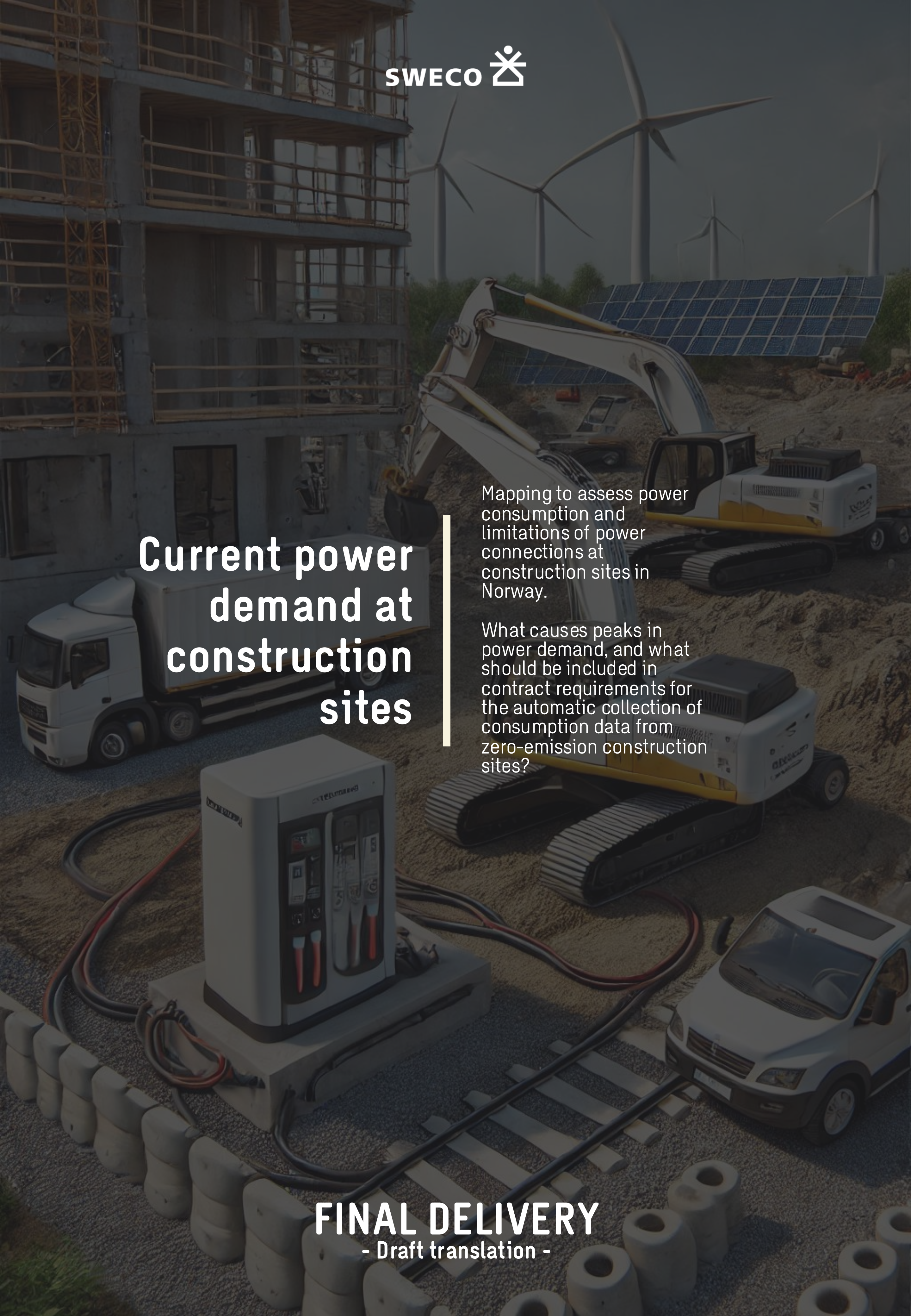


SWECO

Current power demand at construction sites

Mapping to assess power consumption and limitations of power connections at construction sites in Norway.

What causes peaks in power demand, and what should be included in contract requirements for the automatic collection of consumption data from zero-emission construction sites?

FINAL DELIVERY

- Draft translation -

Document Information

Client	Climate Agency, City of Oslo
Contact Person	Petter N. Christiansen
Report Title	Current Power Demand at Construction Sites
Norwegian Title	Dagens effektbehov på bygge- og anleggsplasser
Project Name	Mapping of Power and Energy Demands for Zero-Emission Construction Sites
Project Number	10235820
Prepared by	Eirik Hordnes, Linna V. Nguyen
Project Manager	Eirik Hordnes
Availability	Open
Cover image	Generated with ChatGPT DALL-E
Translation	Aurora Stenmark, Petter N. Christiansen, Linna V. Nguyen
Translation Version	0.1 Draft version of translation. Final translated version will be ready by end of October 2024.

Rev	Date	Description	Prepared by	Approved by
00	25.06.2024	Draft for comment by the Climate Agency in Oslo	Eirik Hordnes Linna V. Nguyen	Eirik Hordnes Linna V. Nguyen
01	05.07.2024	Report of the Final Delivery	Eirik Hordnes Linna V. Nguyen	Eirik Hordnes Linna V. Nguyen
02	23.08.2024	Revised version 2	Linna V. Nguyen	Eirik Hordnes

Foreword | Final delivery

Sweco has conducted a study on behalf of the Climate Agency in the City of Oslo. The purpose of the survey was to collect data from ongoing construction projects within the municipality to gain a better overview of energy, and particularly power demands, for zero-emission and partially zero-emission projects. This is intended to provide the municipality and the industry with a better knowledge base regarding actual power capacity and energy needs.

The project has been challenging. Construction sites are chaotic, with many activities occurring simultaneously. Gathering sufficiently accurate data with high-resolution energy consumption measurements distributed across circuits is uncommon. Only a few projects are equipped for this, likely due to cost considerations. We have mostly relied on data from the utility companies' smart meters. These provide energy data with hourly resolution, i.e., kWh/h, which can also be translated into average power [kW] per hour. However, this data does not capture the highest power peaks, especially for short-term effects. For example, an excavator capable of charging at 200 kW will draw exactly that amount of power from the grid. If it charges for only half an hour, the smart meter data will show it as 100 kW, since it was charging at 200 kW for 30 minutes. Thus, hourly measured power will underestimate the registered power by 100 % in this case.

We have surveyed 4 construction projects and 8 infrastructure projects as part of this assignment. For 2 of the 4 construction projects (Tøyenbadet and Stovnerbad), we had access to higher resolution data and more circuit meters than just the standard smart energy meter. In these projects, we measured consumption at the circuit level with a 10-minute data resolution. Second-by-second resolution would have been ideal but given the cost/benefit considerations of the assignment, a 10-minute resolution was deemed sufficient.

The focus has been primarily on the two construction projects with high-resolution energy measurement available. In addition to these construction projects, we analyzed data from the Sophies Minde project, as it is an interesting project with the goal of achieving a 100% zero-emission construction site. So far, they have succeeded, and they even plan to use an electric drilling rig. Unfortunately, this will occur after the cutoff date for data collection in this assignment, so the electric drilling rig is not included. Nonetheless, it is expected to draw up to a maximum of 600 kW, based on the maximum technical capacity of the drilling rig (a 110 kW hydraulic generator and a 500 kW compressor). This will create a new power peak for the project, compared to the one we documented at 397 kW (hourly measured). In addition to Sophies Minde, we were fortunate to obtain data from the Garnes Ungdomsskole construction project, which is currently being built in Arna outside Bergen. Skanska has kindly shared data, for which we are very grateful. This project aims to be 90% zero-emission, which it is on track to achieve if one disregards the drilling rig, as an electric variant was not available at the time.

A central part of this project has been to identify the causes of power demand and propose measures to mitigate the largest power peaks. Zero-emission construction sites will largely rely on electricity. There has been significant development in the types of machinery available in electric versions on the market, including asphalt pavers, drilling rigs, and rollers. Investment costs for electric machines are still significantly higher than their diesel counterparts, so investment support from Enova will be important in further developing this market. Additionally, more and more actors are offering smart construction power cabinets, battery containers, and charging containers in various sizes and degrees of mobility. We see this as central to the future of smart management and good planning of such projects. If implemented, it will be possible to avoid the largest power peaks, which is beneficial for the power grid and the overall economy. It is worth considering that many of the circuits in a construction project can be disconnected during periods of high power demand, such as for site facilities, building heating, and building drying. Fast charging of larger construction machinery is currently a clear cause of the highest peaks in power demand, but if some of the base load can be switched off or the charging can be distributed more evenly, the peaks can be reduced. Alternatively, this could be addressed with stationary batteries for peak shaving or by rotating multiple machines. Additionally, systems should be put in place to allow users of construction machinery being charged to input when the machine will be used again. In some projects, we observe unnecessarily high power peaks at the end of the workday. This is because the machines are set to charge, and the charging infrastructure does what it is designed to do—charge as quickly as possible. This is unnecessary, as the machines will remain idle from 4-5 p.m. until the next day's start, which allows for a low average charging power over the entire period.

Thorough planning of zero-emission construction sites will be beneficial. Some contractors have gained experience and will use it in the future. However, public developers must ensure as equal competition conditions as possible, so that contractors can compete on equal terms. Therefore, it may be most rational for the developer to order power from the utility company and include it in the tender documentation. This provides specific and fundamental conditions for the contractors to work with, knowing, for example, that they have 350 kW available from the grid for a particular project.

We would like to thank everyone who generously shared data with us, allowing us the opportunity to study the data with the eyes of independent advisors, free from product preferences and trade secrets.

Special thanks to Project Manager Petter N. Christiansen at the Agency for Climate for excellent collaboration, and to Christoffer Venås at Oslobygg for his enthusiasm and willingness to engage in discussions despite a busy schedule.

Summary | Final Delivery

The final delivery contains findings from the survey of data and related data analysis for ongoing construction projects: Tøyenbadet, Stovnerbad, Sophies Minde, and selected historical infrastructure projects.

In the work of mapping energy and power demands, the following general points and issues, regardless of construction and infrastructure projects, should be addressed:

- To what extent is power availability a limiting factor for the operation of zero-emission construction sites?

- Proposals to avoid undesirable power peaks.

- Specify the necessary prerequisites for optimal planning by contractors and developers.

- Assess the measures and prerequisites needed to optimize the planning of a zero-emission construction site.

For each of the analyzed construction projects, the objective has been to analyze energy needs, power demands, and the causes of power peaks.

In the Tøyenbadet construction project, district heating is used for building drying and heating. Electricity is used for the site facilities, as well as for a larger share of construction machinery and equipment. Biodiesel HVO is also used for construction machinery. 87 % of the energy use has so far been clean energy. The construction site has approximately 800 kW available from the grid and has also installed a solar power plant on the site facilities with about 11 kWp.

The highest power peak in the Tøyenbadet project occurred on Wednesday, January 17, 2024, at 11:00, reaching 510 kWh/h. At the time, both outdoor and indoor construction activities were taking place simultaneously. Part of the cause of the power peak has been identified, but due to some unmeasured consumption, it has been challenging to pinpoint all the exact causes. It was identified that the circuit-measured consumption of the site facilities, crane 1, crane 2, and excavator charger accounted for 54% (277 kW) of the power peak. It is likely that the charging container for the excavator triggered 30% (152 kW), while the remaining 16% (81 kW) of the peak power during the hour could be a combination of various activities.

Overall, the project has used 6.1 GWh so far, with electricity accounting for 50%, biodiesel for 13%, and district heating for 37%. The project has been carried out with 87% of the energy use being clean energy.

In the Stovner bad construction project, the site is fossil-free, with some zero-emission construction machinery. The project uses electricity for site facilities, charging construction machinery, and the building itself, as well as biodiesel HVO for construction machinery not powered by electricity. Stovnerbad is to be connected to the district heating network, but this has not been utilized during the project period. The project will continue until the summer of 2026 and is planned to be completely zero-emission from 2025 onwards. Based on available data, a power peak was identified on Tuesday, October 17, 2023, at 11:10, at 522 kW (10 min). In reality, the peak could be even higher, due to missing circuit consumption data for the crane and welding, and it is also possible that other peaks have occurred that the project has not yet identified.

The identified peak of 522 kW (10 min) occurred during the groundwork phase at Stovnerbad. Activities that are particularly noisy and energy-intensive (such as excavation, sheet piling, piling, mass filling, and demolition/filling of the underpass) were ongoing at the time. It was also identified that concrete work with in-situ cast concrete started on October 16, 2023. With the help of the circuit meters on-site, the power peak can be distributed as follows: 52% (270 kW) from site facilities, 31% (162 kW) from BoostPoint, 0% from the building, and 17% (90 kW) from Hummingbird. Thus, charging with BoostPoint and Hummingbird contributed 48% of the peak. The peak also occurred during one of the two periods with the highest recorded power levels during the project period, with the other occurring at 16:00.

In total, the project has used 0.9 GWh so far, with 42% of the construction site being zero-emission.

In the Sophies Minde construction project, which is a renovation project, only electricity has been used as an energy carrier so far, meaning the construction site has been 100% zero-emission during the first seven months of the project. The remaining 12-14 months are also expected to be carried out without emissions. Based on available data sources, the highest power peak occurred on Thursday, January 4, 2024, at 16:00, reaching 397 kWh/h. The construction site has a total available grid capacity of 2,000 kW, distributed across three transformers, which all were pre-existing. After the analysis period ends, an existing transformer will be replaced with a new one to supply power to an electric drilling rig for drilling energy wells. The drilling rig has a total (and maximum) capacity of around 600 kW. This will create a new power peak for the project.

The cause of the power peak on January 4 has been identified and is linked to the simultaneous fast charging of two excavators. This power peak of 203 kW accounts for 51% of the project's highest power to date. With 20 site facilities accounting for around 30 kW, it is reasonable to assume that the remaining 164 kW goes to charging other excavators, as it was reported that there were four excavators on-site in January. The two excavators not fast charging can charge at a maximum of 80 kW. It was also reported that there were six 18 kW heaters used for building drying/heating during the winter, amounting to a maximum of 108 kW. Beyond this, some of the power was used for lighting and the site's one tower crane.

Summary | Final Delivery

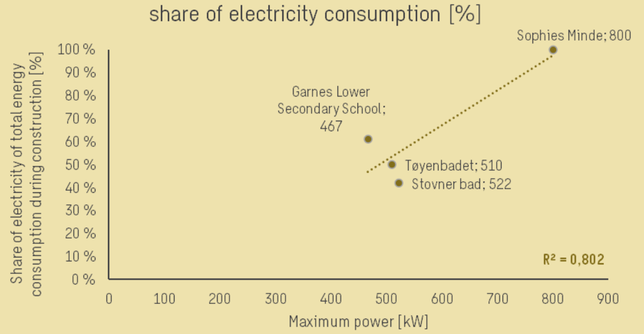
Summary for Construction Projects

The peak power demand for the surveyed construction projects varies between 397-522 kW. Interestingly, there does not appear to be a clear correlation between peak power and an increasing degree of zero-emission construction sites. There are many potential explanations for this. The projects differ in scope, the analysis period covered different construction phases, planning varied, the sample size was limited (4 projects), among other factors. For example, Tøyenbadet has a peak power of 510 kW with 87% of totalt energy use being zero-emission, while Stovner Bad has 522 kW with only 42% of totalt energy use being zero-emission. They are otherwise relatively similar; 37% of the 87% for Tøyenbadet comes from district heating, so the project has an electric consumption share of 50%, which is relatively similar to Tøyenbadet. In this project, Sophies Minde had a short analysis period, and the heavy groundwork with an electric drilling rig was not included in the consumption during the analysis period. It is estimated that peak power, with the use of drilling rigs and other simultaneous consumption, could potentially range from about 800 kW up to 1350 kW if everything happens simultaneously on a cold day. This results in a high positive correlation between the degree of an electric construction site and peak power, between 0.895 and 0.93. The correlation is also not independent of the size of the construction project. These projects are relatively similar in scope (square meters of gross floor area) and can be generalized as a function of, for example, the building area.

Common across most projects are higher power peaks around 11-12 o'clock, coinciding with lunch break and related charging during the break, or towards the end of the day when the machines are reconnected for charging. The latter issue is easy to address with good charging management.

All projects experienced their peak power during the autumn and winter seasons. Two projects had their peak power in January 2024, while the other two had it in October 2023. There is a slight negative correlation between overall consumption and outdoor temperature, meaning that consumption on construction sites tends to increase as the outdoor temperature decreases. From our available data, this seems primarily related to site cabins and possibly building heating or drying. Drying out buildings typically does not occur simultaneously with other demanding phases, such as groundwork, which is the most energy-intensive phase. Therefore, there is a lower chance of power for building drying coinciding with extensive simultaneous fast charging of excavators.

Maximum power [kW] as a function of the projects share of electricity consumption [%]



	Tøyenbadet	Stovner bad	Sophies Minde	Garnes Lower Secondary School
	New construction	New construction	Renovation	New construction and Renovation
Including demolition contract [YES/NO]	Unknown	Unknown	NO	YES
Area BTA [m²] New construction / Renovation	15 800	8 600	13 000	9 300 / 1 600
External area [m²]	Unknown	Unknown	7100	Unknown
Grid capacity [kW]	640	640	2 000	640
Number of construction site cabins	61	11	20	30
Max. power, hourly [kW]	510	522	397	467
Date and time for registered max power, hourly	17.01.2024, at 11:00	17.10.2023, at 11:00	04.01.2024, at 16:00	09.10.2023, at 12:00
Avg. power, hourly [kW]	106	45	117	74
Emission-free share of energy use [%]	87 %	42 %	100 %	61 %
Electrical share of energy use [%]	50 %	42 %	100 %	61 %
Avg. energy consumption, daily [kWh]	2 386	1 326	2 375	1 782
Avg. energy consumption, monthly [kWh]	71 325	38 476	74 802	50 298

Derived indicators					Comments
Max. power, hourly / Sum area [kW/m2]	0,032	0,061	0,020	0,043	Can be used to calculate maximum hourly power, based on developed area.
Energy consumption, monthly / Sum area * 12 [kWh/m2yr]	54,2	53,7	44,7	55,4	Can be used to estimate annual electricity consumption, based on developed area

Summary | Final Delivery

The project has also looked more closely at a selection of construction projects managed by the Water and Sewerage Agency (VA-etaten). These projects include the renovation or construction of new water and sewage systems, with extensive use of excavators for trenching and pipe bursting machines to insert new pipes into old ones. Work often involves manholes, excavation, and casting. VA-etaten's projects already feature a high degree of zero-emission operation. In these projects, we have had access to machinery lists but not detailed energy consumption data for the different machines. When looking at the share of zero-emission machines in the projects, regardless of usage, the zero-emission share ranges between 70-100%.

The peak power in the examined projects varies between 30-260 kW. The highest power peaks for the various projects occur at 09:00, 11:00, 12:00, and 14:00. Among the eight projects, the peak occurs at 09:00 for three projects, at 11:00 for three projects, while for one project it occurs at 12:00 and for another at 14:00. All peaks occur in autumn or winter. For most projects, there is little correlation between outdoor temperature and consumption. For some, there is a weak correlation. Projects showing some correlation between outdoor temperature and consumption likely have more site cabins, but this information was not available for this project.

General Findings: Zero-Emission Construction Sites

- Meters with a 10-minute time resolution or higher provide better insight into consumption and help understand energy use. This requires clear requirements for monitoring and that logging is performed for the data to be useful later. Accurate measurements with sufficient time resolution are crucial to capturing real peak power events.

- It is important to identify the causes of power peaks to implement measures and avoid undesirable peaks. Peaks are often due to the simultaneous fast charging of multiple machines. High base loads typically occur in winter due to temperature-dependent consumption, such as site cabins. This can lead to the highest peaks in winter if the construction phase requires fast charging of multiple machines simultaneously.

- A fully electric construction site can experience various power peaks depending on the energy solutions and the use of electric machines. Depending on how the project is set up and carried out, construction projects can create peaks in power demand over 1000 kW. However, it seems possible to avoid this, potentially limiting peaks to 600-700 kW at worst for a medium-sized new construction project.

- Various measures can be implemented to minimize unwanted peaks in power deamnd, including using multiple machines, stationary battery banks, good planning and charging logistics, smart management of charging and other loads, and energy-efficient site cabins.

- Site cabins use between 1-3 kW per cabin. On larger construction sites with many cabins, this can contribute to power peaks in winter when the power grid is most stressed. Energy-efficient cabins are therefore an important measure to minimize base loads in winter.

- Clear requirements for prerequisites and specific contract requirements are crucial for ensuring effective planning and operation of zero-emission construction sites.

Recommended Requirements

- These include meter setup, time resolution for energy data, and data collection from energy meters.

- Include communication between chargers and battery-electric machines, as well as communication between chargers and charging platform.

- Include data collection from machines to link energy consumption to specific machines.

- Include standardized data transfers between different cloud-based platforms.

- The municipality should consider requiring contractors to demonstrate how they will implement smart management of consumption and how this can reduce power peaks and be implemented effectively.

- Further Details: See pages 91-96.

Table of Contents

1 Introduction

Background of the Project and Issues to be Addressed

Around 1.2% of Norway's total greenhouse gas emissions come from the construction industry, equivalent to about 660,000 tons of CO_2e. The City of Oslo has decided to reduce the entire municipality's greenhouse gas emissions by 95% by 2030, compared to 2009. In Oslo, emissions from the construction industry account for about 10% of total greenhouse gas emissions. By 2030, this segment must be emission-free or use sustainable renewable fuels. In practice, this means that all construction machinery and transport to/from construction sites must run on electricity, hydrogen, or biofuels (preferably biogas).

To help achieve this goal, the municipality has set a target that all its own construction projects will be emission-free by 2025. To ensure this is feasible and that all relevant parties can best plan such projects, the municipality seeks more knowledge about zero-emission construction sites, particularly regarding actual power and energy consumption and the use of electric machinery.

One of the main objectives of this assignment is for the project to establish a standard contract requirement for the automatic data collection of power and energy consumption, which can be used in connection with upcoming construction projects.

In addition, data from several projects will be collected and analyzed to answer the following questions:

- What are the actual power and energy needs of construction sites?
- To what extent is power demand a limiting factor for the operation of zero-emission construction sites?
- Assess the relationship between power and energy consumption and operation.
- What are the causes of power peaks at construction sites? How and to what extent can these be avoided (through planning, adapted routines, technical equipment, etc.)?
- What prior knowledge is required from contractors and clients to optimize planning regarding energy and power needs for zero-emission construction? What should be the standard knowledge for contractors and clients about power and energy planning?
- Assess, together with the grid company (Elvia), which results from the work can assist them in processing or planning grid expansion.

It should be noted that although the actual power and energy needs are determined based on the specific projects examined, this will not be definitive for other projects. The City of Oslo has aimed to base its findings on the most representative projects possible, but in practice, there may be relatively large variations from project to project.

The projects included in this report were selected in consultation with Sweco, the Climate Agency, and Oslobygg. Several different projects, both within Oslobygg and other entities in Oslo municipality, were considered, such as the Fornebubanen and the Water and Sewerage Agency. The focus was on a small selection of projects with high levels of electric use, sufficient data availability, and representativeness, making the findings transferable to other projects. As shown in Chapter 2, data from an additional three projects were collected but not included in the delivery due to limited data availability.

