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Method for high resolution emission estimations from construction sites

Phase I: Mapping input data

Susana Lopez-Aparicio and Henrik Grythe

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PROJECT LEADER

Susana Lopez-Aparicio

NILU PROJECT NO.

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AUTHOR(S)
Susana Lopez-Aparicio and Henrik Grythe

QUALITY CONTROLLER

Claudia Hak

REPORT PREPARED FOR

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ABSTRACT

This report presents the results from exploring the available input data to develop a model for estimating air pollutants and GHG-emissions based on a bottom-up approach, including both exhaust and non-exhaust emissions. The availability of reliable input data is the limiting factor and the most critical part of designing such a bottom-up approach. In this study, we have focussed on assessing input data that allow defining; i) the exact location and area affected during building and construction; ii) the starting and finalization dates; iii) the type of construction activity; iv) the non-road mobile machinery (NRMM) activity within building and construction; v) roads in the vicinity of construction sites.

NORWEGIAN TITLE

Metode for høyoppløselige estimater fra byggeplasser

Fase I: Kartlegging av inngangsdata

KEYWORDS

Bottom-up Emissions
Construction Activity
Model development

ABSTRACT (in Norwegian)

Denne rapporten presenterer resultatene fra analyse av tilgjengelige inngangsdata for å utvikle en modell for estimering av luftforurensende stoffer og klimagassutslipp basert på en «bottom-up»-tilnærming, inkludert både eksos- og ikke-eksosutslipp. Tilgjengeligheten av pålitelige inngangsdata er den begrensende faktoren og den mest kritiske delen av utformingen av en slik «bottom-up»-tilnærming. I denne studien har vi fokusert på å vurdere inngangsdata som gjør det mulig å definere; i) den nøyaktige plasseringen og området som påvirkes under bygging og konstruksjon, ii) start- og sluttdatoer; iii) typen byggeaktivitet; iv) aktiviteter med ikke-veigående mobile maskiner (NRMM) innen bygg og anlegg; v) veier i nærheten av byggeplasser.

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Preface

This technical report is the final report of the EmSite project “Metodikkutvikling for finskala utslippsberegninger fra anleggsarbeid” (In English: Method development to estimate high resolution emissions from building and construction). The project is funded by the Norwegian Environment Agency, and started in August 2020.

The EmSite project aims at setting the basis for developing a model to estimate emissions from construction activity based on bottom-up principles; from the individual construction site to municipal and national level. In developing this emission model, as in all bottom-up processes, the most critical aspect is the availability of reliable input data. This technical report, therefore, focuses on mapping out and evaluating available data necessary to define emissions. The data can be divided in two parts in terms of the type of data they represent:

- The location, time reference and physical properties of historical and active building and construction sites.
- Machine activity on these sites that are responsible for emissions of air pollutants and greenhouse gases (GHGs).

The work has been carried out by Susana Lopez-Aparicio, who has also led the project, and supported by Henrik Grythe. We thank Scott Randall from the Norwegian Environment Agency (NEA) for his support, help and cooperation during the project. We thank all the municipalities that provided datasets on construction permits, insights and advice. Special thanks to Justus Fredrik Stelpstra from Trondheim municipality, for his support to understand construction permits and the centralization in national databases. This has been essential for defining the spatial and temporal location of construction activity in Norway. We would like to thank Magni Busterud and Nils Ivar Nes from the Norwegian Mapping authorities for their support discussing the “felles Kartdatabase – FKB” and “Matrikkelen”, in addition to preparing a dataset from “Matrikkelen” for this project. We would like to thank Randi Lekanger and Pablo Gonzalez from SKANSKA, for their support to get an understanding on the existing databases concerning machinery and the processes within a construction project. The quality control at NILU has been carried out by Claudia Hak. The report has benefited from the feedbacks and comments from Scott Randall, Tomas Siem and Christine Maass from the Norwegian Environmental Agency.

Contents

Summary

The interest in off-road transport and specifically non-road mobile machinery (NRMM), is increasing over time. At urban scale, NRMM associated with building and construction may constitute a significant source of air pollutants and greenhouse gases (GHG) emissions after road traffic and residential heating. However, building and construction activity is a very defragmented and heterogeneous sector, which shows important variability in space and time and heterogeneous activities that results in emissions.

Currently, and to our knowledge, no method exists to estimate and spatially distribute emissions from NRMM in building and construction based on the exact location where the construction activity takes place. Most of the methods rely on downscaling proxies based on population, building/road constructed area or land use data.

This report presents the results from exploring the available input data to develop a model for estimating air pollutants and GHG emissions based on a bottom-up approach, including both exhaust and non-exhaust emissions. This will allow to get a better knowledge on emissions at different scales, from individual construction sites to municipality and national level.

The availability of reliable input data is the limiting factor and the most critical part of designing such a bottom-up approach. In this study, we have focussed on assessing input data that allow defining:

- the exact location and area affected during building and construction;
- the starting and finalization dates;
- the type of construction activity;
- the NRMM activity within building and construction;
- roads in the vicinity of construction sites.

The exploration of available data has required to contact a wide range of potential data holders. These have ranged from planning and building agencies at municipality level, mapping authorities, private building and construction companies and / or associations of machinery in Norway. The wide range of data holders has been one of the challenges of this project. Within the timeframe, we have been able to identify and access input data to define one of the crucial variables, i.e., spatial and temporal location of building and construction activities in Norway over time.

The access to input data to define machine activity at individual sites and the NRMM fleet composition has been more challenging. Further communication and collaboration with data holders is required to get site-specific data to the purpose of individual site emissions. Based on ongoing communication with operators in the building and construction sector, the data exist and it comes down to practical issues to have them shared, as they can include sensitive company information. However, the bottom-up method can be developed even without these data if needed.

A model concept based on specific building sites and possibly also direct information on NRMM operating on the site, will constitute a significant advance from current state-of-the-art models. A bottom-up method for estimating emissions from NRMM in building and construction can be considered “one of its kind” on a country scale. A concept model of how to define historical and present emissions based on selected input data, along with further updates to improve representation of emission processes, is presented. The concept model is based on defining i) the spatial and temporal distribution of building and construction; ii) the machine demand per construction site; iii) the scaling up from site level to municipality and national level. The report also includes a discussion on the need to connect non-exhaust emissions from affected roads in the vicinity of construction sites.

Exploring Input data for emission model for building and construction

1 Introduction

The development of accurate emission inventories is essential to evaluate the progress towards emission targets set by the authorities. Moreover, reliable emission are essential input data for dispersion models, which thereafter are used to evaluate pollution levels, population exposure and to determine the effects of measures to comply with limit values established by air quality directives. Therefore, the accuracy of emission inventories is essential for monitoring and planning purposes concerning both air pollution and climate mitigation.

In order to apply emission inventories, emission estimations need to be developed at high spatial and temporal resolution. However, the development of such emission estimates poses important challenges, especially regarding data availability. The needed input data commonly exist, however, under the responsibility of different data holders and/or decentralized. The different datasets need to be combined and evaluated to assess that the emission process is properly represented and it allows for the characterization of the local scale. This challenge requests the collaboration between different experts and data holders, as emission experts, authorities and the private sector. The magnitude of this challenge varies from sector to sector. Hereby, traditionally studied sectors (e.g., on-road traffic) may pose less challenges than other sectors that have received less attention.

The displacement of industrial pollution sources away from urban areas over time has led to a change in the configuration of the main contributing sources to urban air pollution. Where heavy industries once were the main contributors to urban pollution, the most important sectors when assessing emissions at local scale currently are considered in Norway to be on-road transport and residential heating. These sectors have, therefore, received increasing attention from a regulative perspective, and consequently from the point of view of method development. As a consequence of this attention, emissions from these sectors (e.g., on-road transport and residential heating) have been better quantified. Other sectors, such as emissions from construction, are receiving more attention now.

In part driven also by climate mitigation efforts across all sectors, the interest in off-road transport and specifically NRMM is increasing. This is a very defragmented and heterogeneous emission sector, therefore keeping accurate and updated emission inventories has so far been a challenge. Viaene et al. (2016) stated that "*Compared to road traffic, the off-road traffic and machinery fleet is often more heterogeneous with more variable emissions. As the movement of the vehicles and sales of fuels are not comprehensively monitored at a local level and the activities are often outside the road networks, the estimation of the activity and emissions is challenging for off-road transport and machinery*". In this project we focus specifically on the emissions from NRMM at building and construction sites. In this work, we refer to "building and construction" as any physical activity that involves the demolition and/or erection of buildings (residential and non-residential), roads and / or infrastructures (e.g., water system, bridges, tunnels).

1.1 Emission estimates in Norway

In Norway, emissions to air of pollutants and GHGs are reported to the CLRTAP[1] and to the UNFCCC[2], respectively. Emissions are reported per sector, and exhaust from NRMM in construction are included

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[1] CLRTAP: Convention of Long-Range Transboundary Air Pollution

[2] UNFCCC: United Nations Framework Convention on Climate Change

as part of the subsector "*Mobile Combustion in manufacturing industries and construction*" (NFR[3] sector 1A2gvii), within the sector Energy Combustion (1A). Non-exhaust emissions in building and construction are reported in subsector "Construction and Demolition" (NFR subsector 2A5b). Based on the Informative Inventory Report (IIR) and the National Inventory Report (NIR) by the Norwegian Environmental Agency (NEA, 2019a; 2019b), exhaust emissions are calculated from fuel consumption. The fuel consumption is, for both CLRTAP and UNFCCC reporting, estimated following IPCC guidelines (IPCC, 2006), and thus based on the fuel sales, i.e., sales of petroleum products reported by Statistics Norway.

Exhaust emissions from NRMM are in Norway denoted as "motorized equipment", which comprises all mobile combustion sources except on-road, maritime, aviation and railways. Within the motorized equipment category, construction machinery is together with farming equipment the two main emitting sources, other smaller sources included are machinery used in mines and quarries, forestry, snow scooters, household equipment and recreational boats. Emissions from NRMM are thus split in the following subcategories in the official reporting of emissions;

- Manufacturing and construction (1A2g-vii; Figure 1);
- Commercial and institutional (1A4a-ii);
- Households (1A4b-ii);
- Agriculture/forestry/fishing (1A4c-ii);
- Military (1A5b).

Motorized equipment fuels include gasoline, bioethanol and tax-free auto-diesel. The latter one is an important key to define fuel consumption by NRMM as in Norway, as since 1994, auto-diesel used in off-road vehicles is tax-free. This allows to distinguish fuel sales for NRMM.

The spatio-temporal distribution of air pollutants and GHGs emissions in Norway is not part of the official yearly reporting. For both GHGs and air pollutants, a higher resolution than national level is required to evaluate individual mitigation measures and to evaluate the progress towards local emission targets. For air pollutants, high resolution emissions are also crucial to the assessment of local air quality and human exposure. In Norway, there are limited spatio-temporally resolved emission inventories for NRMM, and none that details construction activities. Regional or global emission inventories such as CAMS-REG-AP (Granier et al., 2019) are relatively coarse and inaccurate and they cannot be used to model air quality at urban scale.

Another source of spatial information is the accounting of GHGs emissions at municipality level by the Norwegian Environment Agency[4]. In this case, emissions from construction activity, which is included in "motorized equipment", are estimated by Statistics Norway based on the same methodology used for the official reporting of emissions. National emissions from NRMM are distributed to municipality level based on a distribution key described in NEA (2020). The distribution of emission is performed based on the delivery address of tax-free auto-diesel sales. When the delivery address is not available, the organization number of the fuel buyer is used and linked to the address of the company in the Business and Enterprise Registry. In the case the organization number is not available, emissions are estimated at county level and distributed at municipality level based on population. The fuel sales without i) delivery address; ii) organization number or iii) county information are not included in the GHGs emission accounting at municipality level. In many cases, the petroleum products sales do not occur to an end user but to a distribution company that received large quantities. The share sold to large distributors differs between 40 and 60% of total from 2009 to 2019. For large fuel distributors, the location of pumping stations for machinery diesel is used, along with information on the

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[3] NFR: Nomenclature for Reporting

[4] https://www.miljodirektoratet.no/tjenester/klimagassutslipp-kommuner/?area=618&sector=-2

distribution area of the company and population at the municipality level, to further distribute the fuel sales and therefore emissions. Population is not always a correct indication where the fuel is used. Therefore, there is a substantial uncertainty in which municipality a large share of the fuel is actually combusted.

