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A survey of the requirements for emission-free building and construction sites

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A survey of the requirements for emission-free building and construction sites

This is an English translation of the report ***Erfaringskartlegging av krav til utslippsfrie bygge- og anleggsplasser***

Keywords: Emission-free building and construction sites, electric construction machines, vehicles and equipment, charging, peak power, power supply, charging logistics, experiences and barriers

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Preface

The City of Oslo’s Climate Agency has engaged SINTEF to carry out a survey of emission-free building and construction sites for Oslo Municipality's projects. The principal themes are electricity supply, emission-free construction machinery and vehicles, and charging logistics, studying associated experiences and barriers. This report assesses building site experience from relevant projects and includes detailed studies of machine fleets, energy consumption and energy supply. The results indicate that the development towards emission-free building and construction sites is progressing rapidly, although some barriers and challenges remain. All of the municipality's building and construction sites shall be emission-free by 2025.

Oslo, 15. December 2021

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Executive Summary

The City of Oslo's Climate Agency has engaged SINTEF to carry out a survey of emission-free building and construction sites for Oslo Municipality's projects. The principal themes are electricity supply, emission-free construction machinery and vehicles, and charging logistics, studying associated experiences and barriers. This report assesses building site experience from relevant projects and includes detailed studies of machine fleets, energy consumption and energy supply. The results indicate that the development towards emission-free building and construction sites is progressing rapidly, although some barriers and challenges remain. All of the municipality's building and construction sites shall be emission-free by 2025.

Standard climate and environment requirements for Oslo Municipality's building and construction sites were introduced in 2019. With this new framework, contractors who can offer emission free construction machinery and vehicles in building and construction projects are awarded contracts where Oslo Municipality is the building owner. This is an innovative use of procurement, targeted to promote a quicker transition to emission free completion of building and construction activities in Oslo. In 2019, access to emission free equipment was limited, and the market for emission free building and construction services was still in an early phase of development. Standard requirements were introduced to contribute to the Municipality's goal that all building and construction activities in Oslo Municipality's public sector shall be emission free by 2025.

This survey shows that development so far is in line with the goal of Oslo Municipality's public sector shall be emission free by 2025, and the framework has succeeded in its purpose. Between 1st January and 30th June 2021, 73 competitions for tender were published on behalf of Oslo Municipality for the construction sector. Of these, 66 competitions followed Oslo Municipality's standard contractual requirements and award criteria, and eight stipulated the use of emission-free concepts, the minimum requirement in six of these being the use of emission-free excavators. This means that seven of these 73 projects were either too small or did not use electric construction machinery. There are now at least 36 construction projects in Oslo Municipality (mapped in this report) that use emission free construction machinery, vehicles and equipment.

This mapping shows that it is unproblematic with smaller electric machines and equipment. But there are some challenges relating to energy supply and charging logistics when multiple, large construction machineries operate at the same time. It is reported that electric construction machineries generate less noise, less pollution, better air quality and a better working environment. The results show that there are different understandings of what an emission free building or construction site involves, and that definitions of these terms should be standardised. This will most likely be achieved through the on-going development of a Norwegian Standard prNS3770 for emission free building and construction sites. The table below summarises barriers, challenges, possibilities and solutions for emission free construction machineries and vehicles, energy supply and charging logistics.

Barriers, challenges, possibilities and solutions for emission-free building and construction sites

	Barriers and challenges	Possibilities and solutions
Emission-free construction machinery and vehicles	Long distances to disposal sites outside Oslo necessitate the use of vehicles using biofuel or fossil fuel.	Effective local utilisation of masses, and improved charging infrastructure for larger vehicles (outside Oslo).
	New market with few available electric machinery and vehicles.	Make the demand for electric machinery and vehicles visible and collaborate nationally and internationally to affect supply.
	Electric construction machinery has a lower load capacity and heavy electric vehicles have a shorter range – they do not always have enough energy or available electricity to last a full working day.	Adapt work routines, better charging solutions (e.g., rapid charging) and ensure enough electricity supply on the construction site.
	Several emission-free machines are not being used as much as desired.	Follow up contractors actively to ensure they use emission free machineries when they are available.
	Competition for projects is decided according to offers on the machine fleet.	The framework for following up contracts can be further developed with larger weight on documenting the use of emission free construction machineries, instead of todays model that emphasises the composition of the machine fleet.
Electricity supply	Complex process for arranging temporary electricity supplies, especially 400 V – this may lead to delays.	Good process for involving power grid operators in early planning and throughout the project.
	Charging problems – limitations of the supply grid may lead to increased charging times.	Consider the composition of the machine fleet by choosing battery and cable/battery-powered electric machinery to resolve charging capacity problems.
		Other ways to reduce the load on the supply grid may be through the use of a battery container, the use of district heating to heat and dry structures, and arranging one's own energy generation in a building project's early phase.
Charging logistics	Use of cable/battery-powered construction machinery can present challenges related to building site logistics.	Early assessment of which machine types are to be used (battery, cable/battery) to allow suitable arrangement of the building site.
	There may be several different charging systems for different machines.	Appoint a person responsible for charging logistics on the building site.
		Use a battery container that can be kept continuously charged from a 230 V supply, but rapid-charge machinery at 400 V or more from the battery-based mobile solutions.

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APPENDICES

1 Introduction

The City of Oslo's Climate Agency has engaged SINTEF to carry out a survey of emission-free building and construction sites for Oslo Municipality's projects. The principal themes are electricity supply, emission-free construction machinery and vehicles, and charging logistics, studying associated experiences and barriers. This report assesses building site experience from relevant projects and includes detailed studies of machine fleets, energy consumption and energy supply. The results indicate that the development towards emission-free building and construction sites is progressing rapidly, although some barriers and challenges remain. All of the municipality's building and construction sites shall be emission-free by 2025.

2 Background

As part of the Paris Agreement, almost all countries in the world set a goal to keep global warming below 2 °C, compared with pre-industrial levels, and preferably limit the temperature rise to 1.5 °C (1). The IPCC Sixth Assessment Report shows that it will be difficult to limit global warming to 1.5 °C in the period 2021-2040 unless immediate, drastic measures are taken to cut greenhouse gas emissions (2). The construction industry is responsible for approximately 1.2% of Norway's total emissions (3), corresponding to about 660,000 tCO_2e. Around 5% of the emissions result from the heating and drying of buildings in the construction phase, while the remaining 95% originates from transport and machinery operation (3). Oslo Municipality has developed the goal of reducing direct greenhouse gas emissions by 95%, compared with 2009, by 2030, and by 52% by 2023 (4). In 2018, road traffic was the largest source of greenhouse gas emissions in Oslo, amounting to almost 50% of total emissions. Emissions from other mobile combustion sources, largely construction activity, amounted to 20%.

According to the Municipality's climate strategy, shall all construction activity in Oslo be fossil-free and then emission-free, by 2025. By 2030, all vehicles shall be emission-free and all heavy transport in Oslo shall be emission-free or use sustainable renewable fuels. According to Oslo Municipality's climate strategy, the Municipality itself shall carry out climate-friendly construction and shall set aside funds for innovative tendering and development projects for emission-free vehicles and machinery in the Municipality. Oslo will co-operate with other cities to encourage more operators to demand emission-free machinery and to create a market for this technology and reinforce co-operation with industry to achieve emission-free construction operations. Oslo will also co-operate with the Norwegian Government to ensure greater incentives for emission-free construction operations (4).

A previous SINTEF Technical Report "Utslippsfrie byggeplasser - State of the art: Veileder for innovative anskaffelsesprosesser" (Emission-free building sites – State of the art: A guide to innovative procurement processes) defines the difference between fossil-free and emission-free building sites (5). A fossil-free building site involves the use of fossil-free concepts (such as HVO biodiesel) for construction activities within the system boundary, while an emission-free building site involves the use of emission-free concepts (such as electricity or hydrogen) for construction activities within the system boundary. A system boundary shall define both what is included and what is not included in a life cycle analysis (LCA) and describe the scope thereof (EN 15643). The system boundary of a building site can vary, depending on the construction method, such as built-in-place, prefabricated elements or modules, or a combination of these. Construction activities that may be included are the transport of construction materials, the transport and use of construction machinery, personell transport, energy consumption and handling (including transport) of waste, as well as additional installation materials (5). Figure 1 provides an overview of these construction activities.

DNV-GL published a guide to facilitating fossil-free and emission-free concepts on building sites and concluded that the transition from the use of traditional diesel-powered to electric construction machinery may contribute to a significant reduction in emissions, amounting to about 99% for CO_2 and about 96% for NOx (6). In 2018, Multiconsult wrote a report for Oslo Municipality on its study of fossil-free building sites (7). The report concluded that there is a need for standardised and unambiguous formulation of requirements, that fossil diesel is generally replaced by HVO fuels within the site boundary, that assessment of energy and power requirements is needed before the construction phase, that some machinery is not certified for use with HVO fuels and that attaining fossil-free building sites is less problematic than expected (7).

Over the past five years there has been a rapid development away from traditional building and construction sites towards sites that are fossil-free and emission-free. In 2016, Oslo Municipality requested the establishment of the first fossil-free building site. After a market dialogue and a positive response from the construction industry, Oslo Municipality stated that all municipal building sites should be fossil-free from 2017. In 2018, emission-free building sites were promoted to an international level by the establishment of the Clean Construction Forum (C40) and Big Buyers Initiative (8). In 2019, Oslo Municipality introduced 'standard climate and environmental requirements' (9), and the first emission-free construction project, Olav Vs gate (10). The most recent development is that the city council, autumn 2020, decided to set requirements for fossil-free building and construction sites in new regulation plans. The city council in Oslo have notified that they wish requirements to be introduced for emission free building and construction sites. The imminent standard prNS 3770 also provides definitions of terms for emission-free building and construction sites and sets out procedures for data acquisition and reporting, energy supply and connection, as well as roles and processes.

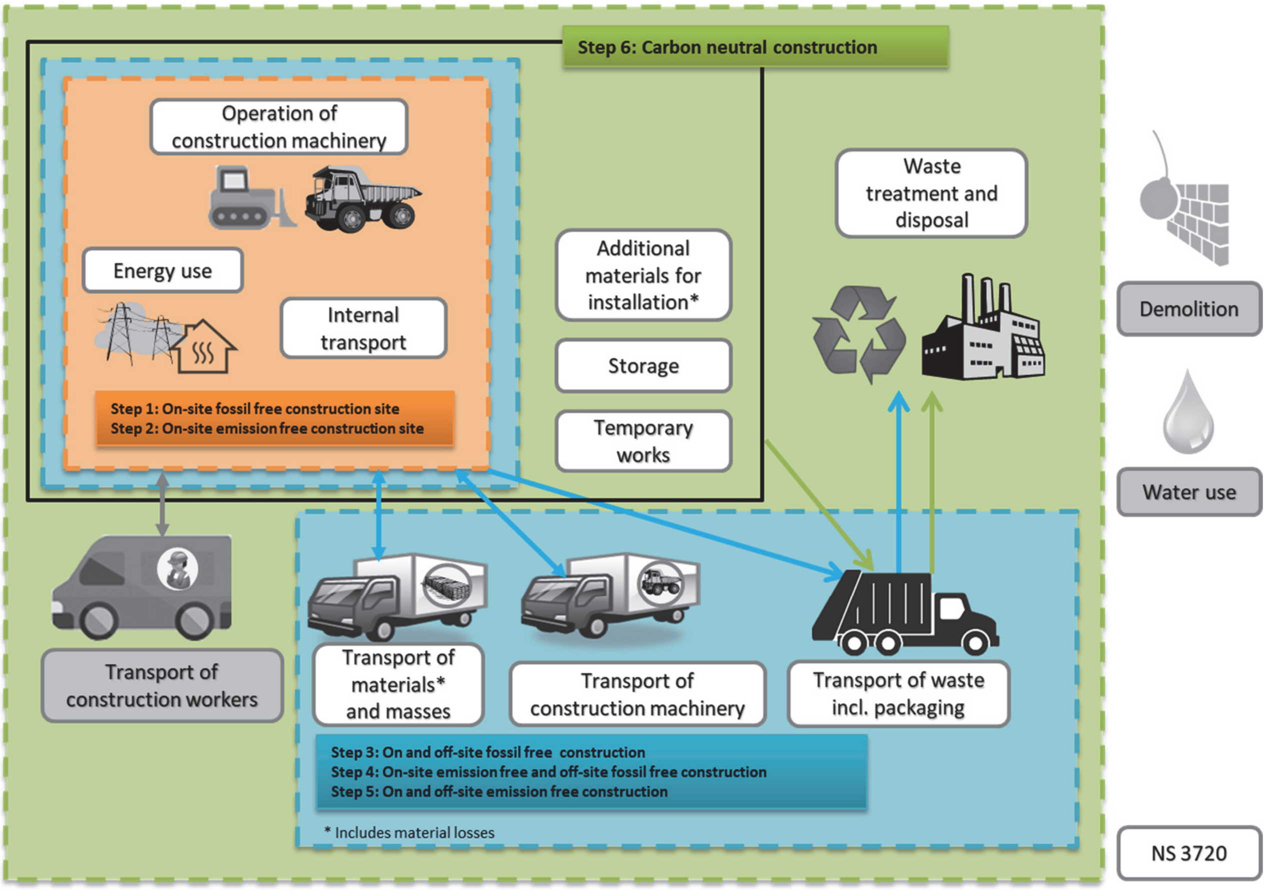


Figure 1. Diagram showing the system boundaries for all construction activities taking place in the construction phase, in a stepwise approach, adapted from (11, 12).
Standard climate and environmental requirements for Oslo Municipality's building and construction sites

