiled for the seven municipality areas follows as far as possible the methodology developed to compile NBV_V1 emissions for the seven city areas. The methods used for the compilation of municipality emissions are those recommended by López-Aparicio et al. (2017) after carrying out a comparison of the NBV_V0 inventory with other emission inventories in the framework of FAIRMODE (Thunis et al., 2016). This inventory benchmarking work provided useful recommendations to guide the development of the NBV_V1 inventory and is the basis for the compilation of emission data both in cities and in municipality areas, where data is available.

Where bottom-up input data for emissions is not available, the NBV-V1 inventory for municipality areas relies on the downscaling emission inventory developed under the NordicWelfair project (http://projects.au.dk/nordicwelfair/). The NordicWelfair (NWA) project has the overall aim to further understand the link between air pollution levels and chemical composition, and to investigate and assess the effects of air pollution on the distribution of related health impacts, socio-economics and welfare in the Nordic countries. NILU is a partner in NordicWelfair (NWA) and has compiled a high resolution emission inventory based on top-down approaches. The inventory covers the whole of Norway with a spatial resolution of 1kmx1km. It is based on national data compiled at county level from Statistics Norway (SSB) and uses downscaling spatial methods to re-locate the county emission data in high resolution. First results for the year 2012 were made available to the NBV project by the time when the compilation of emissions for municipality areas was initiated. NBV favours bottom-up inventory approaches so the data from the NWA inventory has been used only in the sectors where bottom-up data is otherwise missing or non-available. In particular, it has been used as basis for the determination of emissions in the "residential heating" and "other" sectors.

An important difference between the NBV_V1 inventory for cities and for municipalities is the basic year used for the emission calculations. Both inventories are build up around 2015, but they do not use consistently the same year of emissions for all sectors. This is due to differences in the availability of updated emission data. At the time of the compilation of the NBV_V1 emission inventory for city areas, in 2015, the most recent emission information data was from 2013. Therefore, the NBV_V1 inventory for city areas consistently compiled information for the year 2013 across all sectors. By the time of compilation of the NBV_V1 inventory for municipalities, more data for 2015 was available and was therefore used, when possible, in the inventory.

Differences also arise from the availability of key input data to produce the emission estimates, independently of the year of the update. These data are identified below. The bottom-up methodology used to compile emissions in NBV_V1 is more often constrained by lack of data in the seven Norwegian municipalities than in the seven cities.

2.2.1 Traffic

For exhaust emissions from traffic, the emission compilation at the seven municipalities follows a bottom-up approach, similar to the one documented in detail in López-Aparicio and Vo Thanh (2015). The basic traffic volume data originates from the National Roads Database (NVDB). However, information on the traffic volume per road link are only available at NVDB for some roads in municipality areas. Generally, national and county roads have better coverage than municipal roads. The information coverage is very low: in NVDB there is no available traffic volume data for over 90% of all road links in each municipality area. Where traffic volume data is available, we have used the yearly averaged daily traffic volume (ÅDT) data for the year 2015. Where traffic volume data is not available, we have made an estimate for the yearly averaged daily traffic volume according to the speed-limit of the roads. The assumption is based on the fact that roads with high speed limit are usually frequented by a higher number of vehicles. We have assumed larger traffic volumes in Brumunddal, Gjøvik Lillehammer and Moss, than in Halden, Harstad and Mo i Rana, as indicated in Table 2.1. We also made assumptions on the vehicle fleet composition, since these information was not available for all the municipality areas. We have used the same vehicle fleet composition as in Oslo, recognizing that this probably implies an underestimation of the actual emissions because of the higher proportion of new low-emitting vehicles in Oslo and the lower contribution of heavy duty traffic in the calculations.

While in for the city inventories we assumed a weekly, daily and hourly temporal variability of the exhaust traffic emission, for the municipality estimates we have used the daily and hourly variation of Oslo for all municipalities and a generally flat weekly variation throughout the year. It is expected that assigning a refined temporal profile to the exhaust emissions will improve the temporal correlation of the air quality results.

Table 2.1. Estimated traffic volume at different municipal roads, for three different standard speed limits classes, expressed as averaged Annual Daily Traffic (ADT). Units: [number of cars.day^{-1}.roadlink^{-1}]

Speed limit at Road link	Brumunddal	Gjøvik	Halden	Harstad	Lillehammer	Mo i Rana	Moss
70-80 km/h	1300	1300	750	750	1300	750	1000
50-60 km/h	1300	1300	500	500	1300	500	750
30-40 km/h	1300	1300	250	200	1300	200	500

It is recommended to establish a dialog with local authorities in order to check and improve the given exhaust traffic emission assumptions. This is especially important with respect to traffic volume and vehicle composition, but also relevant with respect to the temporal variation of the traffic emissions.

For non-exhaust emissions from traffic, emissions of PM_{10} and $PM_{2.5}$ due to resuspension from the road surface are calculated based on a parameterisation from Tønnesen (2000). This relates the emission of particulate matter to the percentage of studded tyres use, the percentage of heavy duty traffic, the traffic speed, the traffic volume and the road wetness (precipitation). The percentage use of studded tyres was available from the Norwegian State Roads Administration for the year 2015, but only for certain municipalities[1]. For the other municipalities, we have assumed that the percentage studded tyre use in Halden and Moss is 20%, the same as in Fredrikstad/Sarpsborg and that it is 85% in Harstad and Mo i Rana, based on the usage in Tromsø, since these municipalities have similar winter weather conditions. The parametrization is applied for yearly values and no temporal variation has been assumed for these emissions. It is recognized that road dust emissions are very weather dependent and tend to be larger in spring and autumn. These effects are not considered in the present emission calculations. A better approach to calculate road dust emissions and re-suspension is with the help of the NORTRIP model (Denby et al., 2013) that is currently implemented in Bedre Byluft, NBV and uEMEP. This parametrization takes into account actual meteorological conditions and it is expected to reproduce better both the extent and temporal evolution of road dust emissions. We assume that the PM_{10} and $PM_{2.5}$ non-exhaust emission estimates will be improved if the implementation of NORTRIP is done for all areas in Norway.

2.2.2 Residential heating

Residential heating emissions for 2012 from the NordicWelfair (NWA) inventory are used to derive the emission values from this sector in all seven municipalities in the NBV_V1 inventory. This NWA inventory has a detailed spatial allocation of wood burning emissions that makes it a good candidate for applications such as NBV. Wood burning emissions were identified as the largest single source of uncertainty in the NBV results in city areas (Tarrasón et al., 2017). López-Aparicio et al. (2017) reported on important discrepancies in $PM_{2.5}$ emissions from residential wood burning from different inventories and concluded that these discrepancies are associated with the assumptions made for the allocation of these emissions. This findings guided the selection of the NWA inventory as basis for the NBV_V1 inventory in municipality areas, because special attention was given to the allocation of the residential heating emissions.

The NWA inventory is based on wood combustion activity data compiled at county level by Statistics Norway (SSB). The county emission data is then re-located in high spatial resolution (1kmx1km) using information on the dwelling number and the dwelling type as proxies for the spatial distribution. Two types of dwelling types are distinguished: apartments and houses. For all the municipalities, 70% of the wood consumption is allocated in house locations and 30% in apartment locations. Despite the improved system for allocating wood burning emissions, similar problems to those reported in city areas where found for the municipality areas, so that, again, residential heating emissions were adjusted down to meet available

[1] http://luftkvalitet.info/Theme.aspx?ThemeID=13dc725e-fd54-4e78-ad48-64735a844e32

observations of $PM_{2.5}$. We use an averaged scaling of a factor of 2 for all municipalities with respect to NWA inventory values. The scaling factor is determined from indirect validation and by identifying the bias towards observations. Figure 2.1 shows a comparison in five cities of the NBV_V1 inventory (both adjusted and unadjusted with the scaling factor of 2) with the NWA emissions for 2014 and the emissions derived from the MetVed project (López-Aparicio et al., in prep.). The MetVed project was designed to better understand wood burning emissions in Norway and identify the reasons behind the systematic biases reported for these emissions. The methodology developed in MetVed builds on a process oriented approach to residential heating emissions. Figure 2.1 shows that both the NVB_V1 (unadjusted) and the NWA inventories provide significantly larger $PM_{2.5}$ emissions than the NBV_V1 (adjusted) and the MetVed inventories. It also shows that the NBV_V1 (adjusted) and the MetVed inventories give similar results. The figure provides an indication that the prescribed adjustment of NBV_V1 may be explained by the emission process approach developed in MetVed. It also brings further trust in the MetVed methodology since we know that the NBV_V1 (unadjusted) inventory overestimates the $PM_{2.5}$ concentrations in air when validated with observation through a dispersion model, while the NBV_V1 (adjusted) shows good agreement with observations.

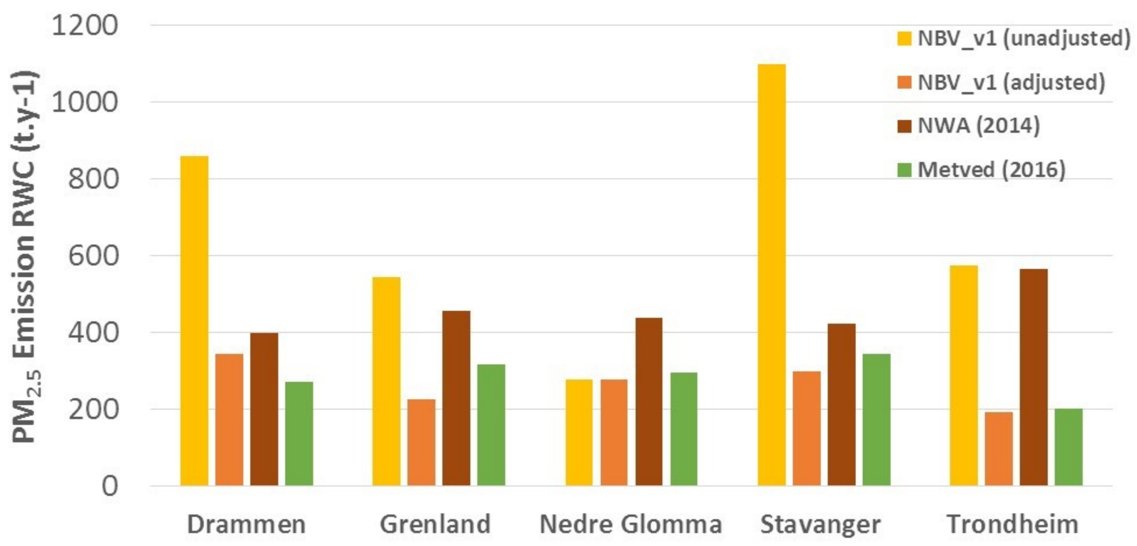


Figure 2.1: Comparison of annual emission estimates of PM2.5 emissions from residential wood combustion (RWC) from different inventories in five Norwegian cities. The inventories are NBV_V1 both adjusted and unadjusted, NWA- Nordic WelfAir project and MetVed (López-Aparicio et al., in prep.). Units: [t.y-1]

The MetVed methodology uses a downscaling method approach and builds on bottom-up principles to derive a wood burning potential for each grid based on the housing type, size and heating technology, energy demand and outdoor temperature of each grid. The emission model builds on the combination of several databases with information at high level of detail. The databases include information on dwelling number and dwelling type at 250m resolution, energy consumption statistics per residential energy commodity and type of dwelling at municipality level, fireplace and stoves locations as point sources (derived from the Norwegian

Fire Department databases), and geo-localised information about dwellings, the type they belong to and the available technology for residential heating. The different datasets are combined and the dependencies between the different variables is analysed in order to define a wood burning potential at a 250m grid. The MetVed model includes estimates of the time variation for residential wood combustion based on the heating degree concept combined with time variation from consumer statistics, and the vertical distribution based on the wood consumption shared in apartment buildings versus houses (López-Aparicio et al., in prep). This on-going work is expected to contribute to further improvements of the emission estimates from the residential heating sector. For the time being, it helps build trust on the current NBV_V1 estimates for the seven municipalities.

2.2.3 Shipping

Following the recommendations by López-Aparicio and Vo Thanh (2015), emission from the shipping sector have been compiled from the AIS service hosted by the Norwegian Coastal Administration. The 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 AIS system is a powerful tool that provides real time information and supports a reliable system to estimate emissions from shipping. Shipping emissions are the dominant source of NO_x in Moss and are also significant in Harstad, Halden and Mo i Rana. The NBV_V1 shipping sector estimates use the 2016 updated AIS data (to avoid the errors identified with the 2015 and reported in Tarrason et al., 2017).

2.2.4 Industry

Emissions from land-based industrial sources are reported every year under the European Pollutant Release and Transfer Regulation (E-PRTR) that establishes an integrated pollutant release and transfer register at EU level in the form of a publicly accessible electronic database. The Norwegian PRTR website[2] provides updated information on industrial emissions, including releases per facility. We have used 2015 data from the Norwegian PRTR register to compile the annual industrial emission from all seven municipalities. These data are introduced in the NBV_V1 inventory as point sources. Industrial emissions are dominating in Mo i Rana, but are also significant in Halden, Brumunddal, and Moss and to a lesser degree in Gjøvik.

