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REPORT

Emission-reduction potential of fossil- and emission-free building and construction sites

Climate Agency, City of Oslo

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SUMMARY

On behalf of the Climate Agency, City of Oslo, DNV GL has estimated the Green House Gas (GHG) emissions from building and construction sites in Oslo Municipality. The study also takes a closer look at the available technology, cost developments as well as the parties that are active on the sites, and own, or have an opportunity to influence, theseemissions. Based on the current situation, a benchmark trajectory and two scenarios have been prepared. The two scenarios represent different implementation rates for new technology, and for achieving emission-free building and construction sites in 2030. The study is based on DNV GL's report entitled *Utslippsfrie byggeplasser* (Emission-free Building Sites), prepared in 2017 on behalf of the Norwegian District Heating Organization, Energy Norway and Enova.

Mapping of emissions

Emissions from activities at building and construction sites have been mapped based on previous empirical figures and data obtained from specific projects in Oslo Municipality. The activities at building and construction sites can be divided into three categories that lead to emissions; the production of heat and electricity for heating and drying out, the use of large construction machinery (>37 kW) and the use of small construction machinery (< 37 kW). No need for heating or drying out has been identified at the reference construction sites.

The energy demand and emissions of building sites have been estimated for five different types of building sites based on three reference projects. The results are shown in the table below, in total and per square metre.

Overview of the total energy demand and emissions of various types of building sites, in total and per square metre

Type of building site		Area [m2]	Energy demand [kWh]	CO_2e [kg]	NO_x [kg]	PM2.5 [kg]
Apartment building – high emissions from heating	in total	10 000	2 757 000	902 000	30 750	620
	per m2		276	90	3,075	0,062
Apartment building – mean emissions from heating	in total	10 000	1 352 000	463 000	4 180	380
	per m2		135	46	0,418	0,038
Apartment building – low emissions from heating	in total	10 000	1 352 000	243 000	3 730	200
	per m2		135	24	0,373	0,020
Multi-use-hall	in total	3600	141 000	108 000	650	10
	per m2		39	30	0,181	0,003
Kindergarten	in total	1650	34 000	30 000	120	2
	per m2		21	18	0,076	0,001

The three apartment buildings used as examples are based on the same reference project but with different assumptions regarding the need for heating. All three reference projects have favorable ground conditions, which leads to lower estimated emissions from construction machinery than if the ground conditions had been difficult.

The energy demands and emissions of construction sites are estimated for three reference projects - a water supply and sewage project and two transport projects. The table below shows the results, in total and per construction-contract krone (measured in MNOK).

Overview of the total energy demand and emissions at three types of construction sites, in total and per construction-contract krone (MNOK)

Type of construction site		Energy demand [kWh]	CO_2e [kg]	NO_x [kg]	PM2.5 [kg]
Water & Sewage project	in total	149 000	131 000	800	40
	per MNOK	5 300	4 700	29	1,43
Small transport project	in total	26 000	23 000	90	1
	per MNOK	2 500	2 300	9	0,14
Large transport project	in total	348 000	308 000	2 900	132
	per MNOK	700	600	6	0,28

The emissions per construction-contract krone vary widely. This can partly be explained by the projects' different contents and percentage of construction work. The water supply and sewage project is comprised almost totally of construction work. The large transport project includes other cost elements that do not lead to the use of construction machinery, and this leads to lower emissions per construction-contract krone.

Emissions from building and construction activity in Oslo Municipality

The annual emissions from building and construction activity in Oslo Municipality are estimated based on information from the reference projects.

For building sites, the emissions per square metre and commissioned floor space area with a start-up permit in 2017 are used to scale up to municipality level. The three reference building sites illustrate the large difference in energy consumption and emissions that there can be between different types of building sites. The multi-use hall and kindergarten are both special buildings and building sites where there has been a focus on reducing the energy demand and emissions. These sites are therefore less relevant to use when scaling up to municipality level. The table below shows the estimated emissions per square metre when applying the same assumptions as for the calculation of emissions per square metre for a "typical" building site in the report on fossil- and emission-free building sites in 2017 /D57/. The share of large building projects has been updatedto 75 per cent, reflecting building activity in Oslo Municipality, compared to 54 per cent for Norway as a whole.

Energy demand of, and emissions (CO2e, NO_x and PM2.5) per square metre from, an average building site in Oslo Municipality. Adjusted for the percentage of large building projects (from 54 per cent nationwide to 75 per cent in Oslo Municipality). Based on /D57/

Activity	Energy demand [kWh/m2]	CO_2e [kg/m2]	NO_x [kg/m2]	PM2.5 [kg/m2]
Heating	47 kWh	10	0,08	0,008
Interior heating	34 kWh	6,1	0,05	0,006
Concrete setting	8 kWh	2,2	0,02	0,001
Concrete setting – grout casting	4 kWh	1,1	0,01	0,001
Façade heating	1 kWh	0,3	0,002	0,000
Construction machinery	30 kWh	24,5	0,37	0,005
IN TOTAL	77 kWh	34 kg	0,45 kg	0,013 kg

However, there is a great deal of uncertainty linked to the estimated emissions per square metre, especially regarding the emissions from construction machinery. As a result of deposits from the sea and fjord, there are large thicknesses of silt and clay in areas of Oslo Municipality. In parts, the thickness of sea and fjord deposits in Oslo city centre is up to 60-70 metres and quick clay has been found in some of these deposits. /D75/ The reference projects for building sites are all examples of building sites with relatively simple ground conditions. It is regarded as probable that the average building site in Oslo Municipality has a greater need for ground work than the reference projects. Based on this, the energy demand for construction machinery is increased by 50%. This increase should be updated as soon as there is data available on a project with difficult ground conditions. The table below shows the estimated energy demand and emissions from an average building site in Oslo Municipality, adjusted for difficult ground conditions.

Energy demands and emissions (CO2e, NO_x and PM2.5) per square metre from an average building site in Oslo Municipality. Use of construction machinery adjusted for difficult ground conditions.

Activity	Energy demand [kWh/m2]	CO_2e [kg/m2]	NO_x [kg/m2]	PM2.5 [kg/m2]
Heating	47 kWh	10	0,08	0,008
Interior heating	34 kWh	6,1	0,05	0,006
Concrete setting	8 kWh	2,2	0,02	0,001
Concrete setting – grout casting	4 kWh	1,1	0,01	0,001
Façade heating	1 kWh	0,3	0,002	0,000
Construction machinery	45 kWh	37	0,555	0,0075
IN TOTAL	92 kWh	47 kg	0,64 kg	0,016 kg

The three reference projects for construction sites are used as the basis for the estimated emissions per construction-contract krone of the average construction site in Oslo Municipality. There is a great deal of uncertainty linked to the share of the construction market that each project may represent. It is assumed that the emission level from the water supply and sewage project is representative of around 60%, while the large transport project is representative of 30% and the small transport project is representative of 10% of the construction market. The table below shows an overview of the resulting energy demand and emissions per construction-contract krone for an average construction site in Oslo Municipality.

Energy demands and emissions (CO2e, NOx and PM2.5) from an average construction site, per construction-contract krone (MNOK).

Type of construction site	Market share	Energy demand [kWh/MNOK]	CO_2e [kg/MNOK]	NO_x [kg/MNOK]	PM2.5 [kg/MNOK]
Water & Sewage project	60%	5 300	4 700	29	1,43
Small transport project	10%	2 500	2 300	9	0,14
Large transport project	30%	700	600	6	0,28
'Average' construction site		3 640	3 230	20	0,96
Larger construction machinery		3 552	3 143	20	1
Smaller construction machinery		106	94	0,38	0,01

New-build activity, measured as the commissioned floor space with a start-up permit in 2017 /D69, D70/, and the size of the construction market in 2017 /D71/ are used to scale the project data up to municipality level. The table below shows the estimated annual emissions from building and construction activity in Oslo Municipality, adjusted for difficult ground conditions.

Estimated annual emissions from building and construction activity in Oslo Municipality, adjusted for difficult ground conditions

Activity	Energy demand [MWh]	CO_2e [ton]	NO_x [ton]	PM2.5 [ton]
Building activity	109 160	55 450	756	19
Construction activity	24 300	21 500	132	6
TOTALT	133 460	76 950	888	25

The scenario calculations in chapter 5 show considerable uncertainty and that the CO2e emissions from building and construction activity in 2018 are between 44,300 and 122,200 tonnes of CO2e, with an expected value of 80,700 tonnes of CO2e.

Heating technology and cost developments

Zero-emission solutions for heating and drying out are in use today, and the technology on the secondary side of the heat exchanger, for example water-borne systems at building sites, is relatively mature. However, it may be possible to extract some economies of scale if the market share of fossil- and emission-free heating solutions increases. Most of the cost developments will probably be determined by the end-user price for the energy carriers.

In the field of heating and drying out at building sites, the developments up to 2020 and 2030 are therefore about other heating alternatives that can be used in those cases when the opportunity to use current alternatives is limited. Examples of such new solutions may be the use of large mobile battery banks or hydrogen.

Emission-free heating based on hydrogen may develop quickly. Natural gas currently used as an energy carrier to heat buildings can be replaced by hydrogen /D68/. The road from there to replacing natural gas with hydrogen for heating and drying out at building sites is probably not long. Given further development of the hydrogen infrastructure in Norway, the parties' expectations of access to hydrogen as a heating alternative by around 2020 may be realistic.

Developments in construction machine technology and costs

There have been huge improvements in emission-free construction machinery over the past few years. Previously, only construction machinery connected to the power grid via a cable, hand-held equipment and small machines were available with an electric drive, while today, for example, large battery electric loaders are used in the US market. In addition, a 25-tonne battery electric excavator will be launched in Norway in 2018 /D72/. The investment costs for electric construction machinery can be anything from 20% higher to around three times as high, depending on the type of machinery.

Most of the additional cost of battery electric construction machinery is due to the price of the batteries. There has been a significant reduction in battery costs over the past few years, and DNV GL expects the costs to continue to fall towards 2020. DNV GL expects strong further growth in the battery market towards 2030, driven by both the increased need to balance the power system and the electric passenger-car market. The expected developments in battery technology make it likely that almost all types of construction machinery can be electrified by 2030.

The emission-reduction potential

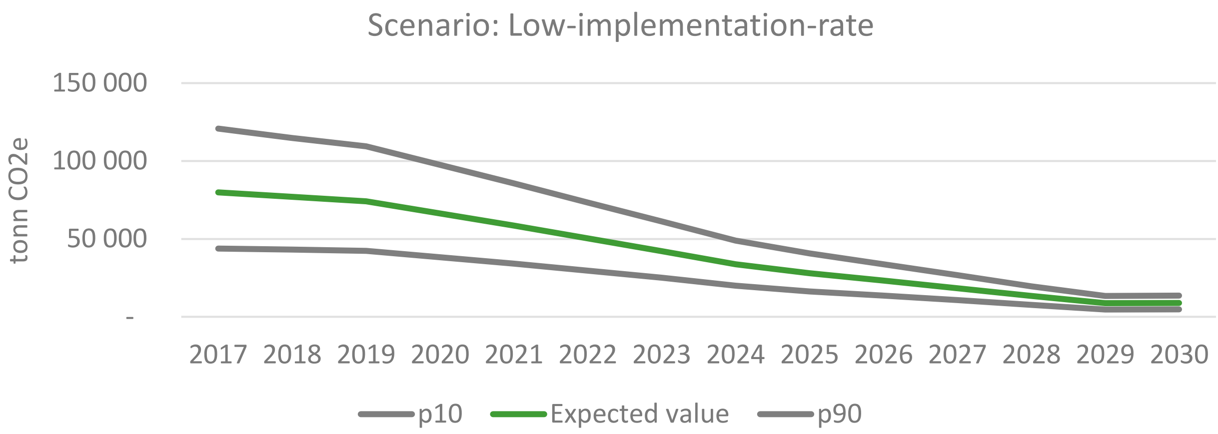
The potential reduction in emissions from building and construction sites in Oslo Municipality is estimated on the basis of a comparison between a benchmark trajectory, without the implementation of emission-free alternatives, and two future scenarios for the implementation of emission-free alternatives at building and construction sites.

The first scenario presumes a low implementation rate for emission-free technologies. This scenario assumes that changes in the industry are required in order for emission-free solutions to be used to a large extent. There is no global demand for construction machinery and/or the battery costs fall more slowly than expected.

Assumptions regarding the implementation rate:

- Zero-emission heating and drying out technologies are gradually implemented leading up to 2025
- Small construction machinery (estimated lifetime 5-7 years) is replaced by fully electric construction machinery by 2025.