Summary of Existing Knowledge Base

Part of this assignment involves summarizing the existing knowledge base. This includes, in addition to Sweco's own experiences and dialogue with the industry, the following literature:

- **SINTEF. 2021. Experience Mapping of Requirements for Zero-Emission Construction Sites.** This report examines opportunities, challenges, barriers, and solutions related to power supply, zero-emission construction machinery and trucks, and charging logistics. In this report, it will be referred to as S21.
- **SINTEF. 2022. Zero-Emission Construction Process in Oslo – Impact Assessment.** The report is based on energy usage data from some of the very first zero-emission construction sites in Oslo and examines additional costs, value creation, employment, market outlook, changes in energy and power usage, and other consequences of transitioning to zero-emission construction sites. In this report, it will be referred to as S22.
- **Hafslund Consulting. 2022. Accelerated Electrification of Heavy Transport and the Construction Sector in Oslo Towards 2030.** This report estimates future activity related to construction in Oslo, the associated electricity needs with a gradual shift to zero-emission activity, and the sector's need for charging infrastructure (including heavy transport) in Oslo towards 2030, along with an assessment of the impact of power demand. In this report, it will be referred to as HR22-30.
- **Climate Agency. 2022. Accelerated Electrification of Heavy Transport and Construction.** This report assesses opportunities and barriers for electrification of heavy transport and the construction sector. In this report, it will be referred to as KE22.
- **SINTEF. 2022. Zero-Emission Construction Sites, Roadmap.** This report was commissioned by Rental.one, a rental provider of construction machinery, and assesses the extent to which they need to adapt to zero-emission construction sites. This was done through experience mapping, calculations, interviews, and workshops. In this report, it will be referred to as S22-vei.
- **SN/TS 3770:2023. Zero-Emission Construction Sites and Areas.** This is a technical standard from Standard Norway, published in September 2023. The document aims to provide a common factual basis for the industry to best plan and operationalize zero-emission construction sites in the most rational way. In this report, it will be referred to as TS3770.

Prerequisites for Contractors and Clients

S22 highlights an increased need for collaboration and dialogue in the early phase between the client, suppliers, and the grid company, as does TS3770. The main reason for this need is that clients who demand zero-emission construction sites do not know which machines will be used and the extent of power and energy consumption. The main challenge is related to the sizing of the electrical power demand, as building large temporary capacity would be inefficient. Therefore, the design power requirement should be minimized as much as possible through early-phase collaboration and clear requirements from the client.

Causes of Power Peaks and How to Avoid Them

Based on its calculations, S22 has shown that power peaks can be significantly reduced by adjusting the timing of charging breaks and selecting appropriate technologies (battery, cable, or cable-battery). S21 and several other reports and experiences support this finding.

Power and Energy Needs

S22, through its survey, has found that groundwork is the most energy-intensive construction phase, followed by structural work and demolition. From their industry interviews, they found that the need for available power varies between around 50-150 kW and sometimes up to 250 kW. For construction sites, they report that the current typical power need is around 400-500 kW, but future needs of up to 1000 kW are estimated when everything is electrified.

Machinery in the Market

S22 has identified that smaller construction machines under 8 tons are mass-produced by several major manufacturers, while larger machines over 8 tons are primarily custom-produced in smaller volumes. It usually takes 2-3 years from the introduction of a machine until it becomes commercially available. Electric versions are available for most types of machinery. Excavators stand out the most, as there are many model options in various sizes.

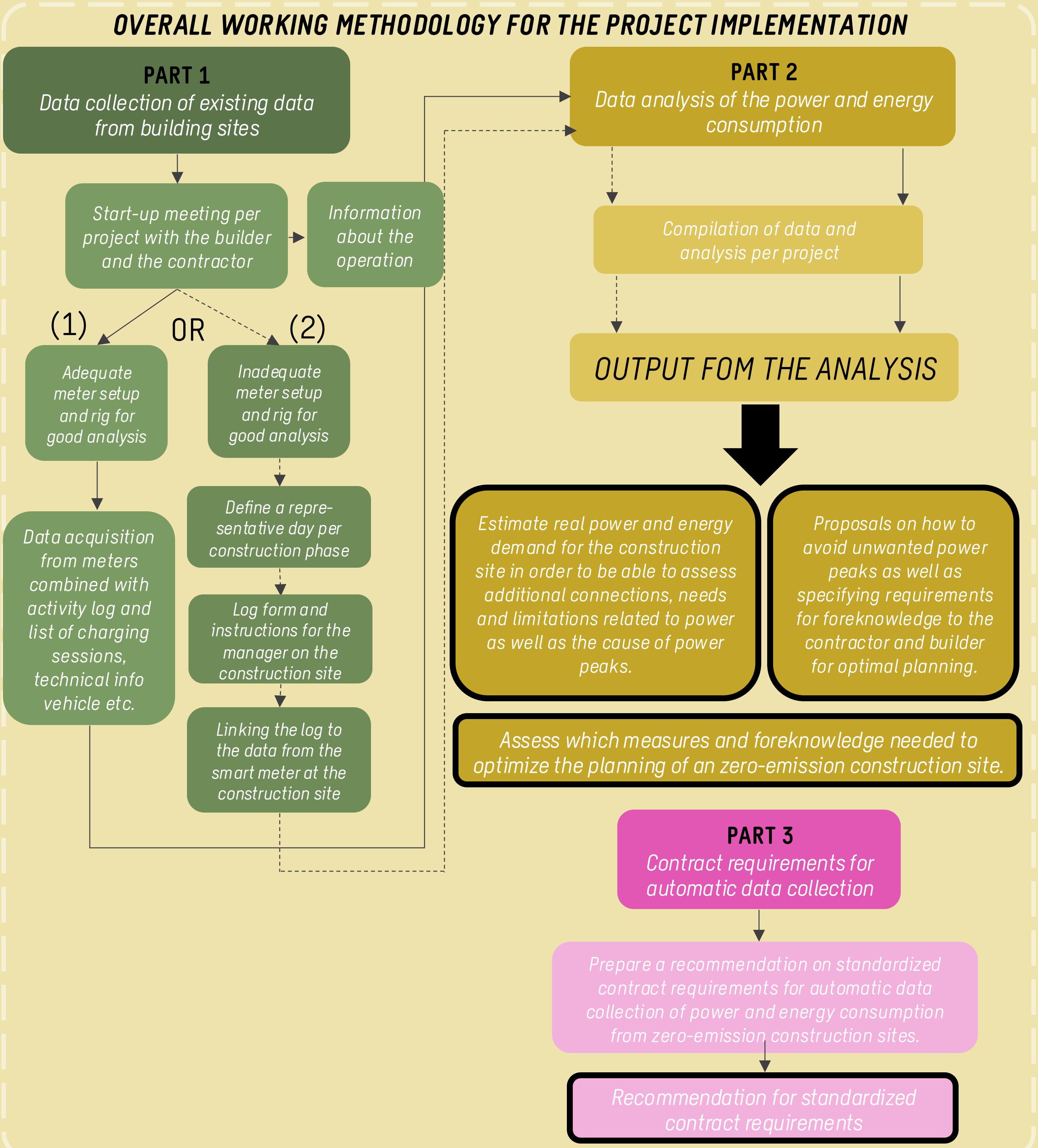
Experiences with the Use of Electric Machines

S22 states that it has been found unproblematic to use smaller electric machines and equipment, but there can still be some challenges with power supply and charging logistics when multiple large construction machines are used simultaneously.

Additional Costs

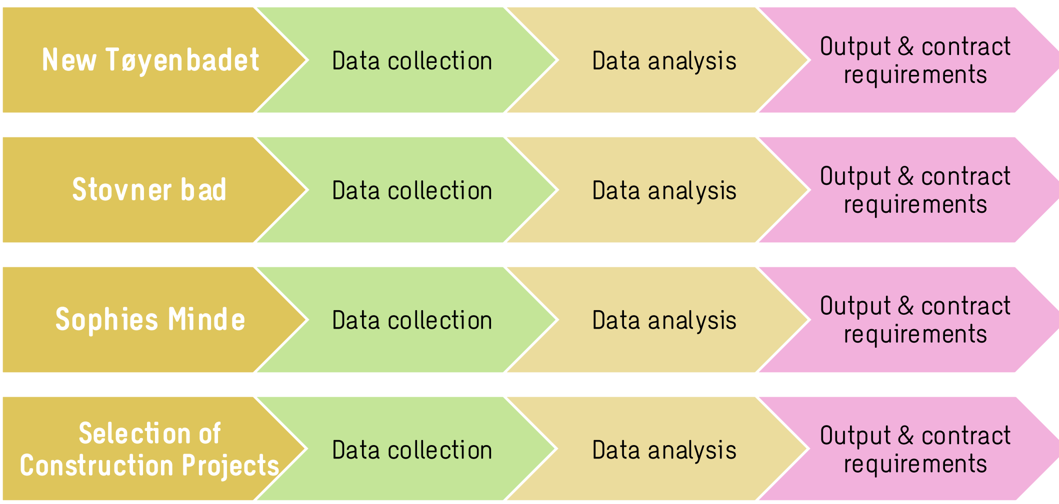
In its report, S22 developed lifetime cost estimates for a small (8-16 tons), medium (16-23 tons), and large (>23 tons) excavator, and for a dump truck with and without a trailer. Construction machines under 8 tons were not included in the analysis. The cost comparison covered diesel, HVO, and an electric alternative, showing that depending on energy prices, the lower operating costs of the electric option can offset the higher investment costs over an analysis period of 5-6 years. Overall, the report suggests that there will likely be additional costs in transitioning to zero-emission construction sites for some time, but by 2030, these costs could break even or even be lower.

Work Methodology



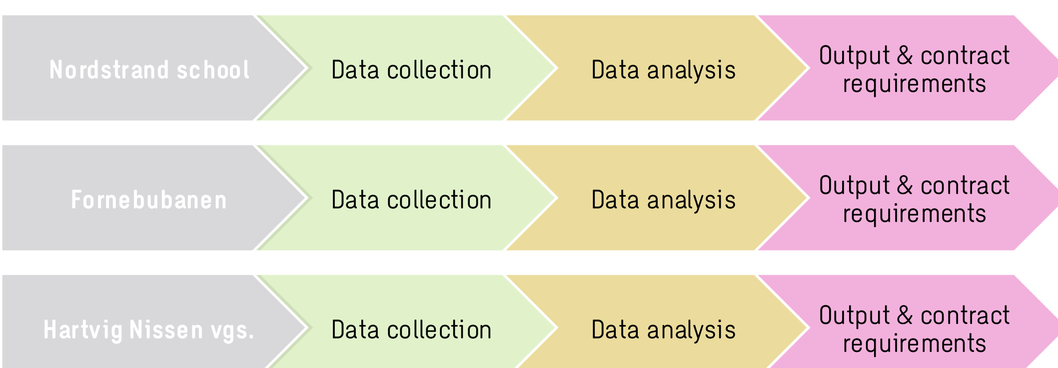
2 Scope of the Delivery

Projects Included in the Final Delivery



Projects Excluded from the Final Delivery

Nordstrand School, Fornebubanen, and Hartvig Nissen High School are among the construction projects excluded from the final delivery. After initial data collection and analysis of materials from these projects, it was determined, in collaboration with the client, that the projects did not have sufficiently relevant information or adequate data access and time resolution for further analysis. Based on this, it was decided to prioritize the main projects in the final report.



Picture: Asplan Viak

3 New Tøyenbadet


Picture: Asplan Viak

New Tøyenbadet | Information

New construction

Potential Demolition – Ground Work – Structural Work – Facade – Interior Work – Exterior Work

The new Tøyenbadet is a new construction project in Oslo municipality that will become the city's largest bathing facility, covering 2,700 m². The building has approximately 15,800 m² of gross floor area. The facility is being built on the same site as the old facility and will consist of both an indoor complex, an outdoor area, and a fully equipped multi-purpose hall. The bathing facility is being constructed as an energy-efficient passive house for sports facilities, and the energy concept includes heat pumps, energy wells, solar energy, and district heating. The facility will have a ground heating system with energy wells as the primary energy source, supplemented by solar energy and district heating as secondary sources.

The construction project is scheduled for completion by June 2024, with some remaining outdoor works expected to be finished by August 2024. The main contractor for the project is AF Gruppen, Asplan Viak is handling the design, and Sweco is responsible for project design and construction management.

The construction site is fossil-free with a significant proportion of zero-emission construction machinery. The site is supplied with an available power capacity of 800 kVA, and the project also uses district heating as part of its energy solution. In addition, two charging containers from Eldrift have been implemented. The new construction project is nearing completion and is currently focused on outdoor works.

The project is well-equipped with measuring equipment. Five meters are installed on the site, including a smart energy meter and an individual meter per circuit (site cabins, tower crane 1, tower crane 2, and machine charger). Measurements began on November 16, 2022, enabling a comprehensive analysis of the project's energy consumption and efficiency.

Sweco has received the following relevant data and information from the project:

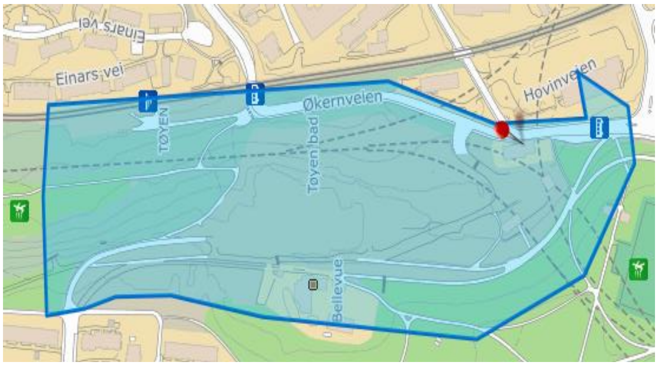
- Monthly machine overview including accumulated consumption

- Smart meter data with hourly resolution [kWh/h]

- Circuit measurements for 4 circuits (tower crane 1, tower crane 2, machine charger, and site cabins with 10-minute resolution) from November 2022. Project start with groundwork was in December 2020.

- District heating consumption from October 2022 – March 2024.

- Grid capacity: 800 kVA transformer in the substation, around 640 kW.



Building boundary for Tøyenbadet

ANALYSIS PERIOD: 09.2021-03.2024

Key figures for the logged part of the construction period:

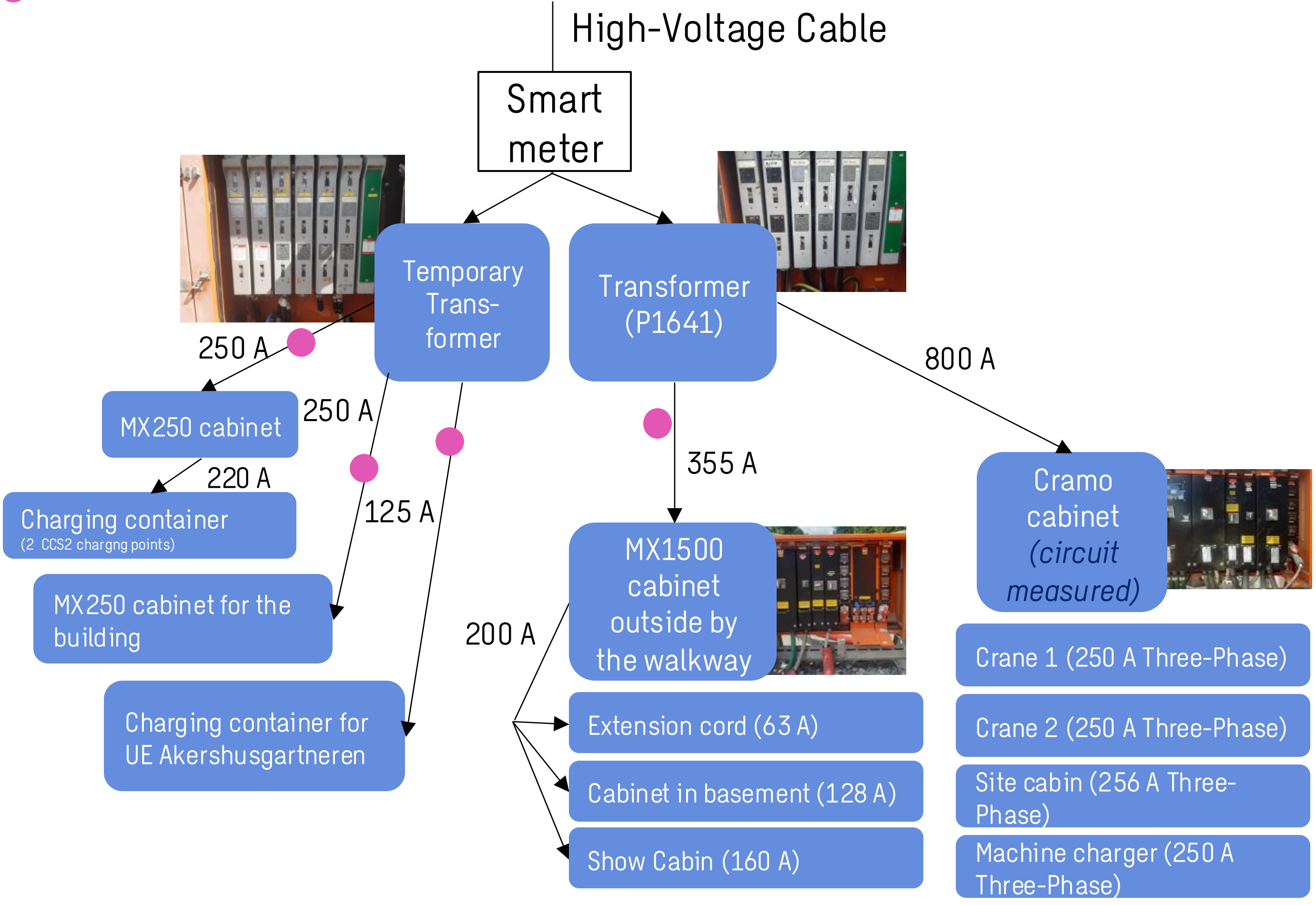
- Maximum Hourly Power: 510 kW (Wednesday at 11:00, week 3 of 2024)
- Average Hourly Power: 106 kW
- Average Monthly Consumption: 71,325 kWh
- Average Daily Consumption: 2,386 kWh
- Total Energy Consumption: 6,152,056 kWh
- Zero-Emission Energy Use During Construction Phase: 87%
- Zero-Emission Machinery Operation on Construction Site: 44%

New Tøyenbadet | Information

Power Rig

COLOUR CODE EXPLANATION

● Circuits without Circuit Measurement



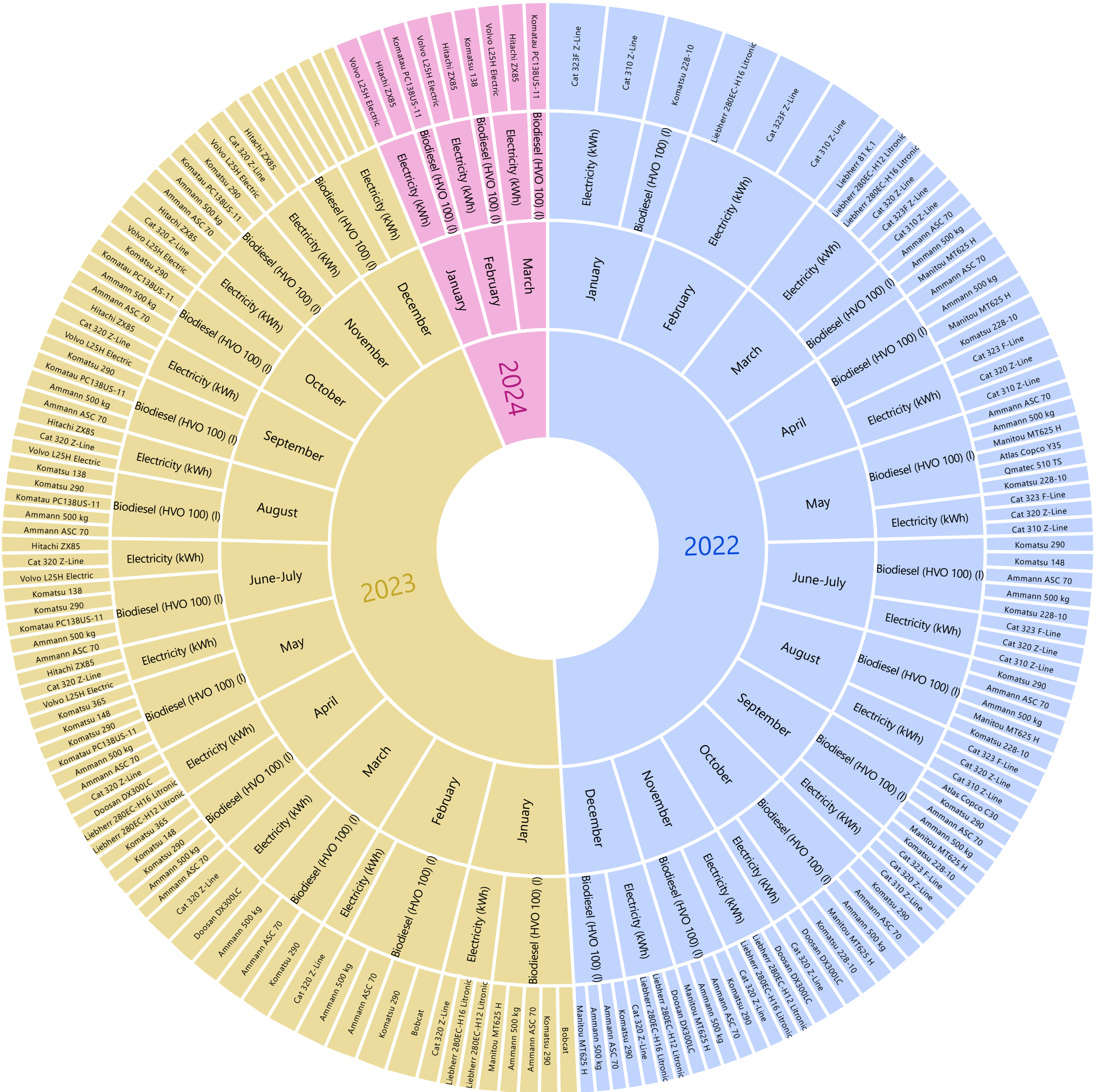
The power at the construction site is distributed to various consumption points using two transformers. One is the network station P1641, set up and operated by Elvia, while Omexon has set up and operates an additional temporary transformer. The total reported capacity of the transformers is around 800 kW. The system operates at 400 V. The temporary transformer has three circuits supplying (1) a charging container from Eldrift via an MX250 cabinet, (2) an MX250 cabinet supplying the building, and (3) a charging container from Eldrift used by subcontractors Akershusgartneren for AF.

The other transformer (P1641) has three parallel circuits with a total capacity of 800 A, which are delivered to Cramo cabinets. These are further distributed to crane 1, crane 2, site cabins, and the machine charger. All these circuits are measured. The transformer also supplies 355 A to an MX1500 cabinet outside by the walkway, which further supplies (stepped down to 200 A) another cabinet in the basement and a circuit to the show cabin. An extension cord has also been taken from the switchboard to supply various consumption points on the construction site. Previously, 2 units of 63 A single-phase industrial sockets were used for mobile cranes, and a 32 A single-phase socket was used for the saw container.