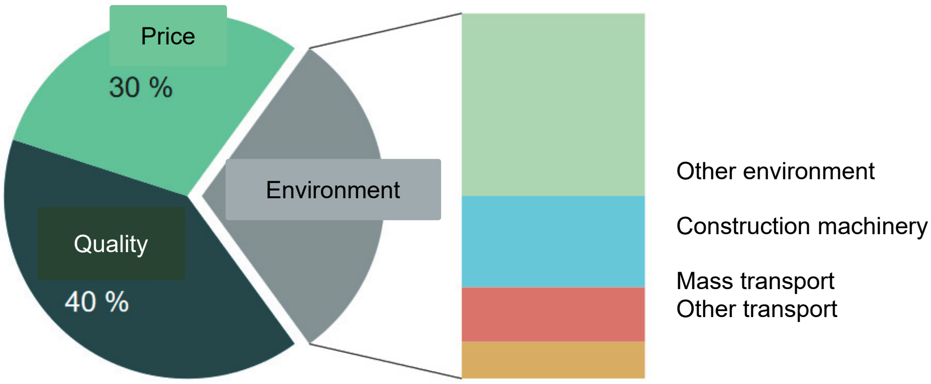
As previously mentioned, Oslo Municipality has issued 'standard climate and environmental requirements' for municipal building and construction sites, whereby all construction projects carried out on behalf of the Municipality shall result in the lowest possible environmental impact (9). The Municipality's procurement strategy lays down that equipment, vehicles and construction machinery shall employ emission-free technology, and that where this is not possible, biofuels shall be used. The minimum requirement is the use of fossil-free construction machinery and vehicles for the transport of materials and waste, and emission-free heating and drying at the building site. The criteria for awarding contracts state that the environment shall be weighted at 30% (minimum 20%), and emission-free construction machinery shall be weighted in turn at 50% of 15% (minimum 10%). It is also possible to use the entire environment criteria for emission free machines and vehicles. A fossil-free energy carrier is defined as one that does not emit CO_2 to the atmosphere during use. Fossil-free energy carriers in this context are biodiesel, bioethanol, biogas, pellets, electricity, hydrogen, and district heating. An emission-free energy carrier is defined as one that does not result in any form of emission during use. This means CO_2 or other gases that affect the local air quality. Emission-free energy carriers are electricity, hydrogen, and district heating (11). The following are examples of Oslo Municipality's climate and environmental requirements:

<u>Heating</u>
Requirements: Heating and drying shall be achieved without emissions, for example using electricity, district heating or other emission-free technology. Documentation requirements: The contractor shall provide a brief written description of how emission-free heating and drying are to be carried out.

<u>Weighting of emission-free machinery</u>
The contractor will be given credit for the proportion of emission-free and/or biogas-based machines planned to be used in a contract. Documentation requirements: The contractor shall enclose a completed 'List of machinery and vehicles' form. For small contracts: provide an overview of machinery and vehicles to be used in the assignment.

<u>Weighting of transport of masses</u>
The contractor will be given credit for the proportion of emission-free and/or biogas-fuelled vehicles used for transporting masses to the building and construction site. The contractor will also be given credit for reduced transport of masses, based on distance and weight. Documentation requirements: The contractor shall enclose a completed 'List of machinery and vehicles' form. For small contracts: provide an overview of machinery and vehicles to be used in the assignment.

<u>Weighting of other transport and other measures</u>
The contractor will be given credit for ability to reduce the use of fossil-fuelled vehicles for transporting materials, waste, equipment, personnel and suchlike within or to and from the building and construction site. The contractor shall describe the measures to be implemented to reduce local pollution and greenhouse gas emissions in the performance of the contract. Credit will be given according to the estimated emission reduction. Documentation requirements: The contractor's description, limited to 3500 characters.



The figure illustrates how weighting for awarding criteria under Environment can be distributed.

Contractual requirements are defined as the general and special conditions applying to a contract (11). Criteria for awarding a contract are defined as those characteristics of tenders that shall be assessed to determine which tender wins the competition (9). Minimum requirements are defined as a description of the characteristics required of a product or service to be procured (9).

Over the past few years we have seen an increase in the production, sale and leasing of electric construction machinery at various building and construction sites around the country. The SINTEF Technical Report '30 tonns utslippsfrie gravemaskin. Teknologistatus, kartlegging og erfaringer' (30-tonne emission-free excavator. Technology status, assessment and experiences) has assessed the available environmentally friendly construction machines and divided them up into five classes (13):

- Machines fuelled by biodiesel (fossil-free)
- Hybrid machines with internal combustion engines
- Cable-connected electric machines (emission-free)
- Battery-powered electric machines (emission-free)
- Hydrogen-fuelled machines (emission-free)

At present about 100 heavy electric excavators (10+ tonnes) are available on the Norwegian market (14). Volvo Construction Equipment (Oslo/Viken) has so far this year sold more than 130 light, emission-free compacting machines, excavators and wheel loaders, amounting to about one third of the total sales volume. Next year sale of 250 new, large, emission-free excavators are expected, which will correspond to a 15% market share in 2022 (14). Electric heavy transport is also on its way into the market because of the weighting of, amongst other factors, emission free transport in the municipality's competitions, however, there are few charging facilities for heavy transport in Oslo.

The SINTEF Technical Report 'Nullutslippsgravemaskin. Læringsutbytte fra elektrifisering av anleggsmaskiner' (Emission-free excavators. Lessons learnt from the electrification of construction machinery) documents experience from the operation of 8.5 t, 17.5 t and 38 t prototype excavators at three building and construction sites in Norway (Olav Vs gate, Oslo City Accident and Emergency and Biri Care Home), and proposes common operating rules for emission-free building sites (15):

- Every building site is unique and tailored solutions should be developed for each construction site.
- Contact the grid and power supplier at an early stage in order to plan the electrification of the building site.
- Choose rechargeable vehicles and construction machinery if available.
- Plan building site activities and power requirements for critical activities such as site preparation.

- Ensure that adequate charging facilities are available so that vehicles and/or construction machines can be powered by electricity as much as possible. If charging is not adequate, consumption of fuel in actual operation can deviate considerably from the figures quoted by the manufacturer.
- Ascertain whether the machinery uses 230, 400 or 1000 V, AC or DC supply for overnight charging or rapid charging.
- A person should be appointed to be responsible for electrical safety (corresponding to the fire safety manager) at the building site when large construction machinery is started up and operated. An example of precautionary measures is that a separation of 20 metres was specified between electric excavators and demolition operations at the Oslo City Accident and Emergency construction site.
- Cable installations at a building site should be adapted to the location.
- Large construction machines should be equipped with their own galvanic isolation transformer in the local grid to suppress electrical noise.
- Plan to carry out charging during lunch breaks. Is there enough capacity for a common lunch break?
- The building site must be closed and under control, and all machine operators must understand its layout.
- Operators of electric construction machinery shall undergo health and safety training, which should be offered.
- Correct power sockets must be used, and no machines may be used on the building site without appropriate planning. Clear marking of power sockets is important.

Oslo Municipality’s Agency for Urban Environment (Bymiljøetaten) has also gathered experience from the use of electric construction machinery in the Olav Vs gate project, where certain challenges were met initially when batteries became discharged. However, the situation improved as the operators learned to run the machines more efficiently and plan the work more carefully (10). The overall experience was a reduction in noise and fumes that led to a better working environment for the construction workers and for the public (10).

The City of Oslo’s Climate Agency has engaged SINTEF to carry out a survey of emission-free building and construction sites for Oslo Municipality's projects. The principal themes are electricity supply, emission-free construction machinery and vehicles, and charging logistics, studying associated experiences and barriers. This report assesses building site experience from relevant projects and includes detailed studies of machine fleets, energy consumption and energy supply. In the study, we have contacted the following:

- Utviklings- og kompetanseetaten (UKE) (the Agency for Improvement and Development)
- Vann og avløpsetaten (VAV) (the Agency for Water and Wastewater Services)
- Bymiljøetaten (BYM) (the Agency for Urban Environment)
- Fornebubanen (FOB) (the Fornebu Railway Line)
- Oslobygg (OBF), the municipal housing development agency formed by the amalgamation of the former agencies: Omsorgsbygg (OBY), (responsible for care homes), Undervisningsbygg (responsible for educational facilities) and Kultur- and idrettsbygg (KID) (responsible for cultural and sports venues), as well as the construction operations of Boligbygg (BBY) (responsible for housing development).

This report commences by explaining the approach used to survey experiences from building and construction sites, followed by a presentation and discussion of the results and finally presents conclusions from the study.

3 Method

The method used for the assessment of experiences at emission-free building and construction sites consists of three parts: 1) a questionnaire to identify relevant projects and assess machine fleets (including vehicles) 2) the acquisition of contractual requirements for relevant projects, and 3) interviews with key participants in some projects to further understand themes such as energy consumption, energy supply, and building site experience. The first two parts collect quantitative data about the projects, machine fleets and contractual requirements, while the final part is qualitative and deals with experiences at emission-free building and construction sites.

<u>Questionnaire</u>

The questionnaire consists of two parts and has been created using Microsoft Forms. The first part focuses on identifying which projects are to be assessed, where the projects are located, who is the contact person to provide follow-up and details about the construction project, such as environmental goals, project type and project phase, which operations shall be emission-free and whether emission-free machines, vehicles and equipment are in use. The second part is used to assess machine fleets and establish a list of machines, vehicles and equipment used, and acquires more details of energy carriers, machine size and type, which project phase the machines have been used in and whether the projects have access to data such as electricity consumption, power peaks, charging or operating hours. An overview of the questions used in the questionnaire is provided in Appendix A.

<u>Contractual requirements</u>

Between 1 January and 30 June 2021, 196 competitions were published on behalf of Oslo Municipality in Doffin (the Norwegian database for public procurement announcements), TED and TransQ, 73 of which involved the construction industry. Students have reviewed these competitions on behalf of Oslo Municipality and summarised which competitions use the Municipality’s standard contractual requirements and award criteria.

<u>Interviews</u>

In this process, selected key personnel were contacted to be interviewed about the principal issues of electricity supply, emission-free construction machines and vehicles, charging logistics, experiences, and barriers. Issues discussed in greater detail included, among other things, available power, advantages and disadvantages of using emission-free vehicles and machinery, which areas of use are suitable for emission-free machines, requirements for electricity supply and dialogue with energy providers, whether power requirements were a problem (and if so, in which phases of the project and how this was resolved), transport logistics, barriers and potential. These issues were assessed relative to each other. An overview of the questions used in the interviews is provided in Appendix B.

4 Results and discussion

The results of the survey for emission-free building and construction sites consist of three parts. The results of Part 1: Assessment of projects, and Part 2: Assessment of machine fleets, are presented first. Information from the questionnaire is supplemented with published information about the various projects in order to provide an integrated picture (10, 15). This is followed by a summary of competitions that use Oslo Municipality's standard requirements and award criteria. Finally, the results of the interviews of key personnel are presented.

Questionnaire

The questionnaire was distributed to the Agency for Improvement and Development (UKE), the Agency for Water and Wastewater Services (VAV), the Agency for Urban Environment (BYM), the Fornebu Line (FOB), the Port of Oslo (HAV) and the housing development Agency Oslobygg (OBF). Five of these six agencies responded, four of which had relevant projects to report on. It took on average 6 minutes to fill in the questionnaire for each project. VAV discovered that they had hundreds of small projects that could be reported. This agency's projects were therefore limited to those commencing in 2021 and with contracts worth more than NOK 50 million. Relevant projects were identified as construction projects using Oslo Municipality's standard contractual requirements and award criteria. A total of 36 relevant projects were identified. These are summarised in Table 1, with information about machine fleets and vehicles in Table 2. Figure 2 presents an overview of the various projects' environmental goals, while Figure 3 is an overview of the construction activities that are required to be emission-free in the various projects.

Table 1. Summary of questionnaire Part 1: Assessment of projects

Project	Responsible	Project phase	Environmental goals	Emission-free construction activities	Emission-free machinery, vehicles, or equipment
Voldsløkka School	OBF	Development	Fossil-free Energy-plus building	Energy consumption	Yes
Sentrum brannstasjon (City centre fire station)	OBF	Development	Fossil-free BREEAM Excellent	Energy consumption (e.g. for heating and drying) On-site transport Use and operation of construction machinery	Yes
Majorstuhjemmet (nursing home)	OBF	Planning	Fossil-free BREEAM Excellent Nearly zero-energy building (nZEB)	Use and operation of construction machinery Energy consumption (e.g. for heating and drying) On-site transport	Yes
Briskeby brannstasjon (fire station)	OBF	Development	Emission-free	On-site transport Demolition Use and operation of construction machinery Energy consumption (e.g. for heating and drying)	Yes
Tåsenhjemmet (nursing home)	OBF	Planning	Fossil-free building or construction site BREEAM Excellent Nearly zero-energy building	Energy consumption (e.g. for heating and drying)	Yes
Bakås School	OBF	Development	Fossil-free Emission-free (partially)	Construction machinery energy consumption	Yes

Project	Responsible	Project phase	Environmental goals	Emission-free construction activities	Emission-free machinery, vehicles, or equipment
			Energy-plus building FutureBuilt ZERO	(e.g. for heating and drying)	
Tokerud flerbrukshall (multi-purpose sports facility)	OBF	Development	Fossil-free Emission-free (partially) Passive house	Construction machinery energy consumption (e.g. for heating and drying)	Yes
Sofienberg School	OBF	Development	Fossil-free Emission-free (partially) Passive house	Construction machinery energy consumption (e.g. for heating and drying)	Yes
K2E: Preparatory work, Fornebuporten	FOB	Complete	Fossil-free Emission-free (partially)	Construction machinery Mass transport	Yes
K4: Site preparation, Fornebu Station	FOB	Development	Fossil-free Emission-free (partially)	Construction machinery Mass transport	Yes
K2C: Skøyen crosscut	FOB	Development	Fossil-free Emission-free (partially)	Construction machinery Mass transport	Yes
K2A: Tunnel Fornebu-Lysaker	FOB	Development	Fossil-free Emission-free (partially)	Construction machinery Mass transport	Yes
K2F: Preparatory work, Lysaker	FOB	Development	Fossil-free Emission-free (partially)	Construction machinery Mass transport	Yes
Arilds vei and Revefaret (suburban streets)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Bernt Knudsens vei (suburban street)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Danmarks gate (urban street)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Fredensborgveien (urban street)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Hoff terrasse and Engebrets vei (suburban streets)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Klosterenga (urban street)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Kongleveien (suburban street)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Kvistveien (suburban street)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Liljeveien and Roseveien (suburban streets)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Lybekkveien (suburban street)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Ola Narr and Finnmarkgata (urban streets)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Raschs vei (suburban street)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Sandstuveien (suburban street)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Ullernchausseen 111 (health centre)	VAV	Development	Emission-free	Construction machinery Mass transport	Yes
Årvoll sammenbinding (connection	VAV	Development	Emission-free	Construction machinery Mass transport	Yes