Figure 1 top shows NO_x emissions in Norway from 1990 to 2018 from NRMM (1A2gvii), and for comparison we include NO_x emissions from off-road (GNFR[5] nomenclature: I_Offroad) and on-road sector (GNFR nomenclature: F_RoadTransport). Figure 1 bottom shows non-exhaust $PM_{2.5}$ and PM_{10} emissions from building and construction, and for comparison the exhaust PM_{10} emissions from NRMM in industry and construction. Figure 1 highlights that while combustion emissions are reduced over time, non-exhaust emissions are increasing. The activity behind exhaust and non-exhaust is mostly construction activity, the increase in non-exhaust emissions indicates the continuous increase in construction activity and therefore, it highlights the need for more attention to the construction sector. At the same time, the decrease in combustion emissions indicates the introduction of technological improvement in NRMM over time.

Figure 2 shows CO_{2eq} sector contribution in Oslo, Bergen, Stavanger and Trondheim. Emissions from motorized equipment ("annen mobil forbrenning" in the figure) constitute a significant source after road transport and energy production, and the maritime sector in the specific case of Stavanger. In Oslo and Trondheim municipalities, the contribution from motorized equipment reaches about 20% of total CO_{2eq} emissions in both municipalities. The high contribution shows the importance of improving the understanding of the emissions from NRMM in building and construction, and properly monitor the emission trends to evaluate the effects of mitigation measures being implemented at local level. A further evaluation of CO_2 emissions at municipality level based on fuel sales is included in this technical report (Section 2.2.1; "Fuel Sales").

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[5] GNFR: Nomenclature for Reporting Gridded emissions.

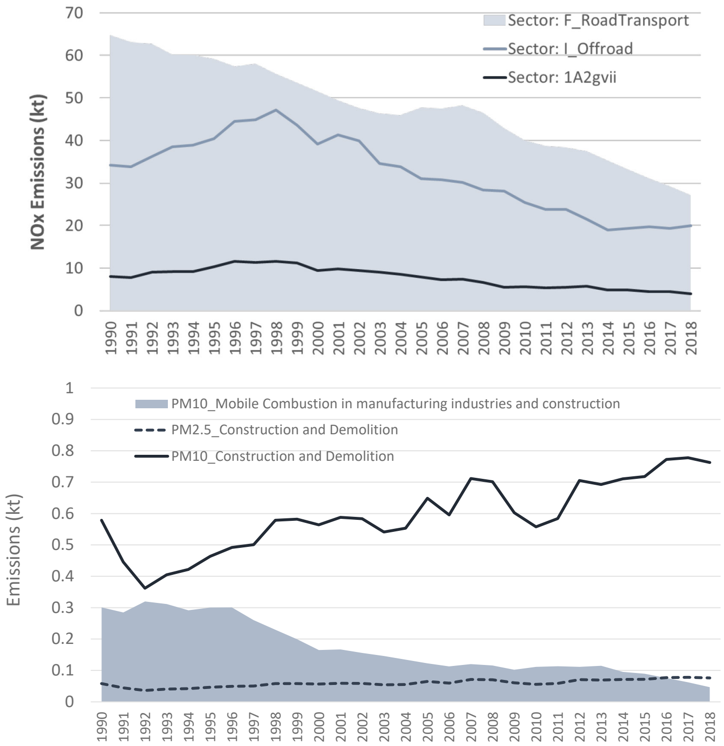

Figure 1: *Top: NO_x Emissions (kt) in Norway officially submitted to the CLRTAP for the sectors F_Road Transport and I_Offroad based on the nomenclature for reporting gridded emissions (GNFR), and for the subsector mobile combustion in manufacturing industries and construction (NFR sector 1A2gvii). Bottom: PM emissions (kt) submitted to the CLRTAP by Norway in construction and demolition (non-exhaust; sector 2A5B). Data source: EMEP CEIP*[6]*.*

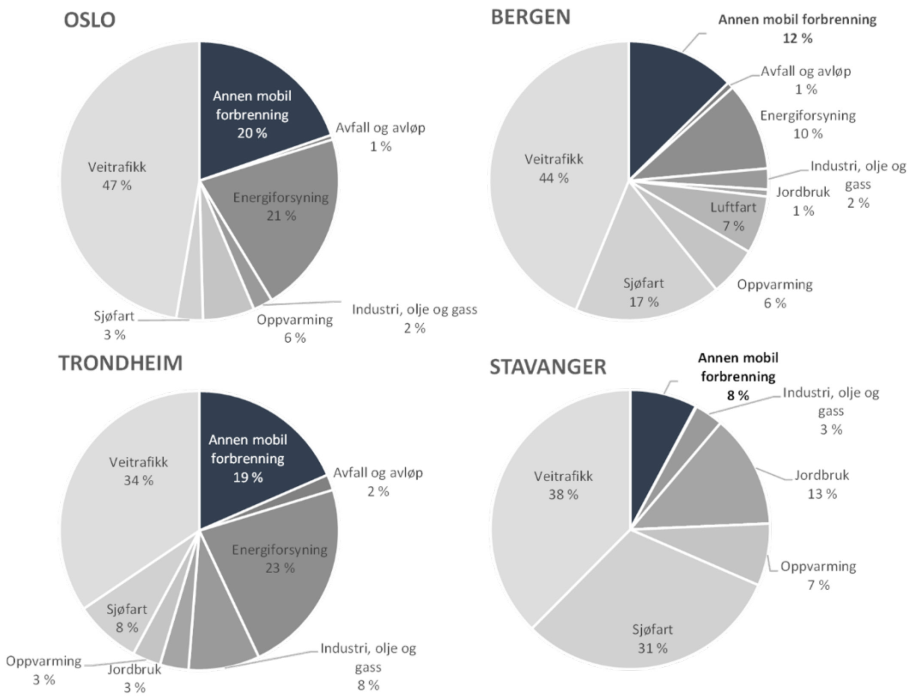

Figure 2: *Sector contribution to CO_{2eq} emissions in Oslo, Bergen, Trondheim and Stavanger. "Annen mobil forbrenning" = motorized equipment. Data source: Norwegian Environment Agency*[4]*.*

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[6] EMEP Centre on Emission Inventories and Projections; https://www.ceip.at/

1.2 Aim of the project

The overall aim of our study is to develop a concept model to estimate emissions (the following components are included: CO_2, BC, CH_4, NH_3, NMVOC, PM_{10}, $PM_{2.5}$ and NO_x) from construction activity based on bottom-up principles. Such a model will allow for estimates of emissions at different levels, i.e., from the individual construction site to municipality and up to national level. To our knowledge, there is no existing modelling approach that provides this information nor any prior assessment of comprehensive basis for its development. The most critical aspect for designing such an approach is the availability of reliable input data that allows defining the activity that generates emissions and their spatial and temporal distribution. In this first phase, the aim is to map the available input data, evaluate them and set up the basis for a potential bottom-up emission model for NRMM in building and construction.

2 Input data mapping

Following the workflow designed in this study and shown in Figure 3, the first step is the identification and collection of needed input data to define emissions from building and construction activity in Norway. This is split in data to define the spatial and temporal location of emissions (Figure 3; presented in Section 2.1), and data to define the activity that results in emissions (Figure 3; presented in Section 2.2). The different datasets are evaluated and we highlight the advantages and disadvantages of their use as part of a bottom-up methodology. This approach (step 3 in Figure 3) will allow scaling emissions from individual construction sites (Em_{ind}) up to municipality (Em_{mun}) and national level (Em_{Nat}). The section is structured in input data to determine i) the spatial location and temporal variation of construction activities; ii) activity data; and iii) specific input data to define non-exhaust emissions. The latter is an important source of PM and it is commonly neglected in the literature, therefore, we have decided to dedicate a specific section to it.

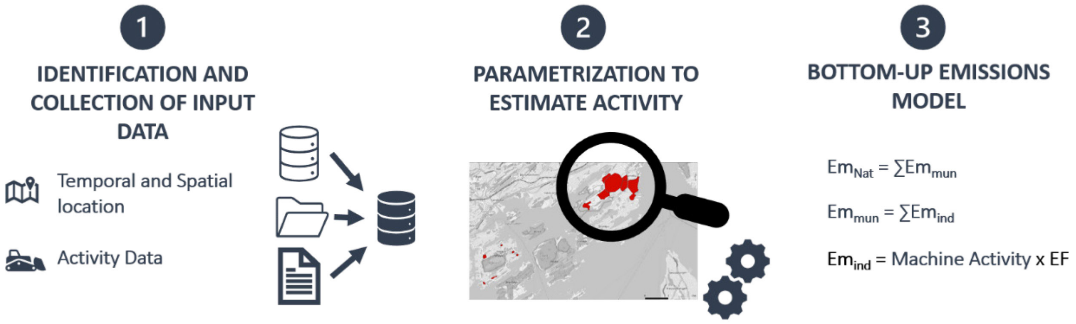

Figure 3: Workflow to define a bottom-up emission model to estimate emissions from construction activity.

2.1 Spatial Location and temporal variation of construction activities

2.1.1 Land cover data

Land cover datasets are commonly used as a key to downscale or distribute emissions from national level to higher spatial resolution. The approach is considered Tier 1 in the guideline for the spatial mapping of emissions by the European Environmental Agency (EMEP/EEA, 2019). Thus it is considered at the same low level of accuracy as using population as a distribution key.

For instance, CAMS-REG-AP regional emission inventory from Copernicus Atmosphere Monitoring Services uses total population to distribute emissions from NRMM used in industry and construction activities (Kuenen et al., 2014). A similar example is the bottom-up module of HERMES, which uses CORINE Land Cover land use data to distribute emissions from NRMM used in the agriculture sector (HERMES does not include NRMM in building and construction; Guevara et al., 2020a). One of the main disadvantages of using land cover data is that it does not properly capture the variability and unpredictable pattern associated with construction activity, and therefore the associated emissions. This is visualized in Figure 4, which shows the CORINE land cover data around Oslo fjord, where the land use category (Category 1.3.3. Construction sites) corresponding to construction site is highlighted in red colour. No land use areas in Oslo or surrounding municipalities are classified as construction, and therefore the use of land use data would involve that no emissions from construction activity would be allocated to these municipalities (Figure 4).

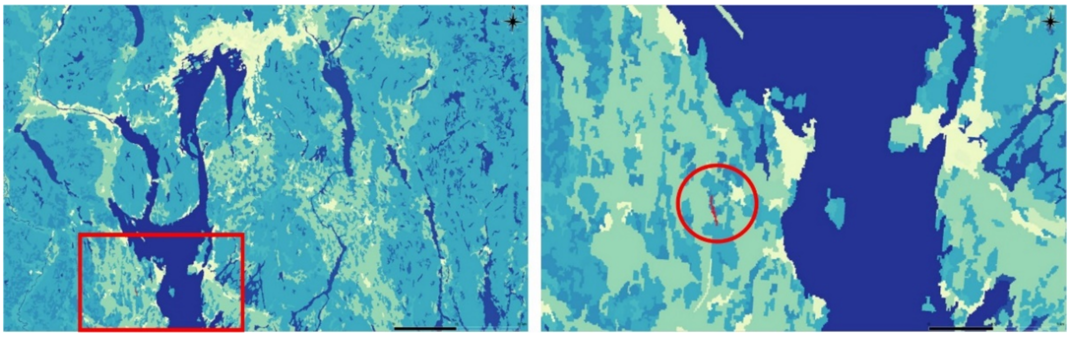

Figure 4: CORINE land cover data. All categories are visualized in yellow-blue tones except construction which is visualized in red. The right figure represents a zoom-in of the red square in the left figure, where one of the few land use classified as construction is highlighted (red circle).

Even though European scale land cover data such as CORINE does not capture the level of detail required for construction activities, another available land use dataset at higher resolution has been evaluated. Figure 5 shows the functional urban areas (FUA) defined in the Urban Atlas for Greater Oslo from Copernicus Land Monitoring Service. The FUA dataset is a very high-resolution land use and land cover dataset extracted from very high resolution satellite imagery combined with in-situ data. The temporal resolution is annual for the years 2006, 2012 and 2018 (being processed when writing this report in the case of Oslo and Stavanger), and the spatial resolution is represented by polygons with a minimum mapping unit of 0.25 ha and 1 ha in urban and rural areas, respectively. The accuracy of the overall classification is above 80 and 85% in rural and urban classes, respectively.