New Tøyenbadet | Information

Machine Fleet

Machines used on the construction site



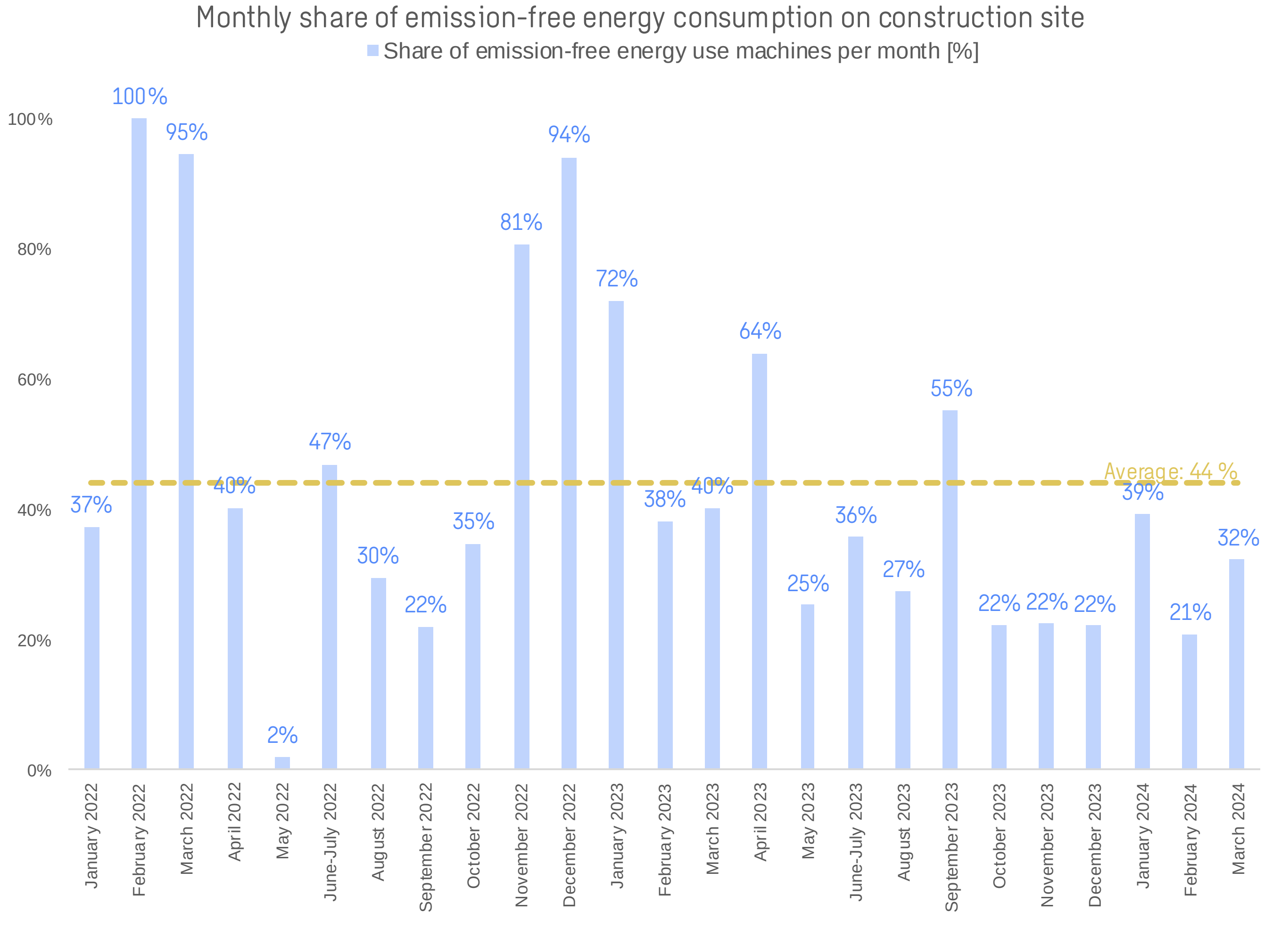
For the period from January 2022 to March 2024, the project has reported consumption for electric and biodiesel-powered construction machinery on the site. The diagram above provides an overview of active construction machines for the project, categorized by fuel technologies: biodiesel (HVO 100) (liters) and electric (kWh), and is organized by month and year. This visual representation shows which machines were most used during different periods. It is important to note that the diagram is not weighted by the fuel consumption of each machine.

New Tøyenbadet | Information

Degree of Zero-Emission Construction Site

Over the years, there has been increasing awareness of the need for more sustainable and environmentally friendly solutions in the construction sector. This has resulted in a gradual shift from traditional fossil fuels to more eco-friendly alternatives. The facility at the new Tøyenbadet is fossil-free, with a significant proportion of zero-emission construction machinery. This means that all construction machinery is either electric or runs on biofuel.

The diagram below provides an overview of the degree of zero-emission operation at the Tøyenbadet construction site for the period from January 2022 to March 2024. The measurement is based on the percentage of consumption from electric-powered units used on the site. The diagram shows that the average for this period is 44%, meaning that just under half of the total operating time was conducted without emitting greenhouse gases.



New Tøyenbadet | Information

Information about Electrical Machines

In the construction of Tøyenbadet, the following types of construction machinery are zero-emission:

- Cranes
- Excavators
- Lifts
- Vibroplates

These machines are powered either as battery-electric or wired units, with the battery-electric ones equipped with built-in battery systems. The batteries supply power to the machine's electric motors, which drive the movement of the machinery. The batteries can be charged by connecting them to an external power source, such as a machine charger or a power outlet. The advantage of battery-electric machines is that they offer mobility and flexibility without relying on a continuous power source. They can be used in different locations and are especially useful in areas where access to electricity may be limited.

The second type, wired construction machines, are connected directly to an external power source via a cable. The cable supplies power to the machine's electrical system, and the machine uses this power to drive motors and perform tasks. The advantage of wired machines is that they do not have to worry about battery life or charging. As long as they are connected to the power source, they can operate continuously. However, they are limited by the length of the cable and may be less flexible in terms of moving around the construction site.

Among the electric machines used on the project, the following electric machines have the highest monthly consumption:

- Tower Cranes
  - Liebherr 280 EC-H12 litronic
  - Liebherr 280 EC-H16 litronic
- Excavators
  - CAT 320 Z-line,
  - CAT 323F Z-line
  - CAT 310 Z-line
  - Doosan DX300LC.

DOOSAN DX300LC (Excavator (EL))
Battery – 390 kWh – max. 145 kW

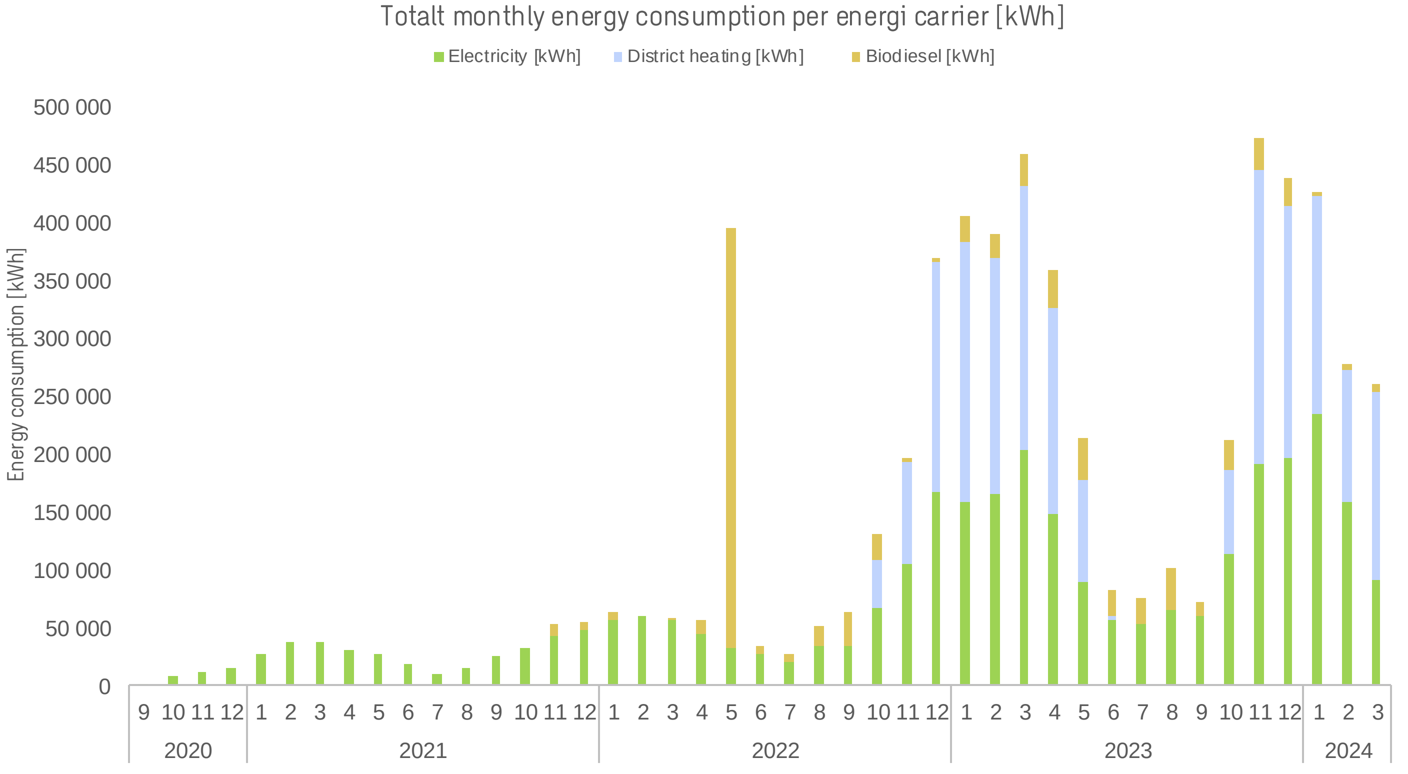
LIEBHERR 280 EC-H12/EC-H16 LITRONIC (Tower crane)

CAT 320 Z-LINE (Excavator (EL))
Battery – 300 kWh – max. 120 kW

3.1 Energy Consumption

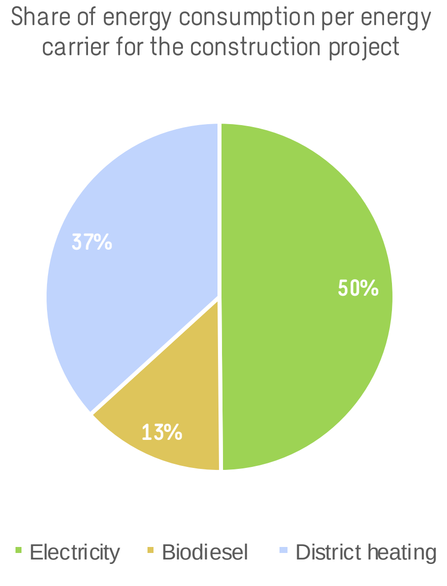
New Tøyenbadet | Energy Consumption

Total Consumption per Energy Carrier



The total energy consumption for the construction project (converted to kWh) up to and including March 2024 has been **6,152,056 kWh**. Electricity has been the most used energy carrier for Tøyenbadet (50%), followed by district heating (37%) and biodiesel (13%). District heating was established in October 2022 and started supplying in connection with structural and interior work. As a result, the project has utilized an **87% zero-emission construction site** in the development of Tøyenbadet.

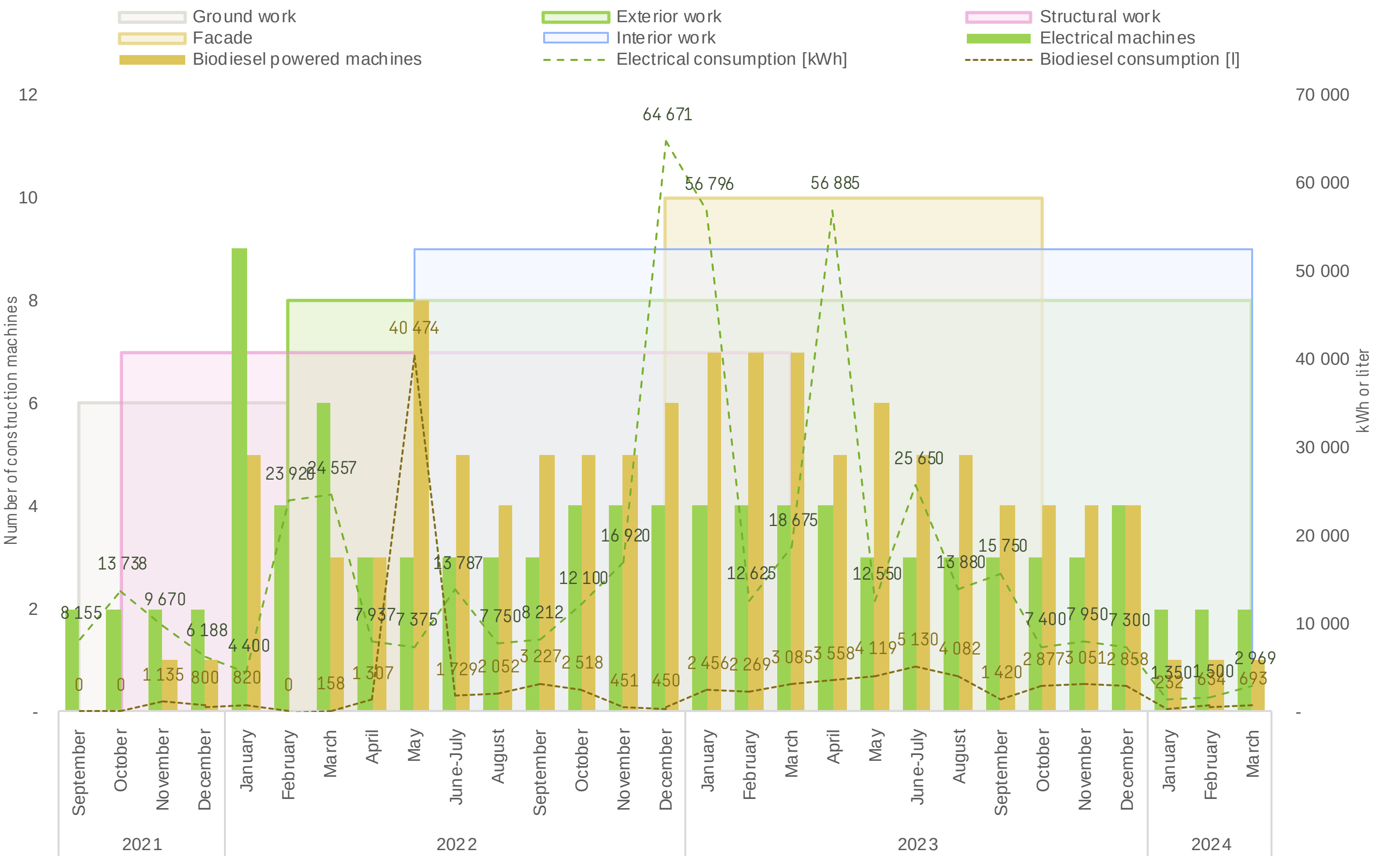
The use of biodiesel is worth noting, with a reported consumption of around 40,500 liters for May 2022. This high consumption is due to the reported use of 2 Atlas Copco Y35 air compressors. These were used for drilling energy wells, accounting for the very high consumption. According to the progress plan, drilling started in April 2022, and most of it was completed by June of the same year. The air compressors are reported to consume about 2.2 liters per meter drilled. With 52 energy wells at 300 meters each, this aligns well with the reported figures, except that the consumption should have been distributed at a minimum across April, May, and partially June.



New Tøyenbadet | Energy Consumption

Monthly Consumption of the Machine Fleet per Energy Carrier

Number of construction machines on the construction site, divided by energy carrier

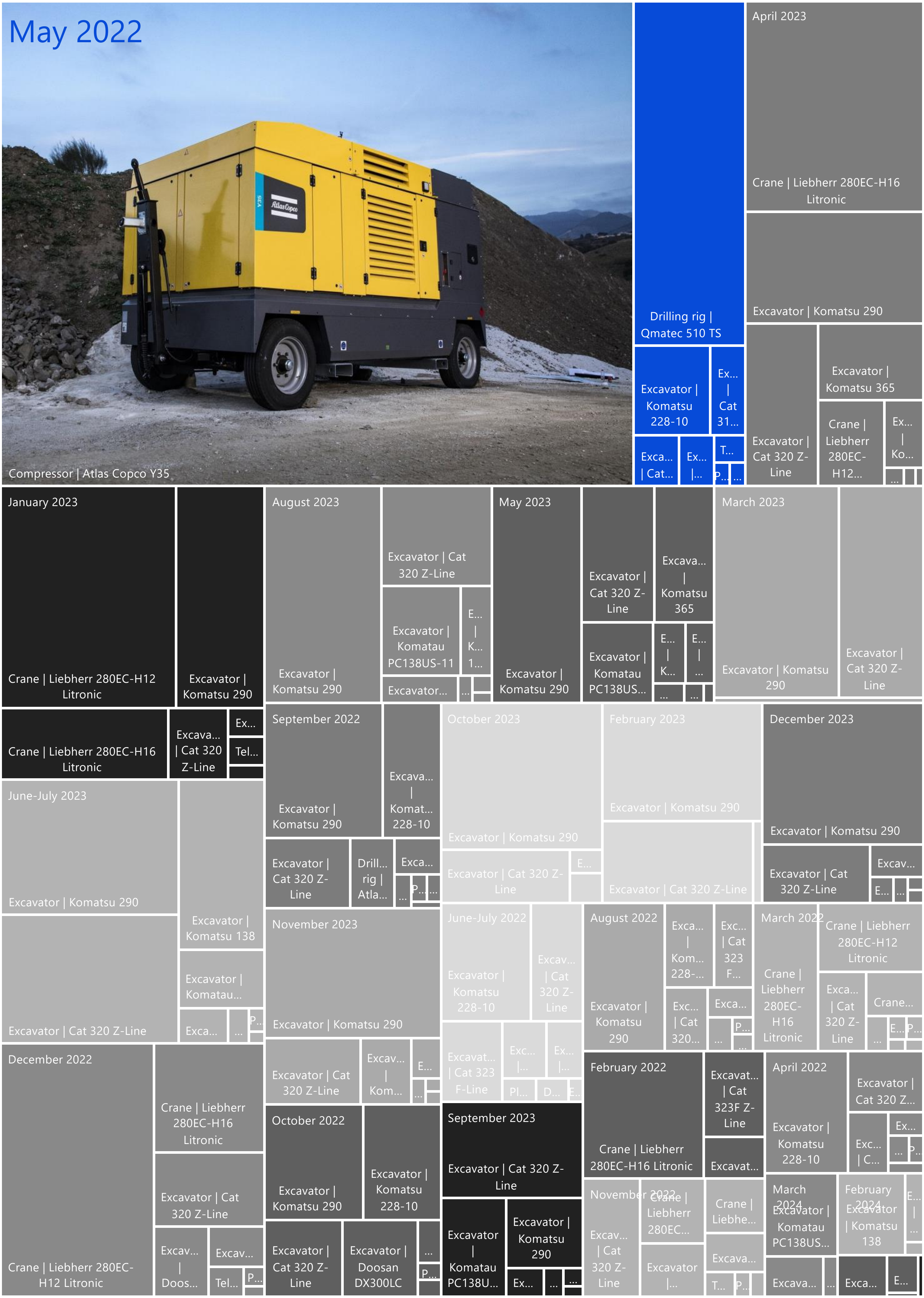


The diagram above shows the monthly composition of electric and biodiesel-powered construction machinery on the site for the various construction phases, with corresponding electric consumption in kWh and biodiesel (HVO 100) in liters. The consumption can also be viewed in relation to the project's construction phases, indicated by boxes representing the duration of each phase.

The electric construction machines with reported consumption have used 191,630 kWh (2022), 235,461 kWh (2023), and 5,819 kWh so far in 2024 (up to and including March). Similarly, machines running on HVO used 53,408 liters (480,330 kWh) in 2022, 34,905 liters (313,922 kWh) in 2023, and 1,558 liters (14,012 kWh) so far in 2024. Electric machines have collectively used an average of **544 kWh** per day for the entire construction project, while machines running on biodiesel have used an average of **113 liters** per day (**1,012 kWh**), with the highest consumption occurring in May 2022 due to the use of air compressors (Atlas Copco Y35) for drilling energy wells. Excluding this, the average daily gross consumption is **63 liters of HVO** (**567 kWh**).

On the next page, the monthly energy consumption for the construction machines is presented. May 2022 accounts for the month with the highest consumption during the project period and is highlighted in blue. The Atlas Copco Y35 is the machine depicted and is responsible for the majority of the high consumption.

Monthly Consumption per Machine Type



New Tøyenbadet | Energy Consumption

Circuit Meters: Energy-Specific Consumption Points

At Tøyenbadet, power measurement has been set up for individual circuits with specific consumption points. Apart from the power consumption from the circuit named “machine charger“, which varies depending on factors such as the type of machine being charged, it is interesting to examine the power consumption and usage for the other measured circuits. These include crane 1, crane 2, and site cabins. The reported consumption is from November 16, 2022, when the circuit meters were installed, up to and including March 31, 2024.

The site cabins consist of 61 units and are supplied by a 256 A three-phase circuit, allowing for a maximum consumption of 177 kW. Crane 1 is a Liebherr 280EC-H16 Litronic with an installed capacity of 110 kW, connected to a 250 A three-phase circuit, which allows for a maximum consumption of 173 kW. Crane 2 is from the same manufacturer and is the 280EC-H12 model.

Energy Consumption from Various Consumption Points:

Site Cabins

- Average Monthly Consumption: 32,076 kWh
- Maximum Monthly Consumption: 61,214 kWh
- Average Daily Consumption: 1,091 kWh

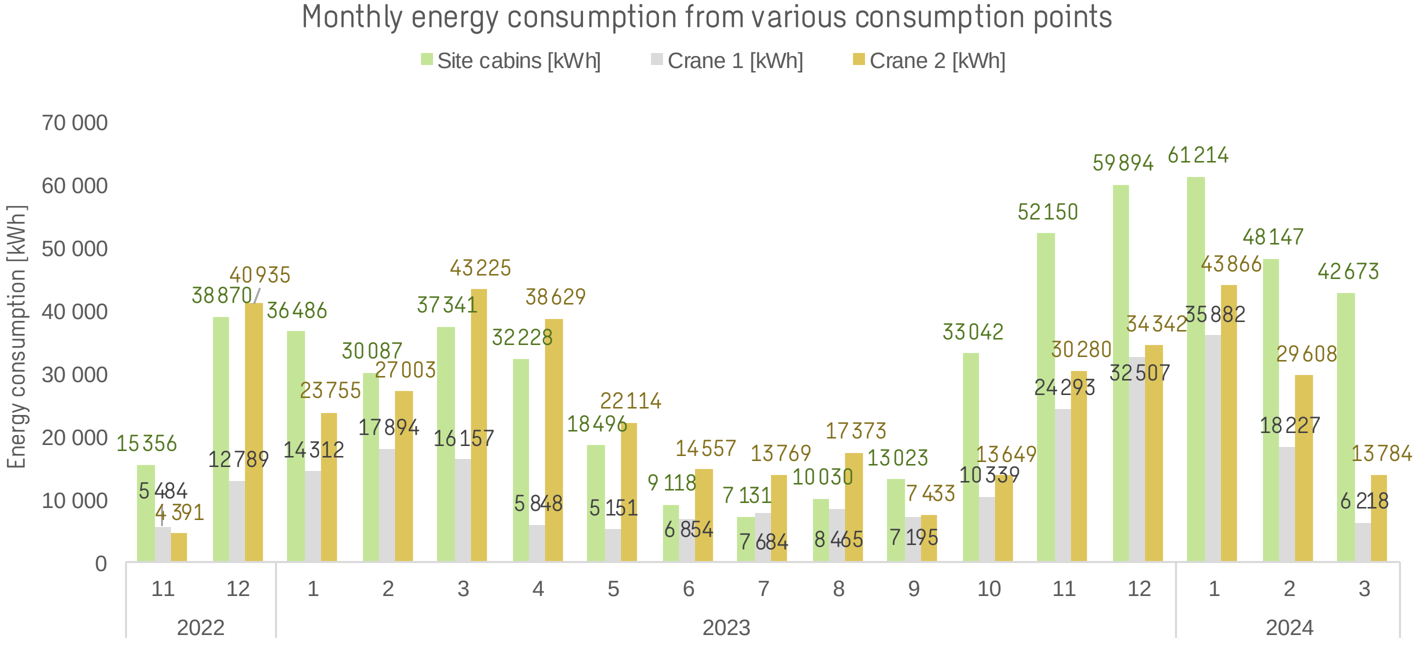
Crane 1

- Average Monthly Consumption: 13,841 kWh
- Maximum Monthly Consumption: 35,882 kWh
- Average Daily Consumption: 468 kWh

Crane 2

- Average Monthly Consumption: 24,630 kWh
- Maximum Monthly Consumption: 43,866 kWh
- Average Daily Consumption: 820 kWh

The highest monthly consumption for all circuits was observed in January 2024.