- Large construction machinery (estimated lifetime 5-15 years) is replaced by zero-emission technologies from 2020 and gradually up to 2030.



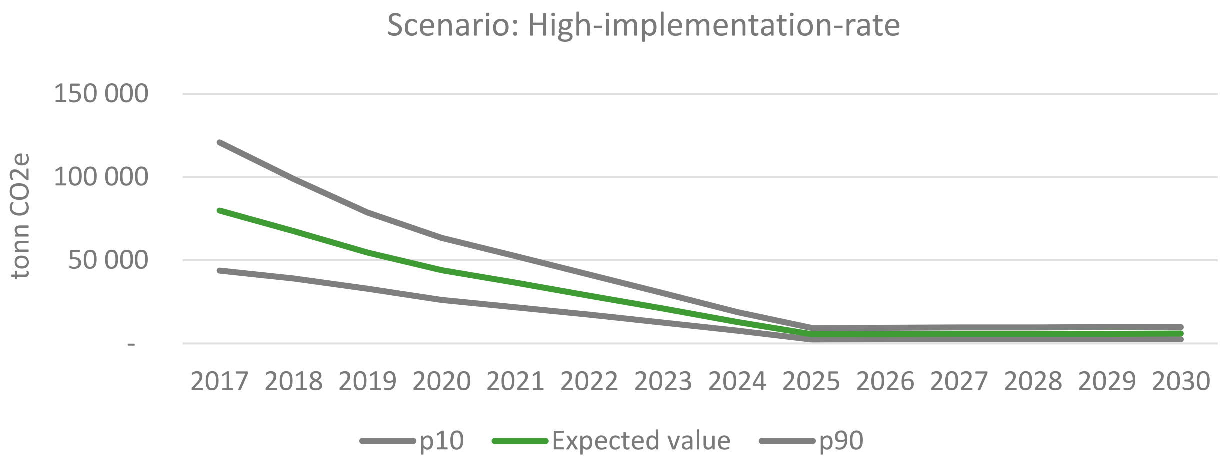
Simulated emissions from building and construction activity in Oslo Municipality leading up to 2030 based on a low implementation rate for zero-emission technologies.

For the scenario with a low implementation rate, the estimated potential for reduction compared to the benchmark trajectory is 17,000 tonnes of CO2e in 2020, 59,000 tonnes of CO2e in 2025 and 83,000 tonnes of CO2e in 2030.

The scenario with a high implementation rate is based on the developer at building and construction sites in Oslo Municipality stipulating a requirement of emission-free building sites. In order to achieve this scenario, all building sites started in 2023 must be almost emission-free and the requirement of emission-free building sites must enter into force at least two years before to speed up developments. In special cases, a need to use conventional technology despite the requirement of emission-free building sites is expected.

Assumptions regarding the implementation rate:

- Zero-emission heating and drying out technologies are implemented by 2020, but 10% of all heating is still based on fossil energy sources in 2020 and up to 2030.
- Small construction machinery is replaced by fully electric machinery by 2025, as in the scenario with a low implementation rate.
- Most large construction machinery is not replaced prior to 2020, but is rapidly replaced by zero-emission technologies during the period leading up to 2025.



Simulated emissions from building and construction activity in Oslo Municipality until 2030 based on a high implementation rate for zero-emission technologies.

For the high-implementation-rate scenario, the estimated reduction potential compared to the benchmark trajectory is 39,000 tonnes CO2e in 2020, 81,000 tonnes CO2e in 2025 and 86,000 tonnes CO2e in 2030.

The involved parties and emission responsibility

Many parties are involved in a building process. The building process starts with the developer's idea for a new building and ends when the building starts to be used. The parties can influence the process in various ways, for example by stipulating requirements for both the actual building process and the final building.

To discover who is responsible for emissions at the building site, we refer to the most-used global standardized framework for measuring and handling greenhouse gas emissions from the private and public sectors, the Green House Gas (GHG) Protocol. This organization is responsible for the world's most used GHG-account standards, including a framework for companies (GHG Protocol Corporate Standard) and a framework for cities (Global Protocol for Community-Scale Greenhouse Gas Emission Inventories).

If the GHG Protocol's framework for cities is applied to building and construction sites, the developer is the party responsible for the emissions. This is because the scope definitions for a city are different from those for a company. Scope 1 emissions are emissions that take place within the city boundary. Scope 2 emissions are emissions that take place as a result of using grid-supplied electricity, heating, steam and/or cooling within the city boundary. Scope 3 emissions include emissions that take place outside the city boundary and are a result of activities within the city boundary. The building site can be taken to represent the city and the building site boundary represents the city boundary. The party responsible for emissions on the building site should thus be the developer, which is the party that is responsible for and initiated the building.

1 INTRODUCTION

Over the past few years, increased attention has been paid to emissions from building sites. Today, building and construction sites mainly use fossil energy sources and untaxed diesel (not subject to road-usage tax) consumption comprises around 10% of Oslo's greenhouse gas emissions[1]. The potential to reduce emissions by using fossil- and emission-free solutions on building sites is regarded as considerable.

In this report, DNV GL, on behalf of the Climate Agency in Oslo Municipality, has estimated the amount of fossil fuel used for heating and construction machinery at, and the associated emissions from, building and construction sites in Oslo. The study also takes a closer look at available technology, cost developments and the parties that are involved, and own, or have an opportunity to influence the emissions. Based on the current situation, two scenarios have been prepared, involving different implementation rates for new technology, for the achievement of emission-free building and construction sites by 2030. The study is based on DNV GL's *Utslippsfrie byggeplasser* (Emission-Free Building Sites) report prepared in 2017 on behalf of the Norwegian District Heating Organization, Energy Norway and Enova /D57/.

The objective of the report is to create a knowledge base for examining measures to provide an increased share of low- and zero-emission vehicles and machinery in the construction industry in Oslo Municipality.

All building and construction projects are different, and there is great variation in the energy consumption and emissions from project to project. In addition, the empirical data on which calculations can be based is so far limited. This creates significant uncertainty about the figures presented in the report. The report must thus be regarded as a first step to obtaining better documentation. As the data basis improves and more empirical data becomes available, the calculations can be updated and the conclusions can be improved.

1.1 Definitions

The concepts of emission-free and fossil-free are often used interchangeably in connection with emissions from building sites. For this reason, definitions of these terms are provided in the following.

An emission-free building site entails the use of energy sources that do not lead to emissions of CO_2e, NOx or PM *at the building site*. Emission-free heating alternatives include heating based on electricity, district heating and other energy carriers that do not lead to CO_2e, NOx or PM emissions at the building site. Emission-free construction machinery alternatives include battery electric machinery and electric machinery connected directly to the power grid. In time, other emission-free alternatives may be developed to replace or supplement the emission-free alternatives mentioned above.

In addition to the emission-free alternatives, fossil-free alternatives include the use of bio-based fuel, including pellets, bioethanol, biodiesel, HVO and biogas. A fossil-free building site entails the use of bio-based energy sources. When areas are managed sustainably, bio-based energy sources do not contribute to net CO_2 emissions. Instead CO_2 which forms part of nature's natural cycle is released and, if areas are managed sustainably, the CO_2 that is released due to harvesting and combustion will be absorbed by new plants and trees. /D59/

[1] Calculated as a percentage of the emissions from diesel-driven utility vehicles as part of the total direct emissions of greenhouse gases in Oslo Municipality in 2016 (Greenhouse gases, according to region, source (activity), component, statistical variable and year (divided by county), Statistikkbanken, SSB 2018).

1.2 Method

In this chapter, we give a brief account of the content and method used to arrive at the results in the report.

In the report, we concentrate on activities *at the building/construction site*. The focus is on activities that lead to the use of untaxed diesel. The energy consumption and emissions linked to the production of materials or other activities connected to the building process that take place somewhere other than at the actual building site are not covered by the analysis. In the report, we also do not discuss or assess emission factors linked to the production of various energy carriers. The report assumes that neither electricity nor district heating will lead to emissions at the building site.

Figure 1 illustrate the activities included in the analysis within the field marked in green. Activities that are outside the field marked in green are outside the scope of this analysis.

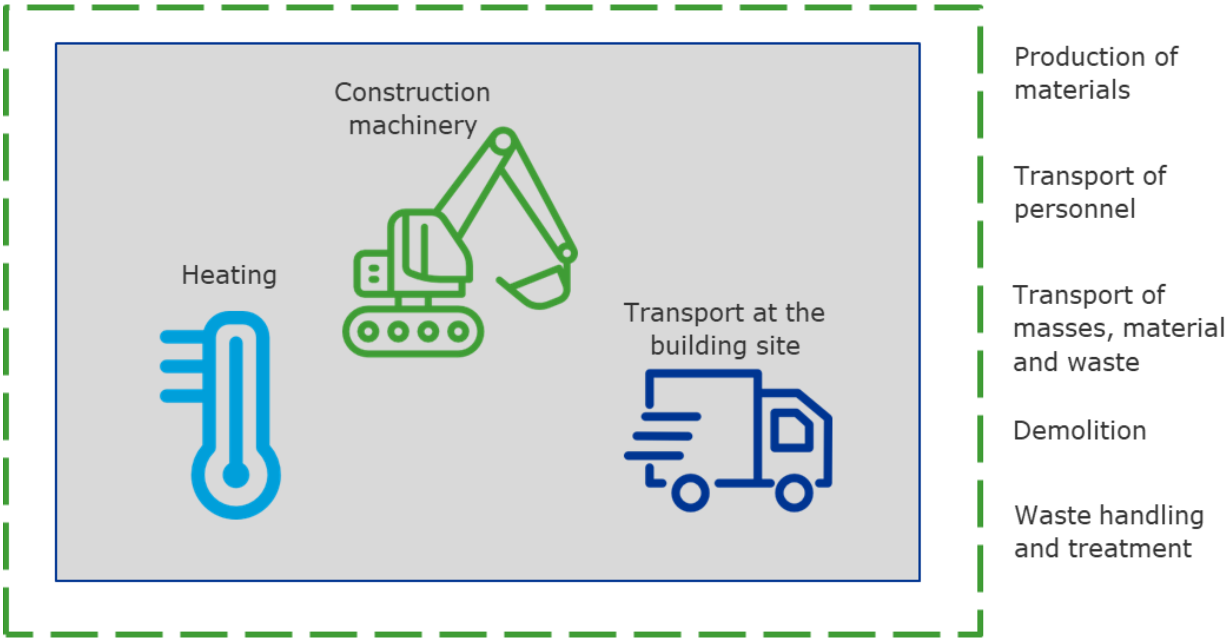


Figure 1. The focus of the analysis is on activities *at the building site* that use untaxed diesel[2].

In chapter 2, the energy consumption and emissions of building and construction sites are mapped, based on various types of building sites; a "typical" building site taken from the report entitled *Fossil and utslippsfrie byggeplasser* (Fossil-and Emission-free Building Sites) /D57/ and new information from building and construction projects in Oslo Municipality. For these projects, the energy consumption and emissions are calculated per square metre and/or per project cost in MNOK.

Based on the mapped energy consumption of, and emissions from, the building and construction sites, we calculate the average annual energy demand of, and emissions from, building and constructgion activity in Oslo Municipality in chapter 3. In order to scale up the values from the example projects, to create regional figures for Oslo, we have used:

- New-build activity in square meters; commissioned floor space with a start-up permit for Oslo, based on Statistics Norway's statistics (building sites) /D69, D70/
- Economic activity in MNOK; market statistics, prepared by Prognosesenteret (construction sites) /D71/

[2] Icons prepared by Freepik; Vignesh Oviyan, www.flaticon.com

In chapter 4, we provide an overview of available fossil- and emission-free alternatives that currently exist, before estimating the potential for reducing emissions from building and construction activity in Oslo towards 2030, based on both a low and high implementation rate, in chapter 5. The potential for reducing emissions is calculated on the basis of a benchmark trajectory. The benchmark trajectory is based on a future without any increased use of fossil-free and/or emission-free alternatives.

The report concludes with a chapter on the parties involved at a building or construction site, commenting on the ownership of the emissions.

1.2.1 Use of emission factors

In the report, greenhouse gas emissions are calculated in the form of CO_2 equivalents (CO_{2e}) and for these we have mainly used emission factors published by Statistics Norway /D60/. For CO_{2e} emissions from HVO100, we have used factors prepared by the UK Department for Environment, Food & Rural Affairs - DEFRA. DEFRA has published updated sets of factors each year since 2002, and the set of factors for 2017 has been used in the report.