The higher level of detail observed in the FUA dataset contrasts with CORINE land cover data, as it shows construction sites in both urban and suburban areas. The results of using in-situ data, in combination with satellite information, show the importance of using in-situ information to produce high spatial resolution information needed for urban studies. However, the use of the FUA dataset to define the spatial and temporal distribution of construction activity presents important disadvantages for the aim of our study. The temporal resolution is rather coarse (2006, 2012 and 2018) and the dataset does not cover the entire Norway. It is available for areas covering several municipalities around Oslo, Kristiansand, Stavanger, Bergen, Trondheim and Tromsø (Figure 5). This dataset could be used to cross evaluate other datasets available for the corresponding FUA years.

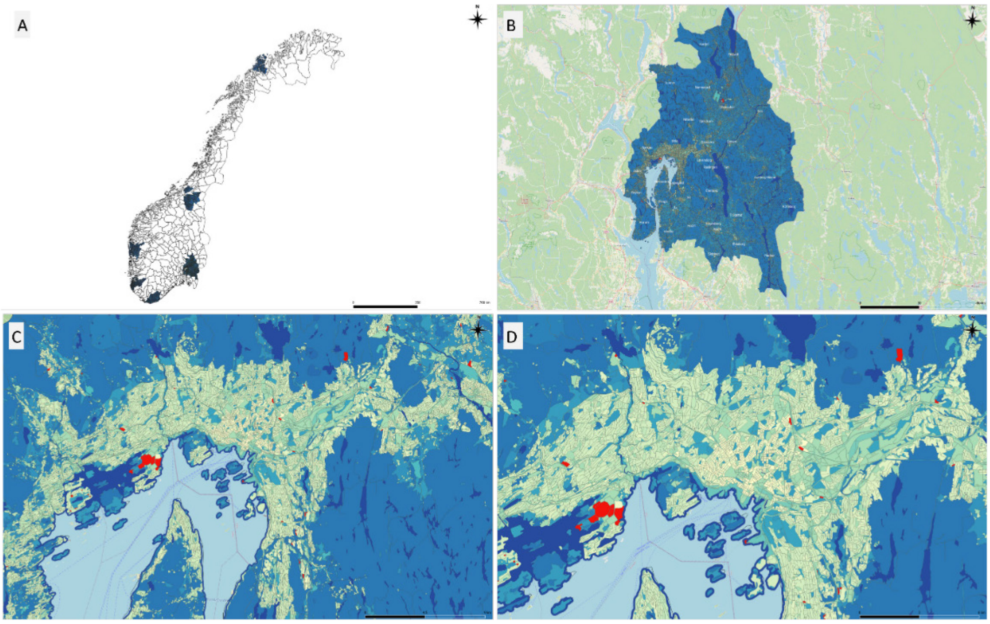

Figure 5: Functional urban areas (FUA) defined in the Urban Atlas for Oslo, Kristiansand, Stavanger, Bergen, Trondheim and Tromsø and municipalities around them (A). B shows the Urban Atlas for Oslo and municipalities around. C and D show two zoom in levels in Oslo, where areas classified as construction sites are indicated as red.

2.1.2 Construction permits

Construction permits from municipalities

Construction permits are official approvals issued by the municipalities that allow private persons or contractors to proceed with a construction project. The first steps that we followed, concerning construction permits, was to contact selected planning and building agencies at municipalities in Norway. Based on this communication, we evaluated the possibility of accessing geo-reference information that allows the spatial and temporal localization of construction projects. We have been given access to construction permits in 14 municipalities in Norway, including some of the most populated areas (i.e., Oslo, Bærum, Trondheim, Midtre Gauldal, Melhus, Skaun, Malvik, Stjørdal, Indre Fosen, Orkland, Kristiansand, Songdalen, Søgne and Lørenskog). In most of the cases, the construction permits datasets cover long time series, include the geographical location of the construction project and provide additional information on the type of construction project. The most important identified challenge is that each municipality uses its own unique system to register the information; some datasets provide information on the starting and finalization of the construction project whereas in others this information is missing. In addition, the datasets are in different formats (e.g., shapefiles, pdf, excel) and the attribute information is not consistent across the datasets.

The left part of Figure 6 shows as an example areas for which construction permits were issued, extracted from the dataset obtained from City of Oslo Planning and Building Services. The dataset contains, among other information, the following:

- case number, which provide the year when the permit was issued;
- Title
- Type of project and corresponding code
- Finalization date.

With regards to the type of projects, they are classified in 26 different types including changes/reparation of the building technical installations, changes in façade, construction of parking places, demolitions, construction of roads, new building, among others. The classification of construction projects will allow us to filter those projects that involve air pollutant and GHGs emissions. For instance, modifications of existing buildings and / or façades will not involve emissions or will be negligible, whereas construction of new buildings will. Another example of dataset is shown in the right part Figure 6, which shows the issued construction permits in the Greater Trondheim region from 2017 to 2020. The dataset covers Trondheim, Midtre Gauldal, Melhus, Skaun, Malvik, Stjørdal, Indre Fosen and Orkland municipalities. Similar information than that in the previously described Oslo dataset is available for the Greater Trondheim region (i.e., type of construction project and finalization date of the construction or when the building comes into use). Information on the duration of the construction project is only available for Oslo municipality and those in the Greater Trondheim area.

Figure 6: Construction permits issued in Oslo municipality in the period between 2000 and 2020 (left) and in the Greater Trondheim area in 2017-2020 (right).

National registries
Together with the national company registry ("*Brønnøysundregisteret*") and the population registry ("*Folkeregisteret*"), the building registry ("*Matrikkelen*") is one of the three official registries in Norway. "Matrikkelen" is a national registry that contains data on all buildings in Norway. Data from "Matrikkelen" is, as the official building registry, used for issues from legal disputes to applications for land-use changes and by rescue agencies. Most importantly, "Matrikkelen" contains information on building size, building history via the regulatory process (e.g. granted permits) and so provides information on where and when all buildings were constructed. It also contains all active building permits and the various stages of the legal process of completion. This means that "Matrikkelen" gives data on when construction of all buildings in Norway was completed, where the buildings are, and when building start was permitted. Therefore, "Matrikkelen" constitutes an important source of information to define building construction, both historical and in the present.

Matrikkelen is accompanied by several datasets which also fall under the responsibility of Norwegian mapping authorities, "*Kartverket*". These accompanying data have information on ownership (*Grunnboken*) and other physical, predominantly land surface structures. Of the available databases, the common map database "*Felles Kartdatabase"* (FKB) contains most of the information from "Matrikkelen", and also takes in other types of constructions from other databases. A part of FKB is called "FKB_Tiltak", which contains ongoing construction activities. However, based on communication with "Kartverket", this dataset needs to be carefully considered as it is not official, can have differences across municipalities in how it is managed and may contain erroneous entries.

For the purpose of placing building and construction sites in Norway in time and space "Kartverket" recommended "Matrikkelen" to be used for placing both current and past building sites through the building history of individual buildings. However, this requires custom retrievals to be done by "Kartverket" as building history is not published in a suitable way. Frequent downloads would be required to keep it updated and there will be a need to set up an agreement with "Kartverket" to set these retrievals. As an alternative, it is also possible to buy the data from private companies that have agreements with "Kartverket" and can do these retrievals.

At the time of writing, only a partial custom retrieval of "Matrikkelen" from Kartverket was available, so we used "FKB-Tiltak", which was fully available for assessment. As it contains much of the same data for ongoing constructions this should not be of major consequence. The "FKB-Tiltak" is used for the processing of administrative cases by municipalities or agencies, on issues related to regulation by the Planning and Building Acts, design, analysis or in the production of maps. The "FKB-Tiltak" contains objects that have been registered at the municipality for their processing after the Planning and Building Act and other legislations, i.e., construction permits. The database therefore contains objects that are undergoing change (Geonorge, 2020). As soon as the alteration (construction / expansion / demolition) is finalized, it is transferred to the corresponding FKB database that cover constructions of different types (e.g., "FKB-Bygning"). Figure 7 shows current "FKB-Tiltak" data in the southern part of Norway and zoom in the area of Oslo. Buildings are shown as polygons in the map, covering the construction footprint. One advantage over the dataset acquired directly from the municipalities is that the construction permits are represented by polygons instead of points. This will facilitate the accurate identification of the areas subjected to construction activity and where the machine activity must be placed.

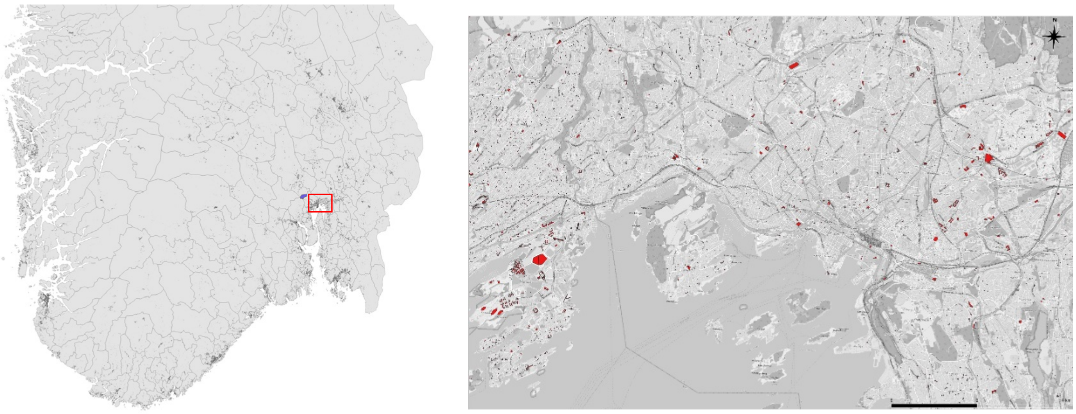

Figure 7: Visualization of "FKB-Tiltak" dataset in the southern part of Norway (left; each dark polygon represents a construction permit) and a zoom in the urban centre in Oslo (right; red polygons represent construction permit). The red square on the left figure represents the zoom in on the right.

The attributes available in the "FKB-Tiltak" provide several important information details for calculating emissions from each construction project. Most importantly, the date and type of permission granted (i.e., building, construction, installation, intervention of the terrain, division, emission, road/traffic and others). Table 1 shows the permission categories in "FKB-Tiltak" along with the code-number it has in the geo-data. Relevance in Table 1 indicates which permissions involve emissions of air pollutants and GHGs. By number of data, 60% are construction of new buildings covering similar total areas of around 35 km^2. Similarly, construction of roads or parking lots constitutes around 0.1% of the data, covering an area of around 1 km^2 and length of around 176 km.

One issue with ongoing construction is that the finalization date is generally unknown. To obtain accurate time for activity and emissions, the progression of a site where active alteration is in place must be known or assumed. For ongoing construction, the appearance (a new construction site) or disappearance (building no longer has ongoing construction) in "FKB-Tiltak" can be found by comparing retrievals from different times. Figure 8 shows the "FKB-Tiltak" retrieved in September 2020 (red colour) and in November 2020 (yellow colour). As indicated previously, as soon as a building or infrastructure comes into use, the object disappears from the "FKB-Tiltak" database and moves to the corresponding FKB database. Figure 8 A and B show buildings that were present in the September dataset (A) are absent in the November dataset (circle in B). In this case, a new building (Code 21) and an expansion of an existing building (Code 23) have been finalized and came into use. The changes in the data can therefore be used to determine the finalization date of construction projects with as high resolution as consecutive downloads of the FKB data is done. Figure 8 also shows the initialization of new projects, as the construction of new buildings appears in the November dataset (circle in D), while it was absent in September 2020 (C). The comparison of datasets retrieved at different times allows monitoring changes in construction activity.

Based on the analysis presented here, both "Matrikkelen" and "FKB Tiltak" are suited for defining the location of construction of buildings in both time and space. Based on communication with Kartverket "FKB-Tiltak" is probably the best way forward, as several continuous retrievals from "Matrikkelen" over time takes considerably more effort.