Project	Responsible	Project phase	Environmental goals	Emission-free construction activities	Emission-free machinery, vehicles, or equipment
between two streets)					
Tåsenveien (urban/suburban street)	BYM	Development	Fossil-free Emission-free (partially)	Construction machinery Mass transport	Yes
Langbølgen (suburban street)	BYM	Development	Fossil-free Emission-free (partially)	Construction machinery Mass transport	Yes
Hoffsveien (suburban street)	BYM	Development	Fossil-free	Construction machinery Mass transport Personnel transport	
Jens Bjelkes gate (urban street)	BYM	Development	Fossil-free Emission-free (partially)	Construction machinery Reuse of mass	Yes
Ytre Ringvei (suburban street)	BYM	Development			
Ekeberg Servicebygg (sports facility)	BYM	Development			
Storgata (urban street)	BYM	Development			
Skullerud arena (sports facility)	BYM	Development	Emission-free (partially)	Construction machinery Personnel transport	

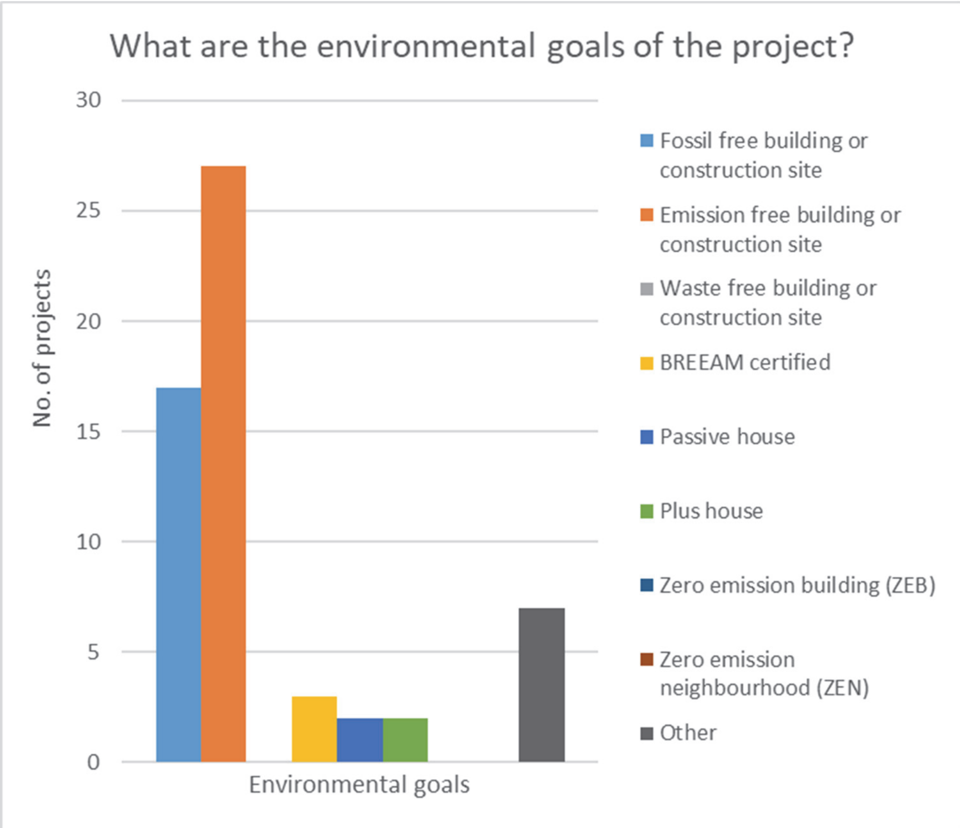


Figure 2. Overview of the environmental goals of the various projects.

<u>Other environmental goals</u>

- *Voldsløkka School*: Award requirements for emission-free concepts at the building site: 50% reduction in greenhouse gas emissions: low-temperature heating and high-temperature cooling in the same water-based system: use of the Osloøkkelen app will provide easier access to municipal services: demonstration project in the EU project "ARV", led by NTNU and SINTEF.

- *Majorstuhjemmet*: Roof-mounted solar panels.
- *Sentrum brannstasjon*: 40% reduction in materials use, compared with a reference building (approximately 460 kgCO_2e/m^2).
- *Tåsenhjemmet*: Low emissions associated with materials use, approx. 160 kgCO_2e/year (approx. 40% reduction, compared with a reference building). Several electric machines will be used. Mass transport using biogas and electricity.
- *FOB* has three climate action projects which have studied measures connected with fossil-free and emission-free construction operations, mass transport, materials optimisation, and more environmentally friendly materials.
- *Danmarks gate:* Recycling of mass.

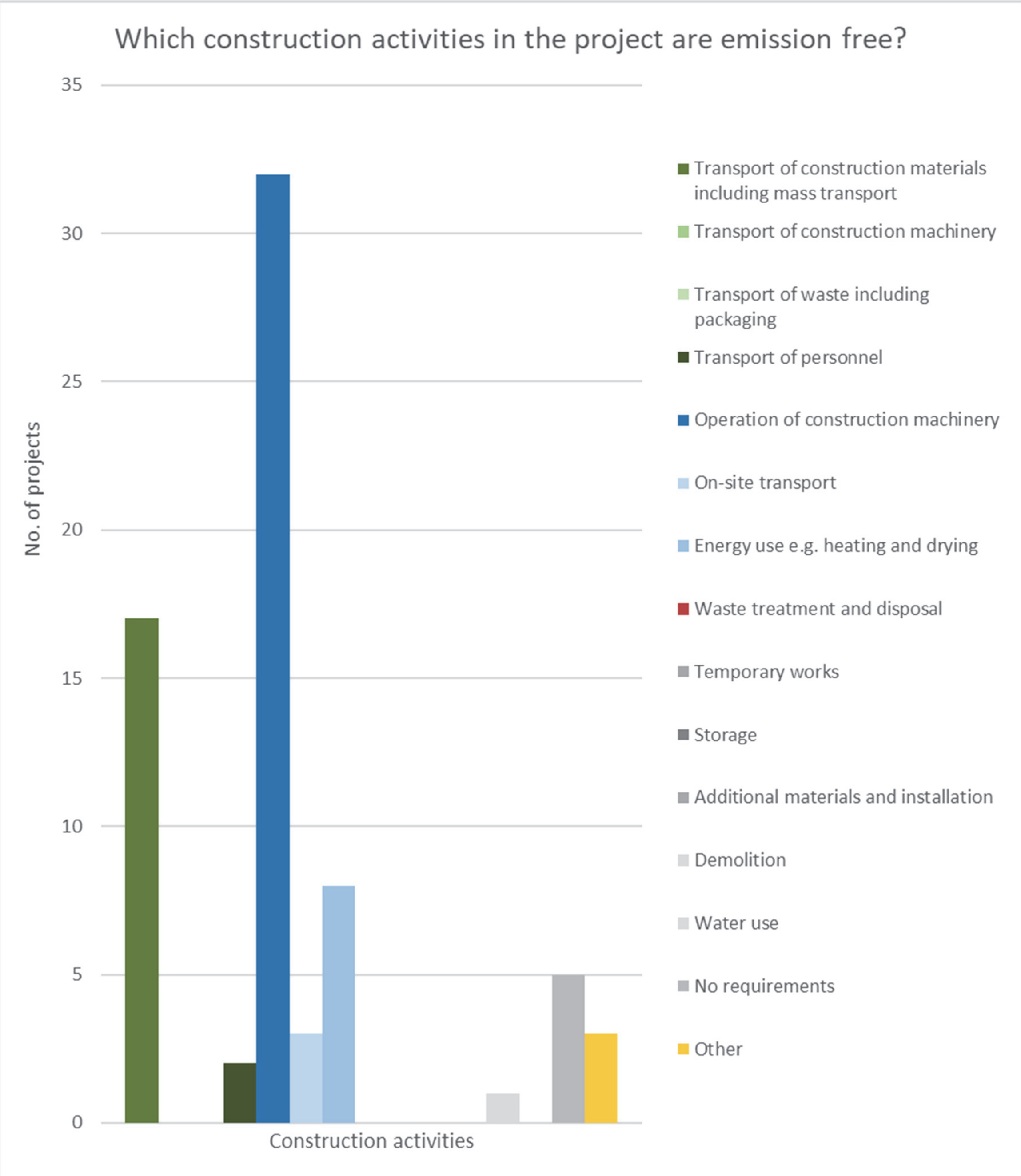


Figure 3. Overview of construction activities in the various projects that are required to be emission-free.

Other construction activities

- *Voldsløkka School and FOB*: Activities involve a combination of machines running on biofuel and electric machines.
- *Sentrum brannstasjon*: Most of the construction machinery operations are emission-free, with only a few exceptions.
- *All VAV projects*: Mass transport.
- *Jens Bjelkes gate*: Reuse of mass

Figure 3 shows all the construction activities to be considered in a life cycle analysis of a construction project (11, 12). The definition of an emission-free building site within the site boundary includes the use and operation of construction machines, on-site transport and energy consumption (blue bars). The definition of an emission-free building site outside the site boundary also includes the transport of construction materials, including transport of mass, transport of construction machines, transport of waste (and packaging materials) and personnel transport (green bars). The results show that few projects succeeded in covering all the construction activities included in the definition of an emission-free building site within the site boundary, and no projects succeeded in covering all the construction activities that shall be considered in a life cycle assessment of a construction project. Building projects often focus on energy consumption and construction machinery, while construction projects focus on mass transport and construction machinery. This indicates that there are differing interpretations of what comprises an emission-free building or construction site.

Table 2. Summary of questionnaire Part 2 - Assessment of machine fleets

Project and project phase	Type of machine	Type of technology	Machine weight	Number
Voldsløkka School – Machine fleet and vehicle emission level not assessed				
Rehabilitation	Boom lift	Electric	<10 t	2
	Scissor lift	Electric	<10 t	10
	Trolley/carriage	Electric	<10 t	
	Glass robot	Electric	<10 t	
Site preparation	Vibrator plate	Electric	<10 t	
	Compactor	Electric	<10 t	
	Crane	Electric	>20 t	
Sentrum brannstasjon – 86% of machine fleet emission-free, vehicles not assessed				
Lifting	Crane	Electric	20.3 t	1
	Lift	Electric		4
	Lift	Electric	6 t	1
On-site transport	Wheel loader	Electric	4.2 t	1
Site preparation	Excavator	Electric	25.4 t	1
	Excavator	Electric	12 t	1
Compression	Vibrator plate	Electric	0.1 t	1
	Compressor	Electric		1
	Roller	Electric	8-20 t	1
Transport	Lorry	Battery		2
Majorstuhjemmet – Machine fleet and vehicle emission levels not available				
	Various machines	Electric		36
Transport	Lorry	Battery		
Briskeby brannstasjon – Machine fleet and vehicle emission levels not assessed				
Site preparation	Excavator	Electric	22 t	2
	Excavator	Electric	<10 t	1
Lifting	Lift	Electric		2
	Wheel loader	Electric	<8 t	2
Outdoor	Demolition robot	Electric		1
Tåsenhjemmet – Machine fleet and vehicle emission levels not available				
	Various machines	Electric		10-20
Tokerud flerbrukshall – 9% of machine fleet emission-free, 0% of vehicles emission-free				
Erection of outside walls	Lift	Electric	<8 t	1
Outdoor	Wheel loader	Electric	<8 t	1
Bakås School – 23% of machine fleet emission-free, vehicles not assessed				
Outdoor	Excavator	Battery	2.5 t	1