NO_x is a generic term for the nitrogen compounds NO and NO_2. In this report, NO_X emissions are calculated based on the Euro IV requirements for emissions of nitrogen compounds relating to transport and environmental requirements for construction machinery, as well as Statistics Norway's factor for *V15 automotive diesel for motorized equipment* /D60/ for those sources where the construction machinery's output is not specified.

In Norway, particulate matter and NO_2 make the biggest contribution to local pollution, and especially particulate matter creates a health risk /D61/. Particulate matter is measured when there are emissions of small particles with a diameter of 10 and 2.5 μm respectively (PM10 and PM2.5). In this report, particulate matter emissions are estimated for emissions of PM2.5. For PM2.5, the emission factorfrom Statistics Norway for *V15 automotive diesel for motorized equipment* /D60/ is used.

2 MAPPING OF EMISSIONS

In this chapter, we calculate the energy demand of, and the associated emissions from, building sites and construction sites respectively.

2.1 The energy demand of and emissions from building sites

Table 1 provides an overview of the estimated energy demand of, and emissions from, various types of building sites, based on empirical data and data obtained from specific projects in Oslo and the surrounding area.

Table 1. Overview of the total energy demands and emissions at various types of building sites, in total and per square metre

Type of building site		Area [m2]	Energy demand [kWh]	CO_2e [kg]	NO_x [kg]	PM2.5 [kg]
Apartment building – high emissions from heating	in total	10 000	2 757 000	902 000	30 750	620
	per m2		276	90	3,075	0,062
Apartment building – mean emissions from heating	in total	10 000	1 352 000	463 000	4 180	380
	per m2		135	46	0,418	0,038
Apartment building – low emissions from heating	in total	10 000	1 352 000	243 000	3 730	200
	per m2		135	24	0,373	0,020
Multi-use-hall	in total	3600	141 000	108 000	650	10
	per m2		39	30	0,181	0,003
Kindergarten	in total	1650	34 000	30 000	120	2
	per m2		21	18	0,076	0,001

Each project can be divided into three activities that lead to emissions:

- The production of heat and electricity for heating and drying out
- The use of large construction machinery
- The use of small construction machinery

A more detailed description of these activities and associated emissions is provided below.

2.1.1 Emissions from the production of heat and electricity for heating and drying out

Temporary heating and drying out at a building site is often called building heat. Building heat is used to heat interiors, dry out damp, set concrete and heat facades and for thawing/frost protection. Today, diesel and propane are the two energy sources mainly used for heating. In connection with interior heating, electricity and district heating are also used to a considerable extent, while pellets and biofuel are used to some extent.

Heating and drying out at the building site can be divided into three activities: 1) heating when casting a concrete surface at the building site (concrete setting), 2) facade heating and 3) interior heating. Heating at the building site is used to dry out materials and to achieve a satisfactory temperature when it is too cold outside to carry out the necessary work. The need for heating is thus to a large extent controlled by the outdoor temperature. In general, it can be said that the need for heating is mainly limited to the period from November until the end of March. During other parts of the year, the need for heating is negligible.

Table 2 provides an overview of the estimated energy required for, and emissions from, the heating of three building sites.

Table 2. Overview of the energy required for, and emissions from, the production of heating and electricity at various types of building sites

Typ of building site	Period	Area [m2]	Energy demand [kWh]	CO_2e [kg]	NO_x [kg]	PM2.5 [kg]
Apartment building – high emissions*	nov-mar	10 000	2 482 500	659 052	27 029	416
Apartment building – medium emissions**	nov-mar	10 000	1 077 750	220 536	454	181
Apartment building – low emissions***	nov-mar	10 000	1 077 750	0	0	0
Multi-use-hall****	nov-des (> 1 yr)	3 600	19 068	41	208	3
Kindergarten	apr-nov	1 650	-	-	-	-

*High energy demand and 100% untaxed diesel, **Medium energy demand and 100% propane, ***average energy demand and 100% district heating, ****100% HVO100

2.1.2 Emissions from large construction machinery

Large construction machinery is defined as construction machinery with an engine power of more than 37kW /D05/. Large construction machinery can be divided into two categories; machinery for ground work and machinery for building work. For ground work, large, diesel-driven machinery, such as excavators and pile drivers, is often used. The quantity of construction machinery and time for which they are used will vary according to the complexity of the ground conditions. The use of construction machinery varies greatly from building project to building project - from projects with simple ground conditions that only require a couple of excavators for a few months to projects that also require machinery to move earth, piling etc. A project's level of complexity considerably affects the energy usage and emissions of construction machinery at the building site.

Diesel-driven mobile cranes, combined with tower cranes and lifts, are often used for building work. The use of tower cranes is not included in the calculations, since these are mainly already electric.

Table 3 provides an overview of the energy demands and emissions of large construction machinery at three different building sites.

Table 3. Overview of the energy demands and emissions of large construction machinery

Type of building site	Ground conditions	Area [m2]	Energy demand [kWh]	CO_2e [kg]	NO_x [kg][3]	PM2.5 [kg][2]
Apartment building	Simple	10 000	246 131	217 809	3 282	164
Multi-use-hall	Simple (tennis courts)	3600	122 407	108 322	444	7
Kindergarten	Simple (berg)	1650	33 520	29 663	122	2

All three examples of building sites have relatively simple ground conditions. This entails the risk that emissions from large construction machinery will be underestimated if the scaling up to municipality level is based on these values.

[3] The much higher emissions of NOx and PM2.5 for the apartment building is due to the construction machinery in this project using motor type Steg IIIA and the emissions are calculated based on emission requirements within the EU for diesel-driven emission-machinery. For the multi-use hall and kindergarten, the motor type and output category are not defined, so Statistics Norway's emission factor for motorized equipment has therefore been used.

2.1.3 Emissions from small construction machinery

Small construction machinery is defined as machinery with an engine output of less than 37kW /D05/. This group includes several traditional fossil-fuel-based types of machinery, such as small articulated dump trucks, mini-excavators, drilling machines, asphalt spreaders, vibrator plates, lawnmowers and chainsaws.

There is little information on the consumption of untaxed diesel as a result of using small construction machinery at building sites. This consumption is probably either reported together with the consumption of the large construction machinery or not reported at all. In the example projects, there is only information on small construction machinery in the form of landscape gardener equipment and vibrator plates. Table 4 provides an overview of the energy demands and emissions of small construction machinery in the example projects.

Table 4. Overview of the energy demands and emissions of small construction machinery, per square metre

Type of building site	Ground conditions	Area [m2]	Energy demand [kWh]	CO_2e [kg]	NO_x [kg]	PM2.5 [kg]
Apartment building	Simple	10 000	28 323	25 064	444	38
Multi-use-hall	Simple (tennis courts)	3600	-	-	-	-
Kindergarten	Simple (berg)	1650	882	781	3	0,05

2.1.4 Any other emissions from using untaxed diesel that is apparent from the data basis

No other use of untaxed diesel has been identified in the reference projects.

2.2 Energy demands and emissions of construction sites

One reference project conducted by the Water and Sewage Department (WSD) and two reference projects conducted by the Agency for Urban Environment in Oslo Municipality were used as the basis for calculating the energy demands and emissions of construction sites.

The WSD reference project is a construction site involving the digging of an around 800-metre-long combined trench with normal to difficult ground conditions. The project is estimated to be representative of around 40% of WSD's projects. The Agency for Urban Environment’s firstreference project is a construction site for a small transport project at Akershusstranda. This is a small bicycle project with a duration of around six months. Their second reference project is a construction site for a large transport project, a tram project near Tinghuset and Tullinløkka that is expected to last for around two years. The project involves upgrading the tram infrastructure from Tinghuset to Holbergs plass, with a temporary tramline over Tullinløka. In addition, floodwater solutions, cable routes and water and sewage infrastructure will be upgraded.

Below, the WSD reference project is referred to below as the water and sewage (WS) project, while the Agency for Urban Environment reference projects are referred to as the small and the large transport project. In the construction site reference projects, there has not been identified any need for heating. However, the use of large and small construction machinery has been identified. Table 5 shows an overview of the three construction sites' estimated energy demands and emissions.

Table 5. Overview of the total energy demands and emissions of three types of civil engineering sites, in total and per construction-contract krone (MNOK)

Type of building site		Energy demand [kWh]	CO_2e [kg]	NO_x [kg]	PM2.5 [kg]
Water & Sewage project	in total	149 000	131 000	800	40
	per MNOK	5 300	4 700	29	1,43
Smaller transport project	in total	26 000	23 000	90	1
	per MNOK	2 500	2 300	9	0,14
Larger transport project	in total	348 000	308 000	2 900	132
	per MNOK	700	600	6	0,28

The emissions per construction-contract krone vary widely. This can partly be explained by the difference between the projects' contents and percentage of construction work. Almost the entirety of the WS project consist of construction work. The large transport project includes other cost elements that do not lead to the use of construction machinery, and this results in lower emissions per construction-contract krone.

Below, the energy demands for, and emissions from, the production of heat and electricity and large and small construction machinery are presented for each project. For detailed information and calculations, refer to Annex A.

2.2.1 Emissions from the production of heat and electricity

No need for temporary heating or drying out has been identified at the reference construction sites.

2.2.2 Emissions from large construction machinery

The WS project has normal to difficult ground conditions and can thus be expected to produce a medium to high estimate of the emissions from large construction machinery.

Table 6. Overview of the energy demands and emissions of large construction machinery

Type of construction site	Energy demand [kWh]	CO_2e [kg]	NO_x [kg]	PM2.5 [kg]
Water & Sewage project	144 076	127 497	783	40
Smaller transport project	25 945	22 960	94	1
Larger transport project	333 206	294 864	2 843	132

2.2.3 Emissions from small construction machinery

The WS project used several small construction machines such as vibrator plates, asphalt spreaders and articulated dump trucks. In connection with the large transport project, the use of two mini-excavators and a small wheel dumper has been reported, while no use of small construction machinery has been reported for the small transport project.

Table 7. Overview of the energy demands and emissions of small construction machinery

Type of construction site	Energy demand [kWh]	CO_2e [kg]	NO_x [kg]	PM2.5 [kg]
Water & Sewage project	4 499	3 982	16	0,25
Smaller transport project	-	-	-	-
Larger transport project	15 214	13 463	55	0,85

2.2.4 Any other emissions from the use of untaxed diesel that can be seen from the data basis

In addition to using large and small construction machinery, the WS project used four trucks that consumed a total of 14,500 litres of untaxed diesel, corresponding to CO_{2e} emissions of around 60 tonnes. Transport data has also been reported for the small transport project.

Transport outside the building site is not included in this analysis and is therefore not included in the further calculations.

3 EMISSIONS FROM BUILDING AND CONSTRUCTION ACTIVITY IN OSLO MUNICIPALITY

In this part of the report, we provide an indication of the energy demand of, and emission levels from, building and construction sites in Oslo Municipality. We use the energy demands and emissions calculated in chapter 2 to estimate the emissions per square metre and per construction-contract krone. The emissions per construction-contract krone are measured per million krone (MNOK). Estimates of the energy demands and emissions of building and construction sites in Oslo Municipality are provided based on the commissioned floor space area with a start-up permit in 2017 and the size of the construction market in 2017.

3.1 Emissions per square metre and construction-contract krone

Based on the mapping of energy demands and calculated emissions linked to the use of heating, construction machinery and transport in chapter 2, we calculate the emissions per square metre for building and construction sites respectively.

3.1.1 Emissions per square metre at building sites

The three building sites in chapter 2.1 are examples of how great a difference in energy usage and emissions there can be between different types of building sites. The multi-use hall and kindergarten are both special buildings and building sites where the focus has been on reducing the energy demands and emissions. These are therefore less relevant for use in scaling up to municipality level. We have therefore chosen to use the same assumptions and calculations that were used to calculate the emissions per square metre for a "typical" building site in the report on fossil- and emission-free building sites in 2017 /D57/. However, the percentage of large building projects is changed. In Oslo Municipality, large building projects make up around 75 per cent of building projects, compared to 54 per cent nationwide.

Table 8 provides an overview of the assumptions used when calculating the energy demands and emissions per square metre, based on the mapping of energy demands in the report on fossil- and emission-free building sites in 2017 /D57/.