2.2.5 Other sources

The NordicWelfair (NWA) inventory for Norway was used as basis for the determination of "Other sources" in the NBV-V1 emission estimates for the seven municipality areas. The emissions included in "Other sources" for municipality areas are a) emissions from agricultural activities, including husbandry and b) emission from off-road activities, including also mobile

[2] https://www.norskeutslipp.no/en/Components/Emission/Nitrogen-oxides/?ComponentType=utslipp&ComponentPageID=159&SectorID=600

sources and machinery from agriculture and forestry activities. The NWA results for 2012 were available in 1x1km in a different grid from the one used in the NBV calculations, so that the data was re-gridded to obtain the NBV-V1 emission estimates.

Currently, emissions from construction sites are not included the NBV_V1 estimates, not even as part of this bulk group "Other sources". It is recognized that this constitutes a potentially important gap and contributes to the uncertainty of the PM_{10} and $PM_{2.5}$ emission estimates. Cooperation with local authorities on the establishment of new methods to determine these type of sources is recommended in order to fill existing emission gaps.

2.2.6 NBV_V1 annual estimates

The resulting annual emission values are presented in Table 2.2 for NOx, Table 2.3. for PM_{10} and Table 2.4 for $PM_{2.5}$ emissions. The contribution from industrial sources dominates the NOx emissions from Mo i Rana, while shipping emissions are dominant in Moss. Otherwise, traffic emissions are the largest single contributor to NOx emissions in most municipality areas, as expected. It is interesting to note that the contribution of off-road and agricultural sources in most municipality areas is significantly higher than it was for the city emissions.

Table 2.2: NBV_V1 emissions for NOx compiled for seven municipalities. Units: [tons/year]

NOX sector emissions	Brumunddal	Gjøvik	Halden	Harstad	Lillehammer	Mo i Rana	Moss
Industry	109	1	122	0	0	1458	19
Traffic	962	261	283	85	375	99	989
Domestic Heating	0	0	0	0	0	0	0
Shipping	0	0	38	136	0	60	1202
Other (incl. off road)	239	27	98	23	77	59	212
TOTAL	**1310**	**288**	**541**	**244**	**452**	**1677**	**2422**

Table 2.3.: NBV-V1 emissions for PM_{10} compiled for seven municipalities. Units: [tons/year]

PM_{10} sector emissions	Brumunddal	Gjøvik	Halden	Harstad	Lillehammer	Mo i Rana	Moss
Industry	4	2	0	0	0	260	0
Traffic	603	153	157	61	219	103	535
Domestic Heating	576	157	97	51	193	50	243
Shipping	0	0	1	7	0	2	77
Other (incl. off road)	13	3	4	3	5	3	12
TOTAL	**1196**	**313**	**260**	**121**	**418**	**420**	**868**

Table 2.4.: NBV_V1 emissions for $PM_{2.5}$ compiled for seven municipalities Units: [tons/year]

$PM_{2.5}$ sector emissions	Brumunddal	Gjøvik	Halden	Harstad	Lillehammer	Mo i Rana	Moss
Industry	4	2	0	0	0	26	0
Traffic	88	25	20	9	39	10	69
Domestic Heating	576	157	97	51	193	50	243
Shipping	0	0	1	7	0	2	77
Other (incl. off road)	13	3	4	3	5	3	12
TOTAL	**681**	**186**	**123**	**69**	**237**	**92**	**402**

Traffic, residential heating and "other" sources dominate the emissions of particulate matter. As expected, traffic is the main contributing sector for PM_{10} while residential heating is the main contributing sector for $PM_{2.5}$ emissions. Comparison between the emissions of PM_{10} and $PM_{2.5}$ from traffic in all municipality areas shows that the coarse fraction dominates the traffic emissions and is an indication of the extent of emissions from the re-suspension of road-dust. The comparison between the emissions of PM_{10} and $PM_{2.5}$ for residential heating shows that the fine fraction dominates the residential heating emissions. In fact, there is no coarse fraction contribution in the emission from that sector in our NBV_V1 estimates.

2.3 The EPISODE dispersion model

EPISODE is the core of the NBV system. This same air quality dispersion model has been used for the calculations at the seven municipalities as it was used for the seven cities. The model has been developed at the Norwegian Institute for Air Research (NILU) for air quality studies at the local scale. It has been the basis for the air quality forecast in the Better City Air program and has been routinely validated with observations as part of the program operations for the last twenty years. Moreover, it is an important tool for regulatory and policy in air quality in Norway and has been used regularly to support the elaboration of plans and programs to reduce air pollution. In the latest years, the EPISODE model was successfully used for planning purposes in Drammen (Wergeland et al., 2017), Bergen (Høiskar et al. 2017), Oslo and Bærum (Høiskar et al., 2016; Høiskar et al., 2014), Stavanger (Denby et al., 2013) and Fredrikstad (Weydahl et al., in prep).

The EPISODE model results have been benchmarked against other European model results within the framework of FAIRMODE. The results are documented in Janssen et al. (2017) and show results comparable with those of state-of-art models used in Europe for air policy applications.

The EPISODE model consists of an Eulerian 3D grid model with embedded sub-grid Gaussian and Lagrangian models, which take care of the dispersion from different type of sources (point, line, and area sources) (Slørdal et al., 2003). The Eulerian part of the model consists of a numerical solution of the atmospheric mass conservation equation of the pollutant species in a three-dimensional Eulerian grid. The Lagrangian part consists of separate sub-grid models for line and point sources. The line source model is an integrated Gaussian type model, while the point source model is a Gaussian puff trajectory model. Point sources are for example stack emissions from industry. Line sources are typically emissions from traffic. Area sources are emissions dispersed in space as for example the emissions from residential heating.

The model is typically used to calculate air pollution concentrations in cities and local areas from multiple emission sources such as road traffic, shipping, residential heating and industry. The model calculates hourly average concentrations as gridded values and in a set of irregularly placed receptor points. The output of the model in hourly frequency is used for calculating long-term average concentrations and other statistical parameters. Traditionally EPISODE has been applied for the calculation of airborne species such as SO_2, CO, NO_X[3], NO_2, PM_{10} and $PM_{2.5}$. Calculations of NO_2 are based on a simplifying assumption of photochemical

[3] $NO_X = NO_2 + NO$

equilibrium between NO, NO_2 and O_3 for each time step. For urban scale applications, the mode does not include neither dry nor wet deposition processes.

In order to make maps of air quality, concentrations must be modelled throughout the model domain. The model simulations are carried out in 1x1km using the EPISODE model and in addition we have used receptor point simulations to better resolve the Gaussian dispersion of line sources so that the final resolution of the maps is 100x100m. In order to create maps at 100 m resolution, the model domain is populated with a large number of receptor points. These receptor points are placed with higher density near roads, out to the extent of the road link influence distance (400 m), the distance to which the line source model is applied. Outside of this region receptor points are placed every 500 m in a regular grid as these sample only from the grid model. The EPISODE model calculates concentrations at the receptor points by adding line source and grid model concentrations.

3 Evaluation of 2015 results with available observations

The validation of air quality levels for nitrogen dioxide (NO_2) and particulate matter (both PM_{10} and $PM_{2.5}$) in comparison with observations is an essential way to understand the validity not only of the model results but also of the emissions used as input to the calculations. However, the evaluation of the air quality results at Norwegian municipalities was far more challenging than it was for city areas because of the lack of monitoring data.

There were only a very limited number of monitoring stations actively compiling air quality data in 2015 in the municipality areas under consideration. For NO_2, there were only three active stations in 2015: one in Gjøvik (Minnesundvegen) and two in Lillehammer (Bankplassen and Lillehammer barnehage). Halden had measured NO_2 concentrations at the Oskleva station earlier in 2010 and 2011, but the measurements were not active in 2015. In addition, at Vangsveien station in Hamar, there were measurements of NO_2 for the last six months of 2015, but not for the full year. For $PM_{2.5}$, the situation was not better. There were only four active stations in 2015 measuring $PM_{2.5}$ concentrations: the same three in Gjøvik and in Lillehammer as for NO_2, and the Vangsveien station in Hamar. For PM_{10}, there were a total of five stations, the same ones as for $PM_{2.5}$ in Gjøvik, Lillehammer and Hamar and an additional one in Rana, namely the Moheia station in Mo i Rana.

It is worth mentioning that the number of monitoring stations increased in 2016 and it is much improved at present. In Halden, at the Vaterland station, there are regular measurements of PM_{10} and $PM_{2.5}$ since December 2017. In Harstad, regular measurements of NO_2, PM_{10} and $PM_{2.5}$ were initiated in January 2018 at Seljestad. In Moss, measurements of PM_{10} and $PM_{2.5}$ were re-established again in 2016 after a break of 4 years, at the Kransen station. And in Hamar, the measurements of NO_2 initiated at Vangsveien station in July 2015 have continued ever since.

Tables 3.1., 3.2. and 3.3. show summary statistics for the validation of model results with observations for respectively NO_2, PM_{10} and $PM_{2.5}$. Validation results at available measurement stations in 2015 are presented by municipality area, that is, Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana and Moss, and per measurement station in each area. Detailed results of the comparison with observations are documented in Appendix A and have served as basis for the analysis summarized below. The statistics and validation values provided in Appendix A and the summary tables are relevant for air quality planning and reporting purposes. This is particularly the case for the correlation coefficient R^2 that is calculated with either hourly or daily frequency to quantify the temporal correlation of the pollution levels, thus providing a measure to what extent the modelled values are able to reproduce the observations during episodes of air pollution. When the correlation coefficient R^2 is calculated for annual means, it quantifies the spatial correlation, which is the ability of the modelled results to reproduce differences between pollution regimes. The spatial correlation is determined to a large extent by the position of the stations and thus the design of the monitoring network. Since most of the stations considered here are placed in urban areas or close to sources, the limited monitoring network represents very similar pollution regimes. Given the existing monitoring network in the seven municipalities, spatial correlation values will only reflect the limitations of this sparse network and are therefore not presented here.

The lack of monitoring data hampers the validation of the modelling results and consequently adds to the uncertainty of the air quality results in this seven municipality areas. We have carried out different types of comparisons with observations, namely, we have compared to observations from one year with model calculation from another year and we have also compared model results in one municipality with observations in another. Such comparisons are only meaningful to assess that the modelled pollution values fall into a reasonable level range. Results from such comparisons are not shown here but demonstrate that the model calculations presented in NBV are consistent with each other provide a reasonable first estimate of the pollution levels in 2015 also in areas without observations. In the following, only results from direct comparison with available observations are presented.

3.1 NO_2

The evaluation of the model results for NO_2 in municipality areas shows a generally good temporal correlation coefficient with available observations. Temporal correlation coefficients for hourly data over the whole year vary between 0.5 and 0.6, which is somewhat better than the results for Norwegian cities. However, this is not the case for the bias and the root-mean square error. The modelled results for the municipality areas underestimate the observed NO_2 values in most available stations by almost 39% while the average fractional bias for the Norwegian cities was 0.5%, a considerably better result. The large negative bias in municipality areas might be taken as an indication that the assumptions on traffic volume and traffic fleet may have been too conservative.

Table 3.1: Summary evaluation results for annual mean value of NO_2 for all municipality domains with monitoring stations in 2015. Units: [µg.m^{-3}]

Domain	**AQ Station - NO_2**	**Emission version**	**Obs mean**	**Model mean**	**Bias**	**RMSE**	**R^2**	**Frequency**
Brumunddal	No station active for the whole year 2015	NBV_V1	-	-	-	-	-	-
Gjøvik	Minnesundvegen	NBV_V1	24,49	18,06	-6,43	19,14	0,52	hourly
Halden	No station active in 2015	NBV_V1	-	-	-	-	-	-
Harstad	No station active in 2015	NBV_V1	-	-	-	-	-	-
Lillehammer	Bankplassen	NBV_V1	32,66	19,48	-13,18	21,50	0,67	hourly
Lillehammer	Lillehammer barnehage	NBV_V1	18,22	8,59	-9,63	16,67	0,61	hourly
Mo i Rana	No station active in 2015	NBV_V1	-	-	-	-	-	-
Moss	No station active in 2015	NBV_V1	-	-	-	-	-	-

The sources affecting NO_2 concentrations are primarily traffic emissions, but there can also be contributions from industrial NO_x emissions, off-road sector and/or from shipping emissions. Of these sources, traffic emissions from municipality roads are subject to the highest uncertainty because of the assumptions made on traffic volume and fleet composition to fill the gaps of official information. Otherwise, the good temporal correlation with observations indicates that the initial effort made to compile high resolution emission data has resulted in a reasonable first emission estimate for this component.