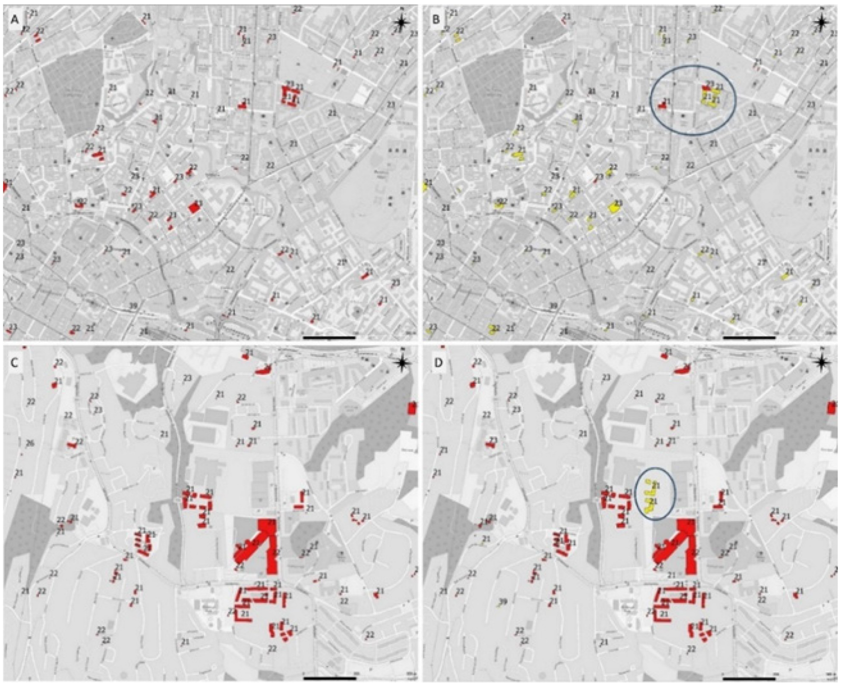

Figure 8: *"FKB-Tiltak" retrieved in September 2020 (red) and "FKB-Tiltak" retrieved in November 2020 (yellow). The numbers represent the type of permit. We refer to Table 1 for the code numbers (e.g., 21: New building). Figures A and C shows only the September retrieval. Figures B and D show both September and November.*

Table 1: *Types of measures provided in the "FKB-Tiltak" database and the corresponding code. Relevance: for emissions*

Name in English	Code	Relevance
Work requires building permit	10	
New building / extensions / infrastructure, construction	20	Yes
New building	21	Yes
Building Extension	22	Yes
Building Expansion	23	Yes
Building Underground structure	24	Yes
Structure	25	Yes
Remodelling	26	
Changes/Reparation of façade	30	
Changes in façade	31	
Reparation	32	
Use changes / expansion / Operation change	35	
Demolition	39	Yes
Changes/Reparation of building technical installation	40	
Lift, escalator	41	
Ventilation system	42	
Joining of utility units in residences	45	
Fencing, signs, advertising, etc	50	
Fence	51	
Wall	52	
Noise Barrier	53	
Signs	54	
Division of property	60	
Boarder line	61	
Boarder adjustment	62	
Land transfer	63	
Significant terrain intervention	65	Yes
Terrain filling	66	Yes
Terrain removal	67	Yes
Road construction, parking lots, etc	70	Yes

Table 1: (Continued)		
Road, parking	71	Yes
golf field, riding field	72	
Other decisions	80	
Authorization for entry to road network	81	
Authorization for closing access to road network	82	
Emission permit	83	

2.1.3 Locations of road construction

The construction of main roads is one of the most NRMM demanding activities and thus important for emissions within the construction sector. The use of heavy machinery is especially intensive when moving ground material but heavy machinery is used for most of the construction process. Whereas "FKB-Tiltak" in part has these data, several issues were identified regarding completeness of non-building structures (e.g., road construction absent in some municipalities). As "Matrikkelen" can only be relied on for buildings, the input data that define road construction must be sourced in from elsewhere.

Information on the construction of roads is available in the National Road Database (NVDB) managed by the Norwegian Road Administration. Figure 9 shows geo-referenced road construction projects based on a retrieval in November 2020, the retrieval contains 345 roads construction projects. Road construction is categorized in different types of projects. Around 91 km of 1 300 km of roads in NVDB are attributed as construction of new roads, which are ongoing or has been finalized in 2020. Additional information on the starting and finalization dates (or planned finalization time for ongoing projects) is attached to each. Only 2 out of 345 road construction projects are dated as finalized before 2018. Therefore this retrieval cannot be relied on for historical road construction projects. It also seem to be several key road construction missing from the data (e.g. E18 south). This information has to be supplemented by additional ancillary data or methods.

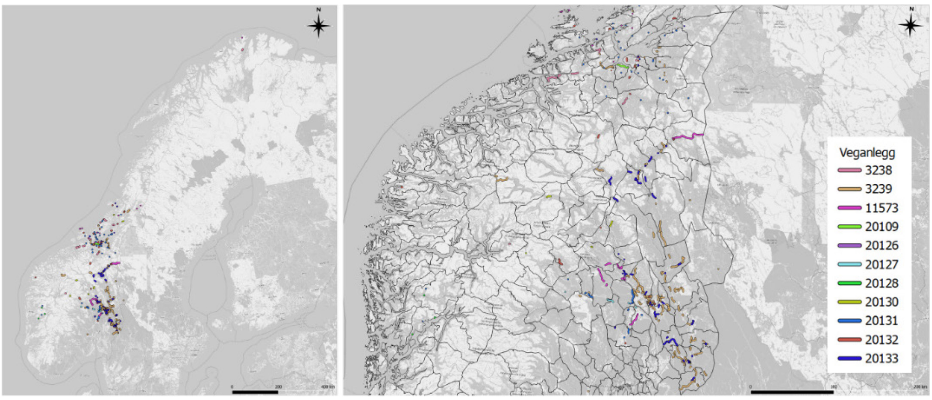

Figure 9: Road construction work in Norway retrieved in November 2020. Source: National Road Database (NVDB) from the Norwegian Road Administration. Types of road construction work: New road construction (3238), road reparation (3239), road maintenance (11573), tunnel upgrade (20109), road lighting (20126), side road infrastructure (20127), signal and marking (20128), landslide protection (20130), road safety measure (20131), construction of sidewalks / bike lanes (20132), other types of project (20133) and green infrastructure, environmental type of projects (not shown in figure).

2.2 Activity data

Input data that define the actual NRMM activity on a building and construction site is needed to estimate emissions. Also other activities affect emissions from a site, such as heavy road vehicles that move materials on and off sites. In this section, we first evaluate fuel sales that are used for official reporting of emissions in Norway to international conventions (Section 2.2.1). These data are also distributed spatially to municipality level for GHGs emissions. Then, other potential data sources that can be used to calculate emissions of individual sites (Step 2 in Figure 3) are described. The latter is defined in this report as “machine activity” and it is described in Section 2.2.2.

2.2.1 Fuel sales

National emissions from NRMM and GHGs emissions at municipality level are estimated by Statistics Norway based on petroleum products sales statistics, and specifically the category tax-free diesel. The distribution at municipality level is hierarchically based on delivery address of the sales, the organization number of the fuel buyer and population, (see more details in Section 1.1 “Emission estimates in Norway”; NEA, 2020). In addition, the location of pumping stations for NRMM diesel, distribution area of large fuel distribution companies and population at the municipality level are used to further distribute the fuel sales in the case of large distribution companies (NEA, 2020). At the national level, around 48% of the fuel is distributed based on the end user information, whereas 52% is distributed based on fuel sales to large distribution companies. Both the input data and the method behind the distribution involve significant uncertainties (NEA, 2020).

Figure 10 shows as example the sales of tax-free diesel and other fuels (i.e., Liquified Petroleum Gases-LPG, Liquified Natural Gas-LNG, amongst others) to the building and construction sector in 2019 and at county level. The distribution is based on the address of the fuel buyer. The use of this data to develop a model for high-resolution emission modelling for building and construction poses important challenges. First, sales figures do not represent where the fuel is used. Also in counties with intense commercial activity such as Oslo, which is both county and municipality, fuel sales can occur to Oslo, but thereafter the fuel is used in for instance the surrounding municipalities. In addition, and based on our understanding, Figure 10 does not include the fuel acquired by large fuel distribution companies.

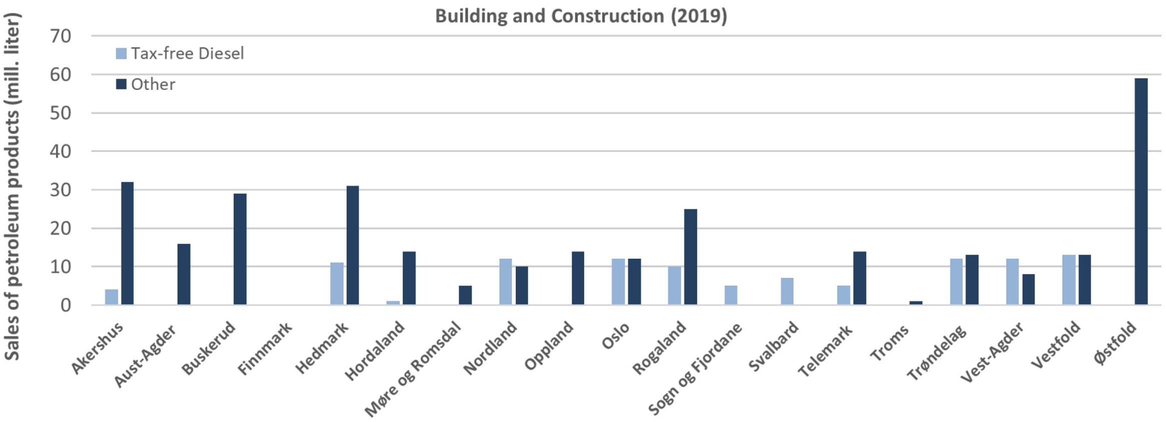

Figure 10: Sales of tax-free diesel and other fuels (million liters) to the building and construction sector in 2019. Data source: SSB (Table 11174; SSB, 2020b).

We have compared the CO_2 emissions from motorized equipment at municipality level estimated by SSB with the building area at the municipalities for the same year. It is important to bear in mind that the CO_2 emissions include NRMM in construction and tractors as main sectors along with other minor sectors. Therefore, it does not represent exclusively the NRMM in building and construction. We assume that construction activities experience higher variability in space and time than for instance those activities where tractors are used (e.g., agriculture). However, this can be a point of uncertainty in this assessment.

The hypothesis behind this comparison is that the amount of area built at the municipality would largely explain the amount of CO_2 emissions associated with building and construction. In this way, we used data available from Statistics Norway that represent the building utility floor area (m^2) both completed and started at municipality level (SSB, 2020c; 2020d). The latter is included as emissions during building and construction are considered higher in the initial phases of the construction project, when heavy machinery is used for removal of ground material and preparation. We consider both dwelling and non-dwelling buildings in order to better represent most of the area subject of building and construction work. We have not been able to include the area associated with road construction as information for the year 2018 (latest available emissions) was not available at the moment of writing this report. The building area data is also currently used in the official reporting of non-exhaust emissions in construction and demolition (NEA, 2019a). Likewise, it is used in other countries to distribute emissions from NRMM in construction at grid level (e.g., Plejdrup et al., 2018).

Figure 11 shows the comparison of CO_2 emissions from motorized equipment and building area, both at municipality level, and the CO_2 emissions residuals (i.e., difference between reported CO_2 and predicted by the linear regression). The comparison shows a strong correlation between building area and CO_2 emissions at the municipalities ($R^2 = 0.81$), so the building area can explain a significant part of the CO_2 emissions associated to building and construction. However, this is very much driven by Oslo, Trondheim and Bergen with the highest activity. When we removed these municipalities, the correlation was significantly reduced ($R^2 = 0.49$). The residuals indicate both higher and lower emissions than those predicted by the building and construction area. In some municipalities, the construction activity predicts CO_2 emissions 200-250 kt higher than those estimated based on fuel sales. This was the case for Lørenskog, Sandnes, Bærum and Vestby. As previously explained, this analysis has to be taken carefully as CO_2 emissions include other minor sectors (e.g., tractors) and the area associated with road construction is not included.

A similar assessment was carried out to evaluate to what extent the yearly variation in CO_2 emissions can be explained by the yearly variation in building area. In this case, we consider separately completed building and started building activity to avoid double counting (e.g., building and construction that started one year but finalized the year after). This assessment has been done for the 3 most populated municipalities; i.e., Oslo, Trondheim and Bergen, and the years for which emissions at municipality level are available (2009, 2011, 2013 and 2015-2018). The results are shown in Figure 12.