Table 8. Assumptions when calculating the energy demands and emissions of an average-size building site. Apartment building of 10,000m2. Based on /D57/

Assumptions	
Area	10 000 m2
Share of large buildings	75 %
Share of other buildings	25 %
Heating demand	November - March

Activity	Heating demand	Share	Area*	Energy demand electricity pr. m2	Energy carrier
Heating	75%				
Concrete setting	5/12	35 %	2 625 m2	70 kWh	Diesel (50%), propan (50%)
Concrete setting – grout casting	5/12	65 %	4 875 m2	15 kWh	Diesel (50%), propan (50%)
Fasade heating	5/12	5 %	375 m2	40 kWh	Diesel (50%), propan (50%)
Internal heating	5/12	100 %	7 500 m2	110 kWh	Diesel (34%), propan (31%), fjernvarme (13%), elektrisitet (18%), pellets (2%), biodrivstoff (2%)
Construction machinery	NA	100 %	10 000 m2	30 kWh	Diesel (100%)

* Area with heating demand. Calculated based on «area», «heating demand» and «share»

Table 9 presents the resulting emissions per square metre, with the percentage of large building projects adjusted from 54 per cent to 75 per cent. The table also includes the calculated emissions of PM2.5.

Table 9. The energy demands of, and emissions (CO2e, NOx and PM2.5) from, per square metre, an average building site in Oslo Municipality. Adjusted for the percentage of large building projects (from 54 per cent nationwide to 75 per cent in Oslo Municipality). Based on /D57/

Activity	Energy demand [kWh/m2]	CO_2e [kg/m2]	NO_x [kg/m2]	PM2.5 [kg/m2]
Heating	47 kWh	10	0,08	0,008
Concrete setting	34 kWh	6,1	0,05	0,006
Concrete setting – grout casting	8 kWh	2,2	0,02	0,001
Fasade heating	4 kWh	1,1	0,01	0,001
Internal heating	1 kWh	0,3	0,002	0,000
Construction machinery	30 kWh	24,5	0,37	0,005
IN TOTAL	77 kWh	34 kg	0,45 kg	0,013 kg

The estimated emissions from heating at the building site, *Boligblokk – høyt utslipp*[4] (Apartment building – high emissions), in chapter 2.1.1 are 65 kg CO_{2e}/m2. The emissions per square metre for a typical building site in Oslo Municipality (Table 9) are considerably lower, 10 kg CO_{2e}/m2, this is due to several factors:

- At a building site, there is only a need for heating from November to March, so not all building sites have emissions from heating.
- Alternative energy sources such as district heating, electricity, pellets and biofuel are already used to heat interiors.

[4] An estimated high energy requirement for heating interiors and drying out, concrete setting when concreting surfaces at the building site, and when there is a great need for facade heating, as well as the fact that all heating is based on untaxed diesel.

- The concreting of surfaces on site (concrete setting) is not relevant at all building sites[5]. If prefabricated concrete elements are used, there is only a need for grouting.
- The percentage of large building projects with a plastered facade or some other facade with a need for facade heating has been limited during the past 10 years. It has therefore been assumed that only 5 per cent of the large building projects have facades that require heating.

In total, these factors reduce the estimated emissions from heating at a typical building site in Oslo Municipality, since this is to be an example of the municipality's average building site. However, there is great uncertainty relating to the estimated emissions per square metre for the municipality's average building site. This uncertainty is discussed further in chapter 3.4.

3.1.2 Emissions per construction-contract krone at construction sites

The three reference projects described in part 2.2 are used as a background for the emissions per construction-contract krone (measured in MNOK) for construction sites. The construction sites' emissions per construction-contract krone vary widely. The emissions per construction-contract krone have been estimated for an 'average' construction site in order to enable aggregation to emissions from construction sites in Oslo Municipality.

There is a great deal of uncertainty related to the share of the contruction market that each project may represent. It is assumed that the emission level of the WS project is representative of around 60%, while the large transport project is representative of 30% and the small transport project is representative of 10% of the construction market. Table 10 shows an overview of the resulting energy demands and emissions per construction-contract krone for an 'average' construction site.

Table 10. Energy demands and emissions (CO2e, NOx and PM2.5) of a construction site, per construction-contract krone (MNOK).

Type of construction site	Market share	Energy demand [kWh/MNOK]	CO_2e [kg/MNOK]	NO_x [kg/MNOK]	PM2.5 [kg/MNOK]
Water & Sewage project	60%	5 300	4 700	29	1,43
Small transport project	10%	2 500	2 300	9	0,14
Large transport project	30%	700	600	6	0,28
'Average' construction site		3 640	3 230	20	0,96
Larger construction machinery		3 552	3 143	20	1
Smaller construction machinery		106	94	0,38	0,01

3.2 Building and construction activity in Oslo Municipality

In order to estimate the annual building activity, we have used Statistics Norway's statistics for commissioned floor space area /D69, D70/, refer to Figure 2. These statistics are based on the dates when start-up permits for new floor space are registered by the municipality. The figures include the construction of new buildings, but not renovation or maintenance projects. The energy consumption and emissions linked to renovating buildings are thus not included in these figures. A start-up permit does not always mean that the building work starts immediately. Building activity especially depends on economic conditions, for example during downturns there may be building projects that are not started on, or that are postponed, after a start-up permit has been granted /D28/. Below, we use the building activity in 2017 to estimate annual emissions.

[5] It is assumed that 35% of large building projects with a heating requirement cast concrete surfaces at the building site, while the remaining 65% use prefabricated elements and thus only require grouting at the building site, ref /D57/.

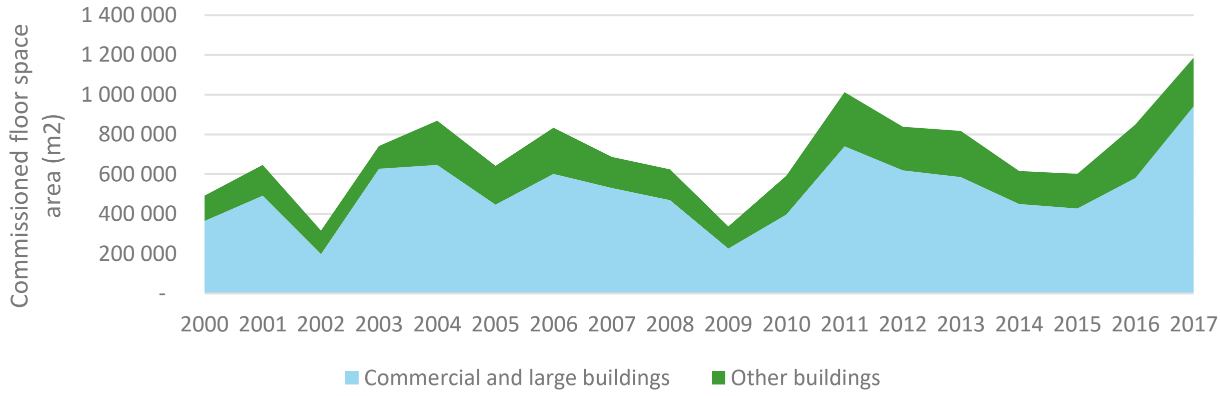


Figure 2. Commissioned floor space area with a start-up permit in Oslo Municipality from 2000 to 2017 (Statistics Norway)

The commissioned floor space area with a start-up permit in 2017 was 1,186,400 m^2 and around 75 per cent of that floor space comprises commercial buildings and large apartment buildings (large building projects) while 25 per cent is made up of other buildings (small building projects). The classification is based on a rough division into building types.

Prognosesenteret has monitored the construction market since 2006. This market mainly comprises investments in and the maintenance of transport facilities, energy facilities, water and sewage facilities, land-based oil facilities, defence facilities and primary industries' facilities /D58/. Road maintenance makes up 70 per cent of the construction maintenance market. /D58/ Statistics Norway has a corresponding estimate for the construction market based on the companies registered in the various counties.

Prognosesenteret's estimate for the total construction market has been used to estimate the annual construction activity in the municipality /D71/. The reason for Prognosesenteret's statistics being used instead of Statistics Norway's is that Statistics Norway's statistics do not reflect the production per county, they reflect the production of the companies registered in the counties. This production can take place anywhere in Norway.

Figure 3 shows the estimate for the total construction market in Oslo that has been used – the figures include construction investments during the period 2007-2016 and road maintenance from 2013 to 2016.

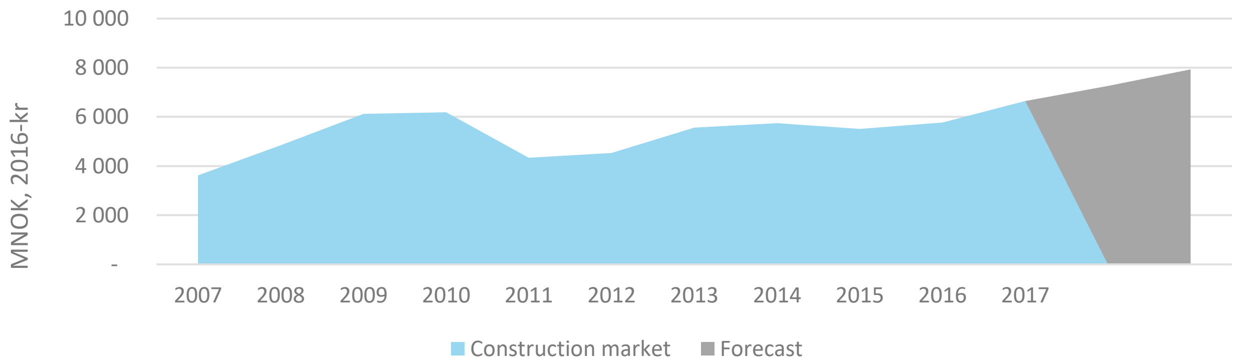


Figure 3. Construction market in Oslo Municipality from 2007 to 2017, forecast for 2018 and 2019 (Prognosesenteret) /D58, D71/.

The data basis is uncertain, among other things because it is incomplete as a lot of the construction maintenance in Norway is not divided into counties. In the forecast for 2018 and 2019, Prognosesenteret's growth forecast for the entire Norwegian construction market has been applied. The entire construction market in 2017 is estimated to be MNOK 6,650.

3.3 Emissions from building and construction activity in Oslo Municipality

Based on the average energy demand and emissions per square metre and construction-contract krone in part 3.1 and the annual building and construction activity in part 3.2, an estimate of the annual energy demand and emissions of building and construction activity in Oslo Municipality can be obtained.

For building activity, the calculations show an energy demand of about 91 GWh per annum and emissions of about 40,600 tonnes of CO2e, 536 tonnes of NOx and 16 tonnes of PM2.5. Refer to Table 11 for details.

Table 11. Average annual energy demands and emissions for building activity in Oslo Municipality

Assumptions	
Area:	1 186 400 m^2
Share of large buildings:	75%
Share of other buildings:	25%
Heating demand:	November - March

Activity	**Energy demand [MWh]**	**CO_2e [ton]**	**NO_x [ton]**	**PM2.5 [ton]**
Heating	55 770	11 520	97	10
Concrete setting	40 340	7 240	59	7
Concrete setting – grout casting	9 490	2 610	24	1,590
Fasade heating	4 750	1 310	12	0,795
Internal heating	1 190	360	2,373	0,199
Construction machinery	35 590	29 070	439	5,9
IN TOTAL	91 360	40 590	536	16

For construction activity, the calculations show an energy demand of about 24 GWh per annum and emissions of about 21,500 tonnes of CO2e, 130 tonnes of NOx and 6 tonnes of PM2.5. Refer to Table 12 for details.

Table 12. Average annual energy demands and emissions for construction activity in Oslo Municipality

Assumptions	
Size of the construction market:	6 650 MNOK

Activity	**Energy demand [MWh]**	**CO_2e [ton]**	**NO_x [ton]**	**PM2.5 [ton]**
Heating	-	-	-	-
Larger construction machinery	23 622	20 904	130	6
Smaller construction machinery	705	624	3	0,04
IN TOTAL	24 300	21 500	132	6

Table 13 summarizes the yearkt energy demand and emissions from building and construction sites in Oslo Municipality.

Table 13. Estimated annual emissions from building and construction activity in Oslo Municipality

Activity	Energy demand [MWh]	CO_2e [ton]	NO_x [ton]	PM2.5 [ton]
Building activity	91 360	40 590	536	16
Construction activity	24 300	21 500	132	6
IN TOTAL	115 660	62 090	668	22

3.4 Uncertainty in the estimated annual emissions from building and construction activity in Oslo Municipality

There is great uncertainty linked to the results presented in Table 13. The calculations are based on empirical data from one building project and three construction projects. The limited data basis means there is a risk that the annual emissions from building and construction activity in Oslo Municipality are underestimated. Below, the uncertainties linked to emissions from building activity and construction activity respectively are described.