3.2 PM_{10}

Table 3.2 summarises the results from the evaluation of the modelled PM_{10} concentrations with available observations at the seven municipalities. The comparison with observations shows very low temporal correlation coefficients, much lower than in the results for the seven cities. In addition, the results show that the NBV model calculations underestimate the observed PM_{10} levels with negative bias. While in average over all stations in the seven Norwegian cities in NBV, the fractional bias for PM_{10} was of -16%, the average bias in the Norwegian municipalities is larger and reaches up to -26%. These results are consistent with the treatment of road dust and re-suspension emissions in this version of NBV, an emission source that generally contributes to increase the mass of coarse particles. This would also explain why the PM_{10} concentration levels are generally underestimated, despite the fact that $PM_{2.5}$ concentrations are more generally overestimated (see Table 3.3). As it is shown in Appendix A, PM_{10} values are generally underestimated in spring and autumn, when the contribution of road dust emissions is generally larger. The parametrisation of road dust in this NBV version is based on the system available in AirQUIS and developed by Tønnesen (2000). This parametrisation affects only yearly values, by adding a resuspension contribution to PM_{10} emissions based on information on the percentage of studded tyres, the traffic volume, the share of heavy traffic, traffic speed, and the road wetness (based on precipitation rates per year). In the current inventory, the temporal distribution of the PM_{10} emissions does not distinguish between re-suspension and other traffic sources, so that the effects of spring and autumn re-suspension are not taken into account. In city areas, we made a distinction in the temporal distribution of these two sources. This can explain why the PM_{10} temporal correlation was better in the city areas than in the municipalities. A new parametrization of road dust emissions and re-suspension is currently implemented in Bedre Byluft. This parametrization takes into account actual meteorological conditions and it is expected to reproduce better the temporal evolution of road dust emissions. It is based on the NORTRIP approach, developed at NILU (Denby et al., 2013) and only implemented in Oslo for the purposes of NVB. So, the expectation is that the PM_{10} estimates can be improved in the future following the implementation of NORTRIP for all areas in Norway.

Another reason why the temporal correlation in municipality areas is lower than in city areas is the larger contribution from off-road and agricultural sources, where no temporal profile is assumed. The negative bias can also indicate that there are missing sources in the inventory, like, for instance, emissions from the construction sector. Further attention should be given in the future to these “other” sources in order to improve the PM_{10} pollution estimates.

3.3 $PM_{2.5}$

The evaluation of the modelled $PM_{2.5}$ concentrations with available observations is summarised in Table 3.3. The results of the comparison shows temporal correlations generally around 0.5, calculated on the basis of daily values. This temporal correlation for the stations available at municipalities is similar to the average temporal correlation in Norwegian cities available at NBV. As indicated in Table 3.3, $PM_{2.5}$ concentrations were overestimated by the model, but with overestimation levels similar to those found in most city area stations, except for the Vansgveien station in Hamar where the model overestimation is considerably larger. The averaged fractional bias for $PM_{2.5}$ in Norwegian cities is very small (-1%) and although the averaged fractional bias for the municipality areas is larger (18%), this result is driven by one single station (in Hamar). For the other stations, the fractional bias is still small and comparable to the results in city areas. This good result is achieved because the NBV_V1 emission estimates include a factor correction of the residential wood burning emissions.

Air concentrations of $PM_{2.5}$ are determined to a significant extent by residential heating emissions although background concentrations and traffic and industrial emission play also a significant role. In order to explain the current observations of $PM_{2.5}$, residential emissions from wood burning derived from national statistics data and certified Norwegian emission factors need to be adjusted. Interestingly, new insights on wood burning emissions from the MetVed project have shown that the adjustment of emissions proposed by NBV can be justified by a more accurate spatial distribution of the emissions (López-Aparicio et al., in prep.). The use of the MetVed emission estimates for the whole of Norway is expected to result in an improvement of the $PM_{2.5}$ modelled concentration values.

Results from this validation chapter need to be considered when evaluating the products available at the NBV portal and presented in detail in the next chapter.

The observed air pollution annual mean levels for NO_2, PM_{10} and $PM_{2.5}$ at the seven municipalities are generally lower that for the seven city areas, although there are individual differences depending on the positioning of the stations. However, the averaged observed values for the seven municipalities are considerably less representative of the air pollution situation in these areas than for the seven Norwegian cities in NBV. This is because we had at least one or two stations operating in each city, while monitoring network for the seven municipalities is considerably more sparse. The monitoring network in the seven municipalities has improved in coverage since 2015. This is a positive and welcomed development because an accurate representation of the status of air quality levels in Norway relies on the improvement of the spatial and temporal coverage of its air pollution monitoring network.

Table 3.2: Summary evaluation results for annual values PM_{10} for all municipality domains with monitoring stations in 2015. Units: [µg.m^{-3}]

Domain	**AQ Station – PM_{10}**	**Emission version**	**Obs mean**	**Model mean**	**Bias**	**RMSE**	**R^2**	**Frequency**
Brumunddal	Vangsveien in Hamar	NBV_V1	20,38	18,39	-1,99	25,27	0,19	daily
Gjøvik	Minnesundvegen	NBV_V1	18,74	16,70	-2,04	21,43	0,20	daily
Halden	No station active in 2015	NBV_V1	-	-	-	-	-	-
Harstad	No station active in 2015	NBV_V1	-	-	-	-	-	-
Lillehammer	Bankplassen	NBV_V1	21,10	15,10	-6,00	29,72	0,15	daily
Lillehammer	Lillehammer barnehage	NBV_V1	15,30	10,36	-4,94	20,40	0,21	
Mo i Rana	Moheia	NBV_V1	19,43	13,24	-6,19	16,90	0,24	daily
Moss	No station active in 2015	NBV_V1	-	-	-	-	-	-

Table 3.3: Summary evaluation results for annual values of $PM_{2.5}$ for all municipality domains with monitoring stations in 2015. Units: [µg.m^{-3}]

Domain	**AQ Station - $PM_{2.5}$**	**Emission version**	**Obs mean**	**Model mean**	**Bias**	**RMSE**	**R^2**	**Frequency**
Brumunddal	Vangsveien in Hamar	NBV_V1	7,48	12,08	4,6	8,66	0,51	daily
Gjøvik	Minnesundvegen	NBV_V1	7,07	8,74	1,67	5,42	0,52	daily
Halden	No station active in 2015	NBV_V1	-	-	-	-	-	-
Harstad	No station active in 2015	NBV_V1	-	-	-	-	-	-
Lillehammer	Bankplassen	NBV_V1	7,52	9,77	2,25	7,09	0,55	daily
Lillehammer	Lillehammer barnehage	NBV_V1	6,68	7,94	1,26	6,55	0,52	daily
Mo i Rana	No station active in 2015	NBV_V1	-	-	-	-	-	-
Moss	No station active in 2015	NBV_V1	-	-	-	-	-	-

4 NBV air quality products in Norwegian municipalities

The air quality products developed in the Norwegian planning tool are the same for the seven municipalities as for the seven cities, namely:

1) Air pollution indicator maps
2) Air quality zones
3) Exposure calculations
4) Emission data
5) Main contributors to pollution
6) Data downloads

All products are available at the NBV portal at http://www.luftkvalitet-nbv.no. They are based on calculations carried out with the EPISODE air pollution model. As explained in chapter 2, the air quality calculations use background data from the Copernicus Atmosphere Monitoring Service at https://atmosphere.copernicus.eu/ documented in Marecal et al., (2015). They rely on meteorological data for the year 2015 operationally calculated by the AROME-MetCoOp system with a spatial resolution of 2.5x2.5km and downscaled to 1x1km and on emission input data, NBV_V1, developed as part of NBV with a common methodology for all municipalities. The spatial resolution of the mapping results is 100x100m.

Results are provided for nitrogen dioxide (NO_2) and particulate matter (both $PM_{2.5}$ and PM_{10}). These pollutants have been selected as they are priority components of air pollution in cities and are regulated under the European Air Quality Directive 2008/50/EC and Norwegian law (Forurensningsforskriften, chapter 7). All indicators chosen in NBV and further explained in the next subsections follow the Norwegian air pollution regulations for the protection of human health. Table 4.1. shows the limit value established by the current regulation, while Table 4.2 shows the current upper threshold values. While exceedance of the limit values over permitted values implies non-compliance with air pollution regulations, exceedance of the upper threshold values triggers the need for the elaboration of air quality plans and evaluation of possible control actions.

Table 4.1. Limit values according to current Norwegian legislation.

Pollutant	**Averaging time**	**Limit value**	**Allowed number of exceedances per calendar year**
Nitrogen dioxide (NO_2) - Yearly mean limit value	1 year	40 $\mu g.m^{-3}$ NO_2	0
Nitrogen dioxide (NO_2) – Hourly mean value	1 hour	200 $\mu g.m^{-3}$ NO_2	18
Particulate matter (PM_{10}) – Yearly mean value	1 year	25 $\mu g.m^{-3}$ PM_{10}	0
Particulate matter (PM_{10}) – Daily mean value	1 day	50 $\mu g.m^{-3}$ PM_{10}	30
Particulate matter ($PM_{2.5}$) – Yearly mean value	1 year	15 $\mu g.m^{-3}$ $PM_{2.5}$	0

Table 4.2 Upper threshold values according to current Norwegian legislation that trigger need for plans and programs

Pollutant	**Averaging time**	**Upper threshold value**	**Allowed number of exceedances per calendar year**
Nitrogen dioxide (NO_2) - Yearly mean value	1 year	32 µg.m^{-3} NO_2	0
Nitrogen dioxide (NO_2) – Hourly mean value	1 hour	140 µg.m^{-3} NO_2	18
Particulate matter (PM_{10}) – Yearly mean value	1 year	22 µg.m^{-3} PM_{10}	0
Particulate matter (PM_{10}) – Daily mean value	1 day	35 µg.m^{-3} PM_{10}	30
Particulate matter ($PM_{2.5}$) – Yearly mean value	1 year	12 µg.m^{-3} $PM_{2.5}$	0

4.1 Air pollution indicator maps

The air quality indicator maps in the Norwegian planning tool are provided both as yearly mean values and as short term values. For the short term indicator maps, the values presented are those of the 19th highest hourly mean values over the calendar year for NO_2 and for PM_{10}, are those of the 31st highest daily mean values. With this choice of indicators, the maps provide a good way to quickly evaluate the status of air quality in an area. All maps show calculated concentrations for 2015 in µg .m^{-3}.

The color scale in the air pollution indicator maps reflects the current limit values and upper threshold limits. In all maps, red zones indicate areas above allowed limit values, while the orange zones indicate areas with values above the upper threshold values but below limit values. The persistent existence of orange areas in an area will trigger the need for elaboration of plans and programs to control air quality.

When used for planning purposes, it is important to consider that the current indicator maps are valid for the year 2015 and are not representative for other years. For long-term planning purposes, indicator maps for additional years need to be compiled. It is generally recommended to use averages of at least 3 to 5 meteorological years for planning applications.

The maps are valid down to a resolution of 100x100m and for surface level and do not resolve details beyond that horizontal scale because the model set-up does not allow for further detail.

As documented in chapter 2, these maps are based on modelled values and are subject to both systematic and random errors in comparison with observations. These errors are known through regular validation and can be accounted for. Ideally a combination of measured and modelled values, preferably through the use of data fusion or data assimilation techniques could be used for compliance applications.

The data from the indicator maps should always be complemented with information on the model performance against observations, as we have done here. The comparison with available observations carried out in chapter 3 indicate that the current maps constitute a reliable first estimate of the air pollution levels at the seven municipalities. We can however expect higher NO_2 and PM_{10} levels than those provided in the 2015 maps, because the model results tend to underestimate the available observations for these two components. For $PM_{2.5}$, the NBV estimates for the municipalities areas were generally higher than the available observations, meaning that the identified areas with no exceedances of limit values are probably correct.

4.2 Air quality zone maps

Air quality zones are calculated according to the national regulations provided in the T-1520 Guidelines for air quality treatment in area planning. The T-1520 guidelines provide advice on how air quality should be handled in area planning. They are part of the national "Planning and Building Regulations" and help ensure that the use of land and building areas is as beneficial as possible for the individual and for society, facilitating good living environments and promoting the health of the population.

The T-1520 guidelines specify how air quality zones are to be determined. The air quality zones provided by the Norwegian Air Quality Planning Tool are based on model calculations alone. They identify and define red and yellow zones based on the modelled concentrations of NO_2 and PM_{10}. In areas defined as Yellow Zones, the municipality should exercise caution in allowing the construction of buildings for use with a purpose that can be sensitive to air pollution, such as hospitals or kindergartens. The municipality should exercise caution in allowing the establishment of new activities and substantial expansion of existing activities if it causes a significant increase in air pollution. Areas defined as Red Zones, are not suitable for residential use that is sensitive to air pollution due to the high air pollution levels expected in that areas. Red zones are also not suitable for the establishment of new business or substantial expansion of existing activities if it causes a significant increase in air pollution.

The concentration indicators chosen for the elaboration of the air quality zones are provided in Table 4.3. As it can be seen from direct comparison of the values in Table 4.3 with the values in Tables 4.1. and 4.2., the red zone delimitation for long-term planning is more restrictive than the compliance with daily limit values with respect to PM_{10} concentrations in terms of the number of exceedances allowed. The delimitation of the yellow zones is more stringent than the upper threshold value (the value that triggers the need for elaboration of plans and programs) with respect to PM_{10} concentrations, in term of the number of exceedances allowed. However, for NO_2 concentrations, it is not obvious which of the two indicators is more restrictive, in some cases it is the winter mean value of 40 $\mu g.m^{-3}$ NO_2 as requested in the air quality zone determination in other places it can be the yearly mean upper threshold value of 32 $\mu g.m^{-3}$ NO_2.

It is the responsibility of the municipality to produce their own air quality zone maps or to declare which map that is valid. The air quality zone maps developed under NBV are meant only as reference to allow an expert comparison of the air quality zones in different municipalities and cities across Norway.