Project and project phase	Type of machine	Type of technology	Machine weight	Number
	Wheel loader	Battery	5 t	1
	Vibrator plate	Battery	147 kg	1
	Excavator	Battery	8.5 t	1
	Excavator	Battery/cable	14 t	1
Sofienberg school – 89% of machine fleet emission-free, vehicles not assessed				
Lifting	Crane	Electric	>20 t	1
	Lift	Electric	8-20 t	1
Site preparation	Excavator	Electric	8-20 t	1
	Excavator	Electric	<8 t	1
On-site transport	Compact loader	Electric	<8 t	1
Compression	Vibrator plate	Electric	<8 t	1
K2E: Preparatory work, Fornebuporten – Machine fleet and vehicle emission levels not assessed				
Site preparation	Excavator	Electric	>20 t	1
K4: Site preparation, Fornebu Station – 34% machine fleet emission-free, vehicles not assessed (biogas for waste transport)				
Site preparation	Excavator	Electric	22 t	2
	Excavator	Electric	<10 t	1
	Crusher	Electric		1
	Lift	Electric		8
K2C: Skøyen crosscut – 33% of machine fleet emission-free, vehicles not assessed				
Site preparation	Tunnelling rig	Electric/biodiesel		1
	Injection rig	Electric/biodiesel		1
	Piling rig	Electric/biodiesel		1
On-site transport	Wheel loader	Electric		1
	Front end loader	Electric		1
K2A: Tunnel Fornebu-Lysaker – 18% of machine fleet emission-free, vehicles not assessed				
Site preparation	Piling rig	Electric		1
	Drilling rig	Electric		1
K2F: Preparatory work, Lysaker – 33% machine fleet emission-free, vehicles not assessed (biogas for mass transport)				
Site preparation	Excavator	Electric		1
Arildsvei and Revefaret – 100% of machine fleet emission-free, 100% of vehicles emission-free				
Site preparation	Excavator	Battery		3
Mass transport	Tipper lorry	Battery	27 t*	1
Bernt Knudsens vei – 50% of machine fleet emission-free, 100% of vehicles emission-free				
Site preparation	Excavator	Battery		1
On-site transport	Wheel loader	Battery		1
Compression	Roller	Battery		1
Mass transport	Tipper lorry	Battery	27 t*	
Danmarks gate – 50% of machine fleet emission-free, 100% of vehicles emission-free				
Mass transport	Tipper lorry	Battery	27 t*	
Fredensborgveien – 50% of machine fleet emission-free, 100% of vehicles emission-free				
Site preparation	Excavator	Electric		2
Compression	Vibrator plate	Electric		1
	Compactor	Electric		1
Mass transport	Tipper lorry	Battery	27 t*	
Hoff Terrasse and Engebrets vei – 65% of machine park emission-free, 50% of vehicles emission-free				
Site preparation	Excavator	Electric		1
	Dumper truck	Electric		1
Compression	Vibrator plate	Electric		1
On-site transport	Wheel loader	Electric		1
Mass transport	Tipper lorry	Battery	27 t*	
Klosterenga – 90% of machine fleet emission-free, 90% of vehicles emission-free				
Site preparation	Excavator	Cable		
Kongleveien – 50% of machine fleet emission-free, vehicles not assessed				
Site preparation	Excavator	Cable/battery	>20 t	1
	Excavator	Electric	8-20 t	2
Compression	Vibrator plate	Electric		1
Kvistveien – 55% of machine fleet emission-free, 100% of vehicles emission-free				
Site preparation	Excavator	Electric	8-20 t	1
Compression	Vibrator plate	Electric		1
On-site transport	Wheel loader	Electric		1

Project and project phase	Type of machine	Type of technology	Machine weight	Number
Mass transport	Tipper lorry	Battery	27 t*	
Liljeveien and Roseveien – 67% of machine fleet emission-free, 100% of vehicles emission-free				
Site preparation	Excavator	Electric	>20 t	1
	Excavator	Electric	8-20 t	1
	Roller	Electric		1
Compression	Vibrator plate	Electric		1
On-site transport	Wheel loader	Electric		1
Mass transport	Tipper lorry	Battery	27 t*	
Lybekkveien – 55% of machine fleet emission-free, 70% of vehicles emission-free				
Site preparation	Excavator	Electric	8-20 t	1
	Sieving rigg	Electric		1
Compression	Vibrator plate	Electric		1
On-site transport	Wheel loader	Electric	<8 t	1
Mass transport	Tipper lorry	Battery	27 t*	
Ola Narr and Finnmarkgata – 100% of machine fleet emission-free, 100% of vehicles emission-free				
Site preparation	Special blocking machine	Electric		1
	Excavator	Electric		1
	Dumper truck	Electric		1
Mass transport	Tipper lorry	Battery	27 t*	
Raschs vei – 50% of machine fleet emission-free, vehicles not assessed				
Site preparation	Excavator	Electric	>20 t	1
On-site transport	Wheel loader	Electric	<8 t	1
Compression	Vibrator plate	Electric		1
Sandstuveien – 75% of machine fleet emission-free, vehicles not assessed (biogass for mass transport)				
Site preparation	Excavator	Electric	>20 t	1
	Excavator	Electric	8-20 t	2
On-site transport	Wheel loader	Electric	<8 t	1
Compression	Vibrator plate	Electric		1
	Compactor machine	Electric	8-20 t	1
Ullernchausseen 111 – machine fleet not assessed, 20% of vehicles emission-free				
Site preparation	Excavator	Cable	>20 t	1
Mass transport	Tipper lorry	Battery	27 t*	
Årvoll connection – 80% of machine fleet emission-free, vehicles not assessed				
Site preparation	Excavator	Electric	17 t	2
	Excavator	Electric	8-20 t	1
	Blocking rig	Electric		1
	Drilling rig	Electric		1
	Vibrator plate	Electric		1
	Compressor	Electric		1
On-site transport	Wheel loader	Electric		1
Tåsenveien – 59% of machine fleet emission-free, 29% of vehicles emission-free				
Site preparation	Excavator	Battery	25 t	1
	Excavator	Cable	17 t	1
	Excavator	Battery	8 t	1
On-site transport	Wheel loader	Electric	<8 t	2
Compression	Compressor	Electric	<8 t	1
Lifting	Lift	Electric	<8 t	1
Compression	Vibrator plate	Electric	<8 t	4
Retaining wall	Concrete pump	Electric	<8 t	1
Mass transport	Lorry	Electric	27 t*	2
Langbølgen – 50% of machine fleet emission-free, 27% of vehicles (tonnes) emission-free				
Site preparation	Excavator	Battery	2.8 t	1
	Excavator	Battery	8 t	1
	Excavator	Cable	25 t	1
On-site transport	Wheel loader	Battery	<8 t	1
Mass transport	Lorry	Cable	27 t*	1
Hoffsveien – 83% of machine fleet emission-free, 8% of vehicles (tonne-kilometres) emission-free				
Stone works	Excavator	Electric	2.5 t	1
Site preparation	Excavator	Electric	8-20 t	1
	Excavator	Electric	25 t	1
On-site transport	Wheel loader	Electric	5 t	1
Compression	Vibrator plate	Electric	<8 t	1

Project and project phase	Type of machine	Type of technology	Machine weight	Number
Mass transport	Tipper lorry	Electric	27 t*	1
Jens Bjelkes vei – Machine fleet and vehicle emission levels not assessed				
Site preparation	Excavator	Electric		1
On-site transport	Wheel loader	Electric		1
Skullerud arena – 83% of machine fleet emission-free, vehicles not assessed				
On-site transport	Wheel loader	Electric	<8 t	1
	Dumper truck	Electric	<8 t	1
	Generator	Electric	<8 t	2
	Milling machine	Electric	<8 t	1
Compression	Roller	Electric	<8 t	1
Site preparation	Excavator	Electric	8-20 t	1
Lifting	Lift	Electric	<8 t	2
Transport	Tipper lorry	Electric	<8 t	1
Ytre Ringvei – 33% of machine fleet emission-free, vehicles not assessed				
Rock works	Excavator	Electric	<8 t	1
Demolition	Excavator	Electric	8-20 t	1
	Excavator	Electric	>20 t	1
Unloading	Wheel loader	Electric	<8 t	1
Compression	Vibrator plate	Electric	<8 t	1
Ekeberg Servicebygg – 50% of machine fleet emission-free, 19% of vehicles (tonnes) emission-free				
On-site transport	Dumper truck	Electric	<10 t	1
Compression	Compressor	Electric	<10 t	1
Transport	Lorry	Electric		3

* 27 tonnes gross weight, 13-14 tonnes load capacity

Oslo Municipality groups machines in the following sizes: >8 tonnes: small, 8-20 tonnes: medium and <20 tonnes: large. Some challenges were experienced when collecting information about machine fleets and vehicles, since the agencies collect different types of data and different levels of detail in different project phases. Another difficulty is in determining what proportion of the construction phase achieves emission-free operations, especially when the machinery list filled in by the contractor says nothing about the degree to which the emission-free electric machines shall be used (operating hours) or how much of the mass transport shall be electric powered (tonnes) or the distance carried (kilometres). In some cases, electric transport was not assessed.

Altogether the projects outlined in Table 2 use more than 230 electric construction machines, vehicles, and equipment units. These comprise 32 lifts, 26 medium excavators, 21 small wheel loaders, 19 lorries and tipper lorries, 18 vibrating plate compactors, 17 large excavators, 10 small excavators, 4 compressors, 4 rollers, 4 dumper trucks, 3 cranes, 2 compact loaders, 2 tampers, 2 piling rigs, 2 drilling rigs, 2 blocking rigs, 2 compacting machines, 2 generators, 1 trolley/carriage, 1 glass robot, 1 demolition robot, 1 crusher, 1 tunnelling rig, 1 injection rig, 1 screener, 1 concrete pump, 1 milling machine and 46-56 undefined construction machines. It is important to remember that the information in Table 2 is a summary produced as part of the study and not necessarily a complete list of electric construction machinery, vehicles, or equipment. Table 2 presents a snapshot of the project about what equipment, construction machinery, and vehicles are electrically powered and in use at the present time. Fossil-free construction machinery, vehicles and equipment are not included. The information is also obtained at various stages of the projects, which may lead to deviations or discrepancies. Table 2 shows that most contractors succeed in supplying electric alternatives for small items of equipment and small to medium electric construction machines, and that the large electric construction machines are only used in the largest projects.

Figures 4, 5 and 6 show the proportion of electrification of mass transport and construction machinery used in the projects presented in Table 2. Of a total of 35 projects, 77% have produced estimates of the emission-free level for construction machinery and 43% of the level for mass transport. Figure 4 shows that the projects have attained different proportions of both electric construction machinery and mass transport. Figure 4 shows that most projects have begun to electrify construction machinery and that thirteen of these have also, to a certain extent, acquired both emission-free construction machines and emission-free mass transport. This is a transition that is developing rapidly and by 2030, all public building and construction projects in Oslo shall attain 100% emission-free construction machinery and vehicles. Figure 5 shows the extent to which the construction machinery has been electrified. Eight projects have yet to assess this, although they are currently using emission-free construction machinery. What is positive is that eight projects have achieved a 75-100% emission-free level. Figure 6 shows the extent to which mass transport has been electrified. Twenty projects have yet to assess this (or do not have mass transport).

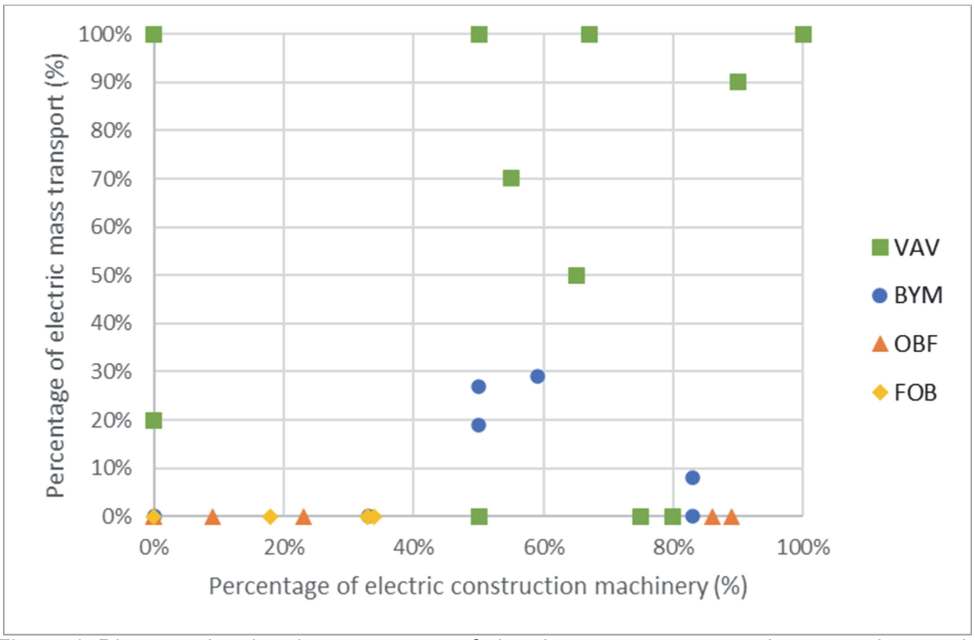


Figure 4. Diagram showing the percentage of electric mass transport and construction machinery in the projects presented in Table 2.

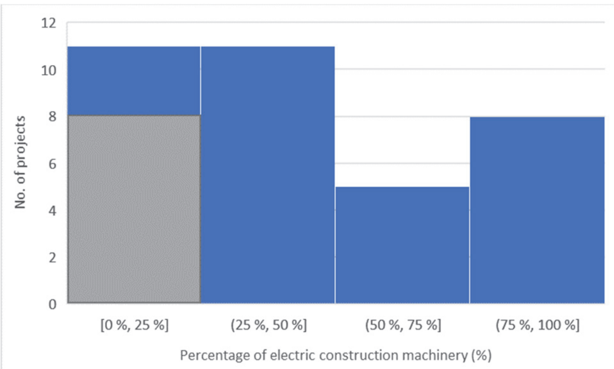


Figure 5. Diagram showing the proportion of electric machinery used in the projects from Table 2.

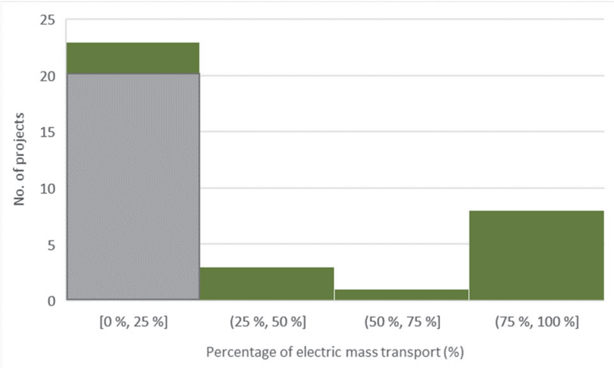


Figure 6. Diagram showing the proportion of electric mass transport used in the projects from Table 2.