3.4.1 Uncertainty about the estimated annual emissions from building activity

The building activity calculations are based on data for a large apartment building of 10,000 square metres, ref. chapter 3.1.1. This project is intended to exemplify the typical building site in Oslo Municipality. Several factors affect how representative this project is, and give rise to uncertainty related to the estimated annual emissions from building activity in Oslo Municipality. The main uncertainty factors are described below:

- For the typical building site, relatively simple ground conditions are presumed and this leads to less use of construction machinery than in a project with difficult ground conditions. If the average building site in Oslo Municipality requires more ground work and site preparations than assumed, then the emissions from construction machinery are underestimated.
- There is assumed to be a need to heat only in large buildings (75%) and only from November to March. If the percentage of large buildings is greater or the period when there is a need for heating is longer, then the emissions from heating are underestimated.
- Alternative energy sources, such as district heating, electricity, pellets and biofuel, are already used to heat interiors. National market shares for the various energy sources have been used to calculate the average emissions from a building site in Oslo Municipality. If alternative energy sources are used to a greater extent in Oslo than nationwide, then the emissions from heating interiors have been overestimated.
- The percentage of large building projects with a plastered facade or other facade that requires facade heating has been limited during the past decade. It has therefore been assumed that only 5 per cent of large building projects have facades that require heating. If the need is greater, then the emissions from heating have been underestimated.
- The commissioned floor space area with a start-up permit in Oslo Municipality is used to aggregate the energy demand and emissions of typical building sites to achieve a total for the municipality. These figures do not include renovation and maintenance projects, which leads to the energy demands and emissions of the municipality's building sites being underestimated.

In total, these factors indicate that the annual emissions from building activity in Oslo Municipality are underestimated.

3.4.2 Uncertainty about the estimated annual emissions from construction activity

The calculated emissions from construction activity is based on three reference projects and aggregated up to municipal level by using estimates for the total construction market, refer to chapters 3.1.2 and 3.2. Below is a list of the parameters that lead to uncertainty related to the estimated annual emissions from construction activity in Oslo Municipality:

- The construction-contract krone (MNOK) is used as a unit of measurement for aggregating emissions at project level to municipality level. This leads to uncertainty, as there may be more or less emission-intensive elements included in the project costs.
- The three reference projects are used to create an average construction project for Oslo Municipality. There is a great deal of uncertainty linked to this distribution, and in addition not all types of construction projects are represented. This leads to a great deal of uncertainty about the actual emission level, which may be lower or higher than estimated.
- A lot of the construction maintenance in Norway is not divided into counties, and this leads to the municipality's share of the construction market being underestimated and thus a risk of emissions being underestimated.

In total, these factors indicate that there is a lot of uncertainty about the estimated annual emissions from construction activity in Oslo Municipality. There is too little information available to say anything about whether the emissions are most probably over- or underestimated.

3.5 Adjusting the estimated annual emissions from building sites

The annual CO2e emissions from building and construction activities in Oslo Municipality are estimated to be 62,090 tonnes (chapter 3.3). The scenario calculations in chapter 5 show considerable uncertainty and that the CO2e emissions from building and construction activity in 2018 are between 44,300 and 122,200 tonnes of CO2e, with an expected value of 80,700 tonnes of CO2e. In addition, the uncertainty discussed in chapter 3.4.1 indicates that the average energy demands and emissions per square metre are underestimated for building sites.

It is regarded as probable that the average building site in Oslo Municipality requires more ground work than is the case in the reference projects. As a result of sea and fjord deposits, there are large thicknesses of silt and clay in the areas from Oslo city centre via Groruddalen to Strømmen. In parts, the thickness of the sea and fjord deposits in Oslo city centre is up to 60-70 metres. Quick clay has been proven at points in these deposits. /D75/

The reference projects for building sites are all examples of building sites with relatively simple ground conditions. Based on this, the energy demand for construction machinery is increased by 50%, refer to Table 14. This adjustment should be updated as soon as there is data on a project with difficult ground conditions.

Table 14. Energy demands and emissions (CO2e, NOx and PM2.5) per square metre of an average building site in Oslo Municipality. Use of construction machinery adjusted for difficult ground conditions.

Activity	Energy demand per m2	CO_2e [kg/m2]	NO_x [kg/m2]	PM2.5 [kg/m2]
Heating	47 kWh	10	0,08	0,008
Concrete setting	34 kWh	6,1	0,05	0,006
Concrete setting – grout casting	8 kWh	2,2	0,02	0,001
Fasade heating	4 kWh	1,1	0,01	0,001
Internal heating	1 kWh	0,3	0,002	0,000
Construction machinery	45 kWh	37	0,555	0,0075
IN TOTAL	92 kWh	47 kg	0,64 kg	0,016 kg

Table 15 shows the estimated annual emissions from building and construction activity in Oslo Municipality, adjusted for difficult ground conditions.

Table 15. Estimated annual emissions from building and construction activity in Oslo Municipality, adjusted for difficult ground conditions

Activity	Energy demand [MWh]	CO_2e [ton]	NO_x [ton]	PM2.5 [ton]
Building activity	109 160	55 450	756	19
Construction activity	24 300	21 500	132	6
IN TOTAL	133 460	76 950	888	25

3.6 Comparison of results with Statistics Norway's estimate

Statistics Norway's estimated CO_2e emissions for diesel-driven utility vehicles include emissions from the use of untaxed diesel in utility vehicles in the agricultural, forestry, defence, building and construction sectors. In addition, there are some challenges involved in using Statistics Norways municipal estimates of CO_2e emissions for diesel-driven utility vehicles:

- The municipal estimate is based on the petroleum sale statistics, and there is a risk that the untaxed diesel is not used in the municipality where it was sold
- A postal code has not been registered for all sales, so that not all sales are divided among the municipalities
- There may some confusion between direct purchases and distributors. Sales to distributors, however, are not divided among municipalities

Figure 4 shows the estimated emissions from building and construction activity (adjusted for difficult ground conditions) and Statistics Norway's estimated emissions from diesel-driven utility vehicles in Oslo Municipality.

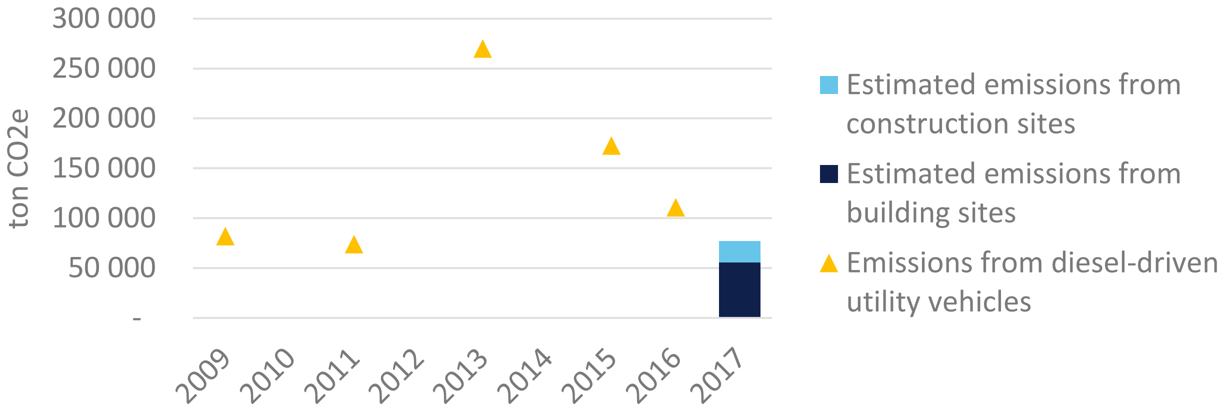


Figure 4. Comparison of the estimated emissions from building and construction sites using the method in this report (adjusted for difficult ground conditions) and emissions from diesel-driven utility vehicles (Statistics Norway) in Oslo Municipality

There is a discrepancy between the estimated annual emissions from building and construction activity and Statistics Norway's estimate for diesel-driven utility vehicles in Oslo Municipality. This discrepancy, together with the considerable uncertainty discussed in chapters 3.4.1 and 3.4.2, also points to the estimated annual emissions from building and construction activity in Oslo Municipality being a starting point, but that, despite the adjustment for difficult ground conditions, these may still be underestimated.

4 TECHNOLOGY AND COST DEVELOPMENTS

This chapter provides a brief overview of the emission-and fossil-free alternative technologies for building and construction that are currently available, and perspectives on expected developments up to 2030.

4.1 Heating and drying out

At building sites, solutions for heating and drying out are used to heat and dry interiors, set concrete, heat facades and for defrosting/frost protection purposes. The need for heating is normally limited to the winter months, from November until the end of March. During other periods, any heating demand is normally covered by electricity.

4.1.1 Technologies currently available

Fossil-free solutions are available and in use today, and several parties offer this in the Oslo area. Biodiesel can replace fossil diesel for heating and drying out, and pellets can be used if a water-borne system is available. The fossil-free solutions function using conventional technology and thus do not lead to any increase in investment costs. The difference in costs is mainly linked to the higher energy costs, since fossil-free fuel is more expensive than diesel or propane, and this especially applies to untaxed diesel, which is not subject to road-usage tax. In interviews DNV GL has held in connection with the project, pellets have been pointed out as a heating solution whose energy costs are in line with those of conventional solutions. Please note that DNV GL has not conducted further analyses to verify this.

Emission-free heating and drying-out solutions are also available and in use in Oslo today, although with some practical restrictions. In order to use both electricity and district heating, new infrastructure must be established up to the building site at an earlier date than is the case for conventional solutions. This requires good planning and it must be possible to put the infrastructure in place within a reasonable time. If the power demand during the building period exceeds the power demand of the building in operation, this may in some cases restrict the use of zero-emission solutions. Apart from this, electricity is available throughout Oslo and the district-heating grid now covers large parts of Oslo city centre (within Ring 3), Groruddalen and southwards to Kolbotn[6].

If the infrastructure required for zero-emission solutions is less than or the same as that required for the building in operation, this will not represent any additional cost. Interviews indicate that the demand of the building in operation usually corresponds to sufficient power during the building period. The main difference in costs for zero-emission solutions is thus given by the energy costs. Based on interviews DNV GL has conducted with several contractors and rental companies, the general picture of district heating is that it is competitive with conventional solutions, while electricity is slightly more expensive. Please note that DNV GL has not conducted further analyses to verify this.

4.1.2 Perspectives going forward

Zero-emission solutions for heating and drying out are currently in use, and the technology on the secondary side of the heat exchanger, for example water-borne systems at the building site, is relatively mature. However, it may be possible to achieve some economies of scale if the market share of fossil- and emission-free heating solutions increases. Most of the cost developments will probably be controlled by the end-user price for the energy carriers.

In the field of heating and drying out at the building site, technology developments leading up to 2020 and 2030 are therefore focusing on other heating alternatives that can be used in those cases when the opportunity to use current alternatives is limited. Examples of such new solutions may be the use of

[6] https://www.fortum.no/fjernvarme-i-oslo

large mobile battery banks or hydrogen. Large mobile battery banks are expected to develop in the same way as batteries in general, with some time lag. For a description of battery developments, refer to chapter 4.2.2.

Several parties have in interviews said they expect hydrogen to be available as a heating alternative in around 2020. It is likely that hydrogen will first be an alternative in the transport sector, since several hydrogen cars and trucks are already being developed and are planned to be launched between 2018 and 2020. It is challenging to establish an infrastructure for selling hydrogen as a fuel before there are enough cars on the roads, while no one will buy hydrogen cars until there are enough filling stations. In December 2017, Norway had nine hydrogen stations in operation and three new ones are being established in 2018 and 2019. As from 2020, there are also expected to be maritime hydrogen stations /D67/.

However, emission-free hydrogen-based heating may develop quickly. Hydrogen can replace natural gas as an energy carrier where natural gas is currently used to heat buildings /D68/. The road from this to replacing natural gas with hydrogen for heating and drying out at building sites is probably not long. Given further development of Norway's hydrogen infrastructure, the parties' expectation of access to hydrogen as a heating alternative in around 2020 may be realistic.

4.2 Construction machinery

The use of construction machinery varies considerably from project to project - for example difficult ground conditions may lead to a need for both more and larger construction machinery.

4.2.1 Technologies currently available

As regards fossil-free alternatives, the vast majority of construction machinery can be run on biodiesel, and this is already available and in use several places in Oslo. In the same way as for heating, the additional cost here will mainly be governed by the energy cost. Since diesel for construction machinery is not subject to road-usage tax, the additional cost of using biodiesel is considerable.