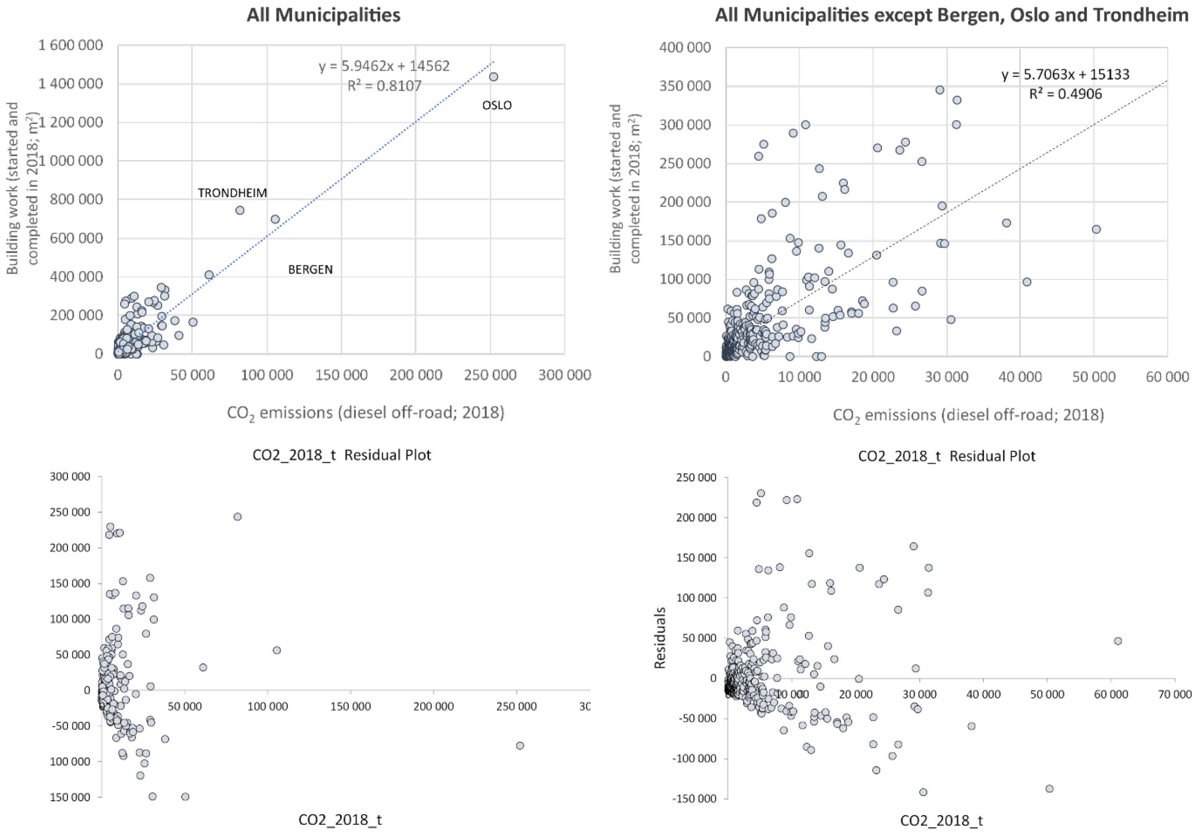

Figure 11: *CO_2 emissions from motorized equipment at municipality level in 2018 and building work started and completed in 2018 expressed in m^2. Number of municipalities = 356. Left figures: all municipalities. Right figures: all municipalities except Bergen, Oslo and Trondheim. The bottom figures represent the corresponding CO_2 residuals. Data Source: SSB (Tables 05939 and 05940; SSB, 2020c, 2020d) and CO_2 emissions from the Norwegian Environment Agency[4].*

The trends of CO_2 emissions from motorized equipment in Oslo, Trondheim and Bergen do not correlate with the building area in neither of the municipalities when considering started nor completed building area (i.e., $R2_{OSLO}$ = 0.11-0.11; $R2_{TRONDHEIM}$ = 0.01-0,02; $R2_{BERGEN}$ = 0.35-0.01). It is important to bear in mind that the methodology to estimate CO_2 emissions at municipality level varies between Oslo and the other two municipalities. Oslo is municipality and county, therefore, it does not require a downscaling process from county to municipality, as in the case of Trondheim and Bergen, when the delivery address of the fuel is not available. Even though there is no correlation, the building area in Oslo seems to reproduce the peaks observed in CO_2 emissions in 2013 and 2018, as the largest started building area corresponds with the year that precedes the highest CO_2 emissions (Figure 12) and the largest value of completed building area (Figure 12). In Trondheim, however, the CO_2 emissions trend is inconsistent with the building area variation. Whilst CO_2 emissions show a continuous increase since 2013 to 2018, the building area does not. Trondheim shows a peak in completed building construction activity in 2013, and seems approximately constant since then. In Bergen on the other hand, low CO_2 emissions in 2009 and 2011 seem to correspond to low building construction area, however, the same building area in 2018 does not correspond with the emissions in 2018 which are the highest.

The data of building area is from Statistics Norway and based on the information from “Matrikkelen”. Therefore, we can assume that this data has the same accuracy as “Matrikkelen”. Based on the previous comparison (Figure 11) and the trends variations of emissions (Figure 12), the methodology used to estimate CO_2 emissions at municipality level does not seem to provide consistent results across municipalities, nor to reproduce the yearly variations observed in building and construction area.

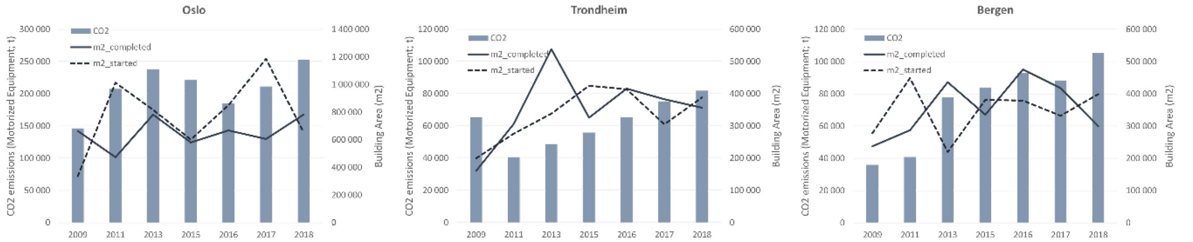

Figure 12: CO_2 emissions from motorized equipment (t) and started/completed building area (m^2) in Oslo, Trondheim and Bergen. Data sources: CO_2 emissions at municipality from[4]; started and completed building area (utility floor space) from SSB (2020c, 2020d).

2.2.2 Machine activity

Understanding the machine usage per construction site is essential to define a parametrization that allows us to estimate activity at the construction project level, and up to municipality and national level (Step 2 and 3 in Figure 3). One avenue we have followed in this first phase has been to contact several construction companies to discuss data availability and the possibility for establishing data sharing practices. Based on communication with one of the biggest construction companies in Norway, databases are available with all relevant information on each construction project. This includes the number and types of NRMM used per construction project and fuel consumption, among other variables. In addition, construction companies use calculators or construction management tools to estimate the machinery demand for a specific construction project before a project start. This type of calculators are used for the preparation of projects and cost estimates. Also internal data is kept on machine use on completed constructions which could be used directly or used to estimate ongoing projects. At the moment of writing, no access to such databases or calculation methods have been forwarded, waiting further internal communication in the construction companies.

There exist also commercial products for calculating machine demand for a specific build. ISY Calculus by Norconsult[7] is a tool designed to calculate, among other things, climate gas emissions from constructing a building (both Life Cycle Assessment and direct emissions) in Norway. It is based on Norsk Standard (NS 3420) governing system for construction of buildings in Norway. Commercial software such as ISY Calculus would provide similar information as the internal calculator the larger companies could provide.

The overall objective of using such databases or construction management tools from construction companies is to define machinery demand (number and type) per construction project (e.g., per m^2 of construction) based on statistical analysis. The analysis of such machinery usage databases will allow in addition to establish the type of machinery used, e.g., NRMM used for ground work (i.e., excavators and piling machines) or NRMM used for construction work (i.e., mobile cranes, lift or tower cranes, which are commonly electric).

Details about the type of construction project are also essential, as the number of NRMM and the operating time largely depends on the complexity of the construction project (DNV, 2017). As such, a simple project with basic ground work would require a couple of excavators during few months, whereas more complex projects would require additional NRMM machines to for instance replace ground material or piling. In addition, the number and machinery demand on a building construction project would differ from those in a road construction.

In addition to NRMM usage, information of the characteristics of the NRMM fleet composition is needed. Accessing NRMM usage databases and evaluating alternative data sources requires more time

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[7] https://www.nois.no/produkter/prosjektstyring/isy-calcus/

than the timeframe of this project has allowed. Section 4 ("Further steps and Recommendations") of this report describes further needed steps.

2.3 Specific data for non-exhaust emissions

This section describes the input data needed to estimate non-exhaust emissions from building and construction sites. Construction sites constitute also a significant source of non-exhaust particulate matter that then is brought to the road. The part of the non-exhaust emission process taking place on roads, needs to be further evaluated (See Section 3 "Concept Model" and Section 4 "Further steps and Recommendations").

The amount of PM emissions from construction activity is proportional to the affected area and to the level of construction activity (US EPA, 1999). Based on the EMEP/EEA guideline (2019), non-exhaust emissions (EM_{PM10}) from construction and demolition work can be estimated based on a tier 1 approach as follows:

$$EM_{PM_{10}} = EF_{PM_{10}} \times A \times D \times (1 - CE) \times \frac{24}{PE} \times \frac{S}{9\%}$$

where EF_{PM10} is the non-exhaust emission factor (kg PM_{10} / (m^2 * y)), A the area affected by the construction activity (m^2), D the duration of the construction or demolition work (year), CE the efficiency of the construction measure, PE the Thornthwaite precipitation-evaporation index and S the soil silt content (%). The area and duration of the construction work can be obtained from the input data defined in Section 2.1 ("Spatial Location and temporal variation of construction activities"), as both parameters would be the same for exhaust and non-exhaust emissions. The soil silt content at specific locations in Norway can be defined based on soil maps. Figure 13 shows as an example the soil maps from Oslo municipality obtained from the Geological Survey of Norway (NGU), where maps are available for all municipalities in Norway. The maps represent the prevalence of soil types covering the bedrock material and are commonly used for land use and environmental planning. A silt content can be attributed to each type of soil based on the recommendations from EMEP/EEA Guideline (EMEP/EEA, 2019) and shown in Table 2.

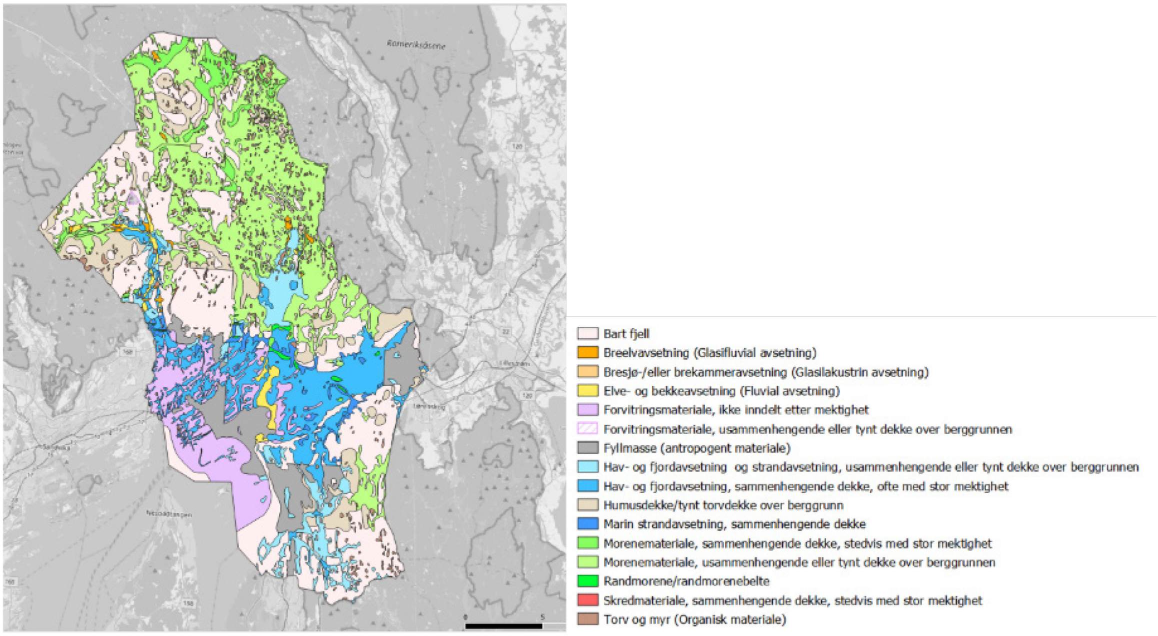

Figure 13: Soil map for Oslo municipality. Source: NGU.