Contractual requirements

Between 1 January and 30 June 2021, 196 tender announcements were published in Doffin (the Norwegian database for public procurement announcements) on behalf of Oslo Municipality, 73 of which involved the construction industry. Of these, 66 announcements followed Oslo Municipality's standard contractual requirements and award criteria, and eight stipulated the use of emission-free concepts, the minimum requirement in six of these being the use of emission-free excavators. This means that seven of these 73 projects were either too small or did not use electric construction machinery. Table 3 presents a summary of the tender announcements. NS 8406 is a simplified Norwegian building and construction contract; NS 8405 is a standard Norwegian building and construction contract, and NS 8407 sets out the general contractual conditions for design-build contractors. Since there is at present there no Norwegian standard that regulates co-operation, NS 8407 is often used as a starting point. OBF states that Ullern skating rink, Etterstadgata 26, the Kvartal 5 housing co-operative, Smestad Nursing Home and Østensjøveien hus (a women's refuge) are projects that are too small to be followed up and reported on as projects in the above-mentioned questionnaire. In addition, Fornebubanen is subject to the Norwegian regulations relating to procurement rules in the supply industry (forsyningsforskriften) and uses Achilles TransQ as a qualification system. They have announced two tender competitions over the EEA threshold value in the period, using standard contractual requirements combined with environment- and climate-related award criteria. These are also included in Table 3.

Table 3. Competitions that use Oslo Municipality's standard contractual requirements and award criteria, published in the first half of 2021.

Project	Responsibility*	Form of contract	Formulations of requirements	Requirement for emission-free concepts?
Contractor for repairs and surface treatment of the steel bridge to the Oslo Tanker Pier	HAV	NS 8406	Standard contractual requirements and award criteria. The award criterion considered environmentally friendly fuel (vehicle list) and recycling of steel. Requirement for electrical heating. No minimum requirement.	No
Ullern skating rink – New refrigeration building General refrigeration engineering contract	KID	NS 8405	Standard contractual requirements and award criteria: environment 30% and price 70%	Yes, 1 emission-free machine
Etterstadgata 26 – Rehabilitation following property purchase	BBY	NS 8407	Standard contractual requirements and award criteria. Report prepared by environmental advisor for the use of contractors, initially prioritising following up the contracts in which emission-free	Yes, 4 emission-free machines (1 excavator)

Project	Responsibility*	Form of contract	Formulations of requirements	Requirement for emission-free concepts?
			machines and/or vehicles are proposed.	
Skullerud arena	BYM	NS 8407	Standard contractual requirements and award criteria.	Yes, 8 emission-free machines (1 excavator and 1 wheel loader)
Ytre Ringvei bicycle lane	BYM	NS 8406	Standard contractual requirements and award criteria. No minimum requirements.	Yes, 5 emission-free machines (3 excavators, 1 wheel loader and 1 compactor)
Installation of sprinkler system in Kvartal 5	BBY	NS 8405	Standard contractual requirements and award criteria.	Yes, 4 emission-free machines (1 excavator and 1 wheel loader)
Procurement of rented machinery to grind park and garden waste	REG		Standard contractual requirements and award criteria. Environmental requirements – absolute requirements: Grinder, wheel loader and excavator used by the contractor shall be powered by HVO diesel.	Yes, 3 emission-free machines (1 grinder, 1 excavator and 1 wheel loader)
Procurement of installation of a fire extinguishing system covering the whole of Smestadhjemmet nursing home.	OBY	NS 8407	Standard contractual requirements and award criteria.	Yes, 1 emission-free excavator
Competition for the procurement of a turnkey contract for rehabilitation of Østensjøveien hus	OBY	NS 8407	Standard contractual requirements and award criteria. Emission-free machines (weighted 70%) and remaining transportation and other logistics (weighted 30%). The award criterion was weighted 20%.	Yes, 2 emission-free machines
K1C: Preparatory work, Madserud	FOB	NS 8405	Standard contractual requirements and award criteria.	No
K2B: Tunnel and site preparation work, Vækerø-Lysaker	FOB	NS 8405	Standard contractual requirements and award criteria.	No

*HAV – Port of Oslo, KID – Kultur og idrettsbygg (Agency for cultural and sports venues), BBY – Boligbygg Oslo (Agency for housing development), BYM – Bymiljøetaten (Agency for Urban Environment), REG – Renovasjons og gjenvinningsetaten (Agency for refuse disposal and recycling), OBY – Omsorgsbygg (Agency for care homes)

In the case of the Ytre ringvei bicycle lane project, BYM has been in contact with the energy supplier to provide information about the project. A higher price was also included in anticipation of additional costs related to environmental requirements.

In connection with the procurement of 'rented machinery to grind park and garden waste', the cost was about 10% higher for emission-free machinery. REG also carried out contractual follow-up to ensure that HVO diesel was used.

In connection with the procurement of 'installation of a fire extinguishing system covering the whole of Smestadhjemmet nursing home', OBY does not believe that the environmental requirements affected the price, since the chosen offer had the best score as regards environmental issues and the lowest price.

> 'This is a building and construction procurement according to the definition in the procurement regulations, although it is not a classic "building and construction activity".

> Because this procurement is principally an installation job, UKE's standard award criteria for environmental work did not apply adequately to the procurement. Hence, special award criteria for environmental work were formulated that were more applicable and had better weighting. This was documented in the contract strategy and formulation of the award criterion was carried out in consultation with the sustainability and innovation department of Omsorgsbygg Oslo KF. Excavation work amounts to a very small part of this procurement and the contractor undertook to use an electric excavator. The contractor also undertook to use electric transport of materials and personnel.'

In connection with the competition for 'the procurement of a turnkey contract for rehabilitation of Østensjøveien hus', the chosen offer had two emission-free machines. In its description, the contractor wrote that "Construction machinery such as excavators, wheel loaders, asphalt spreaders and rollers shall primarily be powered by electricity, biogas or biodiesel", but this was too vague to enable any of these machines to be specified as emission-free on the Excel spreadsheet. Minimum requirements were also specified for heating: "All energy used for heating purposes at the building site shall be emission-free. The minimum requirement applies to the entire building period. The project owner shall pay for electricity during the building period. The tenderer may connect to an existing power supply installation but must make arrangements for its own temporary supply."

<u>The interviews</u>
In all, ten key persons from VAV, FOB, OBF and BYM were interviewed. VAV was represented by a climate and environment project manager who was familiar with all the projects. OBF was represented by an environmental advisor who was familiar with all the projects and a project manager. BYM was represented by a project manager and a construction manager for the Tåsenveien project. FOB was represented by five advisors, project and construction managers for various contracts and fields of responsibility in the Fonebubanen project, including the electrical, tunnelling, external environment, and climate. These interviews are supplemented by comments and examples from the questionnaire, especially regarding the question about which challenges they experienced with the introduction of electric construction machinery, vehicles and equipment. The results of the interviews have been categorised and discussed in four thematic areas: emission-free construction machinery and vehicles, electricity supply, charging logistics, and experiences and barriers.

4.1 Emission-free construction machinery and vehicles

<u>Vann og avløpsetaten (VAV)</u>
VAVs external contractors lease tipping lorries with ca. 13-14 tonnes capacity, whilst other contractors own their own tipping lorries. The electrically powered tipping lorries are driven between the construction site and the mass recycling hotels in central Oslo. Here the mass is sorted into clean stone chippings and contaminated fine matter and then transported out of the town to other disposal sites using tipping lorries powered by biodiesel. Like other electric vehicles, the electric tipping lorries need to be charged after about half a day's operation using an hour of rapid charging at a minimum power of 150 kW. Charging is carried out at various locations. Driving distances in kilometres are often used to estimate greenhouse gas emissions connected with the transport of mass in Oslo Municipality. This does not reflect the volumes transported since electric tipping lorries transport the mass to the nearest disposal sites in Oslo, whilst lorries fuelled by diesel or biodiesel transport (contaminated) mass out of town to other disposal sites. A proposal was made to use tonnes (t) as a unit that reflects how much of the mass is transported to the various disposal sites. VAV commented that it is an advantage to use biogas for this purpose (already have two projects that use biogas) or invest in better charging infrastructure for larger vehicles outside Oslo. This would make it possible to transport the mass out of town using vehicles powered by fossil-free or emission-free tipping lorries.

VAV construction machinery operates for 4 to 7 hours per working day before they must be charged, depending on what type of work is being performed. Development has ensued at a rapid pace, bearing in mind that about a year ago there were few electric construction machines in use. VAV has therefore experienced an increase of 86% (in terms of kWh) in the use of electric construction machinery since the first quarter of 2020.

VAV has received feedback to the effect that the use of electric construction machinery and transport is a major benefit to residents in the area, thanks to reduced noise and pollution. Both residents and construction workers are experiencing better air quality. The one thing that residents complain about is the sound of reversing alarms on vehicles. This is a health and safety feature that all vehicles have when reversing. In VAV's experience, emission-free construction sites are identical to traditional ones. Machine operators think driving electric construction machinery and vehicles is very enjoyable and that it is so comfortable to work with machinery that doesn't make any noise, although charging involves a little planning. Machine operators feel that electric construction machinery has the same power as diesel-powered machinery. Initially they experienced some anxiety about charging but they got used to this and by the end of a week had adopted good charging routines. VAV notices that it makes a difference whether one has only one machine or several in operation at the same time, but this is not a problem if there is enough charging capacity. Rapid charging calls for a power rating of at least 150 kW, and preferably more.

<u>Oslobygg (OBF)</u>

OBF feels that considerations related to reputation have had a major influence on whether a project is successful or not. The general perception is that the contractors have a positive attitude. OBF is also aware of positive attention at a political level since every project is a kind of pilot project. However, this is here to stay and 2025 is not very far off. OBF feels that there are challenges connected with the fact that this is a relatively new market in which there is a shortage of electric construction machines and vehicles. Everything is quite new for the contractors and there is a feeling that in the early stages, things take more time. One observation from OBF was that charging facilities and energy infrastructure place certain restrictions on a project, for example if there is a need to adapt infrastructure or acquire a container to use for charging the larger machines where 400 V supply is not accessible.

OBF mentions that less noise is experienced at the construction site, which can be a health and safety hazard. Situations have arisen in which construction workers have failed to hear the machines, which can be particularly hazardous on a confined building site.

OBF has also experienced some limitations. Electric construction machinery is limited to smaller loads and electric vehicles drive shorter distances, thus restricting operating functions and transport range. This affects the progress of a project. If something takes more time it will cost more. Biodiesel is often used for transport over longer distances. OBF believes that there is a need to look at contract design. Profit will be lost if it becomes necessary to transport large amounts of mass in and out of a building site. It is difficult to say whether the requirements for electric construction machinery leads to increased costs, since this depends on so many different factors, such as location, technology, market, and accessibility.

OBF has experienced specific challenges that hinder the attainment of a 100% emission-free building site. In one project, for example, a mobile crane running on biodiesel had to be used for heavy lifting, since the ground would not bear the load of the planned large electric tower crane. This therefore had to be supplemented with an additional mobile crane for a short period to handle the heaviest lifts, as well as a smaller tower crane. The same project also presented problems for the accessibility of electric lifting machinery.

Bymiljøetaten (BYM)
BYM stated that the contractor had found an innovative concept for handling cable in the Tåsenveien construction project, whereby masts were erected from which to suspend supply cables. A transformer was located 400 metres from the end of the 1300-metre section, so that 800 metres of cable were used to supply the machinery. This is a good system provided that a system exists for suspending the cable. It allows full operational capacity and solves some of the health and safety challenges connected with cable use. BYM also mentioned that the contractor provides two 13-tonne electric lorries for transporting mass to an interim storage location in Oslo, but that the mass was then transported to external disposal sites using biodiesel powered lorries. This is because there are problems with the battery capacity and charging of electric lorries. The batteries have sufficient capacity for 1-2 trips to the interim storage site and must be recharged at the disposal site during the lunch break before the vehicles can be driven again. BYM has gathered experience from a 25-tonne excavator in the Olav Vs gate and Tåsenveien projects, and found that it functioned slightly better at Olav Vs gate because the project involved less excavation. At Tåsenveien, excavation takes place almost continuously throughout the day, which affects the performance of the excavator. BYM has received feedback from the contractor to the effect that it is easier to communicate at the construction site when electric machines are in use, because there is less noise and no mechanical humming. The machine's drum produces some noise, but this is not so hazardous when a stationary excavator is being used. Stationary electric excavators are also beneficial and are experienced as a positive element since they do not produce persistent diesel fumes. At Olav Vs gate it was reported that the machines produce so little noise that it was not possible to hear that work was in progress.

BYM noticed that both at Olav Vs gate and Tåsenveien, the contractors assigned apprentices to operate the electric machines. It is not known whether this was a deliberate choice, but they wonder whether the younger an operator is, the easier it is to become familiar with new technology and more likely to embrace change. It is envisaged that when the older workers see how the apprentices adapt to electric construction machinery, they will also be more willing to try and follow them. The conclusion was that this could be a smart change strategy in other projects.

Fornebubanen (FOB)
FOB has various types of construction sites (such as open pits and tunnels) which present different requirements. In the case of tunnelling there is a great deal of dumping of stone, which makes it difficult to find electric construction machinery with enough capacity to last a full working day. It is also impractical to use machines supplied by cable to move mass back and forth in the tunnel. There was concern that the contractors would not be able to obtain machines or enough electricity, especially in view of the nine-month delivery time, but the contractors wasted no time during the procurement process. So far, electric transport has not been used in the Fornebubanen project, but FOB recognises that stricter requirements for such transport could have been stipulated in connection with transporting mass to the local disposal site.

FOB found that maintaining a battery bank as a buffer for battery-powered construction machinery was an important lesson learnt. It was also felt that the tipping point for the electrification of construction sites will be reached when batteries can last a full working day without recharging, or alternatively if one can operate several machines to do the same job. In the slightly longer term, hydrogen may be an important solution for the electrification of large construction sites. For example, hydrogen powered generators could be used to charge battery-powered construction machinery, reducing power peaks in the supply grid. While this could eliminate the problem of discharged batteries, there are certain health and safety challenges involved in the use of hydrogen as an energy source in a tunnel. Hydrogen generators can also be used to provide energy to electric equipment.