Major developments have taken place in emission-free construction machinery over the past few years. Previously, only construction machinery connected to the power grid via a cable, hand-held equipment and small machines were available electrically, while today, for example, large, battery electric loaders are used in the US market. In addition, a 25-tonne battery electric excavator will be launched in Norway in 2018 /D72/. The costs of investing in electric construction machinery can range from 20 per cent higher to around three times as high, depending on the type of construction machinery. The construction machinery at the high end of this interval are often existing conventional machines that have been modified. However, the energy costs are lower, largely due to the greater efficiency of electrical operations. The maintenance costs are also lower since there are fewer movable parts.

4.2.2 Perspectives going forward

Electric construction machinery can be battery-driven or connected to the power grid via a cable. Both solutions have their advantages and disadvantages, and thus different areas of use. Construction machinery that is supplied with electricity via a cable will, for example, have limited movement, while the utilization period of battery electric machinery is limited by the battery's capacity. Ways to increase the utilization period of mobile zero-emission machinery may be to replace battery packs during operations, or to include a hydrogen tank and fuel cell. An example of the latter is the PILOT-E project in which a hydrogen-electric excavator is being developed /D73/.

Most of the additional cost of battery electric construction machinery is due to the price of batteries. Battery costs have fallen significantly over the past few years and DNV GL expects these costs to continue falling towards 2020, as illustrated in Figure 5.

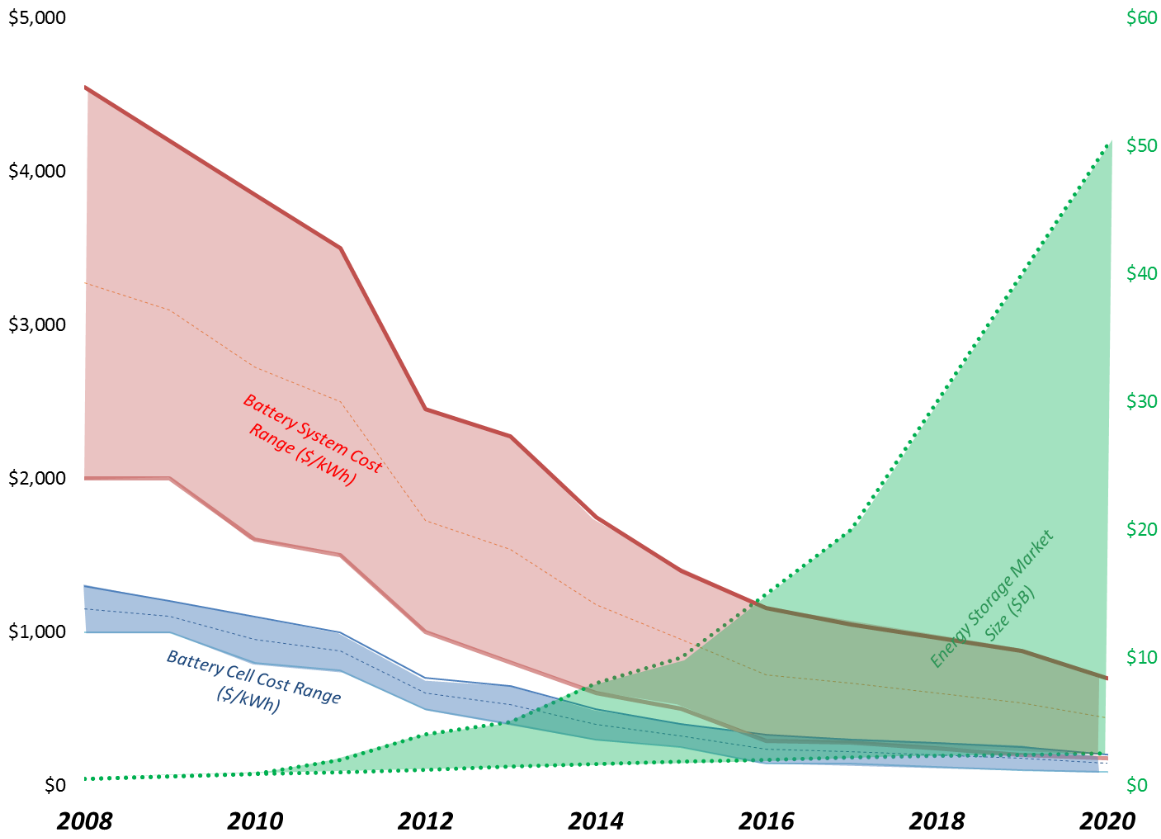


Figure 5. Battery cost developments

DNV GL expects the battery market to continue growing strongly until 2030, driven by the electric passenger-car market and an increased need for balancing in the power system. The Norwegian Water Resources and Energy Directorate (NVE) has analysed the total battery capacity of the electric cars in Norway up to 2030. The growth in the use of batteries is primarily expected to be in connection with electric cars and buildings using solar panels. The report's calculations show that the total battery capacity of electric cars in Norway is expected to grow from around 2.5 GWh in June 2016 to almost 100 GWh in 2030. Literary studies conducted by NVE show that the size of electric car batteries is expected to increase from the current average of around 30 kWh to 80-100 kWh by 2030 /D74/.

When it comes to emission-free construction machinery as a whole, increased demand in the Norwegian market may lead to a slight increase on the supply side, but at the same time Norway is a small market. The demand for emission-free construction machinery in larger markets will have a greater effect on developments. The focus on emissions from building and construction work globally will therefore be important, but developments can also be accelerated by considerations other than simply greenhouse gas emissions. In London, for example, there is a focus on noise in connection with building activity, and this is considerably reduced if electric or hydrogen-driven construction machinery is used, and in the construction and mining industries air quality may be an important driver.

Another factor that will influence developments in the coming years is the automation of vehicles. In time, small, autonomous construction machinery may take over some of the tasks of large construction machinery, for example to transport earth or materials at building and construction sites.

With the expected developments in battery technology, it is likely that almost all types of construction machinery may be electrified by 2030. This is also in line with the parties' expectations revealed in interviews. The interviews have shown a general expectation of good future access to large electric construction machinery and contractors are ready to start using these as soon as they are available. The parties expect broad access to electrical and hydrogen-based emission-free construction machinery in 2030.

5 THE POTENTIAL TO REDUCE EMISSIONS

This chapter analyses how emissions from building and construction sites in Oslo Municipality will develop if no changes are made – a benchmark trajectory. Based on the technology-development perspectives presented in chapter 4, two future scenarios for the implementation of emission-free alternatives at building and construction sites are outlined, one based on a low implementation rate for emission-free technologies and one based on a high implementation rate.

The scenario calculations have been conducted based on Monte Carlo simulations using Palisade @Risk. The level of activity in the building and construction industries is presumed to increase in line with the expected growth in the population. The relationship between building and construction activity and emissions of greenhouse gases and other air pollution is expected to remain unchanged during the entire benchmark-trajectory period. The benchmark trajectory and two scenarios are based on Statistics Norway's medium (MMMM) population forecast for the municipality. This entails an expected annual growth of 1.09% until 2030 and in the benchmark trajectory this equals a growth in emissions from building sites of around 15% between 2017 and 2030.

For developments in building activity until 2030, the starting point is the commissioned floor space area with a start-up permit in 2017 (1,186,400 m^2), while for developments in construction activity, the starting point is the estimated total construction market in Oslo in 2017 (MNOK 6,650).

5.1 The benchmark trajectory

The reference projects mentioned in chapter 2 are used as input values for the benchmark trajectory. The estimated emissions of the average building site (chapter 3.1) is used as the expected value, while the reference projects are used to cover uncertainties. The resulting CO_2e emissions from building and construction activity in Oslo Municipality until 2030 are shown in Figure 6.

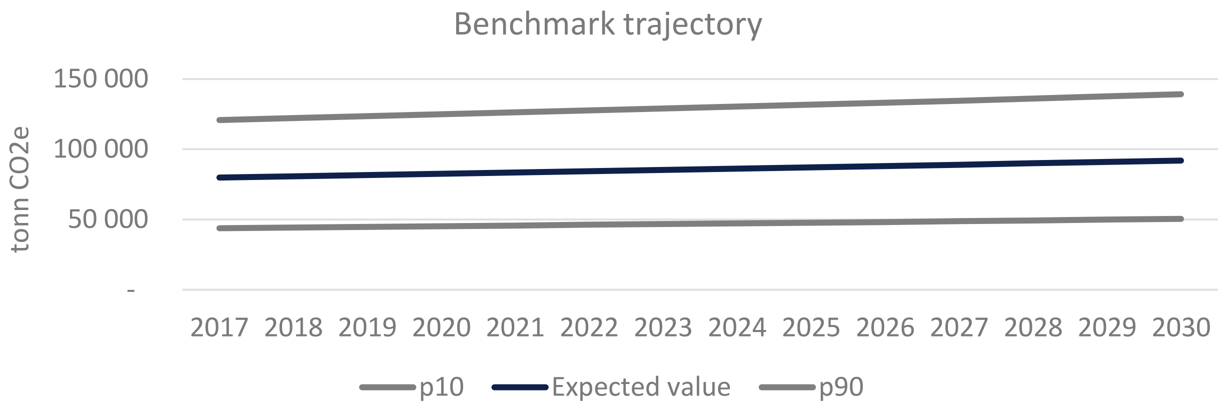


Figure 6. Simulated emissions from building and construction activity in Oslo Municipality until 2030 without the implementation of zero-emission technologies.

Table 16 shows the resulting emissions for the benchmark trajectory for the years 2018, 2020, 2025 and 2030.

Table 16. The results for the benchmark trajectory, emissions in tonnes of CO2e.

	2018[7]	2020	2025	2030
Low estimate (p10)	44 300	45 000	48 000	50 000
Expected value	80 700	83 000	87 000	92 000
High estimate (p90)	122 200	125 000	132 000	139 000

Compared to the estimated annual emissions from building and construction activity in chapter 3.3, here the estimated emissions are higher. This is explained by that we here take uncertainty into account. There is generally greater upward uncertainty compared to the hypothetical average building site and construction site. This is substantiated by the discussions on uncertainties in chapter 3.4, where most parameters indicate that the estimated annual emissions from building and construction activity in chapter 3.3 are underestimated. The 2018 results in Table 16 are in line with the estimated annual emissions in Oslo Municipality adjusted for difficult ground conditions in chapter 3.5.

5.2 Low implementation rate for emission-free alternatives

The low-implementation-rate scenario is based on the industry being required to carry out work and make changes in order for emission-free solutions to be used to a great extent at building and construction sites. Further, it is assumed there is no global demand for construction machinery and/or battery costs fall more slowly than expected.

Assumptions regarding the implementation rate:

- Zero-emission heating and drying out technologies are gradually implemented towards 2025.
    - In 2020, 38% of all heating is expected to be emission-free.
    - 10% of all heating is still based on fossil energy sources in 2025 and until 2030.
- Small construction machinery (estimated lifetime 5-7 years) is replaced by fully electric machinery by 2025.
    - In 2020 38% of all small construction machinery is expected to have been replaced by fully electric machinery.

[7] For building activity, the level of activity for 2018 is based on the commissioned floor space area with a start-up permit in 2017 increased by 1.09%, while for civil engineering activity, it is based on the civil engineering market in 2017, increased by 1.09%.

- In 2025, all small construction machinery is expected to be electrified.

- Large construction machinery (estimated lifetime 5-15 years) is replaced by zero-emission technologies starting in 2020 and gradually until 2030.
  - 9% of all large construction machinery is expected to be replaced by emission-free alternatives in 2020.
  - In 2025, 55% is expected to have been replaced by emission-free alternatives.
  - In 2030, 90% is expected to have been replaced by emission-free alternatives, which means that 10% of all large construction machinery is still fossil-fuel-based in 2030.