It is important to bear in mind that the use of soil maps can lead to an overestimation of emissions as, during construction process, the removal of unstable soils and substitution for more stable ones is a common practice. For instance, loams or clay soils are materials rich in silt but unstable to build upon, therefore they are substituted by sand during the construction process. In cities, moreover, soils are usually anthropogenic, mostly sand (12% silt content). Evaluating the soil maps available through NGU, anthropogenic soils are well characterized ("Fyllmasse" in Figure 13).

*Table 2: Silt content (%) per type of soil. Source: EMEP/EEA guideline (EMEP/EEA, 2019). *US EPA (1999).*

Soil Type	Silt content (%)
Silt loam	52
Sandy loam	33
Sand	12
Loamy sand	12
Clay	29
Clay loam	29
Loam	40
Organic Material*	10-82

Regarding CE, if lacking in-situ data, US EPA (1999) recommends 50% control efficiency for road and non-residential construction activity and 0% control efficiency for residential construction. The Thornthwaite precipitation-evaporation index is used to account for the soil moisture content, which can be estimated based on:

$$PE_{index} = 3.16 \sum_{i=0}^{12} \left(\frac{P_i}{1.8T_i+22}\right)^{\frac{10}{9}},$$

where P_i is the monthly precipitation (mm) and T_i the monthly mean temperature (°C). Both monthly precipitation and mean temperature can be obtained from openly available data e.g. the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis fields at a 0.1° x 0.1° resolution.

2.4 Emission factors

The selection of emission factors will be done in further steps of the model design process and in close communication with the Norwegian Environment Agency. The selection will depend on the activity data, e.g., fuel consumption or annual operating time of NRMM. Currently, emission factors established by Winther and Nielsen (2006) are used for the official reporting of emissions in Norway. The emission factors are weighted by the age and engine rating distribution of the construction machinery population, assumptions on motor load and operating hours, and the introduction scheme for emission regulation by the European Union (Stage I, II, III and IV).

3 Concept model

Several different methods are commonly used in Europe to estimate and spatially distribute emissions from NRMM in building and construction. The methods differ in quality and largely rely on data availability. In Denmark, emissions are estimated based on the number and types of machinery registry and corresponding emission factors, among other variables. The spatial distribution takes into account that large machinery is commonly used in road and building construction, whereas smaller machinery is used in maintenance work (Plejdrup et al., 2018). Then, a geographical distribution key is created as a combination of four different distribution keys which contains i) the share of total new-built square meters per 1 km x 1 km grid cell based on number of new-built square meters at municipality level from Statistics Denmark; ii) the share of the construction road length for major road construction projects per 1 km x 1 km grid cell based on data from the Danish Road Directorate; iii) the share of the construction road length for minor road construction projects per 1 km x 1 km grid cell; and iv) the share of the railway network. The four distribution keys are combined using the following weighting factors 0.5, 0.25, 0.15 and 0.1 for building construction, major road construction, minor road construction and rail construction, respectively (Plejdrup et al., 2018). In Finland, Karvosenoja et al., (2018) evaluated the effects of gridding improvement over the NRMM sector from a proxy based on population to a more diverse one. According to these authors, when changing from a spatial distribution based on population density to more diverse proxy types, population exposure was reduced due to the reallocation of emissions from highly populated areas to more rural areas. The more diverse spatial proxy include population density, road and streets activity and detached houses and greenery areas.

To our knowledge, no method exists to estimate and spatially distribute emissions based on the exact location on where the construction activity takes place or the characteristics of the construction project. Building and construction activity largely vary in space and time, and cover a wide range of project types. Therefore, defining a methodology to estimate emissions over time will depend on acquiring highly dynamic data that define these changes over time and the features of construction activity, i.e., type of construction project (e.g., major or minor road construction, apartment building or house constructions).

Based on the mapping of input data carried out in this project, we present a concept method that can be developed following bottom-up principles. Figure 14 shows the three steps described in the next subsections. First, the spatial and temporal distribution of building and construction activity need to be defined to place NRMM emissions (Step 1 in Figure 14). This process will allow to establish emissions at construction sites, which summed up, will provide emissions at municipality and national level in the latest step (Step 3 in Figure 14). In order to achieve this, we define the principles for placing the NRMM activity in space. This will be done based on defining "NRMM demand per building and construction project" (Step 2 in Figure 14).

Significant parts of the required input data to be able to develop such a methodology have not been acquired in the timeframe of this project. However, **based on the communication with stakeholders from the building and construction sector, we are aware that the data exist. Therefore, we are confident that this method can be developed. This will constitute a significant step forward on the state-of-the-knowledge as this bottom-up method can be considered "one of its kind"**.

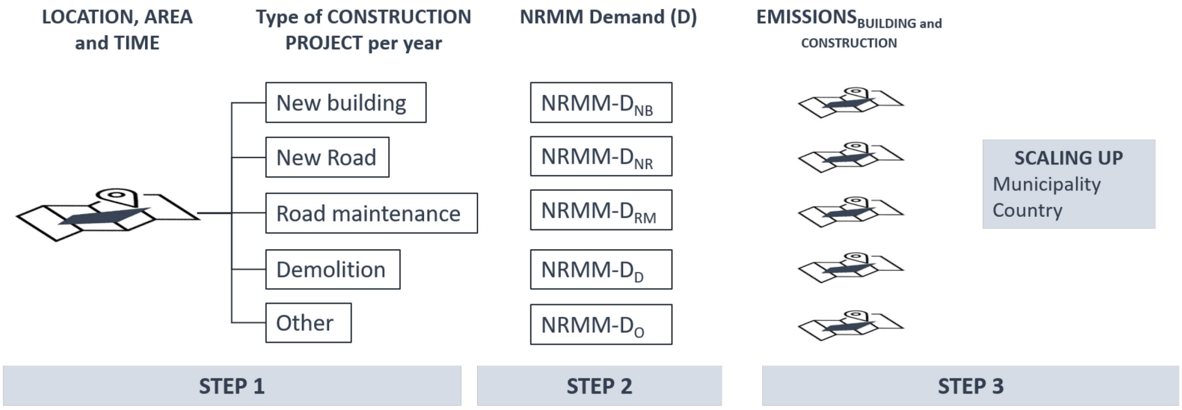

Figure 14: Steps defined in the concept model to estimate exhaust emissions from building and construction from individual site up to municipality and country level. NB: New Building; NR: New Road; RM: Road Maintenance; D: Demolition; O: Others.

3.1 STEP 1 _ Defining spatial and temporal distribution of building and construction

In order to develop a bottom-up approach, the following variables should be defined as well as possible (Step 1; Figure 14);

i) exact location and area affected during building and construction;
ii) starting and finalization dates;
iii) the type of construction activity;
iv) roads in the vicinity of construction projects.

Based on emission studies published in the literature, the most relevant subsectors within building and construction activity are the construction of i) buildings; ii) major roads and iii) minor roads. Based on US EPA (1999), almost all construction activity can be included as either road, residential and non-residential construction. Therefore, the input data to define the distribution of building and construction need to be able to capture as well the type of projects (Figure 14). Other types of construction activities such as rail or other types of infrastructures were not possible to evaluate within the timeframe of this project, and will need to be evaluated in further steps. However, based on literature, other building and construction activity than road and residential/non-residential will be a minor source of emissions.

Datasets describing the location, area and duration of the construction projects (Section 2.1) have been identified along with the advantages and disadvantages associated with their use. Based on our evaluation, the direct use of land use data is not suitable for defining a bottom-up approach. However, it can be used in later steps of the process, e.g., cross checking the results for specific years. Construction permits are the most useful data sources. Unfortunately, all the needed variables cannot be directly defined from one unique database, and different datasets will need to be combined. We identify “Matrikkelen”, “FKB-Tiltak” and “NVDB” as the most suitable databases. Figure 15 shows an overview of the databases and possible combinations to define the temporal and spatial location of emissions when estimating historical emissions, present emissions and for updating processes. In addition, the databases are defined for their use to locate construction of roads or building projects.

The “Matrikkelen” database provides information on construction of all buildings in Norway and when the building process started, i.e., dates of the construction permit, the commissioned permit and the finalization. This database will be crucial for placing both current and historical building and construction work. Based on communication with “Kartverket”, continuous retrievals will be demanding, therefore we have evaluated other alternatives for emission updating processes (Figure

15). At the time of writing, “Kartverket” has delivered the custom extraction dataset with the needed information to place historical sites.

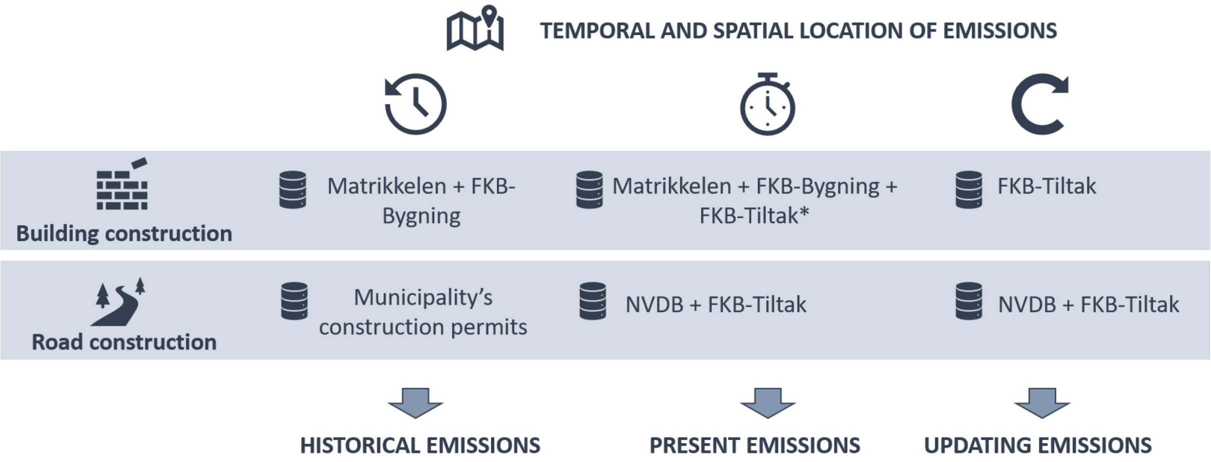

*Figure 15: Databases to establish the temporal and spatial location of emissions from building and construction. *The selection of database will depend on the year that defines “present emissions”. Here we show building (residential and non-residential) and road construction are main contributing activities to emissions.*

The data extraction from “Matrikkelen” provides tabulated information with the relevant dates and the building number at point resolution. Therefore, to define the area affected by construction activity, “Matrikkelen” needs to be combined with other datasets that provide the footprint of the building. Thereafter, the building footprint can be used as reference to determine the area of construction sites. In order to do this, “Matrikkelen” and “FKB-Bygning” (Figure 15) will be combined as the latter one contains all buildings registered in “Matrikkelen” as building footprint polygons. “FKB-Bygning” and “Matrikkelen” will be combined based on the building number.

Once “Matrikkelen” and “FKB-Bygning“ are combined, the polygons contains the necessary information regarding their construction. The area of the footprint, however, does not represent the affected area by a construction process. Therefore, correction factors need to be applied. Table 3 shows the conversion factors compiled in the EMEP/EEA Guidelines (EMEP/EEA, 2019) to obtain affected area based on footprint area.

*Table 3: Compilation of conversion factors to obtain affected area based on the footprint area (EMEP/EEA, 2019). *for large non-residential buildings (more details see EMEP/EEA, 2019). ** if no other data besides the total length of newly constructed road is available, an affected area of 36 000 m^2 per km can be assumed.*

Type of Building	Conversion factor
Detached house	2
Semidetached house	1.5
Terrace	1.5
Apartment building	1.3
Non-residential building	1*
Road construction	**

In order to update emissions, the use of “FKB-Tiltak” offers certain possibilities. Based on the evaluation presented in section 2.1.2 (e.g., Figure 8; “Construction permits”), regular retrievals of “FKB-Tiltak” (e.g., monthly) will allow us to establish the starting and finalization of construction projects.