New Tøyenbadet | Energy Consumption

Circuit Meter: Machine Charger

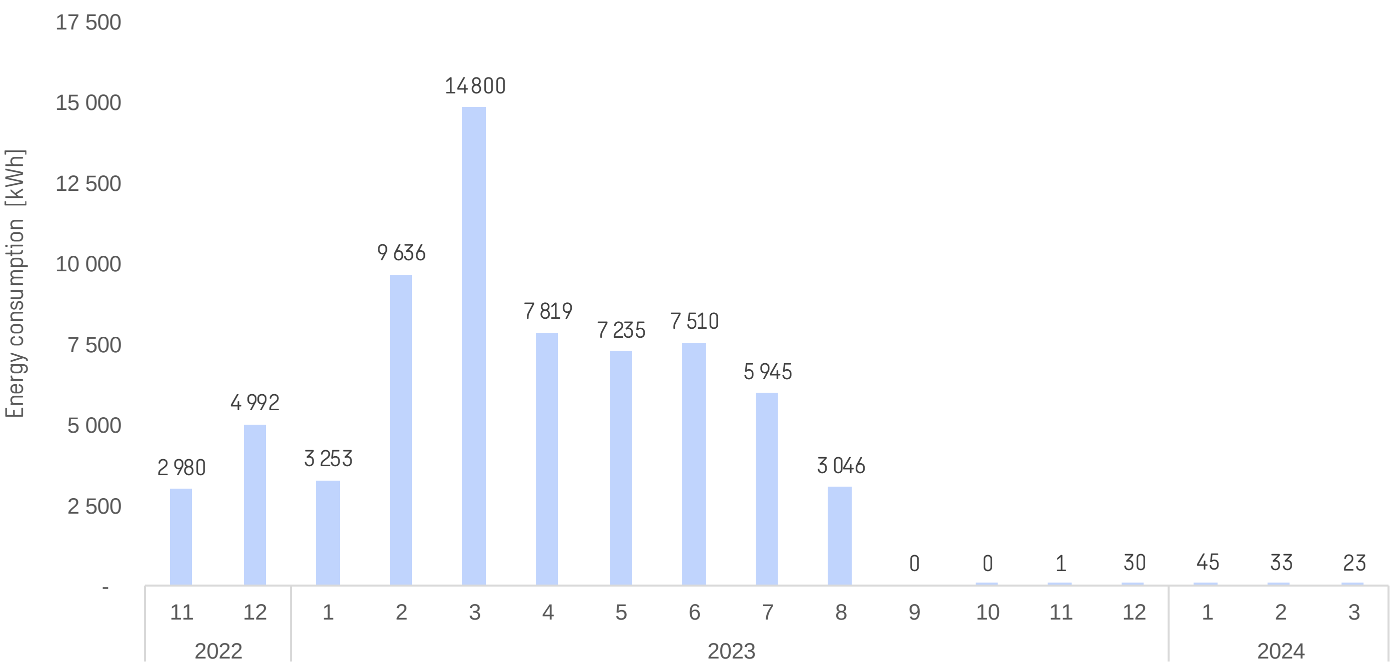
Energy measurement is also conducted for the circuit named “machine charger“. This circuit is equipped with a 250 A fuse and operates at 400 V. It has been reported from the construction site that the loader is connected to the excavator using an industrial plug, which delivers alternating current to the excavator.

Machine Charger

- Average Monthly Consumption: 6,721 kWh*
- Maximum Monthly Consumption: 14,800 kWh
- Average Daily Consumption: 234 kWh*

Cramo Cabinet with Circuit for Machine Charger Marked in Purple

Monthly energy consumption from various consumption points | Machine Charger



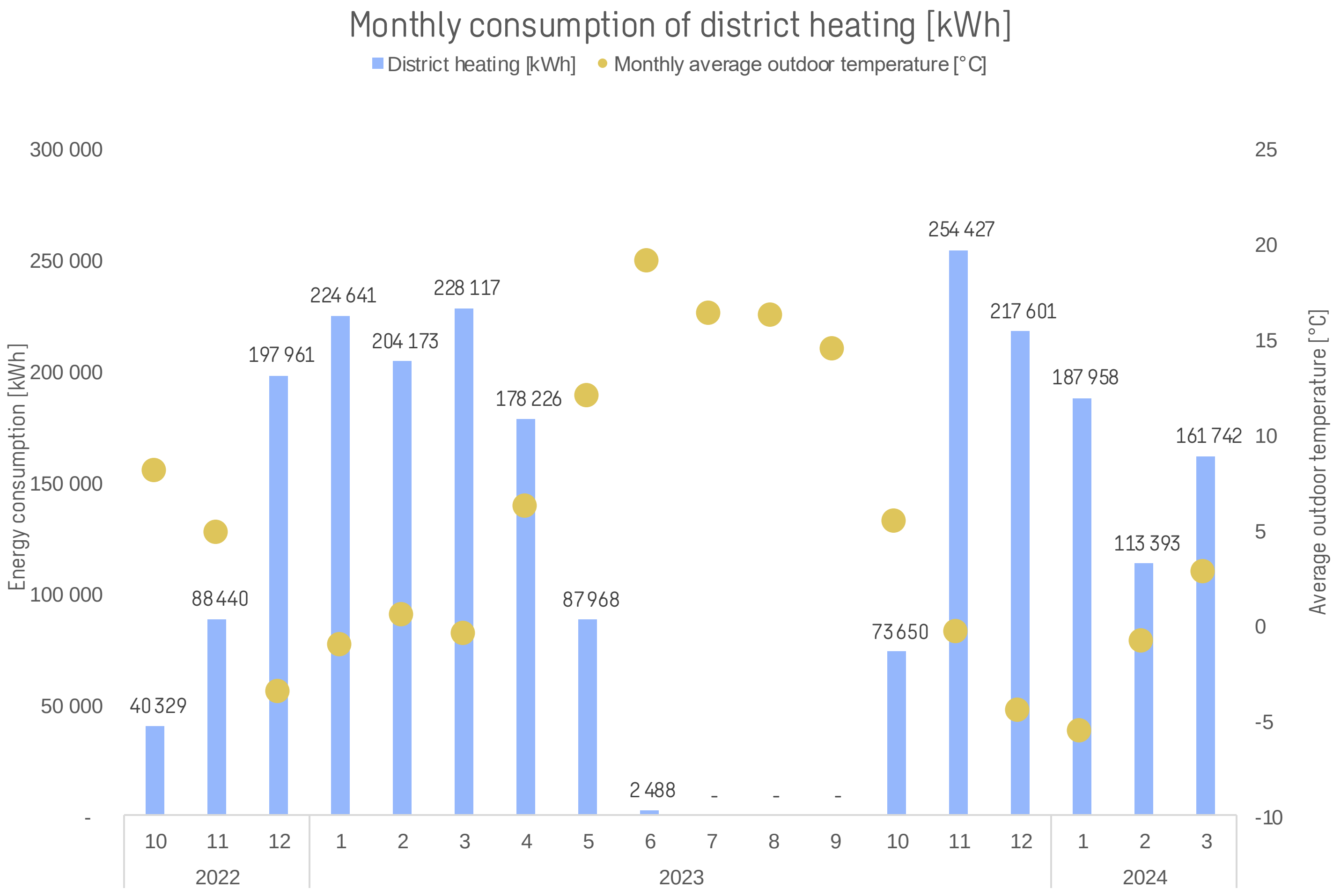
** Average figures only take into account periods of significant consumption, here from November 2022 – August 2023*

New Tøyenbadet | Energy Consumption

District Heating

District heating was installed and began supplying thermal energy for building drying and heating from October 1, 2022. The graph below shows monthly consumption up to and including March 2024, with the following key values:

District Heating
- Average Monthly Consumption: 150,741 kWh*
- Maximum Monthly Consumption: 254,427 kWh
- Average Daily Consumption: 4,964 kWh*

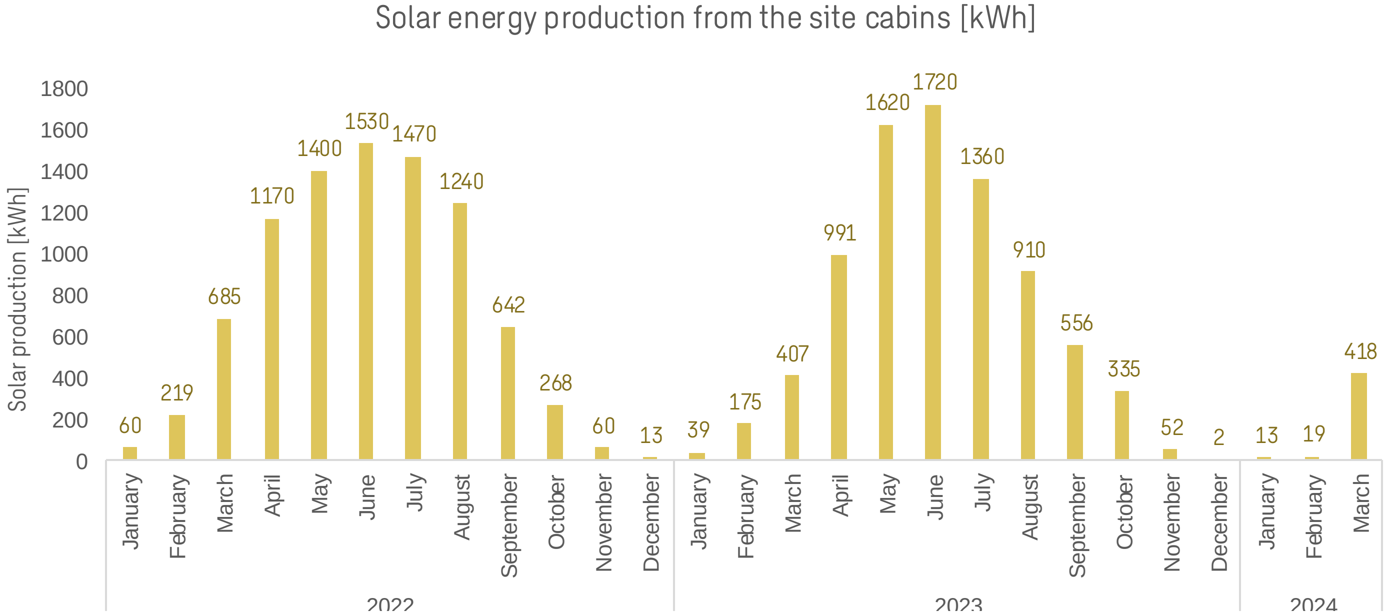


* *Average figures only account for periods with significant consumption, excluding July 2023 – September 2023.*

New Tøyenbadet | Energy Consumption

Energy Production from Solar Power

The facility consists of 10 panels mounted on individual frames covering one site cabin roof each. In total, there are 40 panels in the system. According to the supplier, under optimal solar conditions, the system can produce 11.2 kW. This reduces the need for external grid power to cover the electricity needs of the site setup, such as charging a battery on the construction site. If there is a surplus of electricity, it will be fed into the regular supply grid on the construction site. The system was installed in January 2022, and the following graph shows the monthly solar power production since then:



Compared to the monthly energy consumption at the construction site, the historical solar energy production is so minimal in magnitude that it does not contribute enough to be considered a viable measure for reducing the power demand of the construction site.

3.2 Power Consumption

New Tøyenbadet | Power Consumption

Introduction

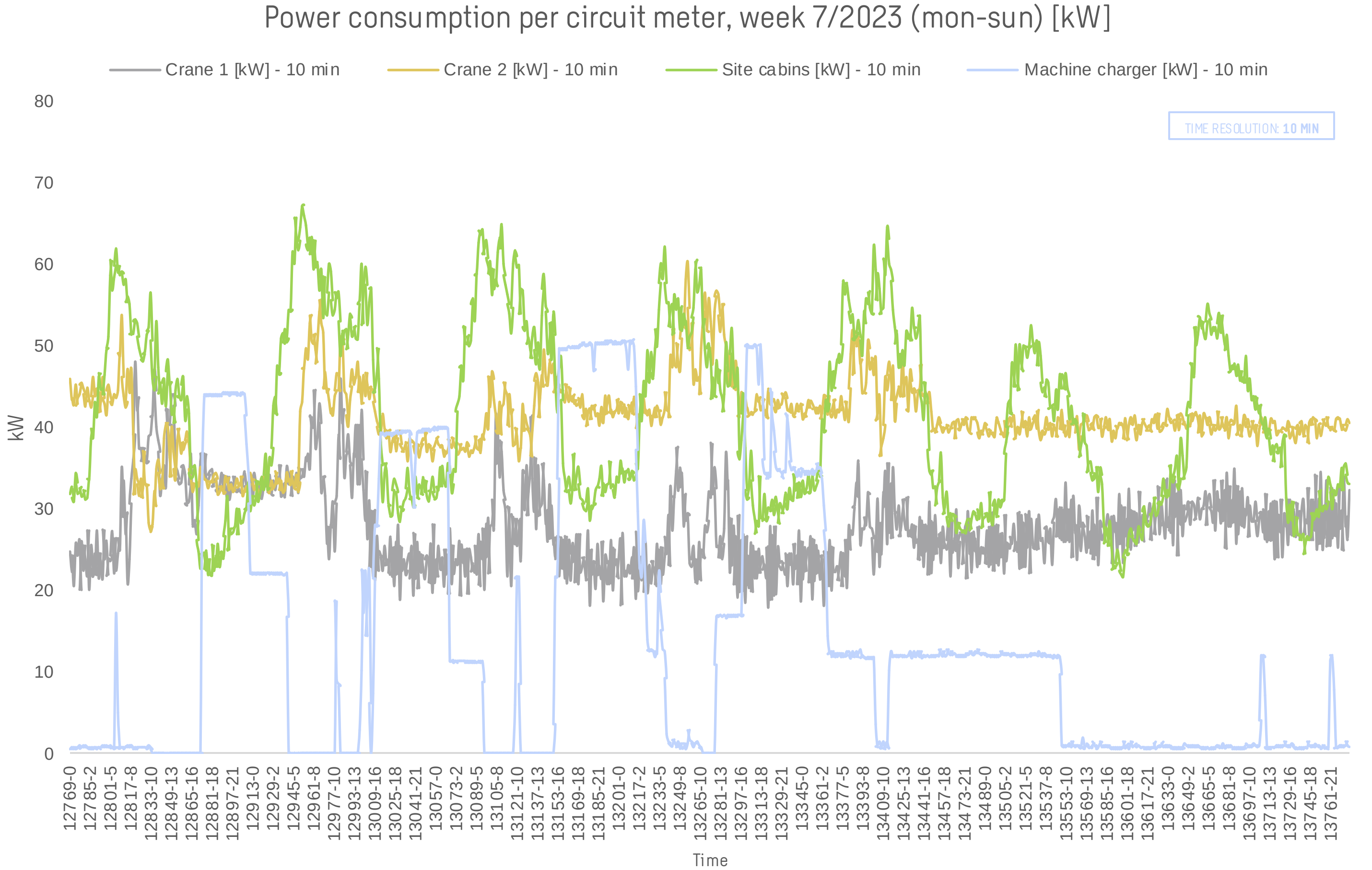
The Tøyenbadet construction project has had better conditions than other ongoing projects for monitoring power peaks on the construction site due to a more extensive setup with energy meters.

Typically, it is mainly the smart energy meter installed by the grid company for electricity billing and network charges that provides the basis for monitoring power consumption. This meter only provides information on average hourly power unless additional equipment is installed. This results in relatively low time resolution, making it difficult to identify significant power peaks that can occur over shorter time intervals.

At Tøyenbadet, in addition to the smart meter and the district heating meter, there are four circuit meters for electricity. These circuit meters are dedicated to measuring specific circuits: tower crane 1, tower crane 2, the site cabin setup, and a machine charger. This setup provides better conditions for identifying the causes of power consumption compared to other construction projects. The circuit meters log consumption every ten minutes, offering higher time resolution than the smart energy meter from the grid company.

Even though the metering setup is better, there are still some unmeasured power circuits.

The diagram below shows the measured consumption per circuit for a selected week in February 2023.



New Tøyenbadet | Power Consumption

Circuit Meters: Power for Specific Consumption Points

Here, the maximum and average power [kW] for the various circuit-measured consumption points are shown. Data is sourced from the circuit meters with a 10-minute time resolution. The meters started logging consumption from November 16, 2022, and the report analyzes consumption up to March 31, 2024.

Construction Site Cabins

- Average Power: 45 kW
- Maximum Power: 158 kW (06:10 Monday, week 1/2023)

The maximum recorded power of 158 kW occurred on Monday, week 1 of 2023. Considering there are 61 cabins, this implies a maximum of 2.6 kW per cabin, which is well within the typical range of 2-3 kW per cabin used for dimensioning. This peak is rare and has only occurred once during the construction period. Site cabins are typically electric in all construction projects.
The second highest measured power is 141 kW, which amounts to 2.3 kW per cabin. On average, the power is 0.74 kW per cabin.

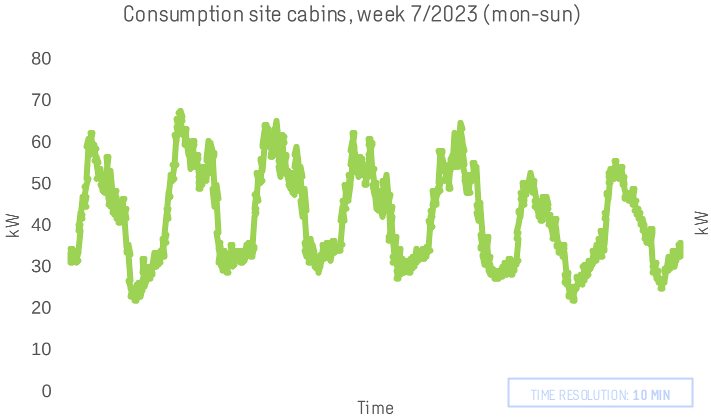
Crane 1

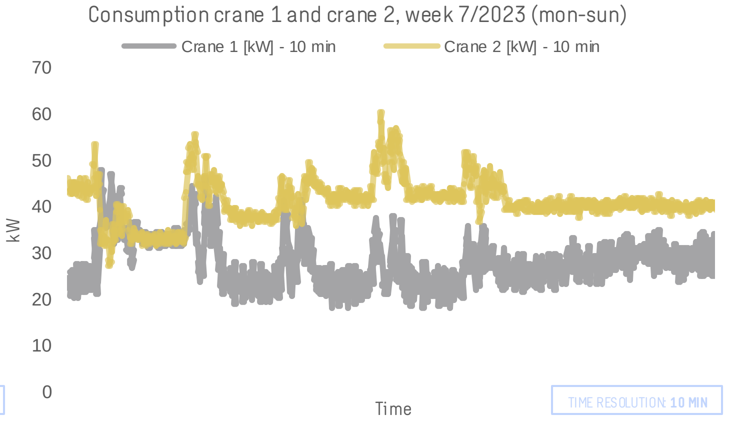
- Average Power: 20 kW
- Maximum Power: 127 kW (13:10 Thursday, week 4/2024)

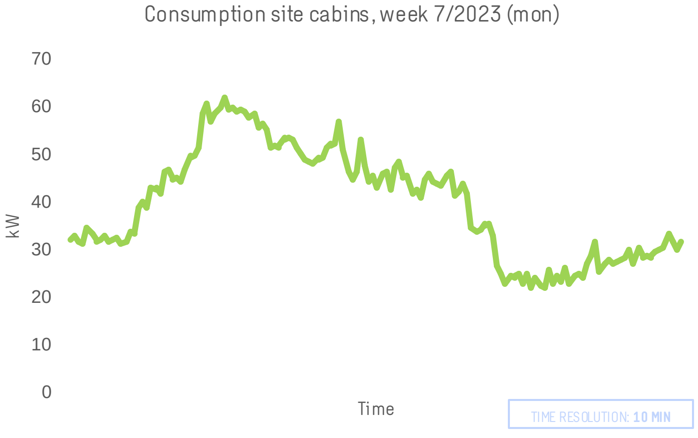
Crane 2

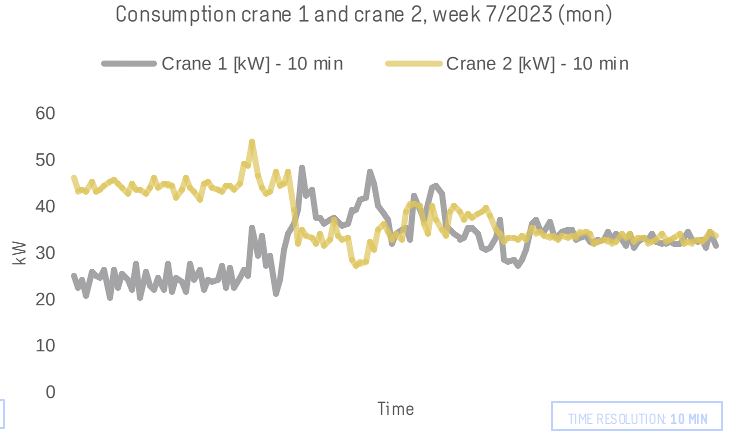
- Average Power: 35 kW
- Maximum Power: 109 kW (11:10 Tuesday, week 49/2023)

Below are diagrams for typical weeks and days for the site cabins. The crane operations have less distinct consumption patterns and vary significantly more.









New Tøyenbadet | Power Consumption

Circuit Meters: Power for Specific Consumption Points

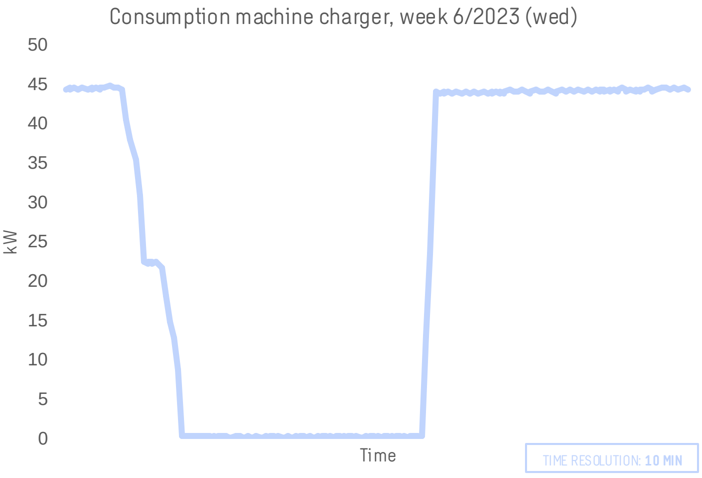
Here, the maximum and average power [kW] for the circuit to the gravel charger is shown. Data is sourced from a circuit meter with a 10-minute time resolution. The meters started logging consumption on 16.11.2022, and the report analyzes consumption up to 31.03.2024. The charger is an industrial socket secured by a 250 A circuit.