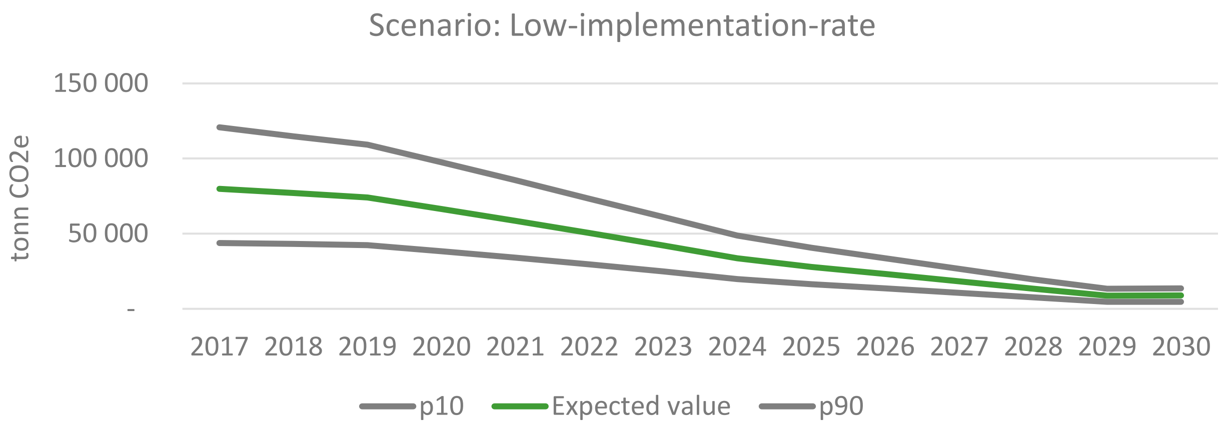


Figure 7. Simulated emissions from building and construction activity in Oslo Municipality until 2030 based on a low implementation rate for zero-emission technologies.

Table 17 shows emissions in tonnes of CO2e for the years 2020, 2025 and 2030 based on a low implementation rate for zero-emission technology.

Table 17. Results for the low-implementation-rate scenario, emissions in tonnes of CO2e.

	2020	2025	2030
Low estimate (p10)	38 000	16 000	5 000
Expected value	66 000	28 000	9 000
High estimate (p90)	98 000	41 000	14 000

The estimated reduction potential compared to the benchmark trajectory is 17,000 tonnes of CO2e in 2020, 59,000 tonnes of CO2e in 2025 and 83,000 tonnes of CO2e in 2030.

5.3 High implementation rate for emission-free alternatives

The high-implementation-rate scenario is based on the widespread adoption of requirements for emission-free building sites by clients. To achieve this scenario, all building sites started in 2023 must be almost emission-free and the requirement of emission-free building sites must enter into force at least two years before this in order to speed up developments. In special cases, it is expected there may be a need to use conventional technology despite the requirement of an emission-free building site. It is important to refer early on to the demand for emission-free technology, and the clearest way to do this is to stipulate a requirement of emission-free building sites.

In addition, this scenario is based on the parties in the market seeing other benefits in a transition from fossil energy sources, such as an environmental profile, a strategic focus and financial benefits. The global demand for electric construction machinery is rising rapidly and development costs can be shared among several parties and markets. Together with falling battery prices, this means the additional cost (investment) decreases and the costs over the construction machinery's lifetime become lower than for diesel.

Assumptions regarding the implementation rate:

- Zero-emission heating and drying out technologies start to be used by 2020, but 10% of all heating is still based on fossil energy sources in 2020 and until 2030. This means that 90% of all heating is expected to be emission-free by 2020.
- Small construction machinery is replaced by fully electric machinery by 2025, as in the low-implementation-rate scenario.
    - In 2020, 38% of all small construction machinery is expected to have been replaced by fully electric machinery.
    - In 2025, all small construction machinery is expected to be electrified.
- Most large construction machinery is not replaced by 2020 but this machinery is rapidly replaced by zero-emission technologies by 2025
    - In 2020, 25% of all large construction machinery is expected to have been replaced by fully electric machinery
    - In 2025, the percentage of fully electric large construction machinery is expected to have increased to 95%, while 5% of all large construction machinery is expected to still be fossil-fuel-based in 2025 and up to 2030

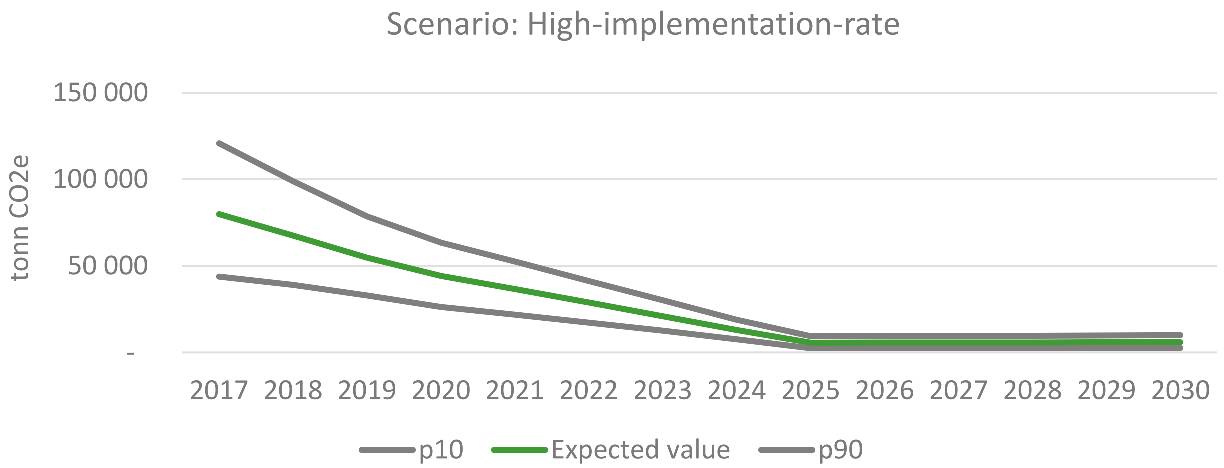


Figure 8. Simulated emissions from building and construction activity in Oslo Municipality until 2030 based on a high implementation rate for zero-emission technologies.

Table 18 shows the emissions in tonnes of CO_2e for 2020, 2025 and 2030 based on a high implementation rate for zero-emission technologies. We see that the emissions rise slightly between 2025 and 2030, which is due to an increase in the building and construction activity in this period that leads to higher emissions (ref. the benchmark trajectory), while the percentage of emission-free technology in this scenario does not change between 2025 and 2030.

Table 18. Results for the high-implementation-rate scenario, emissions in tonnes of CO2e.

	2020	2025	2030
Low estimate (p10)	26 000	2 000	3 000
Expected value	44 000	6 000	6 000
High estimate (p90)	63 000	9 000	10 000

The expected reduction potential compared to the benchmark trajectory is 39,000 tonnes of CO2e in 2020, 81,000 tonnes of CO2e in 2025 and 86,000 tonnes of CO2e in 2030.

6 THE INVOLVED PARTIES AND EMISSION RESPONSIBILITY

This chapter describes the parties linked to a building site and those responsible for the emissions at the building site.

6.1 The parties at the building site

There are many parties involved in a building process. The building process starts with the client's idea for a new building, and ends when the building is in operation, e. g. when the building starts to be used. The parties may influence the process in various ways, for example by stipulating requirements for both the actual building process and the final building. Below is a brief description of the largest groups of parties, based on ENOVA's description of parties in the report entitled *Byggstudien fra 2003* (Building Study 2003) /D64/:

A **Client/Developer**, in the form of either a private or public owner of the building. Private building owners buy and develop properties and plots of land as their core activity. Public building owners are state/county council/municipal owners/managers and developers of property.

Architects join a building project early on in order to design the building and help the developer at the beginning of the building process.

Contractors carry out the building work. Their professional areas are: building contractors, electrical contractors, ventilation contractors, pipe contractors. Several contractor companies carry out multidisciplinary work.

Suppliers/manufacturers work as subcontractors/subsuppliers to the contractors. This group carries out a lot of product-development work and contains many parties. These include several parties that are important for enabling emission-free building sites, such as rental companies (construction machinery, temporary building-site electricity supply, etc) and manufacturers of construction machinery.

Advisors in the construction sector in professional areas such as: project management, building management, technical advice/planning relating to electrical systems, heating, ventilation and sanitary facilities, IT, geo-technology, management, operation and maintenance (MOM), etc. Several advisory companies carry out multidisciplinary work.

One or more **Energy Suppliers** are involved, depending on the chosen energy solution. This group includes Distribution System Operators (DSOs), district heating companies and fuel suppliers.

The building authorities ensure compliance with laws and regulations that are relevant to building projects. These are also the regulating authority. Other public bodies with responsibilities for the building activities are the Electrical Facility and Equipment Supervision Authority and the Norwegian Labour Inspection Authority.

Large tenants may also have an influence and stipulate requirements regarding emission-free building sites and energy-efficient buildings.

Users/neighbours. Users are reference groups in a building process that consist of the building's normal users, the building's neighbours during the building period, operations personnel, safety representatives, trade union representatives and suchlike.

6.2 Who is responsible for emissions at the building site?

In order to define the party responsible for emissions at the building site, we refer to the most-used global standardized framework for measuring and handling greenhouse gas emissions from the private and public sectors, the Green House Gas (GHG) Protocol. This organization is responsible for the world's most used GHG-accounting standards, including a framework for companies (the GHG Protocol Corporate Standard) and a framework for cities (the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories).

The GHG Protocol Corporate Standard divides a company's greenhouse gas emissions into three ‘scopes’. Scope 1 covers emissions that directly arise from self-owned or controlled sources. Scope 2 covers indirect emissions due to the generation of purchased energy. Scope 3 covers all indirect emissions (that are not included in Scope 2) in the value chain of the reporting company, including emissions from both upstream and downstream activities in the value chain. The Global Reporting Initiative (GRI) bases its guide for reporting greenhouse gas emissions (GRI 305: Emissions 2016) on the GHG Protocol's scope division.

If the distribution of responsibilities at a building site is based on the three scopes of the GHG Protocol Corporate Standard, it is primarily the subcontractors, those who own the actual equipment and construction machinery, that are also responsible for the emissions. The reason for this is that the party owning the source of the emission also has the most opportunity to do something about the emission. This is partly true at a building site, but subcontractors are heavily dependent on the types of requirements stipulated by the Client and Contractor. More than other value chains, a building site resembles a small community, so that perhaps the GHG Protocol's framework for cities can be used.

The scope definitions for cities are slightly different to those for a company. Scope 1 emissions are emissions that take place within the city boundary. Scope 2 emissions are emissions that take place as a result of using grid-supplied electricity, heating, steam and/or cooling within the city boundary. Scope 3 covers emissions that take place outside the city boundary and are a result of activities within the city boundary. Figure 9 provides an overview of the scopes for cities.

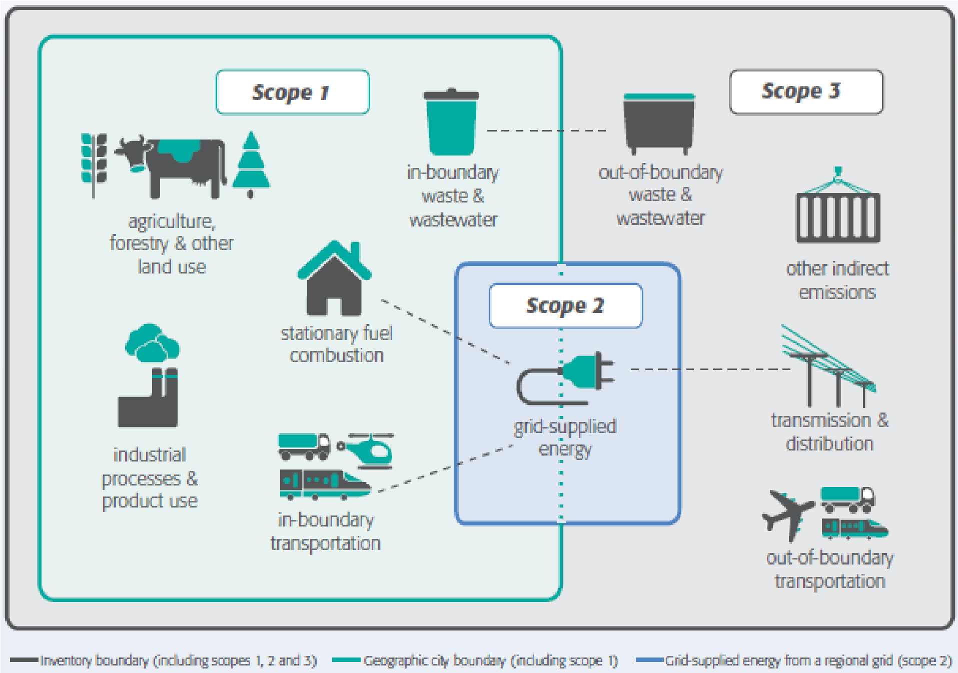


Figure 9. Overview of sources and limits for a city's greenhouse gas emissions, from GHG Protocol /D65/

If the three scopes for a city are applied at a building site, the building site can be imagined to represent the city and the building site boundary represents the city boundary. The party responsible for emissions at the building site should thus be the Client, which is the party that is responsible for and initiated the development.