The location of road construction projects may present additional challenges. The NVDB mainly contains currently ongoing road construction projects (see evaluation in Section 2.1.3). Therefore, NVDB would set up the basis for present emissions and the updating processes (Figure 15) based on regular retrievals. The information can be supplemented with "FKB-Tiltak" as one of the types of permits is road and parking construction (Table 1). However, based on our evaluation, some municipalities were absent, e.g., Oslo. This can be supplemented with the dataset directly obtained from Oslo municipality, where the road construction projects are included from 2000 to 2020. However, a deeper evaluation of "FKB-Tiltak" is needed to assess its overall completeness (e.g., other missing municipalities). In addition, communication with the Norwegian Road Administration is needed to evaluate the possibility to access the information regarding historical road construction projects.

As described in the next section, non-exhaust emissions on the roads in the vicinity of construction projects are higher than the non-exhaust emissions in the construction sites. Therefore, the location of the roads where the material tracked out from the construction site is deposited needs to be defined within the model. This can be done based on the road network in Norway and establishing a radius of influence.

3.2 STEP 2 _ Machine demand per building and construction activity

Once the location of building and construction activity is established in step 1 of the process, the machine demand needs to be estimated; step 2 in Figure 14. At the time of writing we do not yet have access to actual databases or calculation tools, but the data exist. We are confident that further communication may facilitate this process.

Our approach is to define a machine demand based on the specifications and type of construction project and for instance their dimension (m^2). The demand would be established based on statistical analysis of databases containing information on the number and types of NRMM used in actual construction projects. This will require also an analysis to determine to what extent certain variables, e.g., dimension (m^2), would be able to explain the variability of emissions. A similar approach, although more simple, has been previously used. The assessment carried out by DNV (2017) to evaluate the potential for reducing emissions at construction sites assumed the energy demand for a "typical" construction site. The authors assume that the energy used for NRMM varies linearly with the area of the construction site. They considered that the energy demand for NRMM is around 30 kWh per m^2, and subsequently 24.5 kg CO_{2e} and 0.37 kg NO_x per m^2 are emitted. In the case of a typical construction project of around 10 000 m^2, the authors assumed a NRMM demand of 3 excavators and 1 mobile crane with an operation time of 11 months and 1600 hours, respectively. These authors assume that the required number of machines is linear to the dimension of the construction project. However, this needs further evaluation as the complexity of the project will also determine the amount/types of machinery. In addition, emissions of air pollutants will largely depend on the NRMM technology employed in the building and construction activity.

Apart from the amount and type of machinery, other variables need to be considered. The International Council on Clean Transportation (ICCT; Shao, 2016) reviewed the methodologies used in the United States of America and Europe for modelling non-road exhaust emissions. Based on this review, ICCT (Shao, 2016) established that a consistent method to estimate emissions (E, grams) with all methodologies is the one where emissions are the product of five parameters:

$$E = \sum AHP_i \times EF_i \times AOT_i \times LF_i \times \#_i$$

where AHP_i is the average horse-power for each type of machine (i; kW), EF the emission factors (g/kWh), AOT the annual operating time (h), LF the load factor (unitless) and # the number of machines of type *i*. In order to define these parameters, the NRMM fleet composition in Norway needs to be defined. As it is presented in the section 4 "further steps and recommendations", along with continuing the communication with construction companies in Norway, NRMM rental companies may provide significant additional information to characterize the fleet composition and their technological evolution over time. Once the fleet composition in Norway is characterized, information on for instance engine power can be obtained from publicly available databases (e.g., Komatsu, 2020) or built from studies published in the literature. For other parameters such as the load factor, recommendations suggested in the literature will be evaluated (e.g., values from EMEP/EEA, 2019).

As presented in Section 2.3 ("Specific data for non-exhaust emissions"), non-exhaust emissions at the construction site can be estimated following a tier 1 approach as defined by the EMEP/EEA Guideline (EMEP/EEA, 2019). This approach is feasible as the data sources have been identified and the input data is available (i.e., area affected, duration, soil silt content and precipitation-evaporation index). We recommend to apply the tier 1 approach in an early version of the model. However, this needs to be evaluated in foreseen model updates, in which case we would recommend to evaluate the inclusion of more complex processes. For instance, including variables that may play a significant role on emissions, e.g. meteorological parameters (e.g., wind speed), vehicle speed, NRMM kilometer travelled distance, or more detailed physical characteristics of the NRMM (e.g., weight).

Non-exhaust emissions generated at the construction site can constitute a significant source of PM that thereafter is brought to the road. Material tracked out from the construction site is deposited on adjacent paved roads. Thereafter, the deposited PM is resuspended due to on-road traffic, both related and non-related with the construction activity. This process results in emissions that may be more important than all the PM sources within the construction sites (US EPA, 2020). The recommendations from US EPA (2020) is to consider the potential for increasing emissions in the areas adjacent, specifically on the paved roadways. This constitutes a complex process that needs further evaluation, e.g., by adding dust from construction by combining i) non-exhaust emissions estimates on the site and ii) NORTRIP model (Denby et al., 2013) for non-exhaust emissions on the road, for a specific area of influence from the construction site.

3.3 STEP 3 _ From building and construction site to national level and time variation

Once the parameters regarding location, area and duration of the construction project are defined in step 1 (Figure 14) and machine demand per construction project established in step 2 (Figure 14), emissions at specific building and construction sites will be estimated for a specific year (step 3; Figure 14). These emission values will constitute the basis to obtain emissions at the municipality level and national level.

The time variation of emissions is one of the most crucial parameters to model air pollution levels, and hourly, weekly and monthly profiles need to be developed. One of the most updated time variation studies is published by Guevara et al., (2020b; CAMS-GLOB-TEMPO) and currently used by Copernicus Atmosphere Monitoring System. Even though it is the most updated study, the time variation of anthropogenic emissions described in CAMS-GLOB-TEMPO for off-road transportation (Guevara et al., 2020b), and based on Denier van der Gon et al. (2011), is fixed and flat for the three profiles, i.e., monthly, weekly and hourly. Based on the communication with the building and construction sector, the early phases of the building and construction project, when heavy machinery is used for demolition, excavation or moving ground material, involve the highest emissions. Thereafter, emissions decline and a small increase can be observed in the last phase. Therefore, time variation profiles cannot be defined as flat.

Our plan is to develop time variation profiles based on the timeline of the construction project, and establishing the share of the different phases involved in. Figure 16 shows an example based on a planning construction project timeline, where higher emissions are associated with demolition, excavation and concrete filling.

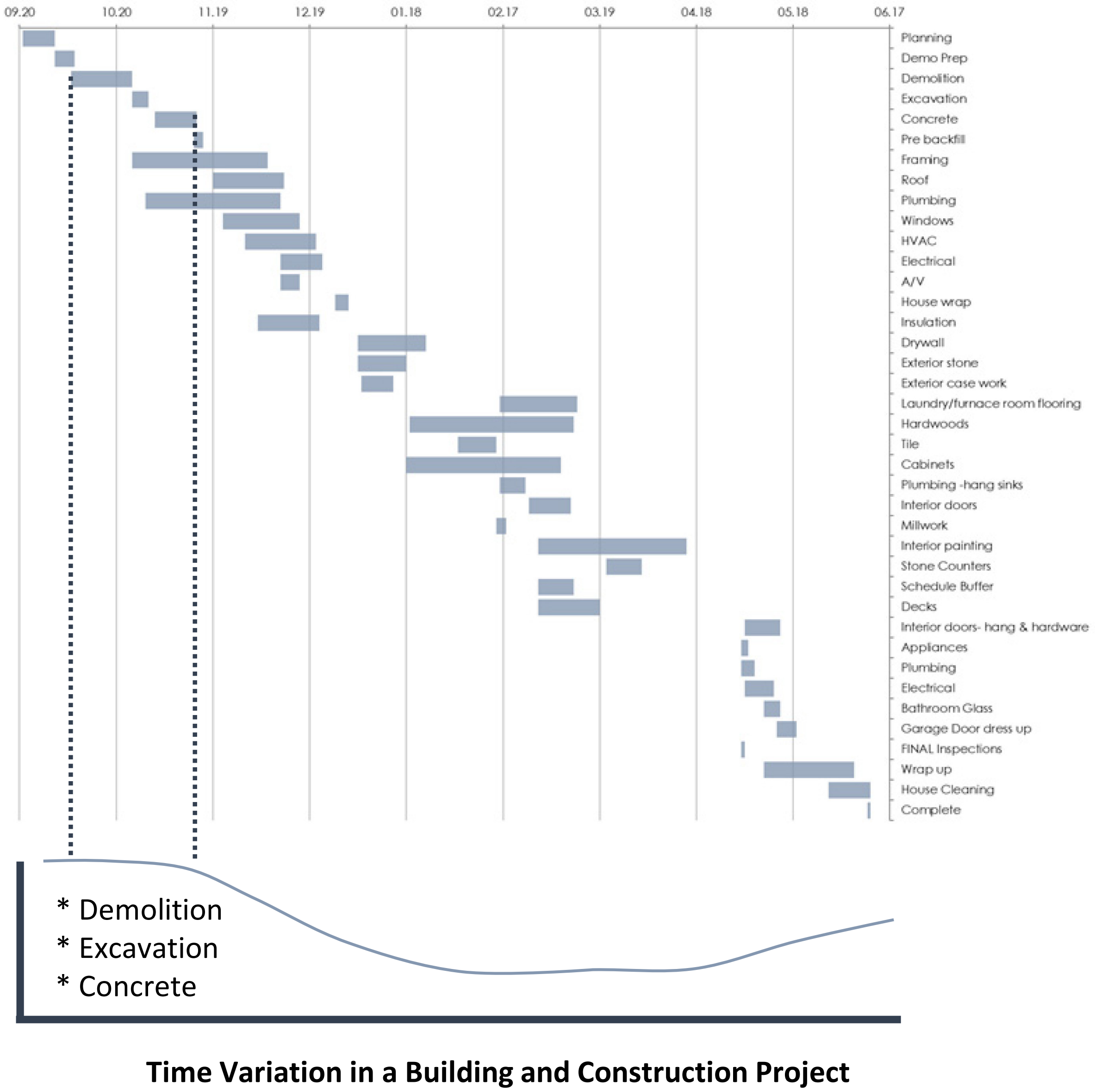

Figure 16: *Example of hypothetical time variation based on the construction phases within the project. The top figure represents the timeline for the multiple phases/tasks within a construction project. The time spans for each phase are default values available through openly accessible templates for construction management*[8].

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[8] Construction Management Templates: https://www.smartsheet.com/excel-construction-project-management-templates

4 Further steps and recommendations

The mapping of input data for this phase of the project has established valuable contact with a wide range of potential data holders; planning and building agencies in municipalities, mapping authorities and corporate building and construction companies. The wide range of data holders is perhaps the biggest hurdle to create an emission model based on bottom-up principles. NILU has been able to identify, access and evaluate input data to define one of the two most crucial variable, i.e., spatial and temporal location of building and construction in Norway. However, the access to data to define the second, machine activity and the NRMM fleet composition, requires additional communication and collaboration with data holders.

In this section, we describe with more detail the needed further steps for acquiring additional input data and developing a bottom-up method to estimate emissions from building and construction activity. The further steps cover data processing, additional mapping of input data, follow up of already established cooperation and starting new ones, and establishing parametrizations.

Spatial and temporal location of building and construction activity

The mapping of input data concerning the location of building and construction activity has provided key outcomes. We have identified “Matrikkelen”, “FKB-bygning” and “FKB-Tiltak” as well suited data sources to define historical and present emissions and perform updating processes. The next step will be to *post-process the data and build specific databases* for defining the geographical and temporal limits in the bottom-up method. The historical information from “Matrikkelen”, i.e., dates of the construction permit, the commissioned permit and the finalization, will be coupled with the location and building footprint from “FKB-Bygning” to define the area affected by construction work. In order to be able to update emissions, we plan to carry out regular retrievals (monthly) of “FKB-Tiltak” to get the needed information to characterize current building and construction work. Currently, retrievals have been done for September, November and December 2020, and we plan to continue this process from January 2021.

Additional work is needed to localize the parts of *road construction projects* that are missing. We recommend a thorough evaluation of “FKB-Tiltak”, where one of the types of construction work is road. In addition, we will target a more specific communication with the Norwegian Road Administration, to evaluate the possibility of accessing information on both historical and ongoing road construction projects currently absent in NVDB.

With regards to the distinction between *type of construction projects*, we have established as first priority to address the construction of new buildings (residential and non-residential), new roads and the maintenance of roads. These sectors have been identified as the most contributing subsectors to emissions. We recommend to carry out an additional evaluation of other construction projects, for instance rail construction projects and those referring to infrastructure, understanding by this as any construction different from residential and non-residential buildings.