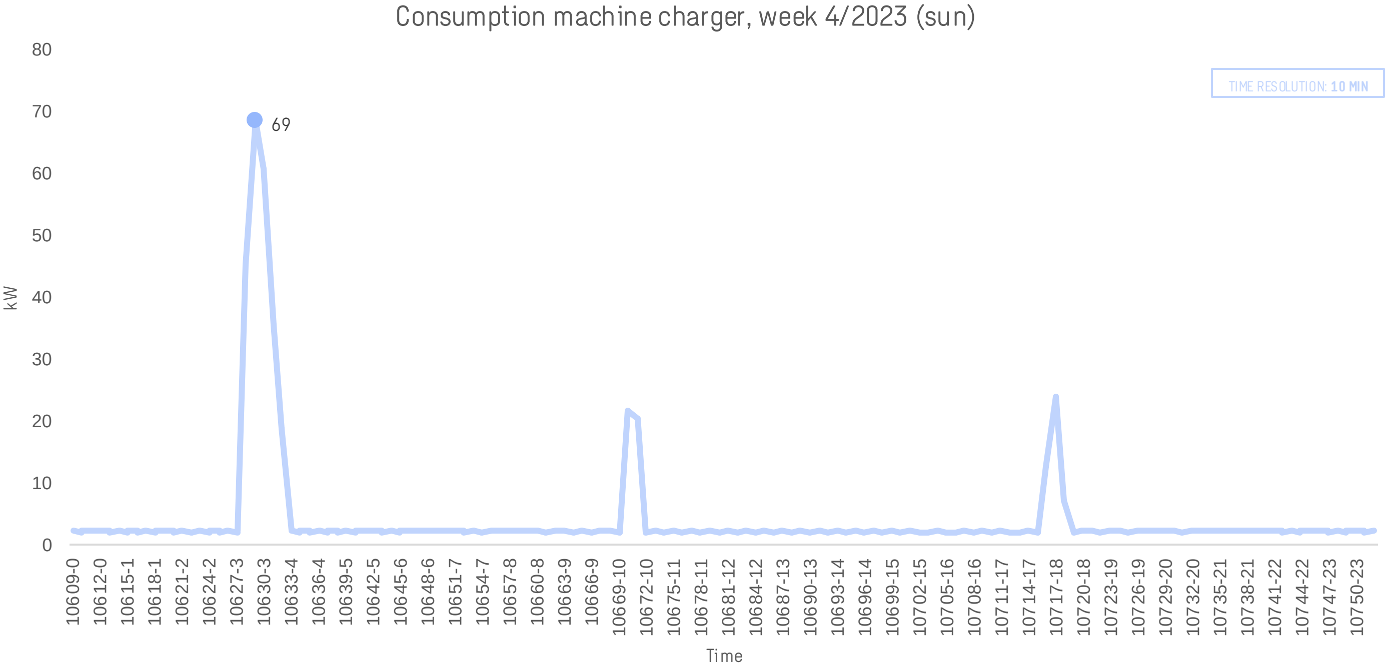
Aside from some lunchtime charging around 11-12, the charging on this circuit appears to have a suboptimal charging strategy. Measurements indicate occasional sudden power peaks that seem unnecessary, as shown in the diagram below.

One of the highest power peaks occurs suddenly at 03:20. It could have benefited from charging at a more consistent and lower power level in the hours prior, which were recorded without consumption.

Gravel Charger

- Average power: 10.1 kW*
- Maximum power: 90 kW (17:30 on Tuesday, week 21/2023)





** The average figures only consider periods with significant consumption. Data from the circuit-measured consumption for the gravel charger show periods where the measurements are uncertain or incomplete after week 33/2023. Therefore, the average will only apply up to this point..*

New Tøyenbadet | Power Consumption

Time Resolution - 10 minutes vs. 1 hour

The time resolution of the meter data is important for planning and sizing facilities in the best possible way.

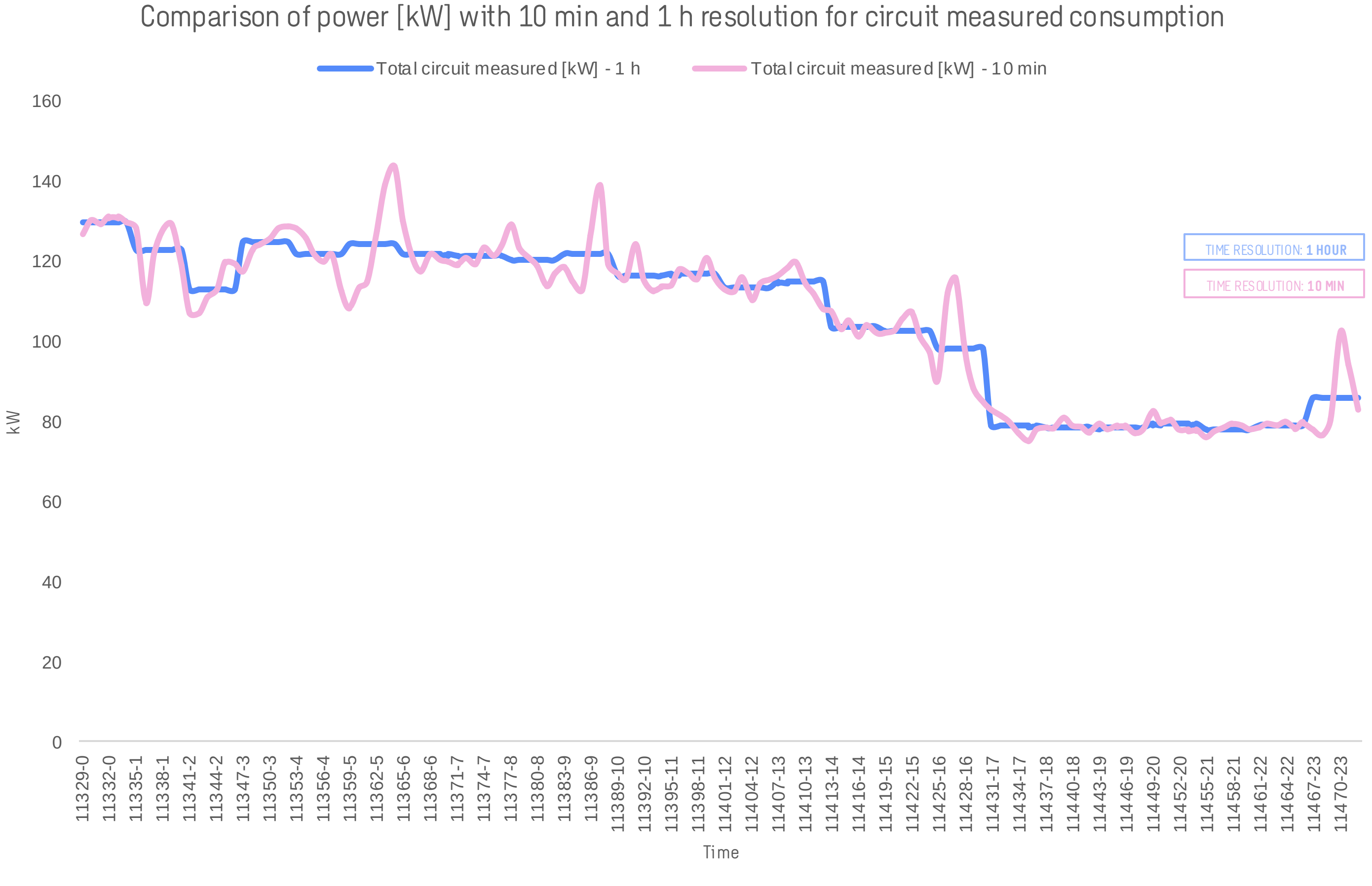
The circuit meters provided by Cramo log consumption every ten minutes. Compared to data from the smart energy meters, this provides a better overview of consumption and a better basis for understanding the electrical energy consumption at zero-emission construction sites.

In the diagram below, the effect of time resolution on recorded maximum power can be seen. While hourly measured consumption gives a more consistent (and lower) power (see blue graph), meters with higher time resolution reveal the peaks (see pink graph).

If the measurement had an even higher time resolution, it could show even higher, real power peaks. With minute- or second-level resolution, even higher real power peaks could be recorded, likely much closer to maximum capacity.

For example, at the most prominent time here (05:00), a measurement every ten minutes registers 144 kW, while the hourly measurement shows only a "peak" of 127 kW.

In other words, the measurement with a ten-minute logging interval shows a power peak that is sometimes about 15% higher than the hourly measurement.



New Tøyenbadet | Power Consumption

Trends Between Circuit-Measured Consumption and Smart Meter Measurements

To provide a visual representation of consumption trends, heatmaps showing maximum hourly values over the period from November 2022 to March 2024 are presented. A heatmap is a graphical representation used to display the intensity of a phenomenon, in this case, maximum power, at different times.

The first heatmap (left) illustrates the consumption measured by circuit measurement. By analyzing this mapping of consumption, we can identify patterns and trends in power consumption on individual circuits throughout the day and over longer periods. For example, we can see if there are specific times of the day or week when power demand is highest or lowest for the four circuits. This can provide valuable insights to optimize and reduce power consumption by identifying inefficient use of electricity and implementing power-saving measures.

The second heatmap (right) shows smart meter-measured consumption over the same time period. Smart meters provides us with the total electricity consumption on the construction site. By analyzing this heatmap, we can detect patterns in consumption across the entire system, not just specifically for circuit-measured activities. This can include information on times of high aggregate consumption, periods of steady electricity use, and any abnormal fluctuations or deviations that are not caused by the circuit meters for the office rig, tower crane 1, tower crane 2, and gravel charger.

Both heatmaps show that consumption patterns vary from day to day, hour to hour. The hours with the most power-intensive activities on the construction site occur between **11:00 and 13:00**.

Over the period, we observe significant activity on the construction site consistently throughout the day, requiring significantly more power than the rest of the period. The average maximum hourly power was **110 kW** and **184 kW** for circuit-measured consumption and smart meter-measured consumption, respectively.

For example, we have:

- December 12 – December 16, 2022
  Circuit Maximum recorded power: **229 kW**
  An increase of 208% from the average
  Smart meter Maximum recorded power: **466 kW**
  An increase of 253% from the average

- January 02 – January 04, 2023
  Circuit Maximum recorded power: **226 kW**
  An increase of 205% from the average
  Smart meter Maximum recorded power: **311 kW**
  An increase of 169% from the average

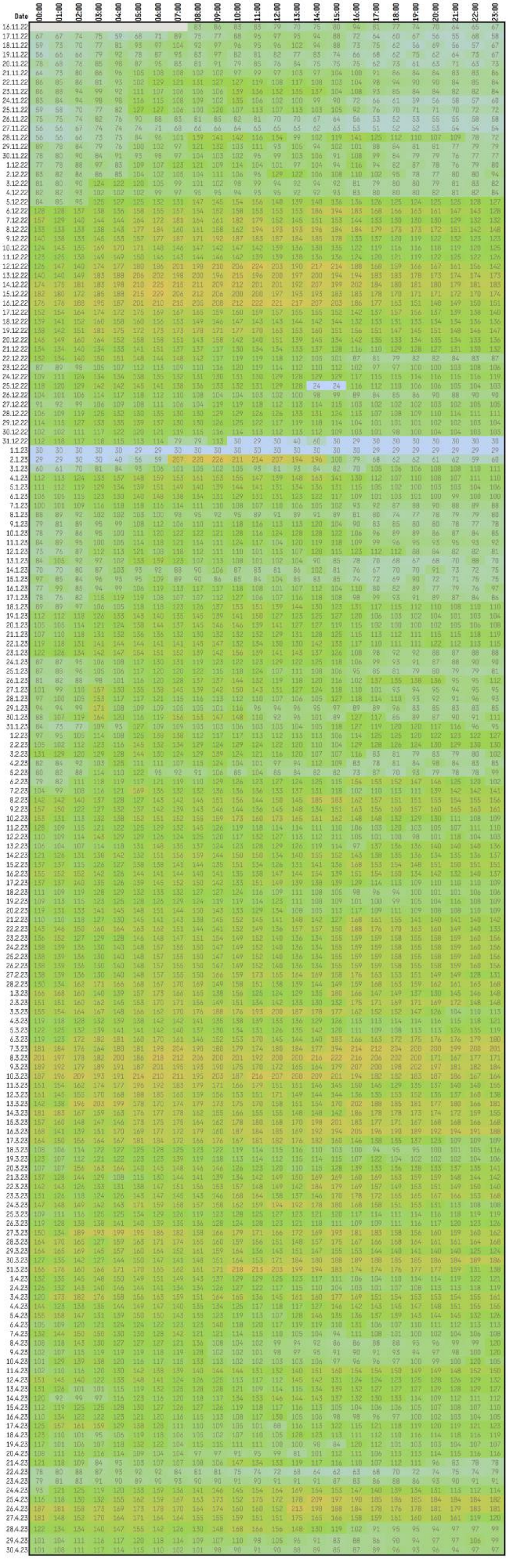
- March 07 – March 10, 2023
  Circuit Maximum recorded power: **222 kW**
  An increase of 202% from the average
  Smart meter Maximum recorded power: **486 kW**
  An increase of 264% from the average

- May 01 – May 04, 2023
  Circuit Maximum recorded power: **184 kW**
  An increase of 167% from the average
  Smart meter Maximum recorded power: **365 kW**
  An increase of 198% from the average

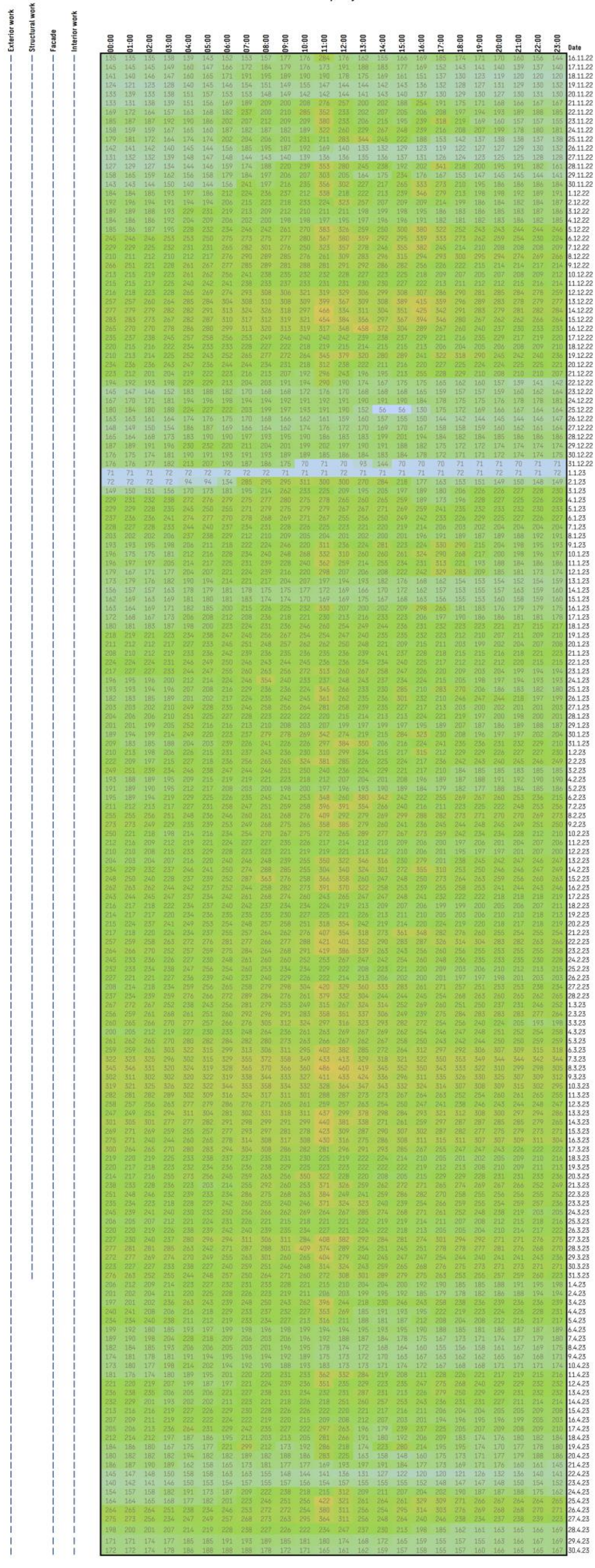
- December 04 – December 08, 2023
  Circuit Maximum recorded power: **280 kW**
  An increase of 255% from the average
  Smart meter Maximum recorded power: **411 kW**
  An increase of 223% from the average

- January 05 – January 21, 2024
  Circuit Maximum recorded power: **304 kW**
  An increase of 276% from the average
  Smart meter Maximum recorded power: **510 kW**
  An increase of 277% from the average

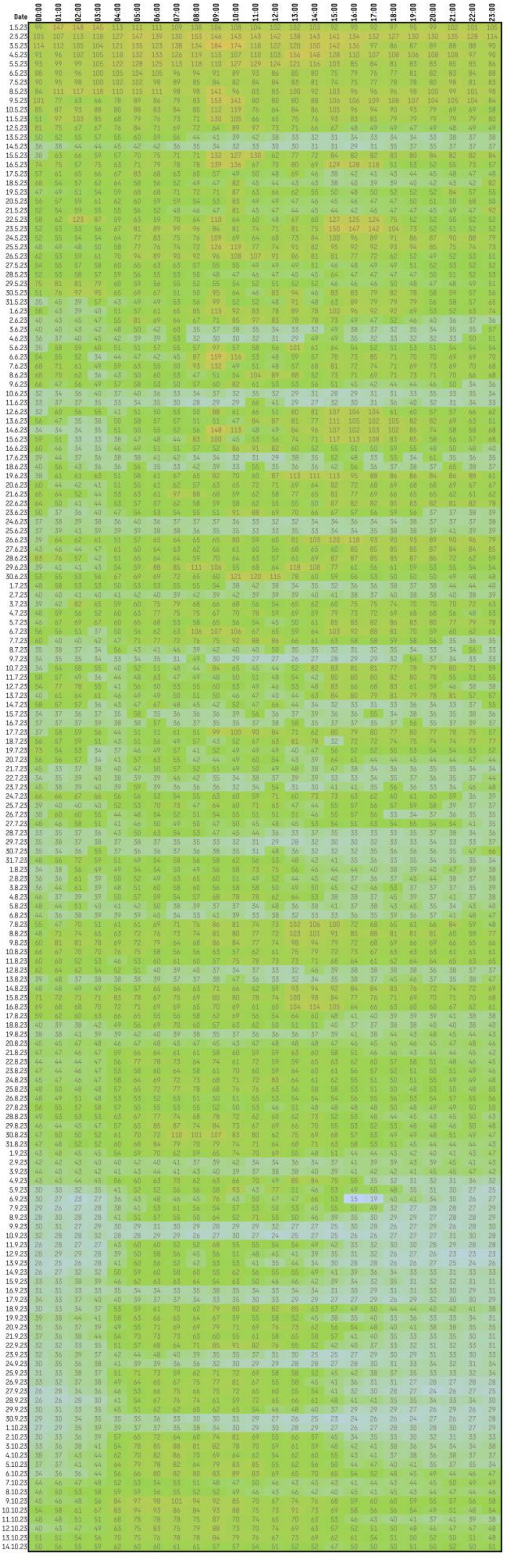
Circuit-measured consumption, per hour per day in the construction project to date



Smart meter measured consumption, per hour per day in the construction project to date



Circuit-measured consumption, per hour per day in the construction project to date



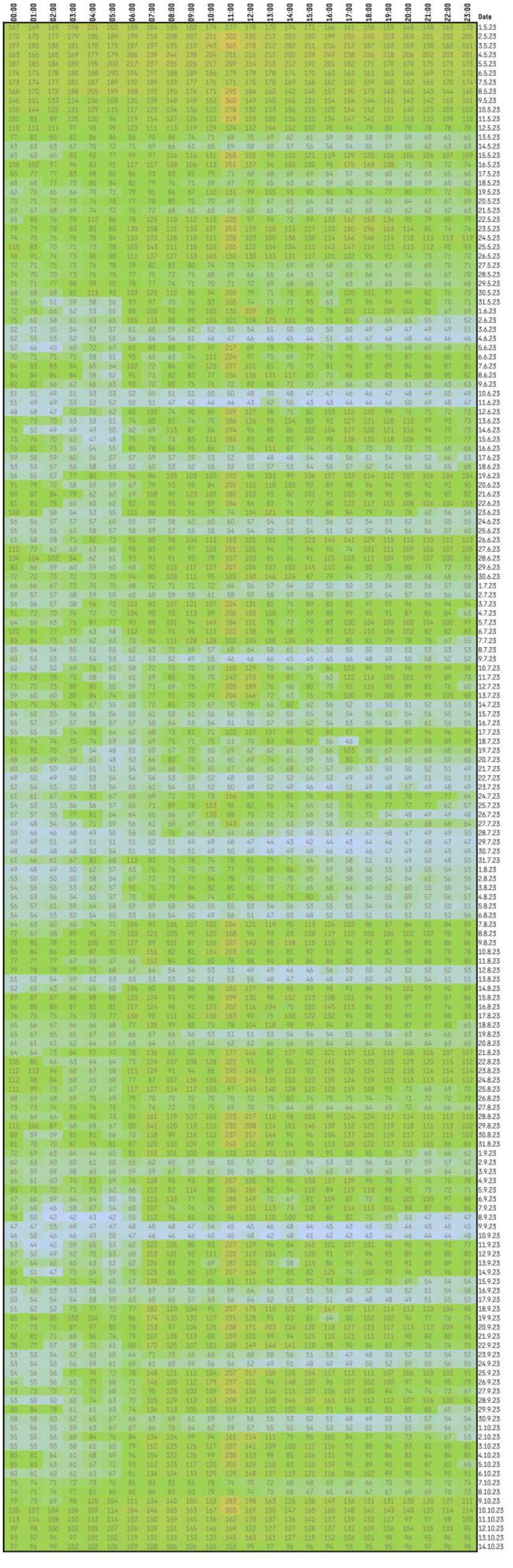
Exterior work

Structural work

Facade

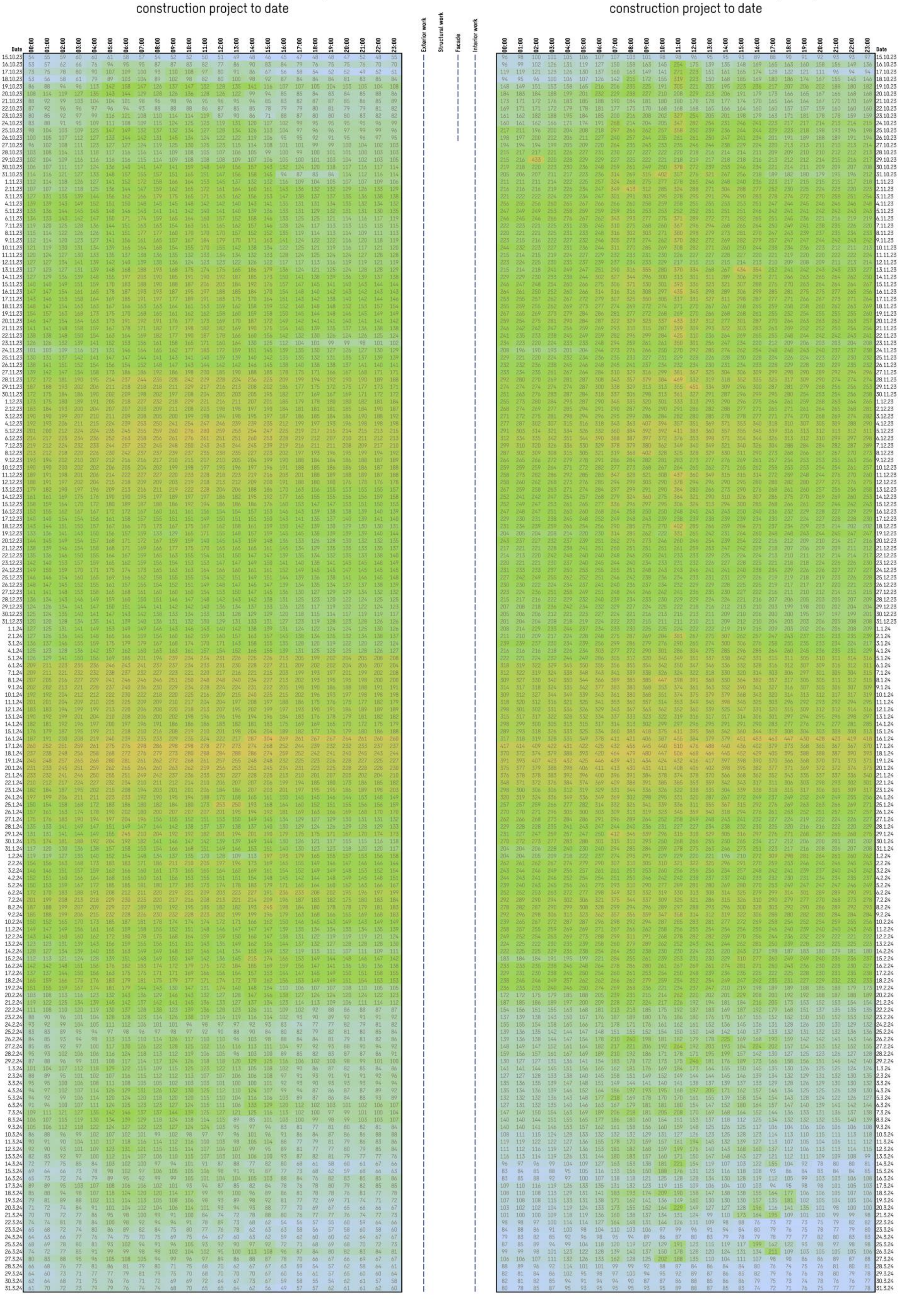
Interior work

Smart meter measured consumption, per hour per day in the construction project to date