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ANNEX A – DETAILS OF A CONSTRUCTION PROJECT

A construction site for a water and sewage (WS) project

The water and sewage project involved digging an around 800-metre-long combined trench with normal to difficult ground conditions. Loose masses (sand, silt, clay, partly quick clay) and rock, with some alum shale. Excavating, breaking up, blasting and suction vehicles. The project is estimated to be representative of around 40 per cent of the Water and Sewage Department's (WSD's) projects.

Summary of the estimated energy demands and emissions at a construction site for a water and sewage project

Activity	Energy demand [kWh]	CO2e [kg]	NO_x [kg]	PM2.5 [kg]
Heating	-	-	-	-
Larger construction machinery	144 076	127 497	783	40
Smaller construction machinery	4 499	3 982	16	0,25
Other (transport)	67 769	59 971	222	3
IN TOTAL	216 344	191 450	1 022	43

Below is an account of the emissions from the production of heat and electricity as well as from large construction machinery, small construction machinery and transport.

Emissions from the production of heat and electricity

In connection with this construction project, there was no need to produce heat or electricity for temporary heating and drying out at the construction site.

Emissions from large construction machinery

The water and sewage project has normal to difficult ground conditions and can thus be expected to produce medium to high estimated emissions from large construction machinery.

Assumptions, energy demands and emissions of large construction machinery

Assumptions	
Type of construction work:	Digging of joint trench
Size:	800 meter
Motor type:	Varied: Step IIIA, Step IIIB, Step IV
Energy carrier:	100% mineral diesel
Efficiency	30 %

Type	Number	Consumption diesel [liter]	Energy demand electricity [kWh]	CO2e [kg]	NOx [kg]	PM2,5 [kg]
Excavator, 14 ton	2	23 400	70 204	62 126	94	6
Excavator, 14 ton	1	9 360	28 082	24 850	374	28
Excavator, 8 ton	1	585	1 755	1 553	27	2
Excavator, 24 ton	1	14 040	42 122	37 275	281	4
Planer	1	638	1 913	1 693	7	0
IN TOTAL		48 023	144 076	127 497	783	40

Emissions from small construction machinery

The WS project used several small construction machines, with a total untaxed diesel consumption of around 1,500 litres and emissions of 4 tonnes of CO_{2e}.

Assumptions, energy demands and emissions of small construction machinery

Assumptions	
Type of construction work:	Digging of joint trench
Size:	800 meter
Motor type:	Not defined, SSB general emission factor used
Energy carrier:	100% mineral diesel
Efficiency	30 %

Type	Number	Consumption diesel [liter]	Energy demand electricity [kWh]	CO2e [kg]	NOx [kg]	PM2,5 [kg]
Vibrator plate 400-600	1	125	374	331	1	0,02
Vibrator plate small	1	62	187	166	1	0,01
Generator	1	75	225	199	1	0,01
Asphalt spreader	1	375	1125	996	4	0,06
Drill	1	263	788	697	3	0,04
Articulated dump truck 1 tonn	1	600	1 800	1 593	7	0,10
IN TOTAL		1 500	4 499	3 982	16	0,25

Any other emissions from the use of untaxed diesel that are apparent from the data basis

In addition to the use of large and small construction machinery, four trucks that consumed a total of 14,500 litres of untaxed diesel, with corresponding CO2e emissions of 60 tonnes, were used in the WS project. The NO_x emissions from truck 2 are less than those from truck 1 because truck 2 is a newer Euro class.

Assumptions, energy demands and emissions of other use of untaxed diesel

Assumptions	
Type of construction work:	Digging of joint trench
Size:	800 meter
Motor type:	Euro V, Euro VI
Energy carrier:	100% mineraldiesel
Efficiency:	30 %

Type	Number	Consumption diesel [liter]	Energy demand electricity [kWh]	CO2e [kg]	NOx [kg]	PM2,5 [kg]
Truck 1 (Euro V)	1	8 073	24 220	21 433	161	1,6
Truck 2 (Euro VI)	1	8 073	24 220	21 433	32	0,8
Truck 3 (Euro VI)	1	6 143	18 429	16 308	25	0,6
Truck - asphalt	1	300	900	796	4	0,0
IN TOTAL		22 589	67 769	59 971	222	3

A construction site for a small transport project

The construction site for a small transport project is represented by a project at Akershusstranda. This is a small bicycle project with a duration of around six months. The project is to create better conditions for cyclists where Akershusstranda crosses Kongens gate. The area is to be modified, including the removal of the alum shale deposits in the area. In addition, a plant area is to be established.

The project is ongoing and there is only information on the fuel consumption for the period from December 2017 until February 2018. This information has been used to estimate the project's total energy demand and emissions and an overview is provided in the table below.

Summary of the estimated energy demands and emissions of a construction site for a small transport project

Activity	Energy demand [kWh]	CO2e [kg]	NO_x [kg]	PM2.5 [kg]
Heating	-	-	-	-
Larger construction machinery	25 945	22 960	94,16	1,45
Smaller construction machinery	-	-	-	-
Other (transport)	88 960	78 723	322,84	4,97
IN TOTAL	114 905	101 683	417,00	6,42

Below is an account of the emissions from the production of heat and electricity as well as from large construction machinery, small construction machinery and transport.

Emissions from the production of heat and electricity

In connection with this construction project, there was no need to produce heat or electricity for temporary heating and drying out at the construction site.

Emissions from large construction machinery

The WS project has normal to difficult ground conditions and can thus e expected to produce medium to high estimated emissions from large construction machinery.

Assumptions, energy demands and emissions of large construction machinery

Assumptions	
Type of construction work:	Mindre samferdselsprosjekt
Size:	Bicycle field in cross-section, re-build of the area, establishment of green areas, removal of Alum Shale Formation
Motor type:	Varied: Step IIIA, Step IV
Energy carrier:	100% mineral diesel
Efficiency:	30 %

Type	Number	Consumption diesel [liter]	Energy demand electricity [kWh]	CO2e [kg]	NOx [kg]	PM2,5 [kg]
Excavator	2	8 648	25 945	22 960	94	1
IN TOTAL		**8 648**	**25 945**	**22 960**	**94**	**1**

Emissions from small construction machinery

No use of small construction machinery has been reported in connection with the small transport project.

Any other emissions from the use of untaxed diesel that are apparent from the data basis

In addition to large construction machinery, two trucks with trailers have been used.

Assumptions, energy demands of, and emissions from, other use of untaxed diesel

Assumptions	
Type of construction work:	Mindre samferdselsprosjekt
Size:	Bicycle field in cross-section, re-build of the area, establishment of green areas, removal of Alum Shale Formation
Motor type:	Euro VI
Energy carrier:	100% mineral diesel
Efficiency:	30 %

Type	Number	Consumption diesel [liter]	Energy demand electricity [kWh]	CO2e [kg]	NOx [kg]	PM2,5 [kg]
Truck w. trailer	2	29 652	88 960	78 723	323	5
IN TOTAL		**29 652**	**88 960**	**78 723**	**323**	**5**

A construction site for a large transport project

The construction site for a large transport project is represented by the tram project at Tinghuset and Tullinløkka. This project involves upgrading the tram infrastructure from Tinghuset to Holbergs plass, with a temporary tramline over Tullinløkka. In addition, floodwater solutions, cable routes, etc, are being upgraded.

The project started in the summer of 2017 and will be completed in the summer of 2019. There is only information on the fuel consumption for February and March 2018. This information is used to estimate the project's total energy demand and emissions and an overview is provided in the table below.

Summary of the estimated energy demands and emissions of a construction site for a small transport project

Activity	Energy demand [kWh]	CO2e [kg]	NO_x [kg]	PM2.5 [kg]
Heating	-	-	-	-
Larger construction machinery	333 206	294 864	2 843	132
Smaller construction machinery	15 214	13 463	55,21	0,85
Other (transport)	-	-	-	-
IN TOTAL	348 420	308 328	2 898	132

Below is an account of the emissions from the production of heat and electricity as well as from large construction machinery, small construction machinery and transport.

Emissions from the production of heat and electricity

In connection with this construction project, no need to produce heat or electricity for temporary heating and drying out at the construction site was reported.

Emissions from large construction machinery

The project is a large transport project and many construction machines have been used, primarily excavators and articulated dump trucks. The estimates here are based on the activities in February and March, but other types of construction machinery will very likely be used later in the construction process.

Assumptions, energy demands and emissions of large construction machinery

Assumptions	
Type of construction work:	Larger transport project
Size:	Upgrade of tram infrastructure from Tinghuset to Holbergs plass
Motor type:	Varied: Step IIIA, Step IIIB, Step IV
Energy carrier:	100% mineral diesel
Efficiency:	30 %

Type	**Consumption diesel [liter]**	**Energy demand electricity [kWh]**	**CO2e [kg]**	**NOx [kg]**	**PM2,5 [kg]**
Excavator	2 245	6 735	5 960	106	9
Excavator	2 993	8 980	7 947	141	12
Excavator	18 995	56 987	50 430	760	57
Excavator	11 926	35 781	31 664	394	3
Tracked excavator	13 722	41 169	36 432	55	3
Excavator	4 259	12 779	11 308	170	13
Excavator	3 223	9 671	8 558	13	1
Excavator	6 396	19 189	16 981	26	2
Loader	15 668	47 006	41 597	63	4
Midi excavator	8 012	24 038	21 272	264	2
Kompakt articulated dump truck	10 879	32 638	28 883	359	3
Midi excavator	4 881	14 644	12 959	229	20
Articulated dump truck	691	2 072	1 834	28	2
Articulated dump truck	7 172	21 517	19 041	237	2
TOTALT	**111 062**	**333 206**	**294 864**	**2 843**	**132**

Emissions from small construction machinery

In connection with the large transport project, the use of two mini excavators and a small wheel dumper has been reported.

Assumptions, energy demands for, and emissions from, large construction machinery

Assumptions	
Type of construction work:	Larger transport project
Size:	Upgrade of tram infrastructure from Tinghuset to Holbergs plass
Motor type:	Varied: Step IIIA, Step IIIB, Step IV
Energy carrier:	100% mineral diesel
Efficiency:	30 %

Type	**Consumption diesel [liter]**	**Energy demand electricity [kWh]**	**CO2e [kg]**	**NOx [kg]**	**PM2,5 [kg]**
Mini excavator	1 531	4 594	4 065	17	0,26
Mini excavator	3 281	9 843	8 711	36	0,55
Small wheel loader	259	777	688	3	0,04
IN TOTAL	**5 071**	**15 214**	**13 463**	**55**	**0,85**

Any other emissions from the use of untaxed diesel that are apparent from the data basis

No transport has been specifically reported in connection with the large transport project.

ANNEX B – INPUT VALUES SCENARIO ANALYSIS

The scenario calculations are conducted based on Monte Carlo simulation using Palisade @Risk. The level of activity in the building and construction industries is expected to increase in line with the expected population growth. The relationship between building and construction activities and emissions of greenhouse gases and other air pollution is presumed to be unchanged throughout the benchmark-trajectory period. The benchmark trajectory and two scenarios are based on Statistics Norway's population forecasts for the municipality (MMMM). These entail expected annual growth of 1.09% until 2030. Other input values are presented in the table below. In addition, assumptions are made regarding the implementation rate for emission-free technologies, see chapter 5.

ID	Activity	Comment	Unit	p10	mode	p90	E
	Building sites						
A1	Heating at a building site	p10: no need for heating. Mode: heating needed is equal to the assumed need of the average building site in Oslo Municipality. p90: high estimate for heating	kg $CO_2e/m2$	-	10	66	30
A2	Use of large construction machinery at a building site	All references have relatively easy ground conditions. P10 Kindergarten. Mode: average for Oslo Municipality. p90: double the need of the multi-use-hall	kg $CO_2e/m2$	18	25	60	37
A3	Use of small construction machinery at a building site	Little empirical data, uniform distribution used. P10: Kindergarten. p90: double that of the Apartment building	kg $CO_2e/m2$	0,47		5	3
	The construction site						
B1	Heating at a construction site		kg CO_2e/MNOK	-	-	-	-
B2	Use of large construction machinery at a construction site	Mode: average construction site Oslo Municipality. p90: WS-project, p10: Larger transport project	kg CO_2e/MNOK	621	3 143	4 553	2 671
B3	Use of small construction machinery at a construction site	Mode: average construction site Oslo Municipality. p90: WS-project. p10: Larger transport project	kg CO_2e/MNOK	28	94	142	87
	Building activity						
	Share of large building projects			60 %	75 %	90 %	75 %

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