Summary
A comment that was repeated in the interviews was that smaller electric machinery and equipment present no problems. It was also found that electric construction machines create less noise and pollution, and lead to improved air quality and working environment. Construction owners do not always stipulate how many electric construction machines should be used. It is left to the contractors to decide what they are able to supply. It is also up to the contractor to decide whether large construction machines are to be supplied by cable, battery, or a combination, but this has a major impact on the planning of maximum power and current requirements, as well as charging facilities. When the various Municipal agencies assessed the machine lists, several commented that the points system did not reflect what happened, since the lists did not consider hybrid machines, area of use, charging arrangements or the total operating time of the various construction machines. Several Municipal agencies recommended the use of percent-based emission-free levels, which would consider what percentage of electric construction machines in different size classes are used in different work operations. The same applies to mass transport, where the use of tonne-kilometres was recommended as a unit to reflect how much material shall be transported to different disposal sites. The machinery and vehicle lists should include operating times and tonne-kilometres to enable estimation of the number of electric units to be used.

4.2 Electricity supply

Vann og avløpsetaten (VAV)
VAV feels that obtaining a temporary electricity supply is a laborious process, since 400 V is needed for most large electric construction machines. There are limitations in the electricity supplier's distribution grid and the number of rapid chargers one can install. Delays result in financial losses while electric machinery is not being used. VAV has experience that the grid operator has been working to simplify the process of providing temporary electricity supplies, see Appendix C.

Oslobygg (OBF)
OBF did not experience difficulties in obtaining adequate electricity supply. They felt that they were fortunate in getting access to electricity because the location already had a permanent transformer installation with adequate capacity. Since this was already known when the pilot project was completed, the contractor did not need to investigate it. OBF does not know whether all contractors investigated this. Other projects were less straightforward, but OBF recommends that preliminary investigations should always be performed at the outset to find out whether anything needs to be adapted or extended, and whether the grid operator is able to supply enough electricity.

Bymiljøetaten (BYM)
BYM did not experience major problems in obtaining adequate electricity supply for the Tåsenveien project. However, several discussions with the grid operator were necessary before the matter was resolved. It may be worth checking electricity capacity at the start of a project, and a contractor that does this may have a competitive advantage. Alternative solutions such as battery containers could then be planned if capacity is limited.

Fornebubanen (FOB)
FOB has a dedicated person for ordering electricity supplies for the Fornebu Line contracts and construction sites. Some difficulties were experienced since preparations were made for the electricity supply before the contractor was chosen or how much electric machinery was to be used. Here it is necessary to consider the maximum anticipated capacity for each construction site. The maximum power requirement is estimated based on experience of, for example, what volume of mass is to be transported, what type of machine is to be used, how many operating hours and how much consumption are likely, as well as the arrangement of the construction site. This was adjusted upwards as time went by. The process is felt to be

laborious. In FOB's experience, the grid operator was not entirely prepared, and a great deal of dialogue was necessary before the issue was resolved. For example, FOB requested an electrical cabinet and 500 metres of cable but had to arrange excavation and a switching installation itself. This calls for a lot of co-ordination between all the parties involved. It has been commented that this work should have started a year before construction start-up. FOB has a list of conditions that must be worked through. Co-operation between the grid supplier and the Municipality is important at an early stage, to reduce delays and secure access to power before the start of construction works. It is therefore important to clarify who is responsible for aspects of the process such as arranging electricity supply to the construction site and ensuring priority for large projects, in accordance with the policy of Oslo Municipality.

<u>Summary from the projects</u>

Several projects have had trouble in obtaining enough power and some projects have resolved this in innovative and creative ways. Before start-up in the Klosterenga project, the electricity supply to the site had low power and the nearest transformer was a long way away. This was resolved by installing a long, high-capacity cable and erecting electrical cabinets at several locations around the site. After start-up, experience with cable-supplied electrical equipment was very positive. In the Arilds vei and Revefaret project the electricity supply issue was resolved effectively by using an external 400-volt transformer and high-capacity cables to deliver electricity along the line of excavation, allowing the charging of machines at several locations.

<u>Electricity suppliers</u>

The electricity suppliers are experiencing a considerable increase in the number of installations for charging infrastructure whilst the power grid operators may encounter capacity problems connected with queues, delivery times and processing time. The considerable increase in demand for electrification has resulted in a 50% rise in the number of applications to the Norwegian Water Resources and Energy Directorate (NVE) in recent years. New grid customers have unrealistic expectations regarding complexity, costs and regulatory requirements associated with the installation of new consumption points. The power grid operators are increasingly expected to take into account opportunities for flexibility, such as among a number of customers in a large area and alternatives to grid construction, and not simply focus on a new customer's individual connection needs to the grid. Contractors often find that temporary electricity supplies are given low priority in comparison with permanent supply installations. There is clearly a need for effective routines and procedures when contractors are to arrange energy supplies. Possible ways of simplifying access to charging include battery containers, district heating for heating and drying buildings and installation of electric vehicle chargers and energy generating technology (i.e., heat pumps and solar cells) early in the project. Hydrogen generators will also become relevant in time.

From the energy provider's point of view, the Norwegian state's revenue ceiling is a serious limitation. The national framework conditions are not adapted to the need for electrification of transport. The revenue ceiling model for local distribution grids should to a greater extent consider the fact that companies have different types of customers. The current model means that power grid operators with heavy investment in the construction industry, which provides few new customers, are at a disadvantage and realise a lower return on their investment. The grid tariff rates must be designed so that they do not result in unreasonably high costs for the electrification of transport. Although the power grid operators have considerable freedom of action, they risk causing unreasonably high additional costs for the customer (in addition to the real costs to which the customer subjects the grid). The nationally imposed framework conditions for the grid operators are not optimally adapted to the need for rapid development of charging infrastructure. The power grid operators' revenue basis is strictly controlled, but the companies have some freedom of action regarding their choice of pricing model, including construction industry contributions and power tariffs that have considerable impact on the profitability of investing in new charging facilities and infrastructure. A pricing model that promotes the development of new and less profitable charging infrastructure will result in additional costs and reduce the grid operator's revenues. Measures should be considered that could make it more attractive for a power grid operator to prioritise the development of, and investment in, charging infrastructure (16). The power grid operators are experiencing considerable power demands from the transport sector through, among other things, charging stations for road transport, domestic charging of electric vehicles, land power installations for charging ships in port (as well as operations and unloading), battery charging of ferries, and construction machinery during building operations at construction sites and other infrastructure such as tunnels (16). The grid operators and the authorities do not have a satisfactory overview of the requirement (16). Any purchasing of flexibility to avoid or postpone an investment in the grid is considered an operating cost for which one receives little in return because of the revenue ceiling model (16).

4.3 Charging logistics

Vann og avløpsetaten (VAV)

VAV pointed out that a couple of construction contractors have acquired mobile rapid chargers at a cost of about NOK 4 million. This is a major investment but means they can charge the battery container at 230 V and transform to 400 V for rapid charging of construction machinery. Electric construction machines must have their own transformers, but VAV has not heard that this has presented problems. Construction contractors handle all the charging logistics themselves and engage subcontractors. VAV has not experienced any problems with cable operation, but it has been pointed out that all the cable and electrical cabinets needed to facilitate electric construction machinery at construction sites are expensive.

Oslobygg (OBF)

OBF experiences that charging vehicles is not a problem since it takes place at the machine rental company's own charging facilities. OBF projects have experienced no problems connecting to charging points since the projects so far have not used a lot of electric construction machinery. OBF acknowledges that in connection with large building projects with several machines and a lot of charging it is an advantage to know beforehand if the machines are supplied by cable or by battery. A general lesson learnt is that it is important to notify the contractor of access to electricity. Large contracting companies have expertise in the planning of electricity supply requirements and can assume responsibility for this, while smaller companies need a little assistance. Hence it is wise to plan in smaller projects and ensure that they have access to a good workplace. OBF often carry out investigations to provide contractors with the information they need to do the job. It is often the contractor that handles the planning of electricity supply to the machine fleet. In OBF's opinion, the preparatory work is important, however much planning is done, and the plan always needs be adjusted after start-up. With regards to this, it is important to reduce risk and keep prices under control.

Bymiljøetaten (BYM)

BYM report that there have been no problems associated with charging electric machinery and provides some details of the charging facilities in the Tåsenveien project. The project uses a combination of battery-, battery/cable- and cable-powered machines, with a person appointed to be responsible for charging logistics for each type of machine. This results in less confusion regarding which charging facilities shall be used for the various types of machines. For example, a transformer has been installed, with cable suspended on masts for a large cable-supplied excavator, while charging points are provided close to the rig for the small battery-powered wheel loaders as well as for electric personnel vehicles. In the Olav Vs gate project, the situation was more complicated, since the charging logistics were not standardised, and each prototype machine used a different method of charging. This was resolved by erecting a separate electrical cabinet for each machine. BYM expects that machine contractors will eventually produce a standard charging concept.

Fornebubanen (FOB)
In FOB's experience, a battery container can be used to reduce the power peaks and it is easy to use battery-powered machines for isolated scooping jobs, but more difficult with tracked machines since these have higher energy consumption than excavators have. Here it was necessary to plan the working day around the charging logistics and provide electricity supply nearby when loading mass for transport, especially when 3-4 machines were to be used simultaneously. It was found that battery-powered machines could not be driven back and forth on tracks, with the work area constantly being moved in the tunnel, because of their limited battery capacity and because cables are impractical when machines are being constantly moved back and forth. In the K4 project, the battery-powered machines were charged frequently, which reduces capacity and leads to a lot of unintentional pauses. The equipment does not function as well as was promised. With cable connection and a rear-mounted drum, mobility is reduced, although this functions well for stationary tasks such as scooping.

Summary
Shared lessons learnt involve dimensioning and ordering construction machines according to the work they are to do and having effective usage routines to adapt the power consumption to the task, rather than running at maximum output. Energy is then used optimally and there is less likelihood of running out of energy. It is difficult to estimate maximum power and plan for adequate electricity supply early in a project. It is therefore helpful to gather experiential data for, among other things, electricity consumption, operating hours, battery capacity, power requirements during operation, charging power and rapid charging power, subsequently identifying power peaks during the implementation of various building activities. Effective charging routines are needed if the machinery is to last for a full working day. Part of the solution involves using battery/cable-powered construction machinery and battery containers to provide more flexibility at building and construction sites. There is also a need for energy management tools in large building and construction projects, especially where several large construction machines and vehicles are used simultaneously.

4.4 Experiences and barriers

Vann og avløpsetaten (VAV)
VAV wishes to expand facilities for the interim storage of transported masses, since transporting mass back and forth wastes time and resources. Municipal excavation rules and the Norwegian Planning and Building Act present barriers for interim storage of masses. There is reluctance in the industry to do things differently since contractors are afraid of making errors and breaking the rules. The practice of dumping contaminated mass outside Oslo is also based on old-fashioned thinking. According to VAV, electric tipping lorries have a range of 100-160 kilometres. This means that they do not have enough range to reach disposal sites outside the large towns to which contaminated mass is supposed to be delivered. There is therefore a need for national investment in charging facilities (rated at a minimum of 250 kW) along main roads and at disposal sites outside the large towns to enable the rapid charging of large vehicles.

Bymiljøetaten (BYM)
BYM commented in connection with the evaluation of the various tenders received from contractors that it is left to the individual contractors to decide which electric machines they can offer, but the machine lists are subsequently weighted according to the number and size of the electric machines without considering how much they are to be used. More credit is given for machines weighing over 20 tonnes and less for those under 8 tonnes. This is slightly unrealistic if one large, 20-tonne excavator is only used for three weeks, while several smaller machines are used for longer periods of time. It is recommended to link the evaluation of the different size classes to operating hours and work operations. Although the contractors claim that they will use electric construction machines, this does not consider how much they will

be used. In the Tåsenveien project it was stated that between 10 and 17 construction machines would be electric-powered (59% of the machine fleet). After weighting, the contractor was given 5 points for the machines over 20 tonnes and 1.43 points for those under 8 tonnes. Figure 7 shows the operating hours for the electric and biodiesel construction machinery used in the Tåsenveien project. Electric-powered construction machines represent 333 operating hours (274 hours for machines over 20 tonnes) of the total of 3429 operating hours. In other words, only 10% of the operating hours are emission-free (8% in the case of machines over 20 tonnes).

BYM desires easier access to information from electricity grid operators about the available capacity of the grid. In BYM's experience, the information received about supply capacity varies, depending on which representative of the grid operator is asked and how early a contractor contacts the operator. Contracts are worded such that contractors shall offer what electric machines they have available and shall plan their own capacity. However, they are not necessarily able to answer the relevant questions at an early stage. BYM asserts that it could be possible to establish a routine for assessing capacity in a pilot project, to make this easier for contractors. BYM also notes that it is important to have the right attitude at all stages of the process. It is important to think positively – to consider the process enjoyable, rather than a necessary evil. Communication and understanding of the reasons behind this activity are therefore important.

Maskin	Størrelse	Energitype	Timer	Energiforbruk
Dumper	Medium (8 - 20 tonn)	Biodiesel	230	1778
Flishugger	Liten (mindre enn 8 tonn)	Biodiesel	7	9
Gravemaskin	Medium (8 - 20 tonn)	Biodiesel	174	673
Gravemaskin	Medium (8 - 20 tonn)	Biodiesel	8	31
Gravemaskin	Medium (8 - 20 tonn)	Biodiesel	305	1179
Gravemaskin	Medium (8 - 20 tonn)	Biodiesel	747	2888
Gravemaskin	Stor (større enn 20 tonn)	Strøm	74	1983
Gravemaskin	Liten (mindre enn 8 tonn)	Biodiesel	410	1057
Gravemaskin	Medium (8 - 20 tonn)	Biodiesel	675	2609
Gravemaskin	Stor (større enn 20 tonn)	Strøm	166	4449
Gravemaskin	Stor (større enn 20 tonn)	Strøm	34	911
Hjullaster	Medium (8 - 20 tonn)	Biodiesel	353	2729
Hjullaster	Medium (8 - 20 tonn)	Biodiesel	162	1253
Hjullaster	Liten (mindre enn 8 tonn)	Strøm	31	831
Hjullaster	Liten (mindre enn 8 tonn)	Strøm	21	563
Lift	Liten (mindre enn 8 tonn)	Strøm	5	67
Lift	Liten (mindre enn 8 tonn)	Strøm	2	27
Vals	Medium (8 - 20 tonn)	Biodiesel	22	43
Veghøvel	Medium (8 - 20 tonn)	Biodiesel	23	138
Vibroplate	Liten (mindre enn 8 tonn)	Biodiesel	Ingen timeteller	0
Vibroplate	Liten (mindre enn 8 tonn)	Biodiesel	Ingen timeteller	0
Vibroplate	Liten (mindre enn 8 tonn)	Biodiesel	Ingen timeteller	0
Vibroplate	Liten (mindre enn 8 tonn)	Strøm	Ingen timeteller	0
Vibroplate	Liten (mindre enn 8 tonn)	Biodiesel	Ingen timeteller	0

Figure 7. Examples of machine use and operating hours. Source: BYM.