Circuit-measured consumption, per hour per day in the construction project to date

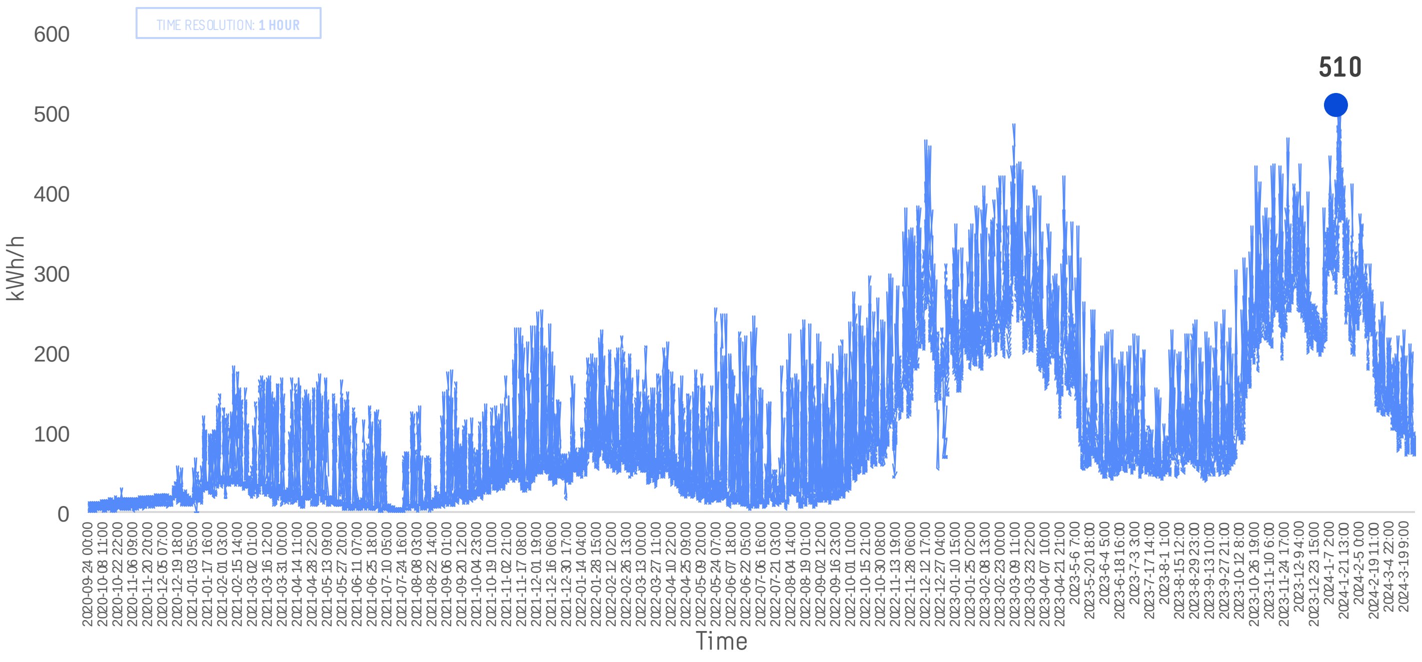
Smart meter measured consumption, per hour per day in the construction project to date



New Tøyenbadet | Maximum Power [kW]

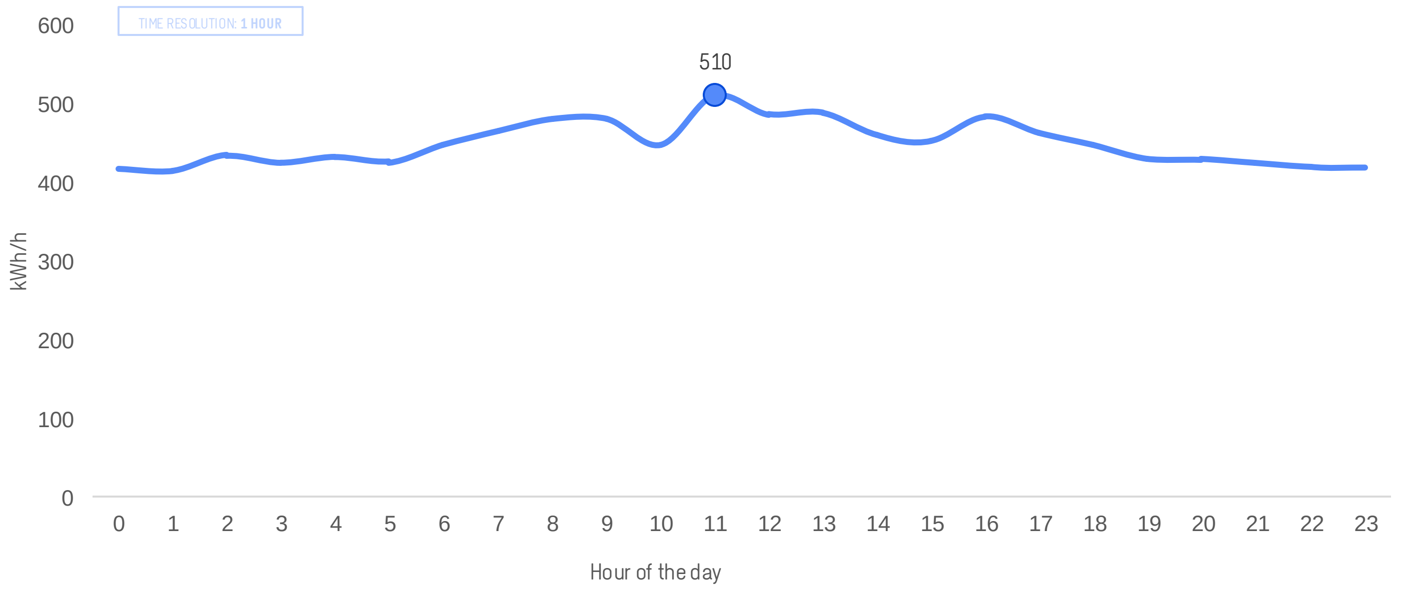
Power Consumption for the Entire Construction Project

Smart meter measured consumption in the construction project to date



The highest power peak for the electrical consumption at the construction site was measured at **510 kW**, recorded on January 17, 2024 (Wednesday at 11:00, week 3 of 2024). The diagram above shows the power consumption for the construction period 2022-2024, while the one below shows the maximum hourly consumption per hour per day so far in the project period. The hour with the highest power is highlighted.

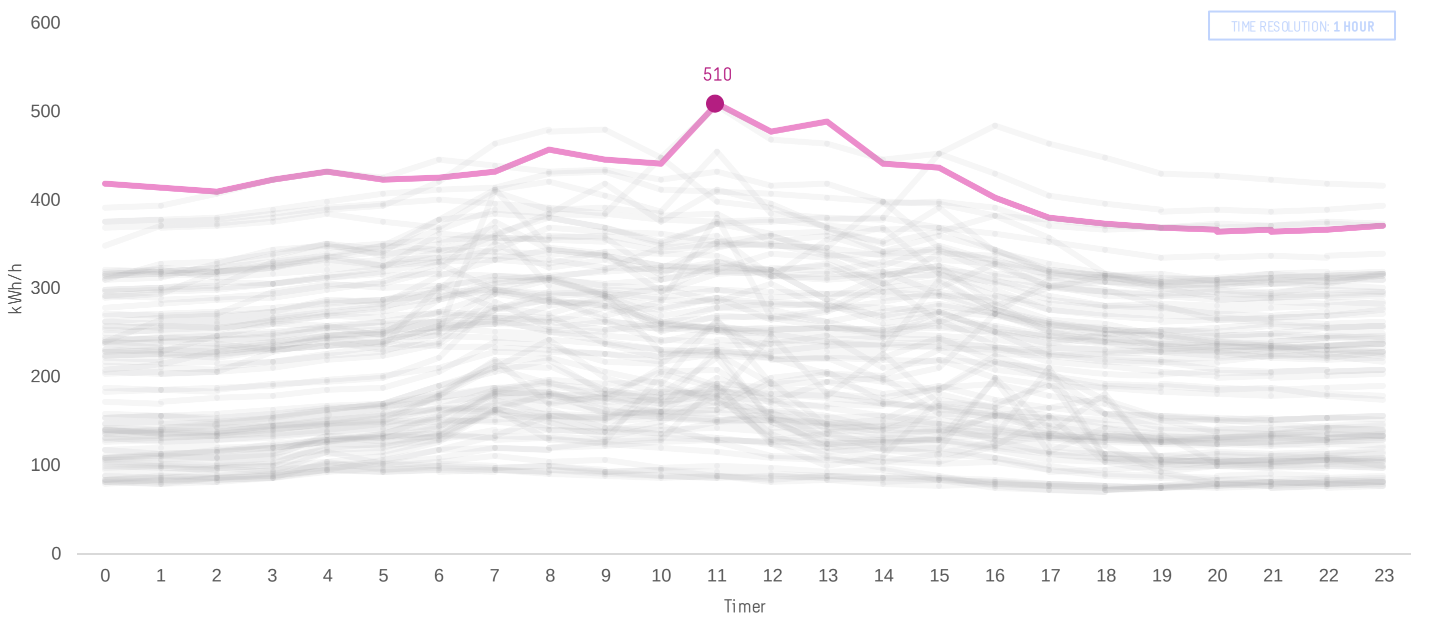
Maximum hourly consumption in the contruction project to date



New Tøyenbadet | Maximum Power [kW]

Day with the Highest Measured Power

Daily power consumption curves in 2024 where the day with the highest power peak is highlighted



The diagram above shows daily consumption curves in 2024, with the day of the highest power peak highlighted in pink. There will be other days (illustrated in gray) where higher power is recorded at other times of the day, and these peaks are accounted for in the previous figure.

Similar to the highest power peak that occurred at 11:00 on Wednesday, week 3 of 2024, most power peaks happen around the same time. This is especially prominent in the heatmaps.

In the table to the right, the average consumption for each hour of each year in the construction project (from 2020 through March 2024) is calculated. Additionally, the average of each hour for each year is shown on the far right (as "average of averages"). We observe an increasing average power per hour over time, with the highest power occurring before lunchtime (07:00-11:00) in 2024 and during lunchtime (11:00-12:00) in 2023.

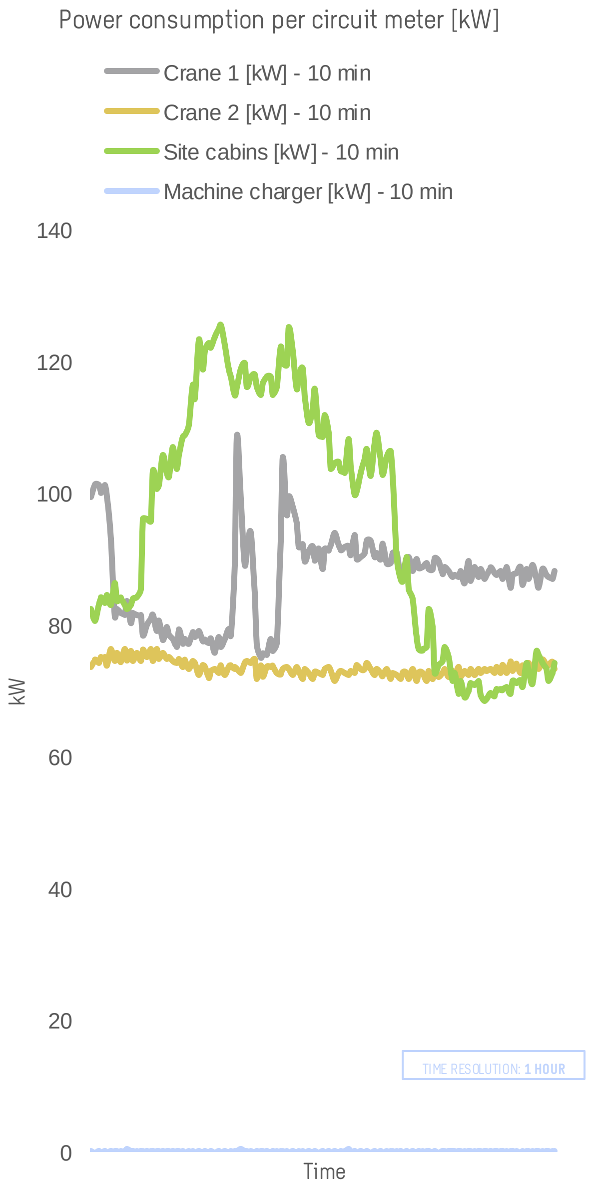
The highest power that occurred at 11:00 on Wednesday, week 3 of 2024, represents an increase of 204% compared to the average power recorded at 11:00 in 2024, 241% compared to 2023, and 561% compared to the average at 11:00 in 2022.

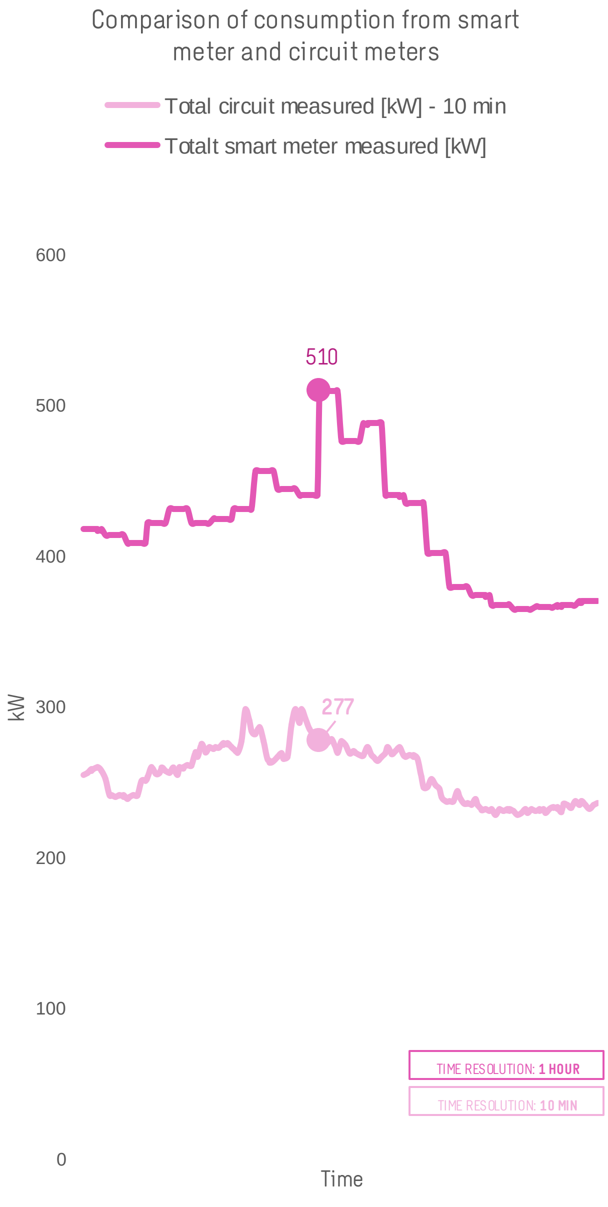
Hour in a day	Average hourly power per year					Average of average
	2020	2021	2022	2023	2024	
0	18	26	60	155	204	93
1	18	26	60	154	206	93
2	18	26	61	154	208	93
3	18	26	61	156	214	95
4	18	29	65	159	222	99
5	18	30	77	161	224	102
6	18	28	71	168	236	104
7	18	34	76	182	253	113
8	17	60	90	183	250	120
9	13	65	90	183	245	119
10	10	64	87	180	240	116
11	10	59	91	211	250	124
12	11	60	129	204	238	128
13	10	61	98	185	232	117
14	10	56	91	176	228	112
15	10	54	85	175	231	111
16	11	50	107	172	226	113
17	15	44	108	171	216	111
18	16	33	92	168	208	103
19	17	26	71	164	202	96
20	19	26	66	161	200	94
21	18	25	63	159	201	93
22	18	25	61	158	202	93
23	18	25	61	157	202	93

Nye Tøyenbadet | Maximum Power [kW]

Day with the Highest Measured Power: Share from Circuit-Measured Consumption

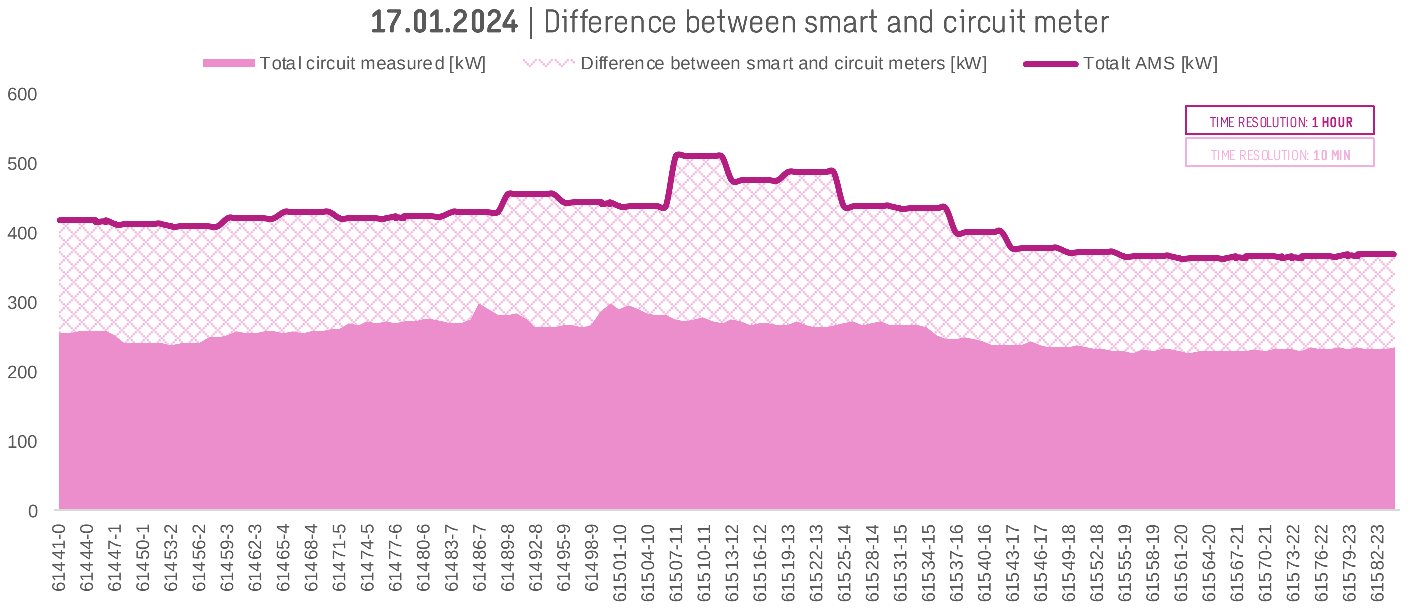
The circuit-measured consumption with a 10-minute time resolution for crane 1, crane 2, the office rig, and the gravel charger accounts for 277 kW of the total power peak on the relevant day, i.e., around 54% of the power peak, as shown in the diagram below. Of these, the gravel charger accounted for 0 kW, "crane 1" 89 kW, "crane 2" 73 kW, and the office rig 115 kW. The remaining gap in power of 233 kW (when looking at power with a 10-minute time resolution) will be explained on the following pages.



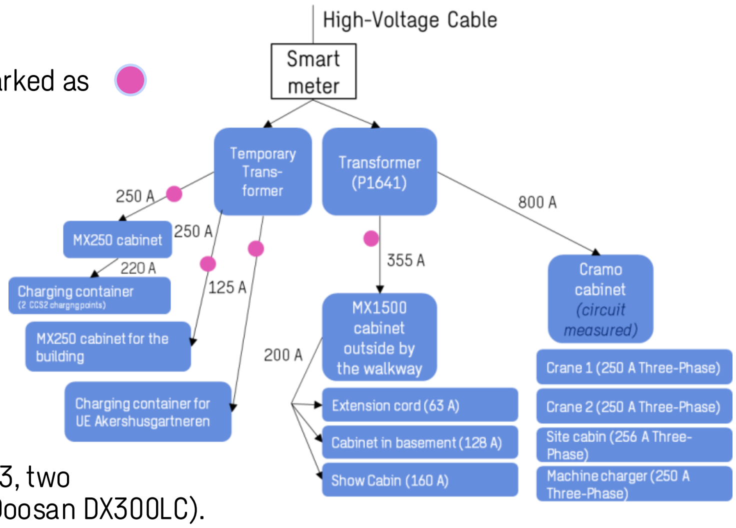


New Tøyenbadet | Maximum Power [kW]

Day with the Highest Measured Power: Share from Circuit-Measured Consumption



Since smart energy meter data is measured hourly, the remaining gap in power is 235 kW when comparing the average power from the energy meter with the circuit-measured consumption. With a 10-minute time resolution on the data, the difference is 240 kW. So, the big question is: **What happened on this day beyond the circuit-measured consumption?**



It is known which circuits are unmeasured, here marked as in the figure on the right.

- 220 A to the charging container (152 kW)
- 250 A to MX250 panel for the building (173 kW)
- 125 A to the charging container for the subcontractor Akershusgartneren (86 kW)
- 200 A to extension cord, panel in the basement, and viewing office (138 kW)

These circuits can deliver a total of around 480 kW.

Based on the reported machine list for January 2023, two electric machines were in use (Cat 320 Z-line and Doosan DX300LC). Neither of these has been charged on the circuit named machine charger which has been measured. That power (0 kW) at the relevant time has already been accounted for. This means that if the machines were charging at 11:00 on the relevant day, they would have charged with a maximum of 152 kW. This leaves **81 kW**, which is either used by the 250 A circuit to the MX250 panel in the building, the 125 A charging container for the subcontractor Akershusgartneren, and/or the 200 A to the extension cord, panel in the basement, and viewing office. Which of them constitutes the remaining consumption is uncertain, and in addition, a list of activities from the progress plan has been compiled that may be potential causes of the remaining unmeasured consumption.