NRMM usage per construction project

One of the key factors to define the NRMM demand or usage per construction project is to build a database with number and types of NRMM used in real construction projects, among other variables, e.g., operating time, fuel consumption. This will allow to perform statistical analysis and define the variable/s at the construction site (e.g., dimension) that best define the machine usage. Building and construction companies have this type of databases as part of their accounting and overview of projects. We have been in communication with one of the biggest companies in Norway and contacted others. We perceive a willingness to share this data, however, additional communication is needed. We recommend to organize meetings with the building and construction companies in collaboration with the Norwegian Environment Agency. This may facilitate understanding and communicating about the correct use of the data, specially concerning the protection of private information relevant for the companies.

NRMM fleet composition

Currently there is no central registry of NRMM in Norway that can provide an overview of the machine fleet composition. We have contacted several machine associations in Norway. However, this process has not yet provided key results materializing in data. This communication needs to be pursued further and diversified with other potential data sources. One path is to contact NRMM renting and delivery companies in Norway. Specific companies to contacts could be "Utleiesenteret"[9], "Cramo"[10], "Renta"[11] or "Limaco AS"[12], and others. Also, the "Maskinregisteret"[13], a common electronic registry for construction machinery and equipment. The aim of this activity is to build a database that represents the NRMM fleet composition at county level or national level, or higher geographical resolution if possible.

Defining the time variation of emissions

In order to define the time variation of emissions, we recommend to establish the shares of the different phases (e.g., demolition, moving ground material) within a building and construction project. In addition, different shares can be established per type of construction project, i.e., road construction, residential and non-residential building. We foresee that the communication with building and construction companies may provide significant insights on these values.

The share of phases in building and construction projects will be also essential to split the type of machinery usage, as the type of machinery differs among the phases. For instance, excavators and piling machines are mostly used for ground work, whereas mobile cranes, lift or tower cranes are mainly used for construction work.

Non-exhaust emissions

Non-exhaust emissions on the road in the vicinity of building and construction activity may be higher than the total non-exhaust emissions within the construction sites. This brings the need to evaluate the possibility of connecting two modelling approaches; i) non-exhaust emissions in the construction sites and ii) non-exhaust emissions on the road (e.g., NORTRIP) in the vicinities of construction sites.

Assessment and potential validation

The early phase of this project does not allow for a detailed description of potential validation exercises. However, the comparison with currently existing data can be used in preliminary assessment of the final results. Potential data source for this assessment are the GHGs estimates at municipality level from the Norwegian Environment Agency, official building and constructed area at municipality from Statistics Norway and/or official reported emissions to air of air pollutants and GHGs by Norway. The most recommended exercise is to carry out an evaluation based on dispersion modelling using the emissions developed within this project and the comparison of the results with observations. To our knowledge, there are currently no measurements or modelling activities in areas characterized by intense building and construction work. However, we are aware on the increasing interest in this sector, and future potential projects on this topic can benefit the assessment and validation.

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[9] https://www.utleiesenteret.no/

[10] https://www.utleiesenteret.no/

[11] https://www.renta.no/

[12] https://limaco.no/

[13] http://www.sfs.no/styled-6/index.html

5 Final Remarks

After a broad and diverse search for available data, the feasibility and potential form of a bottom-up model for estimating emissions from construction have been evaluated and presented. For a model to serve several purposes and produce both air pollutants and climate gas emissions, one has to take many considerations. Not only the scale of interest is different, but also the processes responsible for emissions differ. Whereas climate gas emissions are almost exclusively exhaust emissions from combustion (CO_2, CH_4 and N_2O), for regulated air pollutants (e.g., NO_x, PM) the PM is dominated by non-exhaust. There exist good top-down assumptions for CO_2 emissions due to the relationship between fuel use and CO_2 emissions. However, this will not be as accurate for non-exhaust, or indeed for other exhaust compounds.

A main commonality between estimating air pollutant and climate gas emissions is that the location of where activity is ongoing needs to be known. A main finding of this work is that, through the legal process behind the applications for construction permits, national databases with sufficient information on location, time and magnitude of the vast majority of the construction projects are available. This is as detailed information as can be desired and is used by state-of-the-art models, such as the Danish SPREAD model (Plejdrup et al., 2018), that is used to distribute emissions top-down of both air pollutants and climate gases. Emission maps based on these data would be expected to be vastly superior to existing spatial distributions of emissions for Norway.

Internal company/contractor records, and in some cases public documents, will show CO_2 emissions. However, for the majority of construction work it is hard to see how to obtain wholistic data. For any other compounds than CO_2, there exists limited knowledge even with access to all available data for a given site. For non-exhaust emissions, which are affected by variables such as meteorology, ground conditions and soil moisture, even less accuracy exists in available models. Therefore, general data for sites must be sought on specific machine use and associated emission factors for the stages of the building process. Sources of all required data have been identified and some data have been obtained through this project, though not always with the desired specificity. Soil and meteorological data are available and can be used with, for instance, the equation suggested by EMEP/EEA (2019) to obtain non exhaust emissions. For the identification of machines, a complete and accurate national database does not exist. There are, however, several paths that show the potential of filling these gaps in the data, e.g., voluntary and therefore partial machine registry, company and commercial cost and emission calculators, as well as leasing companies.

The model should also be able to incorporate and evaluate measures taken to reduce emissions. For exhaust emissions, this is as of yet mainly the reduction of idle time, introduction of bio-fuel, but also more types of electric machinery are currently being used. For air pollutants, several measures can be taken such as cleaning and water spraying in the case of non-exhaust emissions. How this should be done and at what level, will depend on available information on these measures, a topic not explored in this project.

The amount of ground work required in the first phase of a construction is perhaps the most important activity for the overall emissions of construction work, and the hardest to describe based on general assumptions. To exploit all possibilities to make the model as accurate as possible, it is therefore a key aspect to obtain a database of built constructions to get a time-line and machine use at the different stages and for a range of construction sites. This will allow to describe these aspects with confidence in the model as well.

Significant parts of the required input data to be able to develop such a methodology, have not been acquired in the timeframe of this phase I of the project. However, and based on the communication with different stakeholders, we are aware that the data exist. Therefore, we are confident that this method can be developed. This will constitute a significant step forward on the state-of-the-knowledge as this bottom-up method can be considered “one of its kind”.

6 References

Denier van der Gon, H., Hendriks, C., Kuenen, J., Segers, A., Visschedijk, A. (2011). Description of current temporal emission patterns and sensitivity of predicted AQ for temporal emission patterns. TNO, Utrecht.

Denby, B., Sundvor, I., Johansson, C., Pirjola, L., Ketzel, M., Norman, M., Kupiainen, K., Gustafsson, M., Blomqvist, G., Omstedt, G. (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. Atmos. Environ., 77, 283–300.

DNV (2017). Fossil- og utslippsfrie byggeplasser. Rapport 2017-0637, DNV GL AS Energy.

EMEP/EEA (2019). EMEP/EEA air pollutant emission inventory guidebook 2019. Technical guidance to prepare national emission inventories. EEA Report No 13/2019. https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

Geonorge (2020). Produktspesifikasjon FKB Tiltak 4.6. Retrieved from: https://register.geonorge.no/register/versjoner/produktspesifikasjoner/geovekst/fkb-tiltak (Accessed in November 2020).

Granier, C., Darras, S., Denier van der Gon, H., Doubalova, J., Elguindi, N., Galle, B., Gauss, M., Guevara, M., Jalkanen, J.-P., Kuenen, J., Liousse, C., Quack, B., Simpson, D., Sindelarova, K. (2019). The Copernicus Atmosphere Monitoring Service global and regional emissions (April 2019 version), Copernicus Atmosphere Monitoring Service (CAMS) report, 2019, doi:10.24380/d0bn-kx16.

Guevara, M., Tena, C., Porquet, M., Jorba, O., Pérez García-Pando, C. (2020a). HERMESv3, a stand-alone multi-scale atmospheric emission modelling framework–Part 2: The bottom–up module. Geoscientific Model Development, 13, 873-903.

Guevara, M., Jorba, O., Tena, C., Denier van der Gon, H., Kuenen, J., Elguindi-Solmon, N., Darras, S., Granier, C., Pérez García-Pando, C. (2020b). CAMS-TEMPO: global and European emission temporal profile maps for atmospheric chemistry modelling. Earth System Science Data Discussions, pp. 1-60. In press. doi:10.5194/essd-2020-175.

IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. (Volume 2: Energy, https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf)

Karvosenoja, N., Paunu, V.V., Savolahti, M., Kupiainen, K., Karppinen, A., Kukkonen, J., Hänninen, O. (2018). A High-Resolution National Emission Inventory and Dispersion Modelling—Is Population Density a Sufficient Proxy Variable?. In International Technical Meeting on Air Pollution Modelling and its Application (pp. 199-204). Springer, Cham.

Komatsu (2020). Crawler Excavators. Retrieved from: http://webassets.komatsu.eu/komatsu-construction-and-quarry-machine.asp?machine_type_id=1 (Accessed in November 2020).

Kuenen, J.J.P., Visschedijk, A.J.H., Jozwicka, M., Denier Van Der Gon, H.A.C. (2014). TNO-MACC_II emission inventory; a multi-year (2003–2009) consistent high-resolution European emission inventory for air quality modelling. Atmos. Chem. Phys, 14, 10963-10976.

NEA (2019a). Informative Inventory Report (IRR) 2019. Norway. Air Pollutant Emissions 1990-2017. Norwegian Environment Agency, M-1270 Report.

NEA (2019b). Greenhouse Gas Emissions 1990 – 2017, National Inventory Report. Norwegian Environment Agency, M-1271 Report.

NEA (2020). Klimagassregnskap for kommuner og fylker. Dokumentasjon av metode – versjon 3. Norwegian Environment Agency Rapport M-989 / 2020. Retrieved from https://www.miljodirektoratet.no/contentassets/684ed944b61948e8adbef6f3f5b699f7/metodenotat_klimagasstatistikk-for-kommuner.pdf#page=40 (Accessed in November 2020).

Plejdrup M.S., Nielsen O-K, Gyldenkærne S., Bruun H.G. (2018). Spatial High-Resolution distribution of emissions to air – SPREAD 2.0. Technical Report from DCE – Danish Centre for Environment and Energy. No 131. Aarhus University, Department of Environmental Science. Retrieved from: https://dce2.au.dk/pub/TR131.pdf (Accessed in November 2020).

Shao, Z. (2016). Non-road emission inventory model methodology. The international council on clean transportation (Working paper), 4. Retrieved from https://theicct.org/sites/default/files/publications/ICCT_nonroad-model-method_20160224.pdf (Accessed in October 2020).

SSB (2020a). Kart og geodata fra SSB. Retrieved from https://www.ssb.no/natur-og-miljo/geodata (Accessed in November 2020).

SSB (2020b). Tabell 11174: Salg av petroleumsprodukter, etter kjøpegruppe og produkttype (mill. liter). Foreløpige tall (F) 2010M01 - 2020M10. Statistikkbanken, Statistisk Norge. https://www.ssb.no/statbank (Accessed in November 2020).

SSB (2020c). Tabell 05939: Byggeareal. Bruksareal til annet enn bolig, etter bygningstype (m^2) (K) 2000 – 2019. Statistikkbanken, Statistisk Norge. https://www.ssb.no/statbank (Accessed in November 2020).

SSB (2020d). Tabell 05940: Byggeareal. Boliger og bruksareal til bolig, etter bygningstype (K) 2000 – 2019. Statistikkbanken, Statistisk Norge. https://www.ssb.no/statbank (Accessed in November 2020).

US EPA (1999). Estimating particulate matter emissions from construction operations, final Report prepared by the Midwest Research Institute (MRI) for US EPA Missouri, United States Environmental Protection Agency, USA 1999.

US EPA (2020). AP 42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Chapter 13: Miscellaneous Sources. Retrieved from https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors#5thed (Accessed in November 2020).

Viaene, P., Belis, C.A., Blond, N., Bouland, C., Juda-Rezler, K., Karvosenoja, N., Martilli, A., Miranda, A., Pisoni, E., Volta, M. (2016). Air quality integrated assessment modelling in the context of EU policy: a way forward. Environmental science & policy, 65, 22-28.

Winther, M. and Nielsen, O.K. (2006). Fuel use and emissions from non-road machinery in Denmark from 1985-2004-and projections from 2005-2030 (No. NEI-DK--4659). National Environmental Research Institute, Denmark.

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

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

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