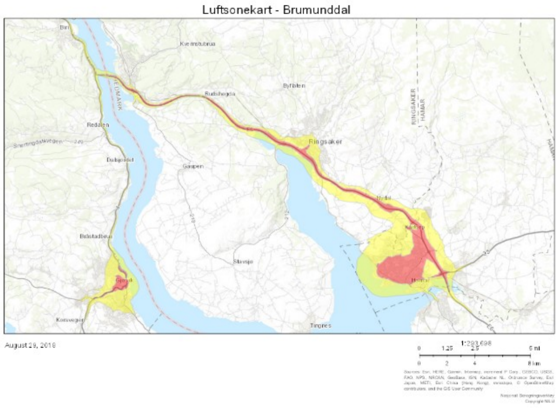
Table 4.3. Criteria for the determination of air quality zones in Norwegian legislation

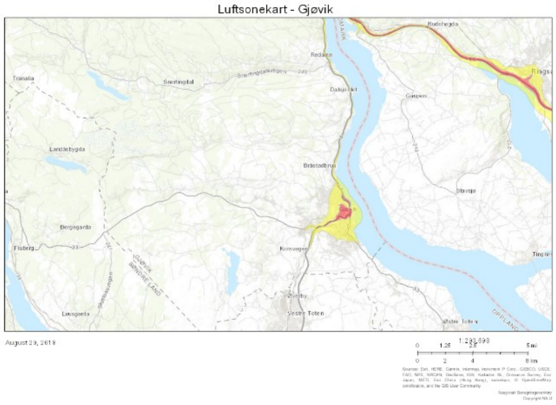
Component	Yellow Zone	Red Zone
PM_{10} concentrations	Daily mean values above 35 µg.m^{-3} PM_{10} allowed a maximum of 7 days per calendar year	Daily mean values above 50 µg.m^{-3} PM_{10} allowed a maximum of 7 days per calendar year
NO_2 concentrations	Winter mean values above 40 µg.m^{-3} NO_2 not allowed Winter mean values defined for the period from 1st November to 30rd April	Yearly mean values above 40 µg.m^{-3} NO_2 not allowed

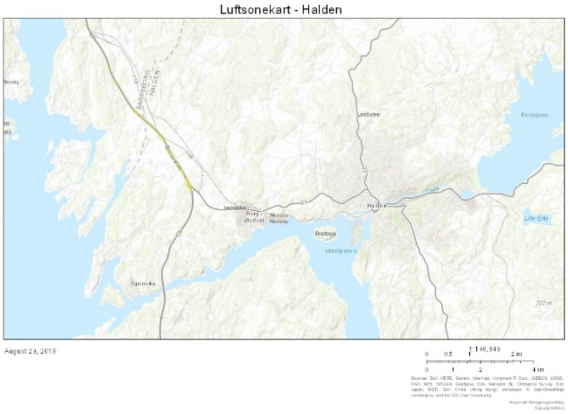
The information in the air quality zone maps can be used down to a resolution of 100x100m and for surface level. However, the air quality zone maps do not resolve details beyond that horizontal scale. Caution is advised when interpreting the limit between red, yellow and open zones beyond the model spatial resolution as this has important consequences for planning applications.

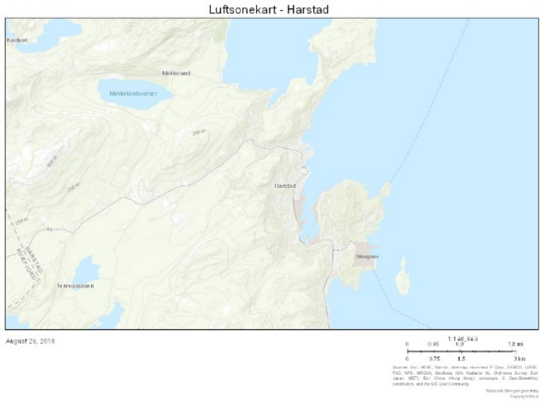
Given the existing year-to-year meteorological variability and the fact that emissions also vary from place to place in the different years, high variability is expected in air quality zones calculated from one year to another. It is recommended that local environmental authorities elaborate their air quality zone maps based on a combination of modelled results (for example from NBV) and observations, and that they take into account the meteorological variability by combining results of 3-5 different years. Further guidance on how to deal with meteorological variability on the elaboration of air quality zones is necessary in Norway under the T-1520 Guidelines (see also recommendations from Tarrasón et al., 2018)

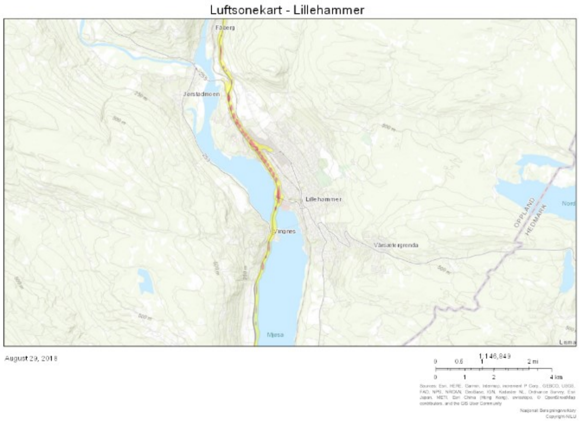
In Figure 4.1., the 2015 NBV air quality zone maps calculated with a common methodology for all seven municipalities are provided. Because the air quality zones are calculated with modelled data that underestimates the observed NO_2 and PM_{10} levels, we can expect that the current 2015 air quality zones are a conservative estimate of the extent of red and yellow zones. Note especially that the lack of red air quality zones in Halden and Harstad may be a spurious effect due to the uncertainties in the input emission data. Unfortunately, there were no observations in 2015 to evaluate the validity of the results.











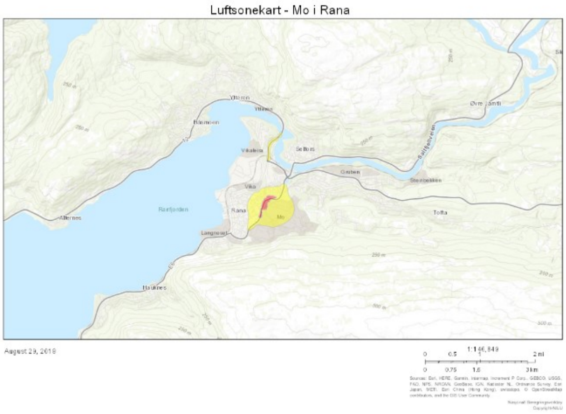


Figure 4.1. Air quality zones as derived by NBV system in 2015 for the seven municipalities.

4.3 Exposure calculations

The effect of air pollution on people's health is generally provided on the basis of population exposure indicators. In the Norwegian Air Quality Planning Tool, the health exposure indicator is defined as the number of people living inside an area where air quality levels exceed the regulatory short and long-term limit values established under Norwegian legislation and listed in Table 4.1.

Exposure numbers have been calculated on the basis of where people live, using the high-resolution NO_2, PM_{10} and $PM_{2.5}$ concentration maps in 100x100m grids. Population data was obtained from Statistics Norway and provides the number of people living in each building in the different domain areas by 1st January 2016. The population data was aggregated to the same 100x100m resolution as the concentration maps. The health exposure numbers for each domain were calculated by identifying the number of people living in an area where modelled air concentration were above the regulatory short and long-term limit.

The exposure numbers in NBV are indicators for how many people within a municipality or region live in areas where air pollution reaches levels that may affect their health. But they are not an estimation of individual exposure. How much pollution an individual is exposed to will depend on where people are staying at any time and can vary widely from individual to individual. This type of individual exposure is not currently provided by NBV.

For planning purposes, the numbers can be used to identify and prioritize measures that aim at reducing the levels of pollution in areas where people are likely to be exposed to high pollution levels. The exposure numbers may also be used to rank and evaluate the effect of different measures against each other.

It is important to note that year-to-year meteorological variability causes large differences in the air pollution levels and that population exposure is a very sensitive indicator. Large differences in population exposure can be expected from just small air quality concentration changes so that year-to-year variability will affect significantly the population exposure estimates. Therefore, it is recommended to take into account this meteorological variability by combining results of 3-5 different years.

For the meteorological conditions of 2015 and with the current NBV-V1 emission estimates, there are no significant levels of population exposure in any of the seven municipalities. Still, one should keep in mind that NBV modelled estimates underestimate the pollution levels of NO_2 and PM_{10}, so that the actual exposure may be higher than calculated. It is important to gather further information on monitoring and emission data at municipality level to determine the levels of exposure with higher accuracy.

4.4 Emission data

Information on emissions for each municipality is provided in the NBV website in three different ways as emission maps, pies and tables.

- The emission data maps show the spatial distribution of annual emissions of the various components (NOx, PM_{10} and $PM_{2.5}$) in tons per year. Total emissions are displayed as grid values with a horizontal resolution of 1 x 1km. In addition, the spatial distribution of emissions from traffic are displayed in separate maps as lines sources.

Emissions from other sources than traffic are all displayed in a common map, named under the common name 'Other'. These emissions are shown as grid emissions with 1x1 km resolution and include residential heating, shipping, industrial, agriculture and off-road emissions, where applicable.

- The emission tables show the annual emission per sector and component in tons per year, where emissions from the different activity sectors are specified in the relevant categories and the term “other sources” in these tables should not be confused with the aggregated information denominated as “Other” in the emission maps. “Other sources” refer to off-road and agriculture emission for the seven municipalities.
- The emission pies show the percentage contribution of each emission sector to the total annual emissions. The information provided in the pies is consistent with the information provided in the tables and the term “other sources” correspond to those identified in the tables for emissions.

The information on the horizontal spatial distribution of the emissions provided in the NBV emission maps allows direct validation of the data by local experts. It is also useful information for local scale planning applications (such as under T-1520) as it allows to identify the main sources in the neighborhood of a specific planning area. Used in combination with the information on air concentration dispersion patterns from the air pollution indicator maps, these data can help determining how different emissions will affect air quality in the planning area. They are also the basis for the evaluation of main contributors to pollution as presented in section 4.5. In the download section, gridded emission data can be retrieved.

The NBV_V1 emission data set is a first valuable estimate for the emission data in the seven municipalities. However, there is room for improvement. Emissions vary significantly from place to place and local understanding of the emission is required to secure reliable air quality assessments and to facilitate the implementation of efficient control strategies. The data is valid for 2015 and it is recommended to update these emission estimates at least evry second year.

The validation work of the emission data carried out through comparison of derived air concentrations with observations shows that there are limitations in certain activity sectors. In particular, NOx emissions from traffic are probably underestimated in the current NBV_V1 estimates. This is related to the lack of information on traffic volume and vehicle fleet composition in municipal roads that are currently not included in the National Roads Database (NVDB). The traffic emission estimates can be improved in cooperation with local authorities by gathering local information and carrying out traffic activity counting campaigns. The traffic sector emissions for PM_{10} are also shown to be underestimated in the validation with observations, in particular in relation with road dust non-exhaust emissions. The on-going implementation of the NORTRIP approach to calculate road dust emissions is expected to contribute to improve these estimates. For $PM_{2.5}$ emissions, the comparison with observations shows that the NBV_V1 estimates are probably overestimated. Improvements are also underway with the on-going calculation of residential heating emissions with the MetVed methodology (López-Aparicio et al., in prep.). All these initiatives are relevant ways to improve the current NBV_V1 emission estimates.

4.5 Main contributors to pollution

The contribution of different emission sources to air pollution concentrations of NO_2, PM_{10} and $PM_{2.5}$ is presented in percentage maps at the NBV website. The maps provide information about how much the different emission sectors contribute in percentage to the total air concentrations. The percentage calculations are presented for annual mean concentrations. The emission sectors considered are traffic, shipping, residential heating, industry and "other", which includes off-road and agricultural emissions. In addition to the contribution from specific emission sectors, information is also provided as to how important is the contribution of background concentrations to the air pollution levels in the modelled domain. Background concentrations are introduced as boundary conditions in the calculations and can be interpreted as the concentrations in air originating from outside the city or the municipality domain.

The contribution of different sources vary considerable from municipality to municipality, for the different components. The background air contribution to pollution levels is significant for all components and is generally larger for $PM_{2.5}$ than for PM_{10} and, while it is generally smaller for NO_2, it is still significant also for this component. Otherwise, NO_2 concentrations are dominated by traffic, off-road and shipping emissions where applicable, except in Mo i Rana, where the influence of industrial emissions is dominating. For PM_{10}, the background contribution dominates in municipality areas, followed by traffic, shipping and residential heating sources. However, this dominance of the background contribution may be related to the recognized underestimation of road dust emissions in the current estimates. The $PM_{2.5}$ concentrations in municipality areas are dominated also by the background component, followed by residential heating and to lesser degree by traffic and shipping sources.

The contributions of different sources in municipality areas apply to the year (2015) and for the emissions in NBV-V1 for which they are calculated. These contributions will change somewhat under different meteorological conditions and more significantly if the emissions from one or more sector change. The relative contributions apply also only for annual air pollution values. For other indicators, such as highest values over threshold limits, the contributions of different sources may differ. For planning applications, in order to make these contribution calculations more robust, it is recommended to use an average of the source contributions for at least 3 to 5 years.

The relative contributions from the different sources to annual pollution levels in the city domains constitute important information for planning applications. Such information is politically highly relevant because it identifies which sources should be targeted in different areas when planning future control scenarios. This is a first step toward the elaboration of future scenarios and it can be used in combination with the emission maps in NBV to support emission planning.