Fornebubanen (FOB)

Inadequate arrangement of charging stations for vehicles and machinery presents problems. FOB has experienced that it is difficult to establish sufficient charging capacity for rapid charging because co-operation with power grid operators and other parties is time-consuming and needs to start well in advance of contract start-up.

If one does not consider a large part of the environmental criterion as 'other environmental considerations', all the credit will be given for machinery and vehicles, whereas other issues or innovative concepts that may have been more beneficial to the environment are not given credit. The project owner must therefore allow latitude for rewarding other, innovative concepts, such as hybrid operation, reuse, etc. in connection with this criterion.

FOB is working on the concept of 'emission-free level', which is the number of emission-free machine hours divided by the total hours of machine operation. This is a more exact method of estimating the degree to which a construction site has been electrified.

FOB was aware of how important it is to order electricity supply at an early stage, preferably a year in advance. FOB feels that using biodiesel-fuelled generators is not a good solution and that these should be replaced with battery banks. Battery banks are not yet available 'off the shelf', but FOB feels that this will change more quickly if Oslo Municipality makes them a requirement. Pilot projects have tested the concept, but it should be promoted in the future, as it results in greater flexibility and reduces power peaks. FOB feels that hydrogen may also be a good supplementary energy source, but not until two to three years from now.

5 Conclusions

The City of Oslo's Climate Agency has engaged SINTEF to carry out a survey of emission-free building and construction sites for Oslo Municipality's projects. The principal themes are electricity supply, emission-free construction machinery and vehicles, and charging logistics, studying associated experiences and barriers. This report assesses building site experience from relevant projects and includes detailed studies of machine fleets, energy consumption and energy supply. The results indicate that the development towards emission-free building and construction sites is progressing rapidly, although some barriers and challenges remain. All of the municipality's building and construction sites shall be emission-free by 2025.

Standard climate and environment requirements for Oslo Municipality's building and construction sites were introduced in 2019. With this new framework, contractors who can offer emission free construction machinery and vehicles in building and construction projects are awarded contracts where Oslo Municipality is the building owner. This is an innovative use of procurement, targeted to promote a quicker transition to emission free completion of building and construction activities in Oslo. In 2019, access to emission free equipment was limited, and the market for emission free building and construction services was still in an early phase of development. Standard requirements were introduced to contribute to the Municipality's goal that all building and construction activities in Oslo Municipality's public sector shall be emission free by 2025.

This survey shows that the framework has succeeded in its purpose. Between 1st January and 30th June 2021, 73 competitions for tender were published on behalf of Oslo Municipality for the construction sector. Of these, 66 competitions followed Oslo Municipality's standard contractual requirements and award criteria, and eight stipulated the use of emission-free concepts, the minimum requirement in six of these being the use of emission-free excavators. This means that seven of these 73 projects were either too small or did not use electric construction machinery. There are now at least 36 construction projects in Oslo Municipality (mapped in this report) that use emission free construction machinery, vehicles and equipment.

This mapping shows that it is unproblematic with smaller electric machines and equipment. But there are some challenges relating to energy supply and charging logistics when multiple, large construction machineries operate at the same time. It is reported that electric construction machineries generate less noise, less pollution, better air quality and a better working environment. The results show that there are different understandings of what an emission free building or construction site involves, and that definitions of these terms should be standardised. This will most likely be achieved through the on-going development of a Norwegian Standard prNS3770 for emission free building and construction sites. Table 4 summarises barriers, challenges, possibilities and solutions for emission free construction machineries and vehicles, energy supply and charging logistics.

Table 4. Barriers, challenges, possibilities and solutions for emission-free building and construction sites

	Barriers and challenges	Possibilities and solutions
Emission-free construction machinery and vehicles	Long distances to disposal sites outside Oslo necessitate the use of vehicles using biofuel or fossil fuel.	Effective local utilisation of masses, and improved charging infrastructure for larger vehicles (outside Oslo).
	New market with few available electric machinery and vehicles.	Make the demand for electric machinery and vehicles visible and collaborate nationally and internationally to affect supply.
	Electric construction machinery has a lower load capacity and heavy electric vehicles have a shorter range – they do not always have enough energy or available electricity to last a full working day.	Adapt work routines, better charging solutions (e.g., rapid charging) and ensure enough electricity supply on the construction site.
	Several emission-free machines are not being used as much as desired.	Follow up contractors actively to ensure they use emission free machineries when they are available.
	Competition for projects is decided according to offers on the machine fleet.	The framework for following up contracts can be further developed with larger weight on documenting the use of emission free construction machineries, instead of todays model that emphasises the composition of the machine fleet.
Electricity supply	Complex process for arranging temporary electricity supplies, especially 400 V – this may lead to delays.	Good process for involving power grid operators in early planning and throughout the project.
	Charging problems – limitations of the supply grid may lead to increased charging times.	Consider the composition of the machine fleet by choosing battery and cable/battery-powered electric machinery to resolve charging capacity problems.
		Other ways to reduce the load on the supply grid may be through the use of a battery container, the use of district heating to heat and dry structures, and arranging one's own energy generation in a building project's early phase.
Charging logistics	Use of cable/battery-powered construction machinery can present challenges related to building site logistics.	Early assessment of which machine types are to be used (battery, cable/battery) to allow suitable arrangement of the building site.
	There may be several different charging systems for different machines.	Appoint a person responsible for charging logistics on the building site.
		Use a battery container that can be kept continuously charged from a 230 V supply, but rapid-charge machinery at 400 V or more from the battery-based mobile solutions.

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Appendix A: Questionnaire

Questionnaire – Survey of emission-free building and construction sites

The City of Oslo's Climate Agency is carrying out a survey of emission-free building and construction sites. The purpose of the questionnaire is to identify relevant projects in Oslo's project portfolio to be included in a survey.

If you decide to take part, you can withdraw your consent at any time without giving a reason. All your personal data will then be deleted. You will incur no negative consequences if you do not wish to take part, or if you decide to withdraw your consent at a later date. We will use information about you only for the purposes described in this document. We process the data in confidence and in compliance with prevailing personal privacy regulations.

*Required

Part 1 – Assessment of projects

1. We process information on the basis of your consent. I consent to my responses being processed until the completion of the project.*

- [ ] Yes
- [ ] No

2. What is your name?*

[ ]

3. What is the title of the building or construction project?*

[ ]

4. Where is it located? (Full address if possible)

[ ]

5. Which enterprise is responsible for the project?*

[ ]

6. What is the name of the contact representative for the building or construction site?*

[ ]

7. What is the contact representative's role?

[ ]

8. What is the contact representative's telephone number?

[ ]

9. What is the contact representative's e-mail address?*

[ ]

10. What type of building or construction project is it? (Please provide a brief description, which may include the name of the project owner, the contractor, the enterprise model, area, budget, etc.)

11. What phase is the building or construction project in?

- Programming
- Planning
- Development
- Completed – in operation

12. What are the environmental ambitions of the project?

- Fossil-free building or construction site
- Emission-free building or construction site
- Waste-free building or construction site
- BREEAM Very Good / Excellent / Outstanding
- Passive house
- Energy-plus building
- Zero emission building (ZEB)
- Zero emission neighbourhood (ZEN)
-

13. Which construction activities in the project shall be emission-free?

- Transport of building materials
- Transport of construction machinery
- Transport of waste, including packaging
- Waste treatment and disposal
- Personnel transport
- Use and operation of construction machinery
- Energy consumption (e.g., for heating and drying)
- Demolition
- Water consumption
- On-site transport
- Temporary installations (e.g., construction offices)

☐ Storage

☐ Supplementary materials and installation

☐

[ ]

14. Are there, or have there been, emission-free machines, vehicles or equipment in operation at the building or construction site?*

○ Yes

○ No

Part 2 – Assessment of machine fleet

The City of Oslo's Climate Agency wishes to collect information about machine fleets connected with emission-free building and construction sites. This part of the questionnaire is to be filled in by those whose reply to the previous question was "Yes". It will be used to create a list of machines used at the building or construction site.

15. How many electric construction machines, vehicles or units of equipment are in use or will be used in the project?

[ ]

16. Please provide a brief description of each electric construction machine, vehicle or unit of equipment. (If possible, please include information about the type and size, and about which project phases the machines, vehicles or equipment are used or will be used in).

[ ]

17. What problems have you experienced with the introduction of electric construction machinery, vehicles or equipment?

[ ]

18. What kind of data do you have access to regarding the operation of the machines? (e.g., electricity consumption, power peaks, charging, operating hours, etc.)

○ Power profiles

○ Charging profiles

○ Usage times

○ Maximum power

○ None

Appendix B Zero-emission construction sites in the City of Oslo – Interview Guide

Introduction:
SINTEF has been engaged by Oslo Municipality to assess experiences from emission-free building and construction sites. Through this interview, we wish to collect construction site experiences linked to machine fleets, potential and barriers, electricity supply and charging logistics. Some details on how the information is processed. We will not send a copy of the interview to you unless you request it.

Personal background information about the interviewee:
- Role
- Experience
- Have you previously worked at building or construction sites where emission-free machinery was used? If so, which projects?

Machine fleet
1. We review the questionnaire and fill in the form relating to machine fleet.
The form is sent prior to the interview and shall be filled in by the project manager or contractor.
Briefly describe how this building site uses emission-free machinery.
Link this to the responses in the questionnaire.
Have heavy machines or vehicles been used, for which tasks, and how were they charged?
What proportion of the machinery and vehicles were powered by electricity? How many operating hours?

2. Experience with emission-free machinery and vehicles at the building site
What practical advantages are there in using emission-free machines at this building site? Provide one or more examples if possible.
What practical disadvantages are there in using emission-free machines at this building site? Provide one or more examples if possible.
To what extent would you say that you work differently at the building site because electric machinery is being used? Provide examples of the differences, if possible.
Planning; charging logistics; machine size; organisation, roles and allocation of responsibility

Electricity supply
Introduction: We are particularly interested in how electricity supply at the building site has affected the use of electric machines and vehicles.
What sort of measures have been necessary at the building site to ensure adequate electricity supply in connection with the charging and use of electric machinery?
How was the electricity supply planned beforehand? At what point in the process did you contact the electricity suppliers?
Technical installation, organisation, use of Oslo Municipality's guide to order electricity supply at the building site.
What challenges (if any) have been experienced in connection with ensuring the necessary electricity supply? (Open question)
Clarifications:
Were there challenges associated with the following, and if so, what were they:
- Establishment (time between decision and start-up, practical establishment)
- Power output
- Supply grid capacity
- Reliability of supply (continuity, outages)
- Scaling in the building phase (costs)

If there were challenges, how were these resolved?

Which parties have been involved in the planning, establishment and use of the electricity supply?
In which different phases of the project?
How has responsibility been allocated?
How did planning and co-operation function?
Should it be done the same way next time, or do you have suggestions for opportunities, changes, or improvements?

Charging logistics
Introduction: We are also interested in how charging logistics (that is, the planning and practical performance of charging) have affected the use of electric machinery and vehicles.
Introduction: We are particularly interested in how charging logistics at the building site affected the use of electric machinery.
What sort of measures have been necessary at the building site to ensure good charging logistics in connection with the charging and use of electric machinery?
How was the charging logistics planned beforehand?
Were power profiles modelled? Or were other tools used in planning and operation?
What challenges (if any) have been experienced in connection with charging logistics? (Open question)
Clarifications:
Were there challenges associated with the following, and if so, what were they:

- Enough charging stations
- Adequate power
- Routines to ensure adequate operating time and low costs
- Health and safety and cable handling

If there were challenges, how were these resolved?
Which parties have been involved in the planning, establishment and use of charging logistics?
In which different phases of the project?
How has responsibility been allocated?
How did planning and co-operation function?
Should it be done the same way next time, or do you have suggestions for alternative approaches, changes, or improvements?