New Tøyenbadet | Cause of Power Peak

The historical activities carried out on the construction site are numerous, and the progress plan gives us an indication of potential consumption items that may have caused the difference in power measurements between circuit-measured consumption and the energy meter.

The activities are taken from the progress plan for the construction phases Outdoor and Interior work, which were the ongoing construction phases on January 17, 2024. It cannot be ruled out that there may be charging of other machines and vehicles not listed in the machine list at the relevant time.

Activities on January 17, 2024

Exterior Work

- Outdoor West
- General, including pedestrian and cycling areas
- Green area East, South
- Outdoor Swimming Pool
- Concrete work for outdoor pool (started 09.01)
- Walkways around pools
- Operational building by the outdoor pool
- Remaining outdoor areas

Interior Work

- Level 02 (U2), Zone 02-4, Zone 02-5
- Level 01 (U1)
- IT rooms in various zones
- Completion
- Level 20 (Stands, office)
- Strength training room and foyer (completion 22.01.24)
- Technical room

New Tøyenbadet | Power Consumption

100% Electric Construction Site

What would the power peaks be if the construction site were 100% electric? Based on the current situation (Scenario 1) with district heating for Tøyenbadet, an exercise has been conducted for this. The current power peak is, as shown, 510 kW. Of the 8 scenarios below, scenarios 2 and 3 have the same zero-emission level as the current project, while scenarios 4-8 are 100% zero-emission, with scenarios 4-6 being 100% electric, and scenarios 7-8 using district heating for heating/building drying.

(Scenario 2) If direct electricity were used to cover the thermal heating needs currently covered by district heating, it would result in a maximum hourly consumption of 813 kW at 11:00 on Wednesday, week 3 of 2024 (510 kW electricity + 303 kW district heating). This is an increase of 60% compared to the maximum power if district heating had been used to cover the thermal energy needs throughout the construction project.

(Scenario 3) Alternatively, heat pump solutions could be used to minimize the electrical power requirement. This would still require more electricity, but only around a 20% increase (101 kW electricity for heating/drying) compared to using district heating.

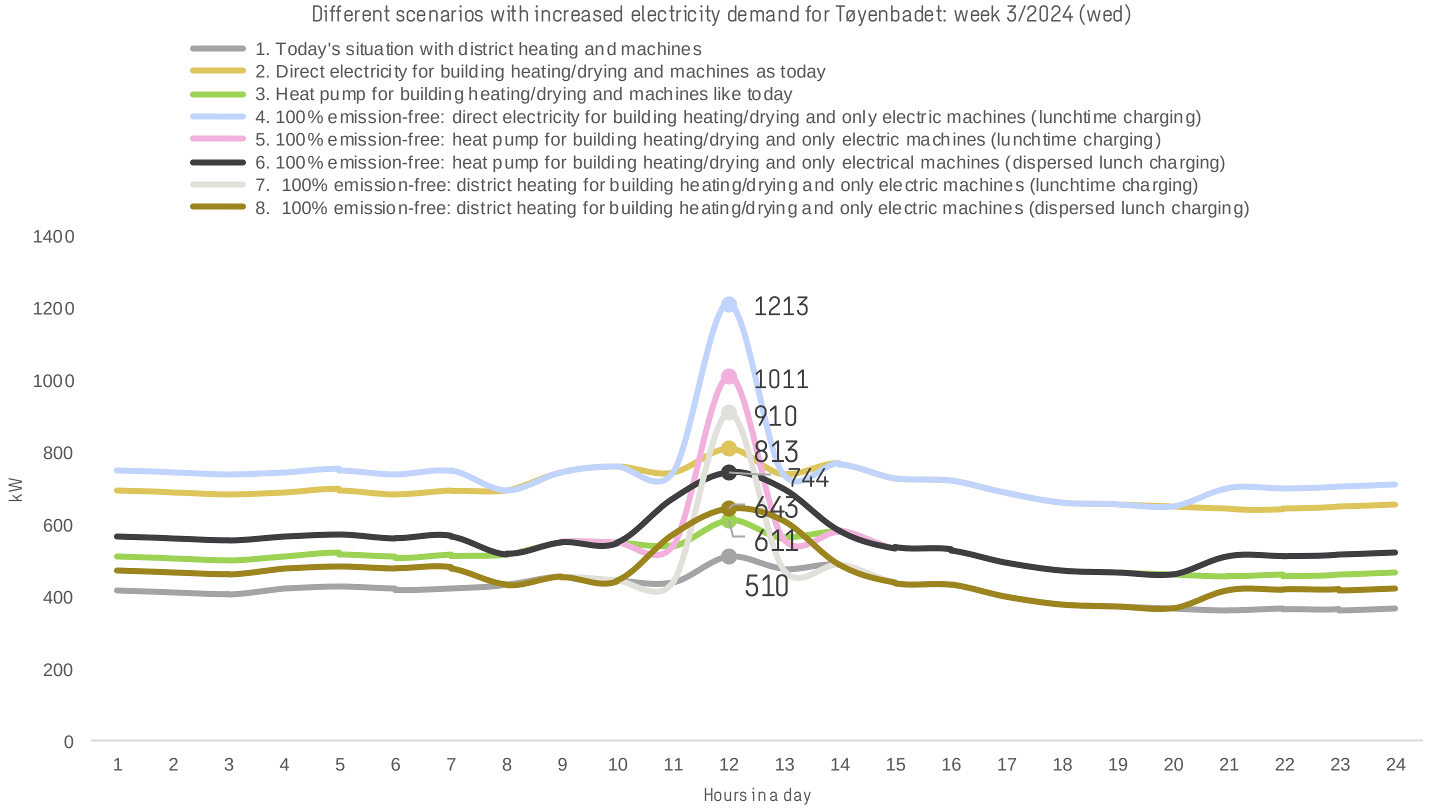
(Scenario 4) In addition to direct electric heating, if there were 100% electric construction machinery in March 2023 (3 larger excavators), this could result in an increased simultaneous power demand of 1213 kW if all three excavators charged simultaneously at 11:00. Overall, this would increase the maximum power demand by around 140% compared to the current maximum power of 510 kW.

(Scenario 5) If heat pumps were used for building drying/heating and only electric machines were used with charging at 11:00, the maximum power would increase to 1011 kW, a 100% increase compared to the current situation.

(**Scenario 6**) If the same as Scenario 5 were done, but lunchtime charging was spread between 10:00-12:00, the power demand would increase to 744 kW, an increase of around 55%.

(Scenario 7) Using only district heating for heating/building drying and all machines electric with simultaneous lunchtime charging at 11:00 would increase the power demand to 910 kW, an increase of almost 80%.

(**Scenario 8**) Using only district heating for heating/building drying and all machines electric with spread lunchtime charging between 10:00-12:00 would increase the power demand to 643 kW, equivalent to an increase of around 25%.



4 Stovner bad

Picture: NUNO Arkitektur

Picture: Nuno Arkitekter

Stovner bad
Information

ANALYSIS PERIOD: June 2023 - March 2024

Key figures for logged part of the construction period:

- Maximum power consumption: 522 kW (10-minute resolution) (Tuesday at 11:10, Week 42 of 2023)
- Average hourly power consumption: 45 kW
- Average monthly consumption: 38,476 kWh
- Average daily consumption: 1,326 kWh
- Total energy consumption: 913,944 kWh
- Zero-emission energy usage in the construction phase: 42%
- Zero-emission share of energy consumption for machinery: 38%

New construction

Potential Demolition – Ground Work – Structural Work – Facade – Interior Work – Exterior Work

Stovner Bad will be a new swimming facility located in Fossumdumpa, in the Stovner district. The facility will cover 8,600 square meters and include five pools: a main pool with eight swimming lanes, a diving pool, a children's pool, a family pool, and a hot water/training pool, as well as a jacuzzi, water slide, warm and cold plunge pools, and saunas. Stovner Bad is being built with water recovery systems for reduced use of water and energy from public networks. Additionally, the energy concept for Stovner Bad will include solar energy and district heating. However, district heating has not yet been installed for Stovner Bad and is therefore not included in the analysis of this project.

Construction work began in 2023, with initial activities including landfilling, sheet piling, and piling on the site. Work on Stovner Bad is ongoing and is expected to be completed by summer 2026. The project is being carried out by NCC, in collaboration with Oslobygg KF, Nuno Arkitektur, and other consultants. The project is being executed as a design-build contract.

The construction site at Stovner Bad is fossil-free, with some use of zero-emission construction machinery. The project has significant sustainability ambitions and aims for the construction machinery to be as electric and completely emission-free as possible. Alternatively, they run on biodiesel. From 2025 onwards, the project will be entirely zero-emission.

The construction site is supplied with an available power capacity of 800 kVA (approximately 640 kW). In addition, BoostPoint and Hummingbird have been implemented in the project. The new construction project is progressing and is currently working on the structural framework and facade.

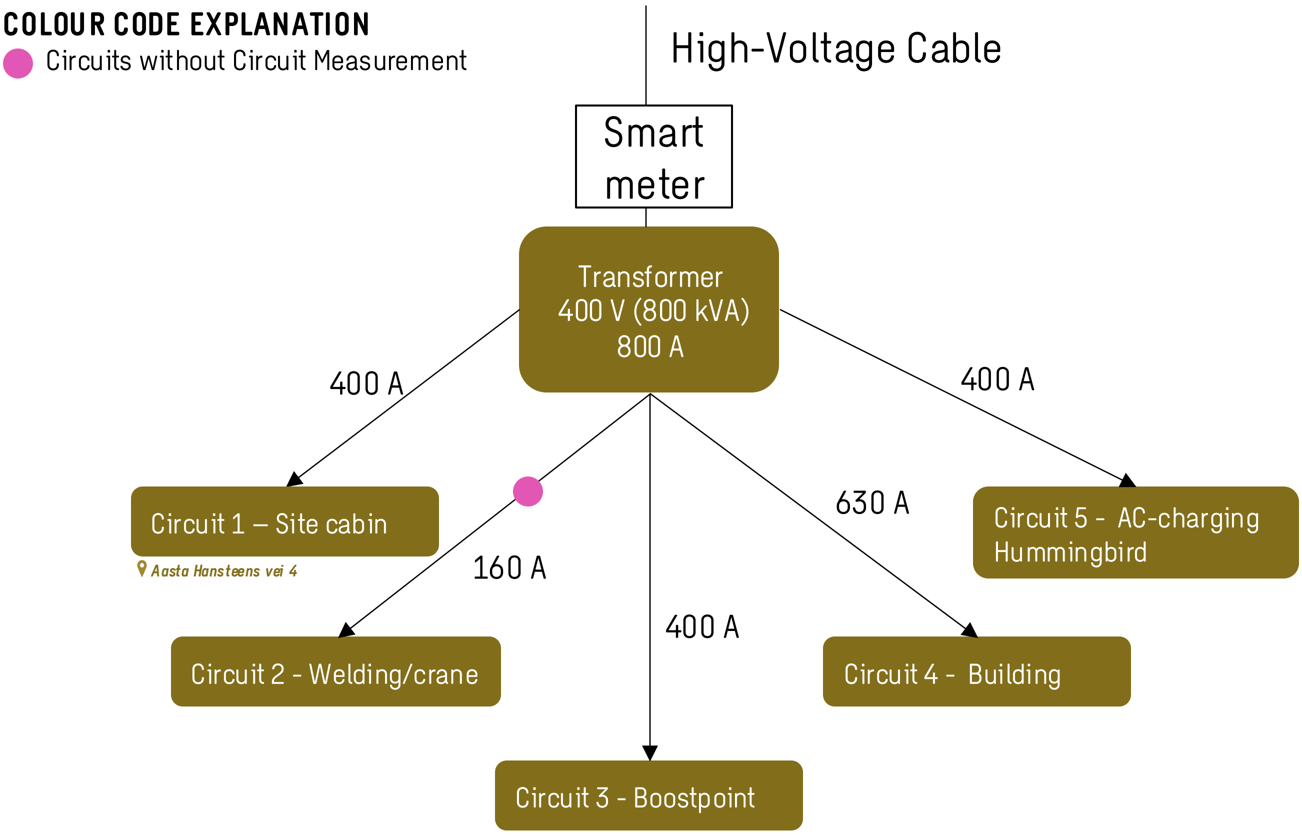
The Stovner Bad project is well-equipped with measuring instruments. Various meters have been installed on the construction site, including an smart energy meter and an individual meter per circuit (building, construction rig, BoostPoint (fast charger), Hummingbird (mobile charging and battery container, standard charger)). Measurements began on June 6, 2023, and such early initiation of energy measurements will enable a comprehensive analysis of the project's energy consumption and efficiency. The project has aimed for several circuit meters to account for various consumption points in greater detail since its inception. Stovner Bad is thus set up for ten circuit meters. However, after a few months of project review, it was discovered that one of the circuit meters had not collected any measurement data. This circuit would have provided the project with better insight into consumption patterns directly related to equipment connected to the circuit (welding and tower crane).

Sweco has received the following relevant data and information from the project:

- Monthly machine overview, including consumption
- Energy meter data with hourly resolution [kWh/h]
- Circuit measurements for four circuits (building, construction rig, BoostPoint (fast charger), and Hummingbird (standard charger) with 10-minute resolution) from June 2023
- Documentation for the facility: main data and distribution network
- Network capacity: 800 kVA transformer in the substation. Around 640 kW.

Stovner bad | Information

Power Rig



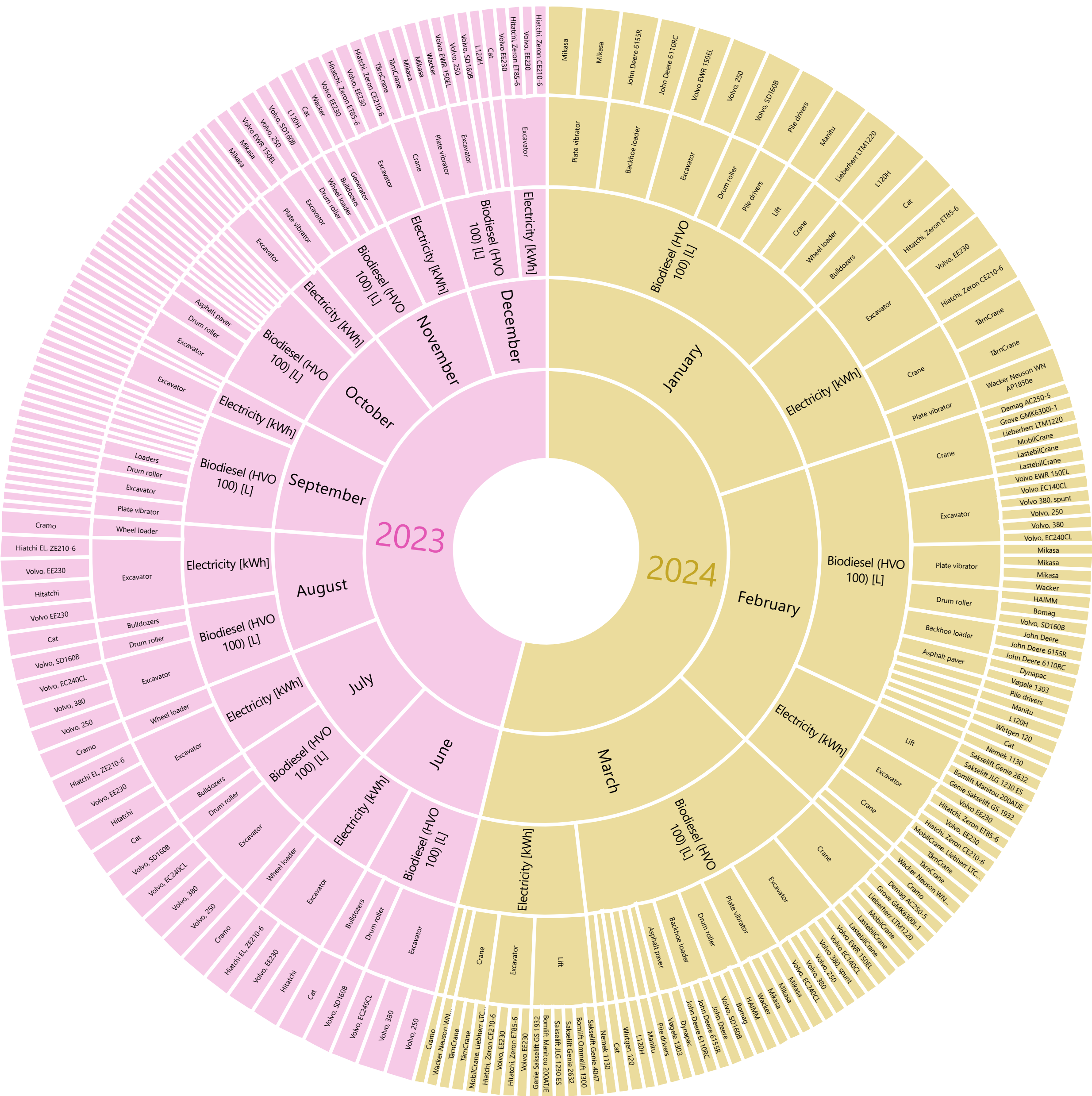
The power at the construction site is distributed to the various consumption points using one transformer of 800 kVA. One transformer, P1641, is set up and operated by Elvia, while Omexon has set up and operates an additional temporary transformer. The total stated capacity of the transformers is around 550 kW. The system operates at 400 V.

The construction power cabinet has a total of 10 circuits, of which 5 are in use for the project. All circuits, except for circuit number 2, are metered. There are 11 construction barracks on the project, in addition to a building used by the project, located on the neighboring site at Aasta Hansteens vei 4, which also functions as a construction barrack and is measured with Circuit No. 1. Circuit No. 2 is connected to welding and the tower crane. This circuit was supposed to be metered, but due to insufficient follow-up from the start, it went unnoticed that no measurements were being recorded. Circuit No. 3 supplies the "Boostpoint 360" produced by Nordic Booster, which has 2 CCS2 charging points. Circuit No. 4 supplies the building, and Circuit No. 5 provides AC charging through Hummingbird, which draws 40 kW from the grid and has various charging points, as well as a usable battery capacity of 170 kWh.

Stovner bad | Information

Machine Fleet

Machines used on the construction site



For the period of June 2023 – March 2023, the project has reported the total consumption of electric and biodiesel-powered construction machinery on the site. The diagram above provides an overview of the active machinery for the project, categorized by fuel technologies: biodiesel (HVO 100) (liters) and electric (kWh), and is organized by month, per year. This offers a visual representation of which machines were used the most during different periods.

It is important to note that the diagram is not weighted by the fuel consumption of each machine.

Stovner bad | Information

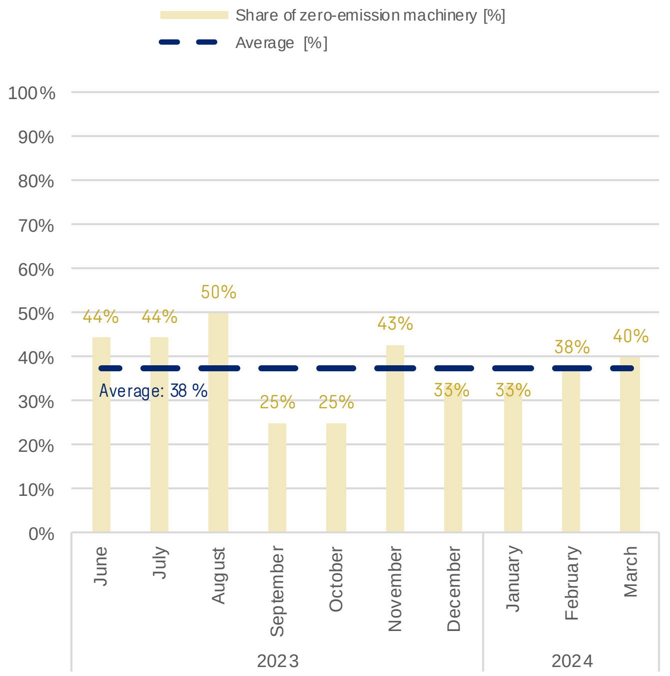
The Degree of Zero-Emission Construction Site

Over the years, there has been an increasing awareness of the need for more sustainable and environmentally friendly solutions in the construction sector. This has led to a gradual shift from traditional fossil fuels to more eco-friendly alternatives. The Stovner Bad site is fossil-free, with a significant proportion of zero-emission construction machinery. This means that all construction machinery is either electric or powered by biofuels.

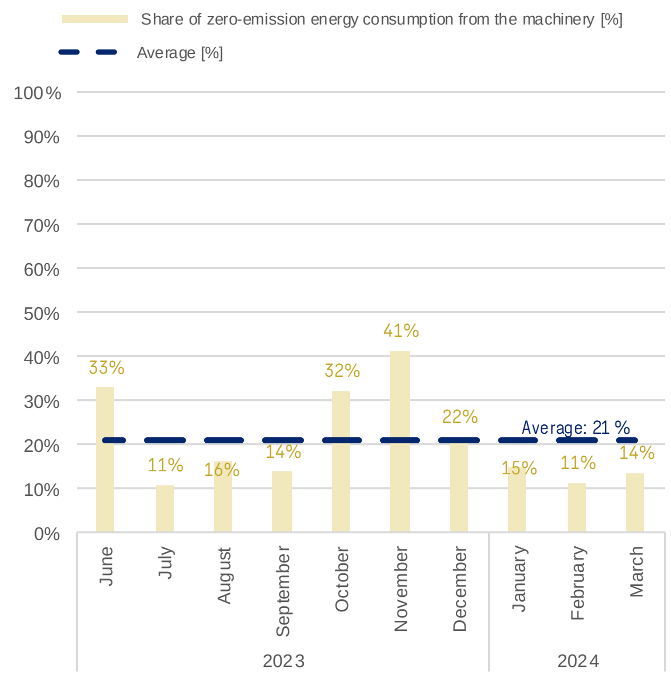
The diagrams below provide an overview of the proportion of zero-emission machinery at the construction site, as well as the degree of zero-emission operation at the Stovner Bad site, for the period from June 2023 to March 2024. The measurements are based on the percentage of electric-powered machines and the energy consumption of these electric machines used on the construction site.

For the project period, it was shown that, on average, 38% of the construction machinery was zero-emission, and 21% of the energy consumption from these machines was zero-emission per month at Stovner Bad. In practice, this means that approximately one-fifth of the total operation was carried out without emissions. The difference between these key figures reflects the share of zero-emission machinery in the equipment fleet, as well as the proportion of energy used by different machines relative to the total energy consumption from the machinery.

Share of emission-free construction machinery on the construction site



Share of electricity consumption by construction machinery on the construction site



Stovner bad | Information

Information about Electrical Machines

In the work at Stovner Bad, the following types of construction machinery are used as zero-emission:

- Crane
- Excavator
- Wheel loader
- Lift
- Vibrating plate

These are powered either as battery-electric or cable-powered machines. The battery-electric machines are equipped with an internal battery system that allows them to move freely, limited only by battery capacity. The batteries supply power to the machine's electric motors, which drive the movement of the construction equipment. The advantage of battery-electric machines is that they offer mobility and flexibility without depending on a continuous power source. They can be used in different locations and are especially useful in areas where access to power may be limited.