4.6 Data downloads

Three types of data are available for download at the NBV website: a) meteorological data, b) emission data and c) air concentration data. These data are mainly intended for air pollution dispersion applications for assessment, forecasting and planning purposes. The data can be used as input or boundary conditions and the different versions and years available provide a good basis for sensitivity expert analysis. All data is downloadable from the NBV website, either in the form of graphs and shapefiles or directly as data files. The data files are available in a set of standard formats. These involve NETCDF format for meteorological and air concentration data, CSV for meteorological coordinate data and ASCII files for emission gridded data. In addition, mapping information is available as PDF or as SHAPE files. These standard formats were identified as the most relevant ones by different users.

5 Conclusions

Results from the air pollution status in 2015 in seven municipality areas in Norway (Brumunddal, Gjøvik, Halden, Harstad, Lillehammer, Mo i Rana and Moss) have been compiled here and are openly available via the NBV web-portal at http://www.luftkvalitet-nbv.no.

The air quality products for Norwegian municipalities are the same that were developed for the seven city areas. As far as possible, the same methodologies have been used as those reported in Tarrasón et al. (2017). The same dispersion model has been used for the air pollution calculations. The model is the EPISODE-model, developed at NILU and widely validated during its 20 years operation under the Better City Air (Bedre Byluft) program. EPISODE has also been regularly tested for policy applications at local scale and has demonstrated ability to support the elaboration of plans and programs to reduce air pollution in Norwegian cities and municipalities. The same background concentrations were also used, namely air pollution data from the Copernicus Atmosphere Monitoring Service. However, the meteorological and emission input data currently available in municipality areas are methodologically different from the data available at main city areas.

The meteorological fields used for the main cities have originally a higher spatial resolution than the meteorological fields used for the seven municipalities. This needs to be considered when evaluating the uncertainty of the resulting air quality calculations, although initial tests carried out during the NBV project suggest that the impact of this difference may be small.

More significant are the differences between the emission calculations. While the methodologies used to calculate emissions are similar to those reported in López-Aparicio et al. (2017) for Norwegian cities, the basic input data is not always available for the seven municipalities. Differences arise mainly from the lack of detailed data necessary to calculate local emissions and the need to make assumptions instead. Such assumptions add to the uncertainty of the emission data from the seven municipalities. They involve, in particular, assumptions on traffic volume and vehicle fleet composition at municipal road level, assumptions on the extent and temporal variation of road dust emissions and assumptions on the spatial distribution of residential combustion sources. Emissions from construction sites are currently missing in the NBV_V1 estimates and such gaps contribute also to the uncertainty of the emission estimates. Other sectors, such as shipping and industry, have better data coverage and availability, so that the current NBV-approach for these sectors provides reasonable emission estimates, comparable for the whole of Norway. The comparison with available observations indicates that uncertainties in the emission data have a significant impact in the air quality calculations.

Differences in the data availability also involve observations from monitoring stations. About half of the municipalities represented lacked operating monitoring stations in 2015, while there were always at least one or two monitoring stations in each city area domain. This affects the validation of the air quality results and hampers the representativeness of the conclusions. Still, the comparison with existing observations shows reliable NBV-calculations in municipality areas. Where observations are available, the validation shows generally good temporal correlation in the municipality results, with levels comparable to the temporal correlations in city areas. This is the case for $PM_{2.5}$ and also for NO_2 (with correlations up to 0.5-0.6 average values), but not for PM_{10}. For PM_{10}, average temporal correlation levels are considerably lower in municipality areas, urging for a revision the temporal assumptions and the treatment of road dust emissions. The validation also shows generally higher bias in the NBV municipality results than those in city areas, due to higher uncertainties in the emission data used as input. Increased interaction with local authorities to improve the information on traffic volume and vehicle fleet composition in local roads, the on-going implementation of the NORTRIP approach to calculate road dust emissions and the evaluation of residential heating emissions through the MetVed methodology, are all identified as relevant ways to improve the NBV air quality calculations and are already underway. Emission data can also be improved with regular yearly updates. The emission work in NBV has pointed out the significance of year-to-year emission variability in particular for the residential heating sector, and for shipping emissions. Industrial emission can also vary significantly from one year to the other, when plants revise their activities, or either open or close. Therefore, it is recommended to continue the effort initiated under the NBV-project by updating emission data at least every two years, aiming at building a robust update system to allow for regular yearly emission estimates. Additional efforts should also be addressed to cover identified emission gaps in sectors currently poorly or not included in the inventories, such as emissions from agriculture, off-road and construction sources.

The air quality results show generally lower averaged levels in municipality areas than in city areas. As a consequence, the calculated air quality zones in the municipality areas have a reduced extension of yellow zones and significantly lower area of red zones. Because the air quality zones are calculated with modelled data that underestimates the observed NO_2 and PM_{10} levels, it is possible that the current 2015-extension of the air quality zones is somewhat optimistic. For instance, the lack of red air quality zones in Halden and Harstad may be a consequence of the inherent uncertainties in the input emission data, but unfortunately, there were no observations in 2015 to determine the validity of these results. It is recognized however, that the number of operating monitoring stations in municipality areas has increased since 2015 and that stations are now operating in both Halden and Harstad. This will facilitate a better characterisation of the air quality levels in these areas.

An interesting result in comparison with the seven cities, is that there is no population exposed to air quality over threshold values in any of these seven municipalities for 2015. Still, one should keep in mind that NBV-modelled estimates underestimate the pollution levels of NO_2 and PM_{10}, so that the actual exposure to these pollutants may be higher than calculated. It is important to keep gathering further information on monitoring and emission data at municipality level to determine the levels of exposure with higher accuracy.

The contribution of different sources vary considerable from municipality to municipality, for the different components. The background air contribution to pollution levels is significant for all components and is generally larger for $PM_{2.5}$ than for PM_{10}, and generally smaller for NO_2. Otherwise, NO_2-concentrations are dominated by traffic emissions and shipping emissions where applicable, except in Mo i Rana, where the influence of industrial emissions is dominating. For PM_{10}, the background contribution dominates in municipality areas, followed by traffic, shipping and residential heating sources. However, this dominance of the background contribution may be related to the recognized underestimation of emissions in the current estimates. The $PM_{2.5}$-concentrations in municipality areas are also dominated by the background component, followed by residential heating and to lesser degree by traffic and shipping sources.

The results presented here are valid for 2015, and extrapolations to other years are not advisable. It is generally recommended that for policy relevant analysis, 3-yearly or 5-yearly averaged data is used instead of data for only one specific meteorological year. The work carried out under NBV shows the importance of continuous dialog with local authorities to gather further information on monitoring and emission data at municipality level. This is to secure higher accuracy in the evaluation of air quality levels and associated air quality indicators.

6 References

Amodei, M., Sanchez, I., & Stein, J. (2015). Verification of the French operational high-resolution model AROME with the regional Brier probability score. *Meteorological Applications*, *22*, 731-745.

Bouttier, F. & Roulet, B. (2008). AROME, the new high resolution model of Météo-France. In The European Forecaster Newsletter, no. 13, pp. 27-30. http://www.euroforecaster.org/newsletter13/full.pdf

Denby, B. R., Sundvor, I., Johansson, C., Pirjola, L., Ketzel, M., Norman, M., Kupiainen, K., Gustafsson, M., Blomqvist, G., & G. Omstedt (2013). A coupled road dust and surface moisture model to predict non-exhaust road traffic induced particle emissions (NORTRIP). Part 1: Road dust loading and suspension modelling. *Atmospheric Environment, 77,* 283-300. doi:10.1016/j.atmosenv.2013.04.069

Denby B.R., Sundvor, I., Schneider, P., & Vo Thanh, D. (2014) *Air quality maps of NO_2 and PM_{10} for the region including Stavanger, Sandnes, Randaberg and Sola (Nord-Jæren). Documentation of methodology* (NILU TR, 01/2014). Kjeller: NILU

Denby, B. R. & Süld, J. K. (2016). *NBV report on meteorological data for 2015. Deliverable 6, Work package 3* (Met Report, 2016). Oslo: Norwegian Meteorological Institute.http://www.luftkvalitet-nbv.no/Shared/pdf/NBV_MET_report_2016_v3.pdf

Haug, T. W., Solli, H., Høiskar, B. A. H., Sundvor, I., & Johnsrud, M. (2017). *Tiltaksutredning for lokal luftkvalitet, Drammen kommune* (UA Rapport, 90/2017). Oslo: Urbanet Analyse.

Høiskar, B.A.K., Sundvor, I., & Strand, A. (2014). *Tiltaksutredning for luftkvalitet i Oslo og Bærum 2015-2020* (NILU OR, 49/2014). Kjeller: NILU

Høiskar, B. A. K., Sundvor, I., & Vogt, M. (2016). *Effekt av lavutslippssoner på luftkvaliteten i Oslo - Utslipps- og spredningsberegninger* (NILU rapport, 22/2016). Kjeller: NILU.

Høiskar, B. A. H., Sundvor, I., Johnsrud, M., Haug, T. W., & Solli, H. (2017) *Tiltaksutredning for lokal luftkvalitet i Bergen* (NILU rapport 15/2017) Kjeller: NILU.

Janssen, S, Guerreiro, C., Viane, P., Georgieva, E., Thunis, P., Cuvelier, K., Trimpeneers, E., Wesseling, J., Montero, A., Miranda, A., Stocker, J., Rørdam Olesen, H., Sousa Santos, G., Vincent, K., Carnevale, C., Stortini, M., Bonafè, G., Minguzzi, E., Malherbe, L., Meleux, F., Stidworthy, A., Maiheu, B., & Deserti, M. (2017). *Guidance Document on Modelling Quality Objectives and Benchmarking – FAIRMODE WG1.* http://fairmode.jrc.ec.europa.eu/document/fairmode/WG1/Guidance_MQO_Bench_vs2.1.pdf

López-Aparicio, S., Guevara, M., Thunis, P., Cuvelier, K., & Tarrasón, L. (2017). Assessment of discrepancies between bottom-up and regional emission inventories in Norwegian urban areas. *Atmospheric Environment*, *154*, 285-296. doi:10.1016/j.atmosenv.2017.02.004

López-Aparicio, S. & Vo, D.T. (2015). *Emission estimates for Norwegian cities. NBV_Emission Database v.0* (NILU OR, 35/2015). Kjeller: NILU.

López-Aparicio, S., Grythe H., & Vogt, M. (2018). *Model development for high-resolution emissions from residential wood combustion.* (NILU report in preparation for the Norwegian Environment Agency).

Marécal, V., Peuch, V.-H., Andersson, C., Andersson, S., Arteta, J., Beekmann, M., Benedictow, A., Bergström, R., Bessagnet, B., Cansado, A., Chéroux, F., Colette, A., Coman, A., Curier, R. L., Denier van der Gon, H. A. C., Drouin, A., Elbern, H., Emili, E., Engelen, R. J., Eskes, H. J., Foret, G., Friese, E., Gauss, M., Giannaros, C., Guth, J., Joly, M., Jaumouillé, E., Josse, B., Kadygrov, N., Kaiser, J. W., Krajsek, K., Kuenen, J., Kumar, U., Liora, N., López, E., Malherbe, L., Martinez, I., Melas, D., Meleux, F., Menut, L., Moinat, P., Morales, T., Parmentier, J., Piacentini, A., Plu, M., Poupkou, A., Queguiner, S., Robertson, L., Rouïl, L., Schaap, M., Segers, A., Sofiev, M., Tarrasón, L., Thomas, M., Timmermans, R., Valdebenito, Á., van Velthoven, P., van Versendaal, R., Vira, J., & Ung, A. (2015). A regional air quality forecasting system over Europe: the MACC-II daily ensemble production. *Geoscientific Model Development*, *8*, 2777-2813, doi:10.5194/gmd-8-2777-2015

Seity, Y., Brousseau, P., Malardel, S., Hello, G., Bénard, P., Bouttier, F., Lac, C., & Masson, V. (2011). The AROME-France Convective-Scale Operational Model. *Monthly Weather Review*, *139,* 976-991.

Slørdal, L. H., Walker, S.-E., & Solberg, S. (2003). *The Urban Air Dispersion Model EPISODE applied in AirQUIS$_{2003}$. Technical Description* (NILU TR, 12/2003). Kjeller: NILU.

Tarrasón, L., Sousa Santos, G., Thanh, D.V., Vogt, M. López-Aparicio, S., Denby, B., Tønnesen, D., Sundvor, I., Vika Røen, H., & Høiskar, B. A. K. (2017). *Air quality in Norwegian cities in 2015 – Evaluation Report for NBV Main Results* (NILU report, 21/2017). Kjeller: NILU. http://luftkvalitet-nbv.no/Shared/pdf/NBV-Luftkvalitet_AP4_D4_Final.pdf

Tarrasón, L., Høiskar, B. A. K., Guerreiro, C., Berge, E., & Selvig, E. (2018). *Kvalitetskrav knyttet til luftkvalitetsberegninger i norsk regelverk - Status og anbefalinger til videre prosess* (NILU rapport, 7/2018). Kjeller: NILU. http://hdl.handle.net/11250/2502926

Tønnesen, D. & Slørdal, L.H. (2000). *Bakgrunnsverdier for VLUFT bestemt med AirQUIS-EPISODE* (NILU OR, 40/2000). Kjeller: NILU.