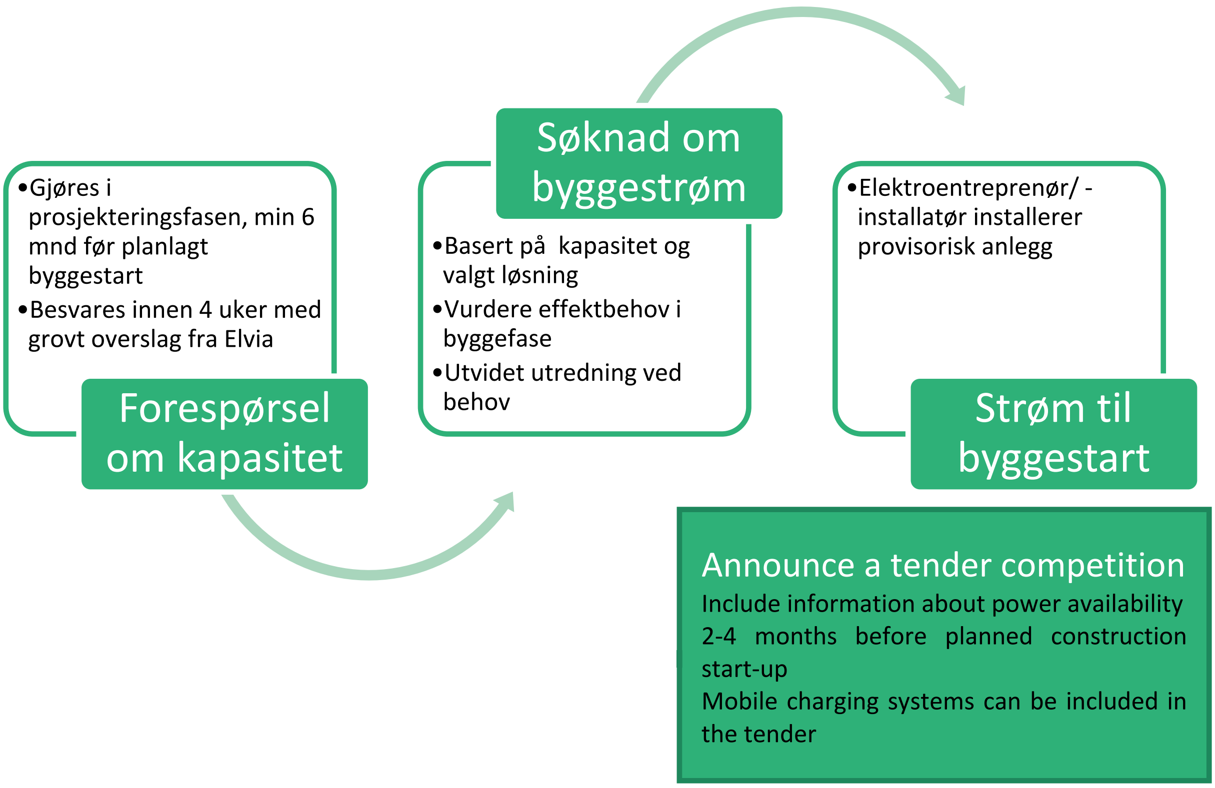
Conclusions and summary
To what extent would you say that the regulations and framework conditions are appropriate to the use of electric machinery at the building site? What can or should be changed if anything? Please provide specific examples if possible.
Are there any experiences with electric machinery and vehicles in this project that you would like to share?

Appendix C – Guidelines for ordering electricity supply for building sites. Source: Oslo Municipality/Elvia.

Electricity supply for electrified construction sites

Ordering electricity supply for Oslo Municipality's building and construction sites should take place before the tender competition is announced, to ensure that projects can be implemented using emission-free heating and that the successful contractors offering electric machinery and vehicles are able to use them from the start of construction. When a tender competition is announced, contractors should be informed of what power output has been ordered from Elvia, so that they can plan their machine fleet accordingly. If a supplier needs more power, this must be supplied as part of the machine fleet delivery.

Process description: electricity supply for building and construction sites



Enquiries regarding supply grid capacity – Elvia

- The project manager shall contact Elvia in the planning phase (6 months before construction start-up should be adequate time). The simplest way to do this is to use the form Forespørsel om tilknytning av større prosjekter (Enquiry regarding connection of major projects) at www.elvia.no
- At this early stage of the process information given must include a description and map of the location, and the estimated power requirement. If the project lacks any of these, one should instead submit a "Technical enquiry".
- An enquiry shall be submitted for the estimation of grid capacity for one or more alternative power requirements, a geographically limited area and a specified start date.

- It is important that a consultant electrical engineer is appointed to the project and participates in the process from the outset.
- The purpose of the enquiry is to determine whether the necessary grid capacity is available in the vicinity, and possibly whether the grid must be upgraded to suit the building or the construction site.

Information to be included in the enquiry

Location, using a map of the operational area	*Hint: Make the operational area slightly larger than the structure to be built to make access to charging supply easier. Proposals for various electrical outlets should be drawn by Elvia on a map*	
Time period for project implementation	From (date)	To (date)
Power requirement in the operational phase (kW)	Min	Max
Building site power requirement (kW) ***(Number of machines to be charged)***	Min	Max
Attachments	*Available information about plans for electrical outlets during operation, drawings*	

Provisional conclusions regarding capacity

Within 4 weeks, Elvia will state whether the surrounding grid has adequate capacity or whether there is a need for upgrading. This is not an order: other customers may approach, changing the situation before an order is placed. Oslo Municipality should apply for construction power before the tender competition is announced, in order to be able to specify the available capacity in the tender documents.

Information in Elvia's response:
Application for construction power and a site

Conclusion	Yes	No		
	The surrounding grid has adequate capacity	**The grid has inadequate capacity and the development may require upgrading of the grid. This will necessitate a customer contribution**		
Means that	The capacity of the surrounding grid is adequate to cover both the demands of the construction site and the power requirements of the building during the operational phase.	The capacity of the surrounding grid is too low for operation of the building or the construction site's power requirement is greater than the requirement during the operational phase. The construction site may be supplied with temporary construction power from grid substations in the vicinity.		
Possible options for electricity supply (maybe a combination of these)	Electricity supply to the building may be arranged before start-up. Permanent electricity supply may be used as construction power.	a) Grid upgrade will take 2-4 months	b) Temporary grid substation connected to low voltage or high voltage supply Must be considered in each case.	c) Mobile electricity supply such as a battery container. [Contact external suppliers]

	A	B
	The surrounding grid has adequate capacity	***The grid has inadequate capacity and the development may require upgrading of the grid***
Before entering into agreement with a contractor	In the case of large building projects, ordering should take place before the tender competition is announced. An authorised electrician shall submit a formal application for construction power or temporary supply, with specific information about the requirement (power) and an approximate start date. Then a supply of a certain capacity can be made available in a technical description in an enquiry to the contractor. If the municipality has not engaged an electrician at this point but is familiar with what will be ordered (e.g., via a	In the case of large building projects, ordering before the tender competition is announced should be considered. An authorised electrician shall submit a formal application for construction power or temporary supply, with specific information about the requirement (power) and an approximate start date. Then a supply of a certain capacity can be made available in a technical description in an enquiry to the contractor. Elvia arranges supply of electricity from the grid but does not lay cables to the construction site. The interface is at the connection point (Low voltage: substation, distribution cabinet. High voltage: high voltage breaker in temporary substation) For more information see https://www.elvia.no/proff/nettilknytning/byggestrom-eller-midlertidig-stromforsyning/

	consultant electrical engineer), it can place the order itself, directly to a customer contact at Elvia. "BP2 Decision to continue"	
Following entry into agreement with a contractor:	In the event of low power requirement corresponding to a standard construction power cabinet rated at 63 A, 25 kW, the construction power cabinet can be obtained without application and estimates. An authorised electrician submits a formal application for construction power or temporary supply, with specific information about the requirement (power) and an approximate start date, 2-3 weeks before the expected start-up. The application shall be sent at the request of the appointed contractor. Notification of installation work shall be sent to authorise switching on.	
Expected response time and/or arrangement	Approx. 2-4 months.	Depending on the project Approximately 2-4 months from ordering to switching on (ready for construction start-up)
Consultation agreement with Elvia	In the first instance, consultation may be agreed consisting of x meetings and x consultation hours. The consultation hours are free of charge. If more guidance is needed from Elvia an assessment agreement may be drawn up. In this case, Elvia must be paid for time involved. An assessment agreement is often used in complex projects when the allowed time has been used up and more assistance is needed. 4-6 weeks, depending on scope.	

Infobox

What can Elvia assist with?

- Providing information about our grid, including capacity connected with the required power, location, and time
- Assessment of the need for upgrading of the grid
- Granting permission for connection to our grid and specifying the point of connection
- Providing information about which prequalified electrical contractors and electricians are permitted to work in our grid.
- Our electrical contractors connect a temporary substation, containing an interface to the grid.

What can Elvia NOT do?

- Supply construction power cabinets or temporary substations
- Connect construction power cabinets to the grid. This must be ordered by the project owner from a prequalified electrical contractor or electrician.
- Lay electrical cables to the project owner's installations at the construction site.
- Dimension the customer's installation, i.e., assess how much electricity a customer needs.
- Carry out detailed studies, unless an assessment agreement has been entered, authorising hourly payment. Elvia must determine internally how much the free consultations shall involve. Work is in progress internally with such agreements.

The figure below illustrates which services a power grid operator can provide and what they charge for.

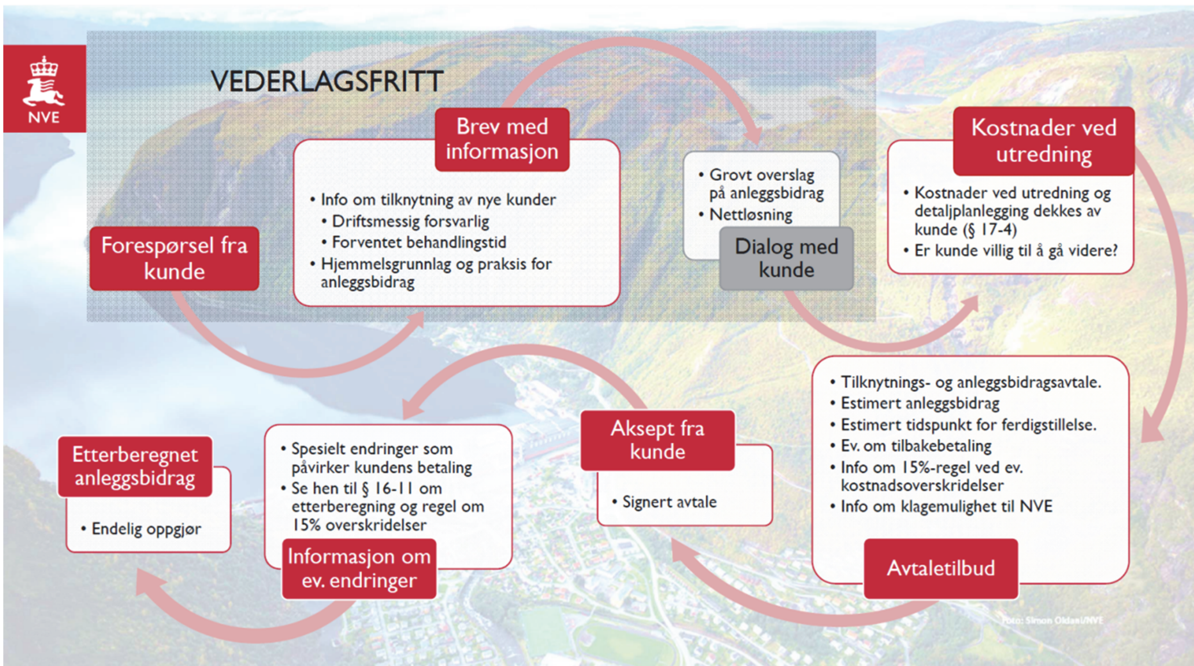
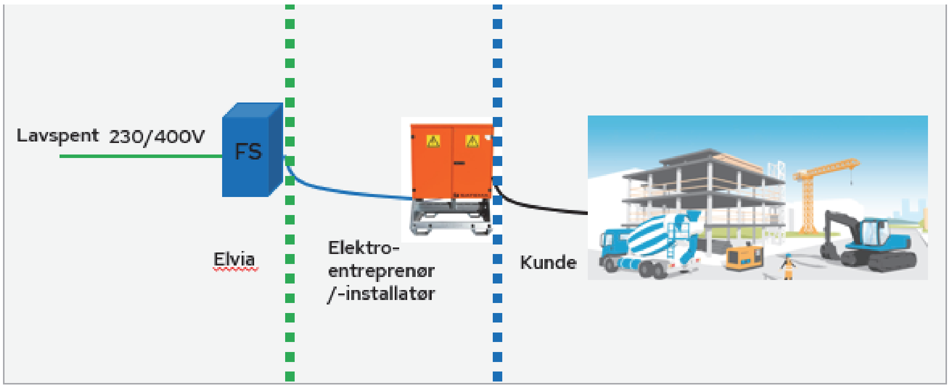
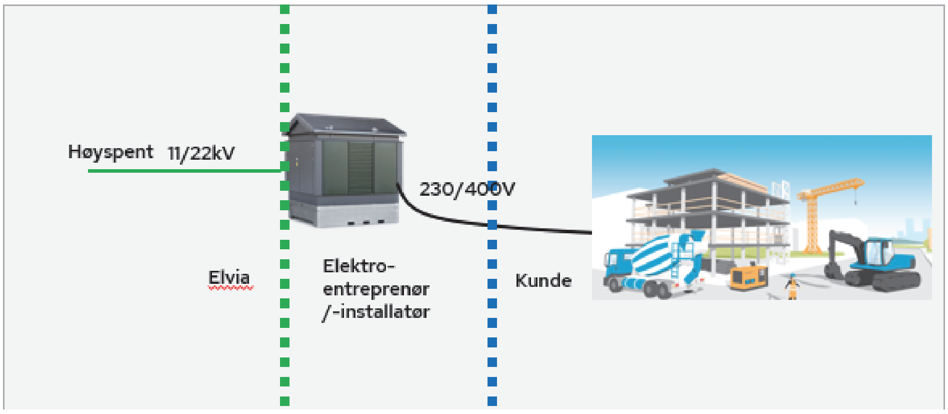


Illustration of interface:





A survey of the requirements for emission-free building and construction sites

Oslo Municipality has decided that all public building and construction sites shall be emission-free by 2025. In 2019, Oslo Municipality introduced 'standard climate and environmental requirements' for all their building and construction sites.

In this report, we present the results from a survey of the requirements for emission-free building and construction sites in Oslo Municipalities projects. The principal themes are electricity supply, emission-free construction machinery and vehicles, and charging logistics, studying associated experiences and barriers. The results indicate that the development towards emission-free building and construction sites is progressing rapidly, although some barriers and challenges remain.

The project is financed by the City of Oslo's Climate Agency in Oslo Municipality.

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