Thunis, P., Degraeuwe, B., Cuvelier, K., Guevara, M., Tarrasón, L., & Clappier, A. (2016). A novel approach to screen and compare emission inventories. *Air Quality, Atmosphere & Health, 9,* doi:10.1007/s11869-016-0402-7

Weydahl, T., Grythe, H., Høiskar, B. A. K., Svorstøl, E. T., & Haug, T. W. (2018). *Tiltaksutredning for lokal luftkvalitet i Sarpsborg og Fredrikstad.* (NILU report in preparation).

Appendix A

Validation with observations

Brumunddal - Vangsveien station in Hamar

PM_{10}

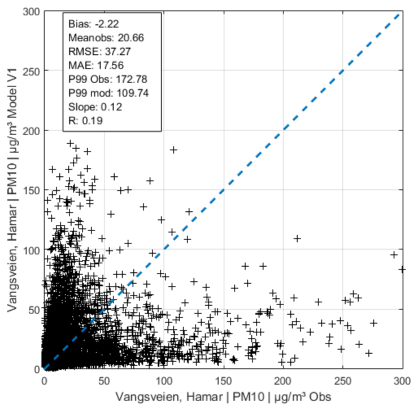


Figure A1: Scatterplot of modelled vs observed hourly values of PM_{10} in Vangsveien, Hamar. Units: [$\mu g.m^{-3}$]

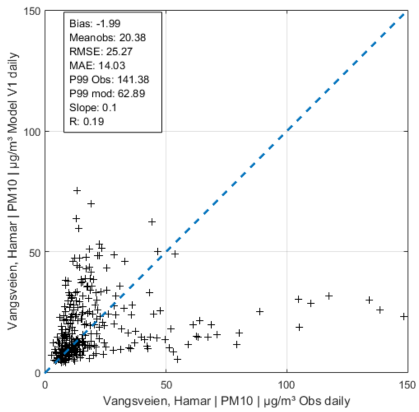


Figure A2: Scatterplot of modelled vs observed daily values of PM_{10} in Vangsveien, Hamar. Units: [$\mu g.m^{-3}$]

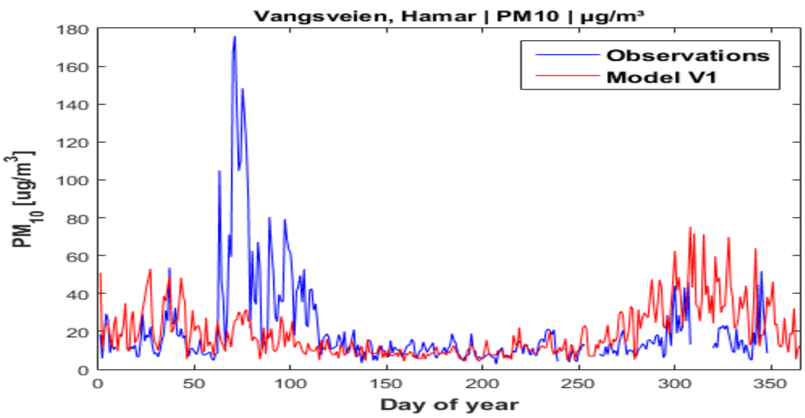


Figure A3: Timeseries with daily PM_{10} in Vangsveien, Hamar. Modelled values for 2015 are given in red and observations in blue. Units: [$\mu g.m^{-3}$]

Brumunddal - Vangsveien station in Hamar

$PM_{2.5}$

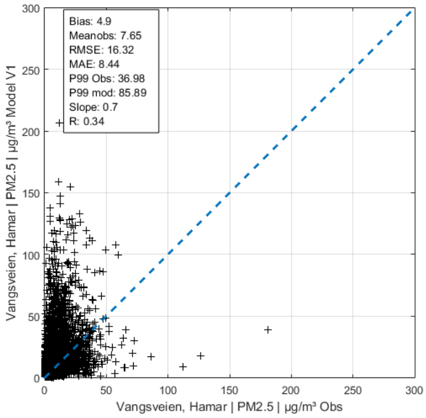


Figure A4: Scatterplot of modelled vs observed hourly values of $PM_{2.5}$ in Vangsveien, Hamar. Units: [$\mu g.m^{-3}$]

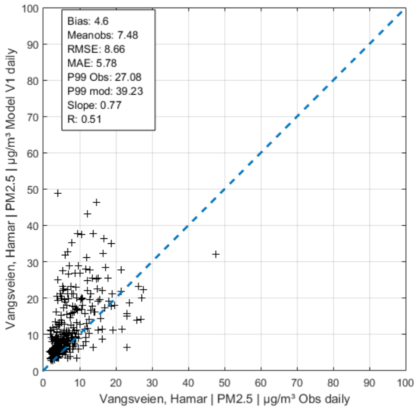


Figure A5: Scatterplot of modelled vs observed daily values of $PM_{2.5}$ in Vangsveien, Hamar. Units: [$\mu g.m^{-3}$]

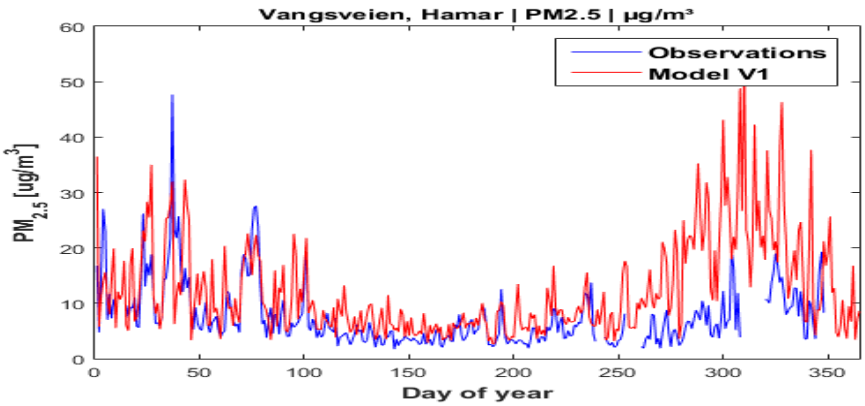


Figure A6: Timeseries with daily PM_{10} in Vangsveien, Hamar. Modelled values for 2015 are given in red and observations in blue. Units: [$\mu g.m^{-3}$]

Gjøvik – Minnesundvegen station

NO_2

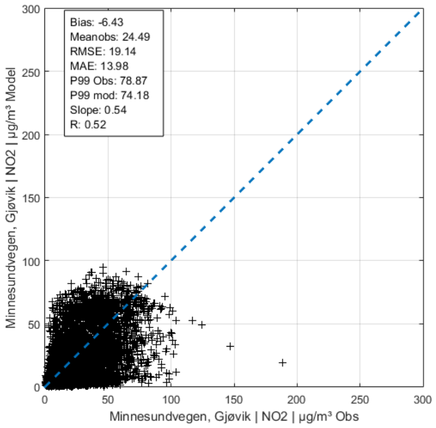


Figure A7: Scatterplot of modelled vs observed hourly values of NO_2 in Minnesundvegen, Gjøvik. Units: [µg.m^{-3}]

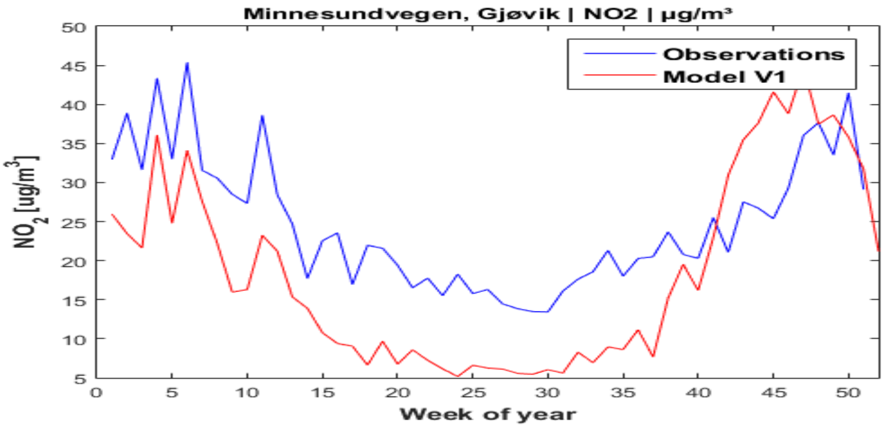


Figure A8: Timeseries with weekly NO_2 concentrations in Minnesundvegen, Gjøvik. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

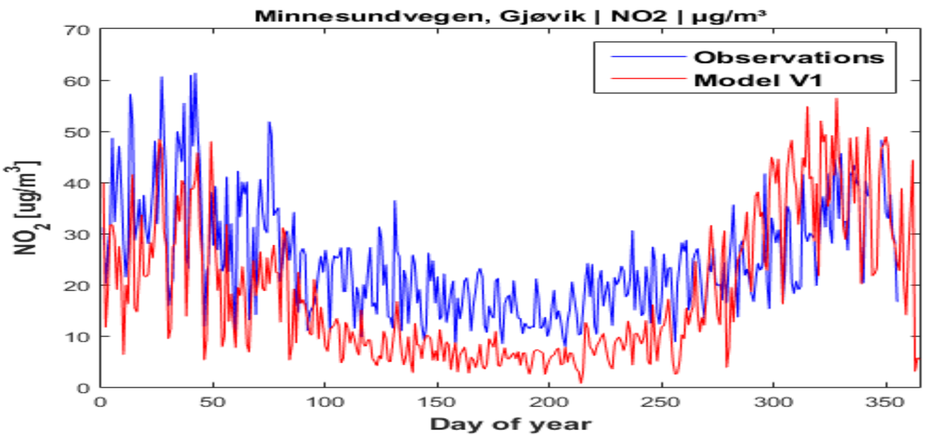


Figure A9: Timeseries with daily NO_2 concentrations in Minnesundvegen, Gjøvik. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Gjøvik – Minnesundvegen station

PM_{10}

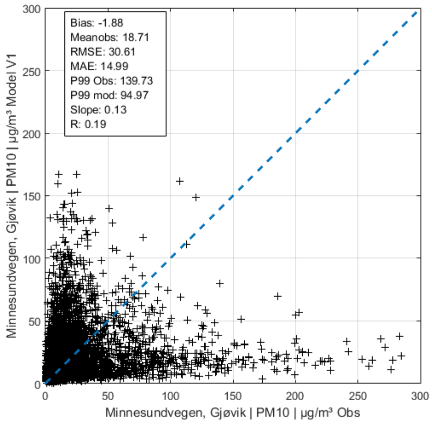


Figure A10: Scatterplot of modelled vs observed hourly values of PM_{10} in Minnesundvegen, Gjøvik. Units: [µg.m^{-3}]

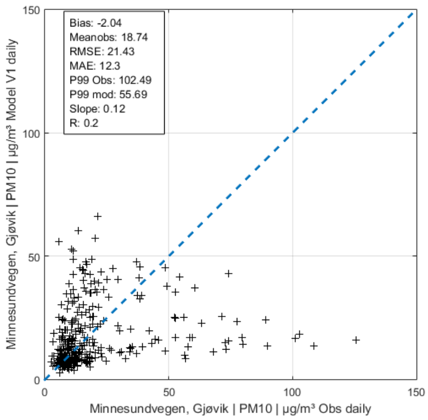


Figure A11: Scatterplot of modelled vs observed daily values of PM_{10} in Minnesundvegen, Gjøvik. Units: [µg.m^{-3}]

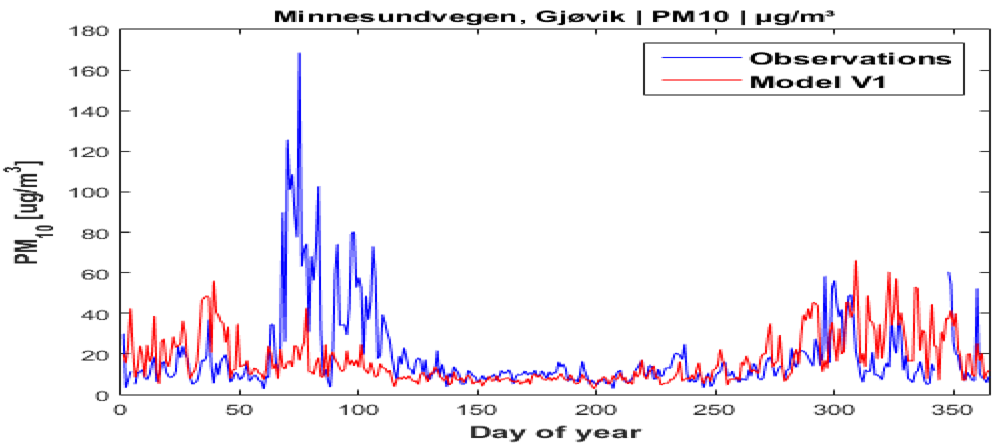


Figure A12: Timeseries with daily PM_{10} concentrations in Minnesundvegen, Gjøvik. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Gjøvik – Minnesundvegen station

$PM_{2.5}$

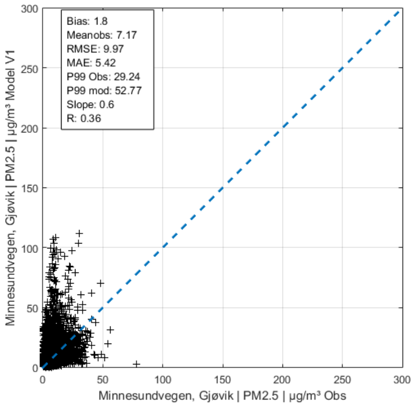


Figure A13: Scatterplot of modelled vs observed hourly values of $PM_{2.5}$ in Minnesundvegen, Gjøvik. Units: [$\mu g.m^{-3}$]

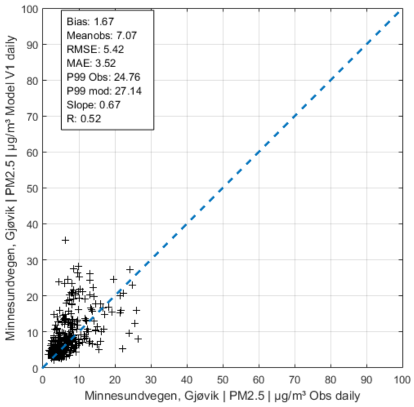


Figure A14: Scatterplot of modelled vs observed daily values of $PM_{2.5}$ in Minnesundvegen, Gjøvik. Units: [$\mu g.m^{-3}$]

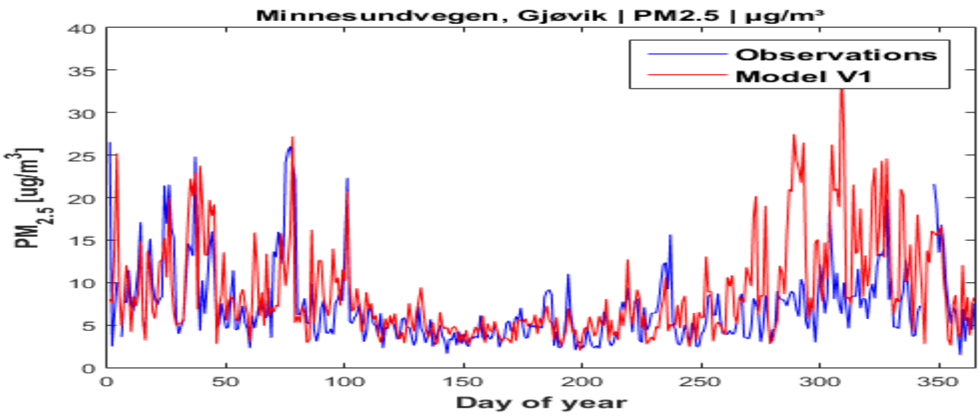


Figure A15: Timeseries with daily $PM_{2.5}$ concentrations in Minnesundvegen, Gjøvik. Modelled values for 2015 are given in red and observations in blue. Units: [$\mu g.m^{-3}$]

Lillehammer – Bankplassen and Barnehage stations

NO_2 -Bankplassen

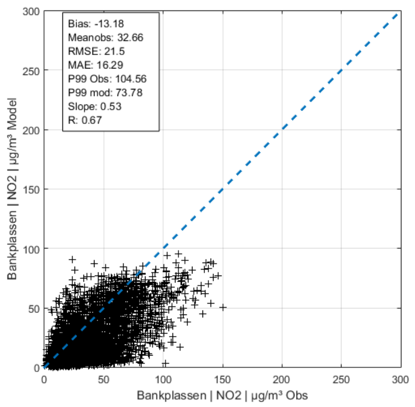


Figure A16: Scatterplot of modelled vs observed hourly values of NO_2 in Bankplassen, Lillehammer. Units: [µg.m^{-3}]

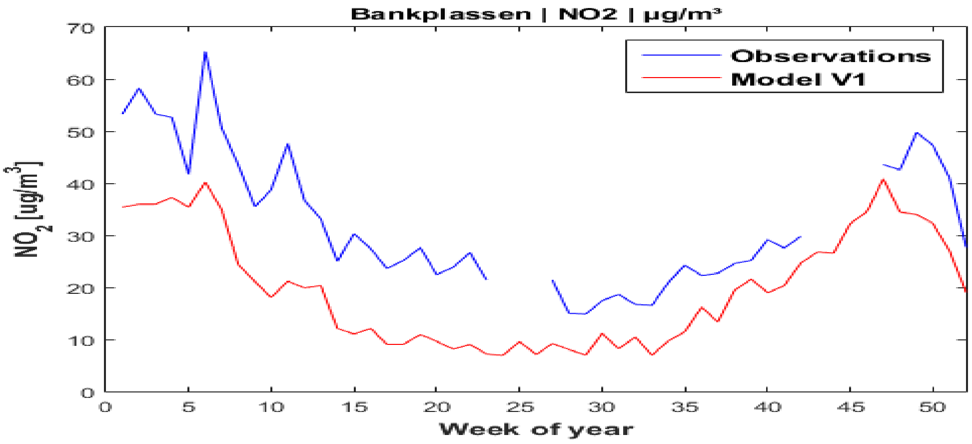


Figure A17: Timeseries with weekly NO_2 concentrations in Bankplassen, Lillehammer. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

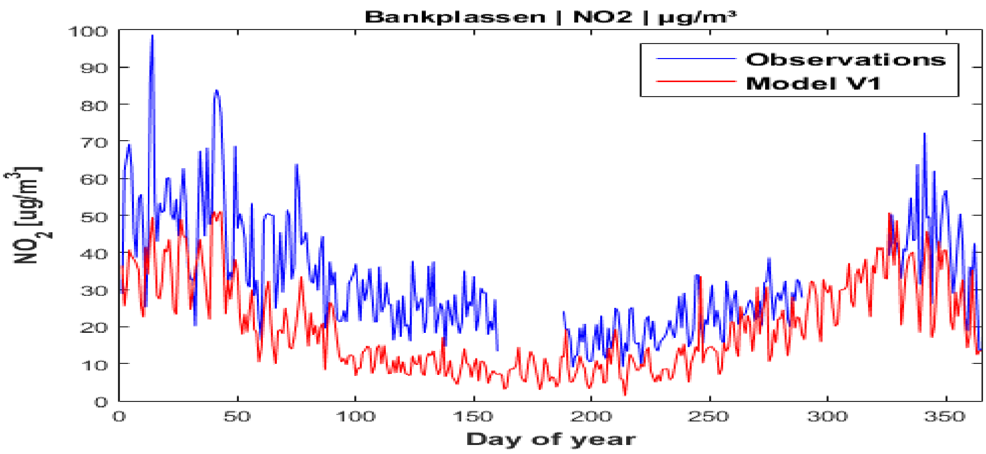


Figure A18: Timeseries with daily NO_2 concentrations in Bankplassen, Lillehammer. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Lillehammer – Bankplassen and Barnehage stations

NO_2 – Lillehammer barnehage

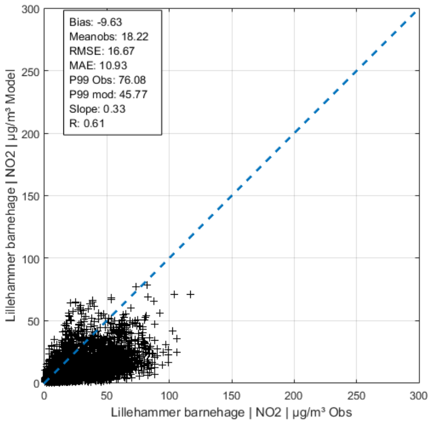


Figure A19: Scatterplot of modelled vs observed hourly values of NO_2 in Lillehammer barnehage station. Units: [µg.m^{-3}]

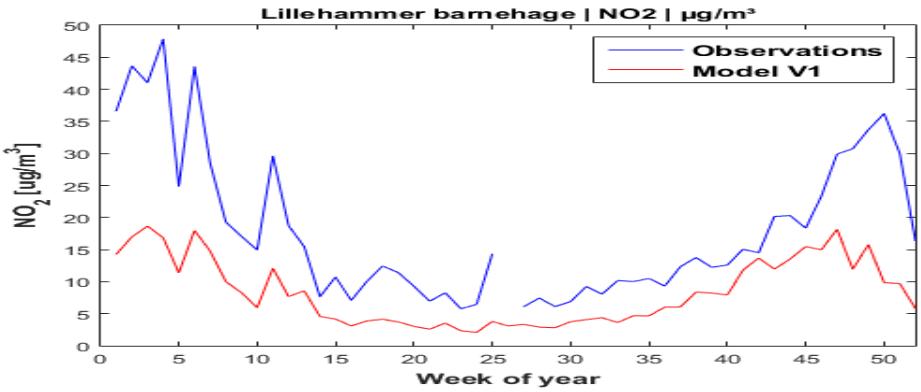


Figure A20: Timeseries with weekly NO_2 concentrations in Lillehammer barnehage station. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

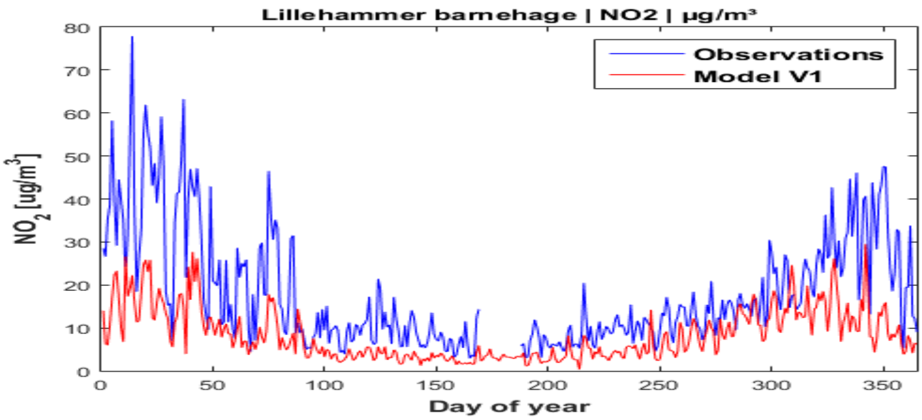


Figure A21: Timeseries with daily NO_2 concentrations in Lillehammer barnehage station. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Lillehammer – Bankplassen and Barnehage stations

PM_{10} - Bankplassen

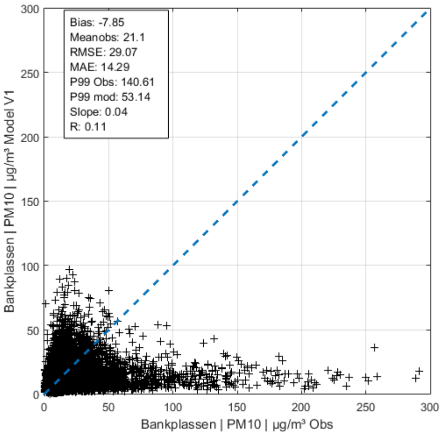


Figure A22: Scatterplot of modelled vs observed hourly values of PM_{10} in Bankplassen, Lillehammer. Units: [µg.m^{-3}]

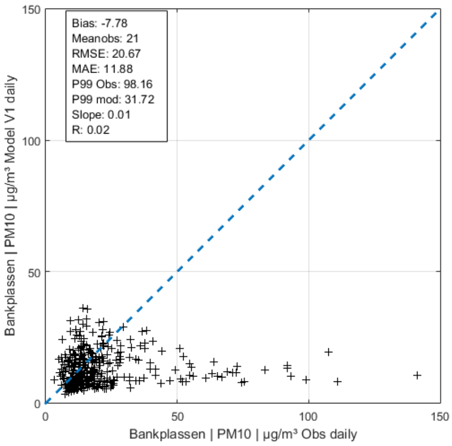


Figure A23: Scatterplot of modelled vs observed daily values of PM_{10} in Bankplassen, Lillehammer. Units: [µg.m^{-3}]

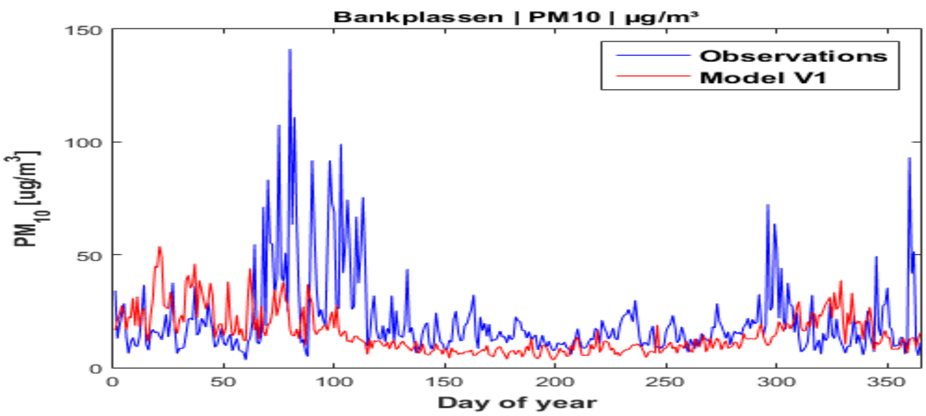


Figure A24: Timeseries with daily PM_{10} concentrations in Bankplassen, Lillehammer. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Lillehammer – Bankplassen and Barnehage stations

PM_{10} – Lillehammer barnehage

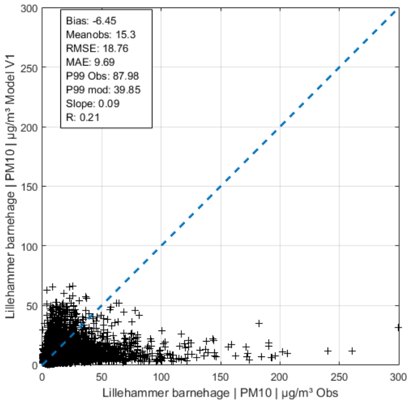


Figure A25: Scatterplot of modelled vs observed hourly values of PM_{10} in Lillehammer barnehage station. Units: [µg.m^{-3}]

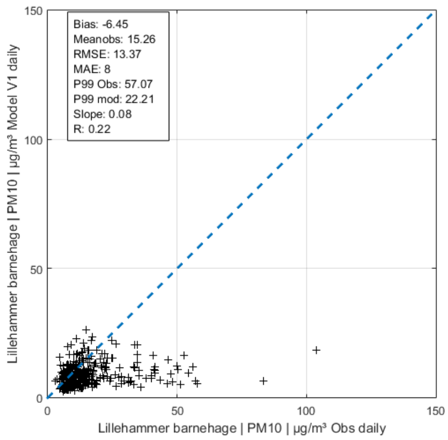


Figure A26: Scatterplot of modelled vs observed daily values of PM_{10} in Lillehammer barnehage station. Units: [µg.m^{-3}]

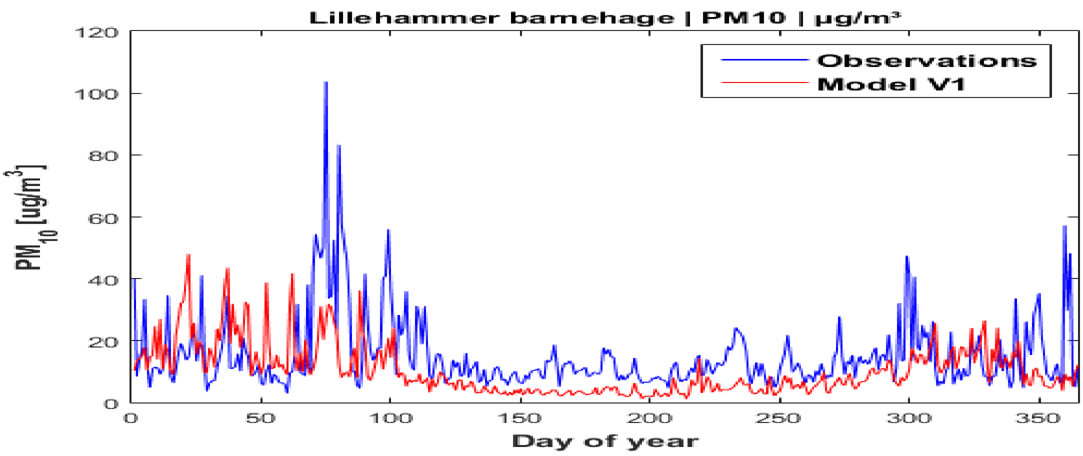


Figure A27: Timeseries with daily PM_{10} concentrations in Lillehammer barnehage station. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Lillehammer – Bankplassen and Barnehage stations

$PM_{2.5}$ - Bankplassen

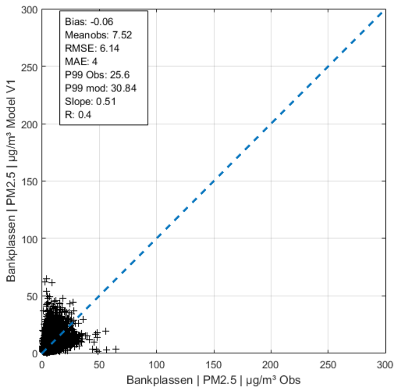


Figure A28: Scatterplot of modelled vs observed hourly values of $PM_{2.5}$ in Bankplassen, Lillehammer. Units: [µg.m^{-3}]

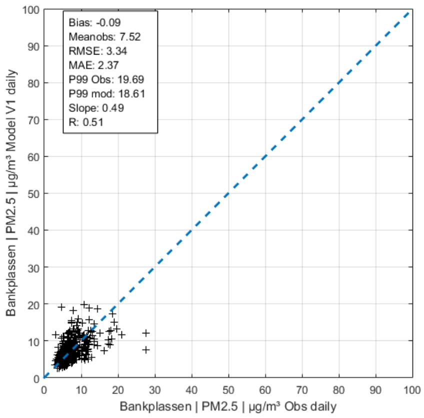


Figure A29: Scatterplot of modelled vs observed daily values of $PM_{2.5}$ in Bankplassen, Lillehammer. Units: [µg.m^{-3}]

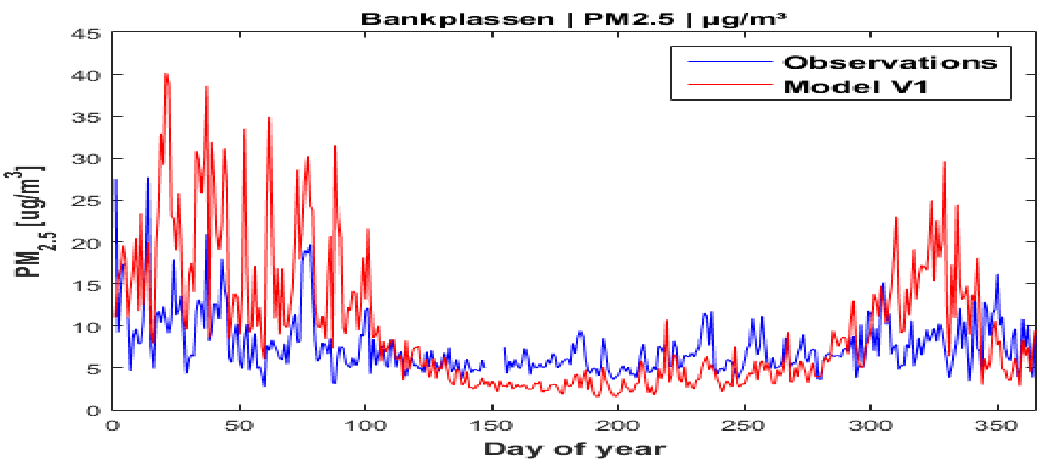


Figure A30: Timeseries with daily $PM_{2.5}$ concentrations in Bankplassen, Lillehammer. *Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]*

Lillehammer – Bankplassen and Barnehage stations

$PM_{2.5}$ – Lillehammer barnehage

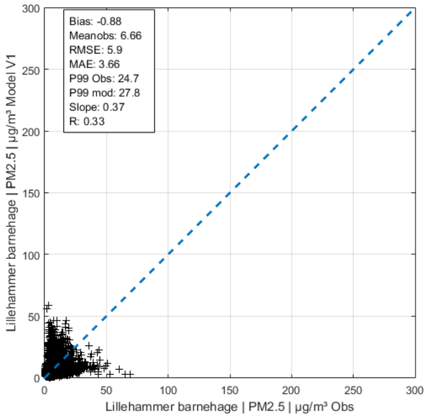


Figure A31: Scatterplot of modelled vs observed hourly values of $PM_{2.5}$ in Lillehammer barnehage station. Units: [µg.m^{-3}]

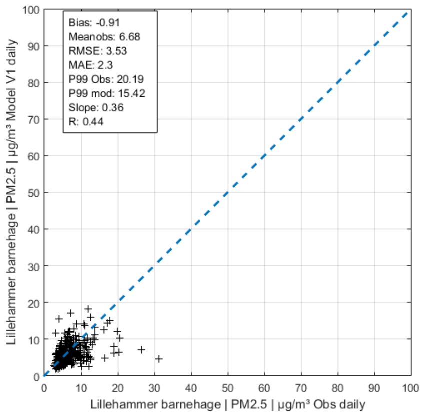


Figure A32: Scatterplot of modelled vs observed daily values of $PM_{2.5}$ in Lillehammer barnehage station. Units: [µg.m^{-3}]

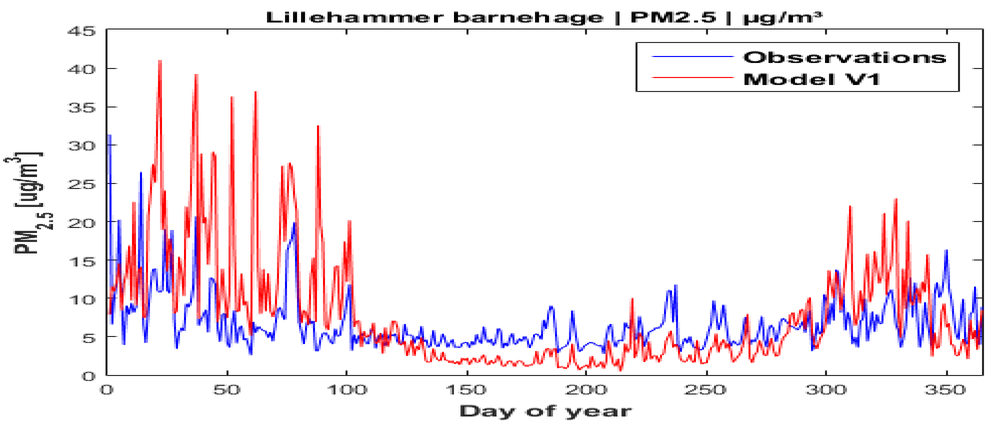


Figure A33: Timeseries with daily $PM_{2.5}$ concentrations in Lillehammer barnehage station. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

Mo i Rana – Moheia station

PM_{10}

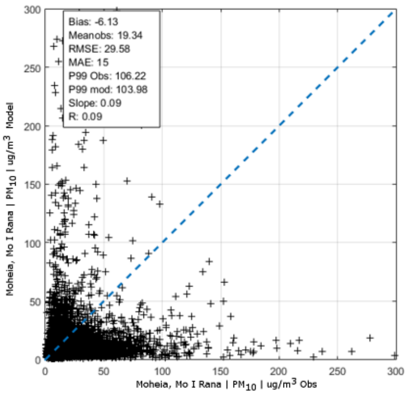


Figure A34: Scatterplot of modelled vs observed hourly values of PM_{10} in Moheia, Mo i Rana. Units: [µg.m^{-3}]

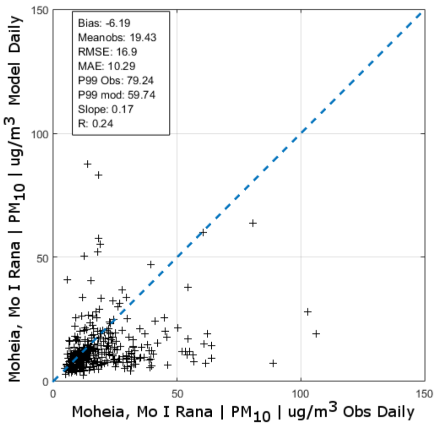


Figure A35: Scatterplot of modelled vs observed daily values of PM_{10} in Moheia, Mo i Rana. Units: [µg.m^{-3}]

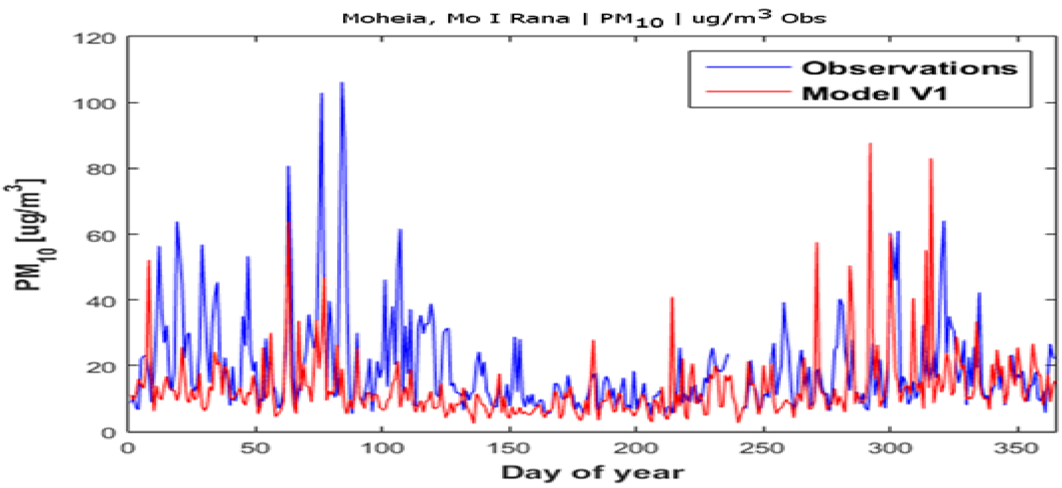


Figure A36: Timeseries with daily PM_{10} in Moheia, Mo i Rana. Modelled values for 2015 are given in red and observations in blue. Units: [µg.m^{-3}]

NILU – Norsk institutt for luftforskning

NILU – Norwegian Institute for Air Research is an independent, non-profit institution established in 1969. Through its research NILU increases the understanding of climate change, of the composition of the atmosphere, of air quality and of hazardous substances. Based on its research, NILU markets integrated services and products within analysing, monitoring and consulting. NILU is concerned with increasing public awareness about climate change and environmental pollution.

NILU's values: *Integrity - Competence - Benefit to society*
NILU's vision: *Research for a clean atmosphere*

NILU – Norwegian Institute for Air Research
P.O. Box 100, NO-2027 KJELLER, Norway

E-mail: nilu@nilu.no
http://www.nilu.no

ISBN: 978-82-425-2933-6
ISSN: 2464-3327

Norsk institutt for luftforskning
Norwegian Institute for Air Research