The second type, cable-powered construction machines, are stationary electric machines connected directly to an external power source via a cable. The advantage of cable-powered machines is that there is no need to worry about battery life or charging; as long as they are connected to the power source, they can work continuously. However, they are limited by the cable's range, which means they remain in a fixed location or move within a limited area and can be less flexible when it comes to moving around the construction site.

The electric construction machinery used at Stovner Bad includes the following models:

- Kraner
  - Mobile crane Liebherr LTC1050-3.1E
- Excavators as
  - Hitachi ZE210
  - Hitachi Zeron ZE210
  - Hitachi Zeron ET85
  - Volvo EC230
- Vibrating plate
  - Wacker Neuson AP1850e
- Lift
  - Snorkel lifts Genie GS-1932,Genie GS-2632, Genie GS-4047, JLG 1230ES
  - Articulating Boom lift Manitou 200 ATJE
  - Telesopic trailer lift Omme 1300

LTC 1050-3.1E (Mobile crane (EL))
max. 72 kW

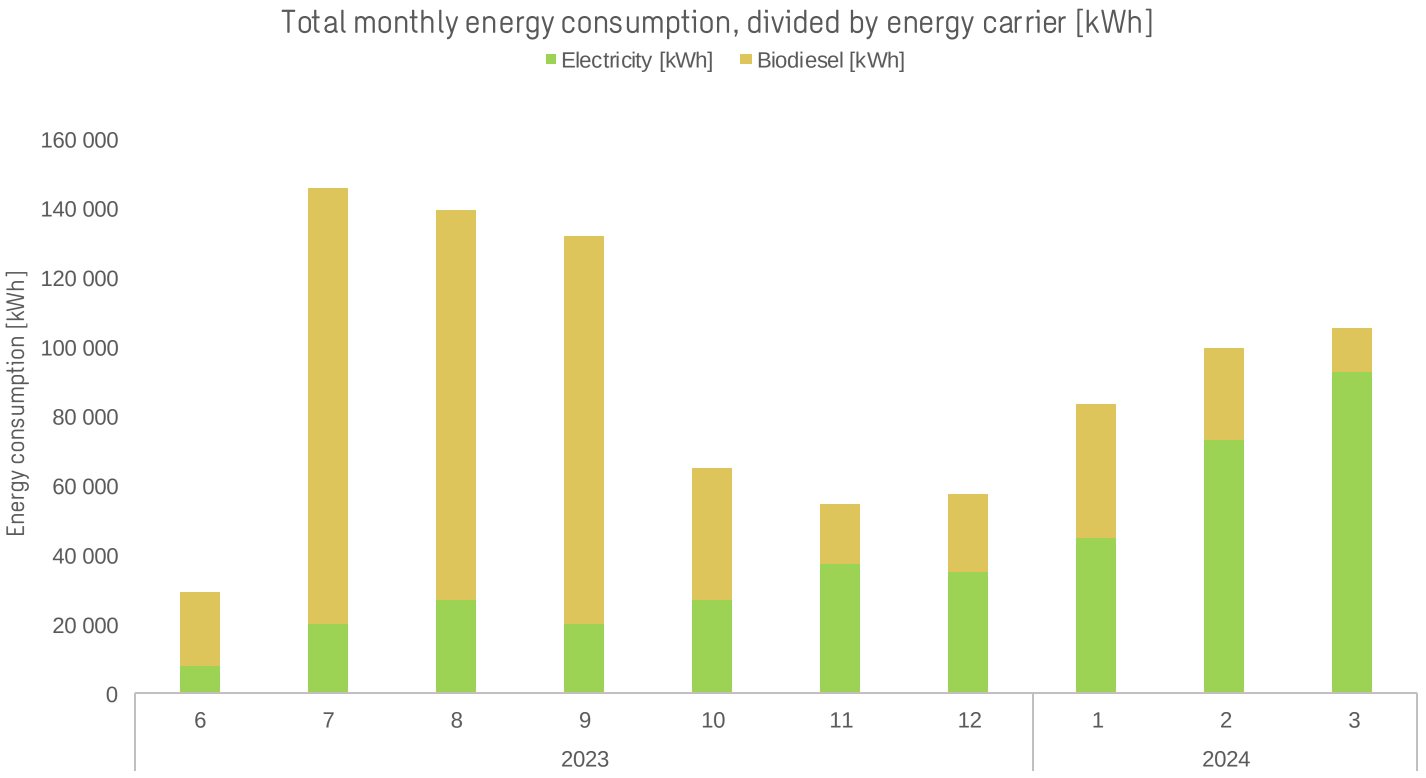
JLG 1230ES (Lift)
Battery

Hitachi Zeron ZE210 (Excavator (EL))
Battery – 300 kWh – max. 128 kW

4.1 Energy Consumption

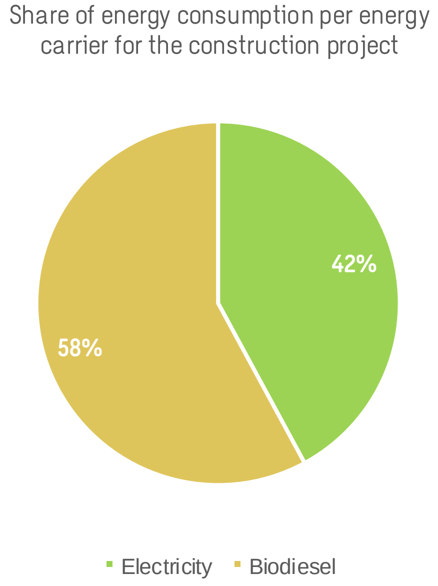
Stovner bad | Energy Consumption

Total Consumption per Energy Carrier



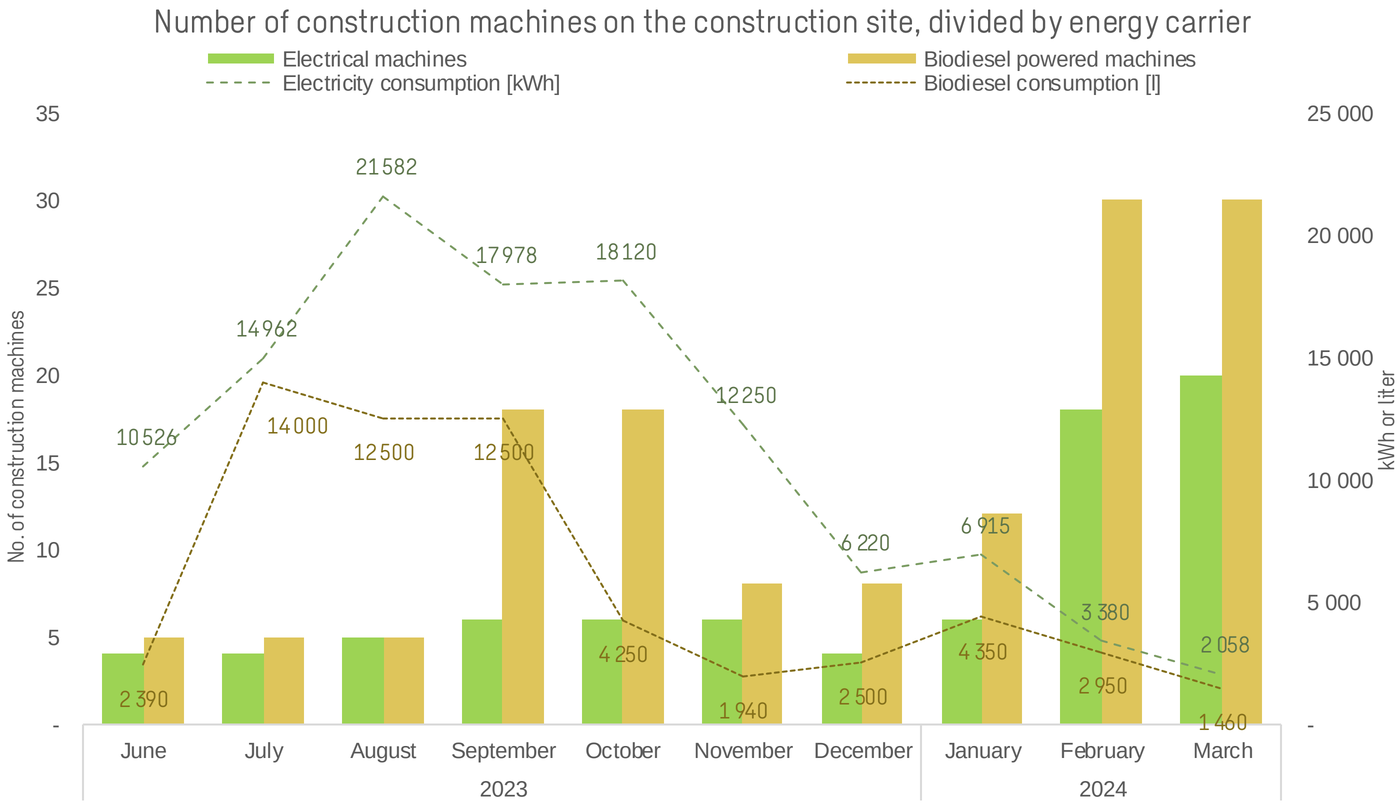
The total energy consumption for the construction project (converted to kWh) has so far been 913,944 kWh. Biodiesel has been the most used energy carrier, accounting for 58%, followed by electricity at 42%. This project has not utilized district heating.

The use of biodiesel was relatively high from July to September 2023, with between 12,500 to 14,000 liters being consumed on the construction site each month. For the relevant months, biodiesel-powered construction machinery, such as bulldozers, excavators, rollers, wheel loaders, cranes, asphalt pavers, loaders, lifts, piling machines, sheet piling machines, backhoe loaders, and vibrating plates, were listed. The exact energy consumption for each piece of machinery is unclear, but according to the progress plan, sheet piling, and tie-back installation were underway at Stovner Bad, followed by assembly of concrete elements, asphalting, piling, and mass filling in September.



Stovner bad | Energy Consumption

Monthly Consumption per Energy Carrier and Number of Machines



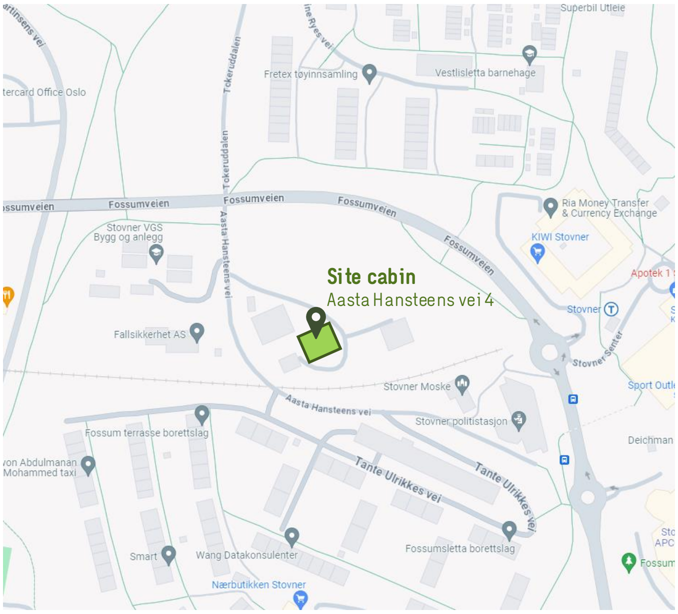
The diagram above shows the monthly composition of electric and biodiesel-powered construction machinery on the site, along with the corresponding electricity consumption in kWh and biodiesel (HVO 100) in liters. The electric construction machines with reported consumption used 101,638 kWh in 2023 and 12,353 kWh so far in 2024 (up to and including March). On the other hand, construction machines running on biodiesel (HVO 100) used 50,080 liters (450,399 kWh) in 2023 and 8,760 liters (78,784 kWh) so far in 2024 (up to and including March).

The electric construction machines have used an average of 373 kWh per day throughout the entire construction period, while biodiesel machines have consumed 192 liters per day on average (1,729 kWh). The highest consumption was observed in July and August 2023 for both biodiesel and electricity. During this period, work was being carried out related to site preparation, mass filling, and removing the topsoil. Additionally, sheet piling and tie-back installation began at Stovner Bad. Towards the end of August, night work also took place due to the asphalting of a detour road.

Otherwise, there is a consistently high consumption of both electricity and biodiesel until September-October, which can partly be explained by the aforementioned work, including the installation of concrete elements near the metro line (which began in week 38 and lasted until week 40), piling and mass filling on the construction site, the demolition of the underpass under Fossumveien, and the construction of a retaining wall with a water and sewage connection near the metro line.

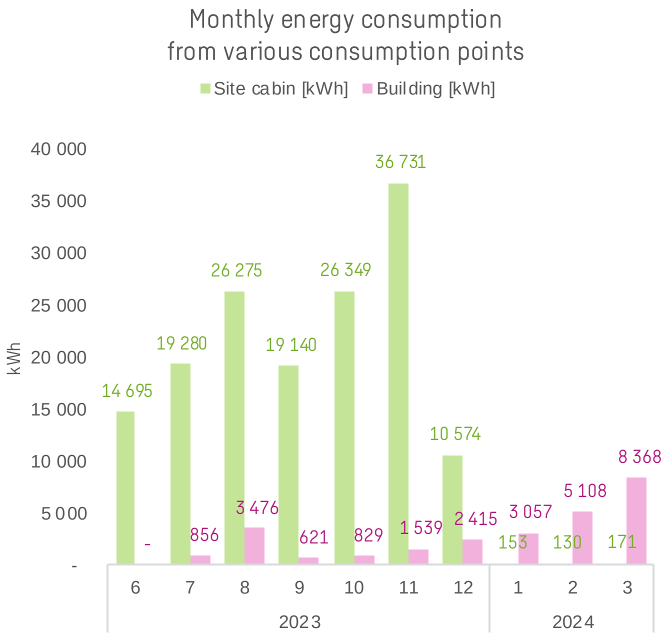
Stovner bad | Energy Consumption

Circuit Meters: Energy-Specific Consumption Points



At Stovner Bad, electricity measurement has been implemented for individual circuits with specific consumption points. In addition to the consumption from two of the measured circuits (named "Hummingbird" and "BoostPoint," which vary depending on the types of machinery being charged), it is also interesting to examine the consumption and power for the other measured circuits. These include **Circuit 1 Site Cabins** and **Circuit 4 Building**. The reported consumption covers the period from June 6, 2023, when the circuit meters were installed, until March 31, 2024.

In this project, an existing building (Aasta Hansteens vei 4), located on the adjacent site, is used as a construction barrack. Therefore, the consumption from this building is logged under **Circuit 1 Site cabins**. In addition to this office facility, there are also 11 crew barracks on the project site. It is currently unclear where the consumption from these barracks is being measured. Furthermore, it has been indicated that the number of crew barracks will increase, but the effects of this are not included in the analysis.



Site cabins

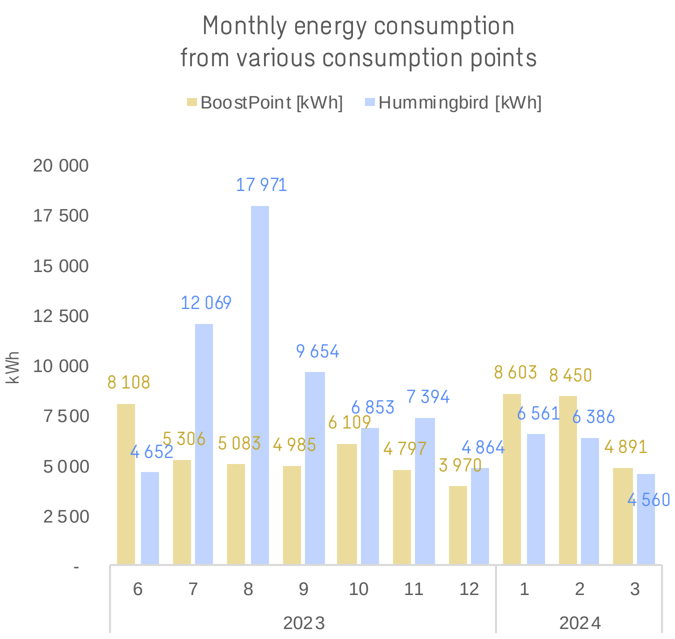
- Average monthly consumption: 15,350 kWh
- Maximum monthly consumption: 36,731 kWh in November 2023
- Average daily consumption: 503 kWh

Building

- Average monthly consumption: 2,627 kWh
- Maximum monthly consumption: 8,368 kWh in March 2024
- Average daily consumption: 86 kWh

Stovner bad | Energy Consumption

Circuit Meters: Energy-Specific Consumption Points



Stovner bad has implemented mobile fast chargers and charging solutions within the project, offering quick and efficient charging for electric construction machinery with minimal installation time. **Circuit 3 BoostPoint** is equipped with fast charging (2 CCS2 charging points) and has a 400 A fuse, meaning it can deliver up to 277 kW. **Circuit 5 Hummingbird** has various AC charging points and a usable battery capacity of 170 kWh.

For these key figures, the reported consumption covers the period from June 6, 2023, when the circuit meters were installed, until March 31, 2024.

BoostPoint

- Average monthly consumption: 6,030 kWh
- Maximum monthly consumption: 8,603 kWh in January 2024
- Average daily consumption: 198 kWh

Hummingbird

- Average monthly consumption: 8,096 kWh
- Maximum monthly consumption: 17,971 kWh in August 2023
- Average daily consumption: 265 kWh

4.2 Power Consumption

Stovner bad | Power Consumption

Introduction

The Stovner Bad construction project has had favorable conditions for gaining a detailed overview of the power consumption at the site, due to an extensive setup with energy meters initiated early in the project.

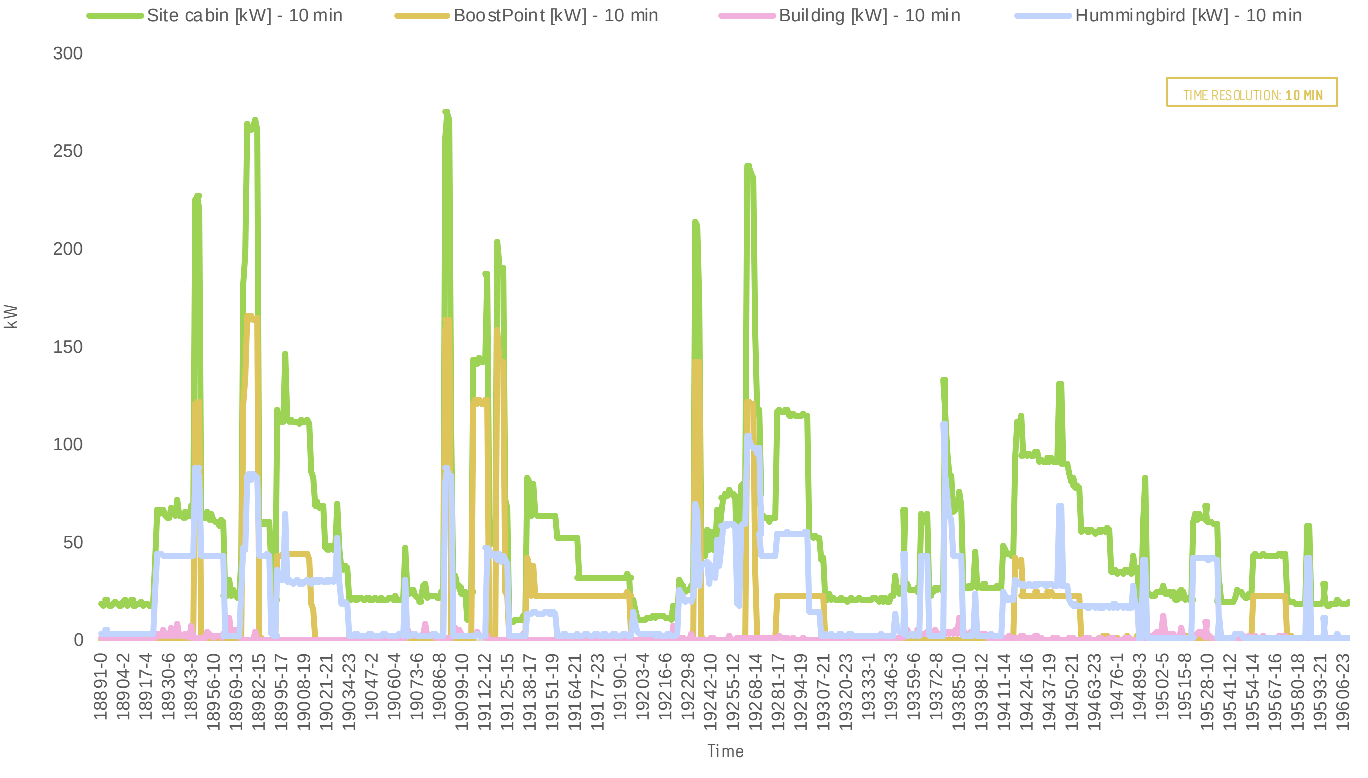
Typically, the main source of consumption data is the smart energy meter installed by the grid company, which is primarily used for billing electricity and network charges. This meter only provides information on the average power usage per hour unless additional equipment is installed. As a result, the resolution of the data from this meter is relatively low, making it difficult to identify significant power spikes that may occur over shorter time intervals.

At Stovner Bad, in addition to the smart energy meter, there are five other circuit meters monitoring electricity. As mentioned, data from one of these is not available for further analysis.

These circuit meters measure dedicated circuits for the site cabins, BoostPoint, the building, and Hummingbird. This setup gives the project better capabilities for identifying the causes of power spikes compared to other construction projects. The circuit meters in this project log consumption every ten minutes, providing a higher time resolution than the smart energy meter from the grid company. Despite this improved metering setup, there are still several unmeasured electrical circuits. Identifying the differences and mapping possible activities that could explain these variations is a key focus in this section.

The diagrams below show the measured consumption per circuit for a selected workweek in October 2023. One can observe the highest power peak registered for the construction barracks and recurring power spikes around 4 PM. These can, in part, be explained by charging sessions starting from both BoostPoint and Hummingbird.

Power consumption per circuit meter, week 42 (Mon-Fri) [kW]



Stovner bad | Power Consumption

Circuit Meters: Power-Specific Consumption Points

Here, the recorded maximum power [kW] for the various circuit-measured consumption points is presented. The data is gathered from circuit meters with a 10-minute time resolution.

Site cabin

- Maximum power: 270 kW (09:20 on Tuesday, week 42/2023)

The maximum recorded power of 270 kW occurred on Tuesday at 11:00 during week 42 in 2023. Considering that the site cabin are located in an existing building, this corresponds to the equivalent energy use of 110 construction barracks (based on typical values of 2-3 kW per barrack). This peak is rare and has only occurred once during the construction period, with a short duration.

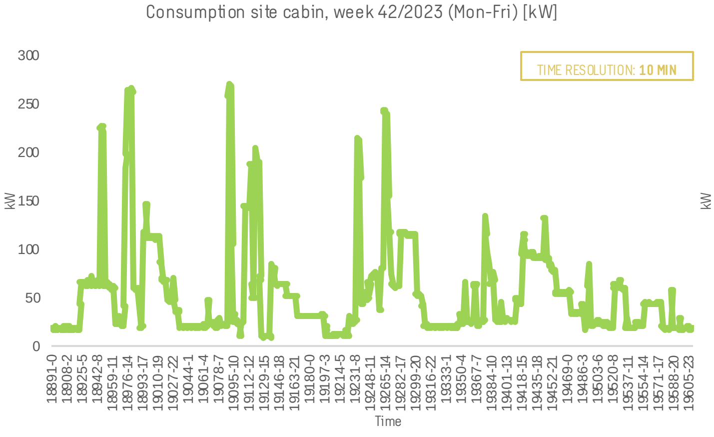
The second-highest recorded power is 264 kW, which occurred the day before the maximum peak.

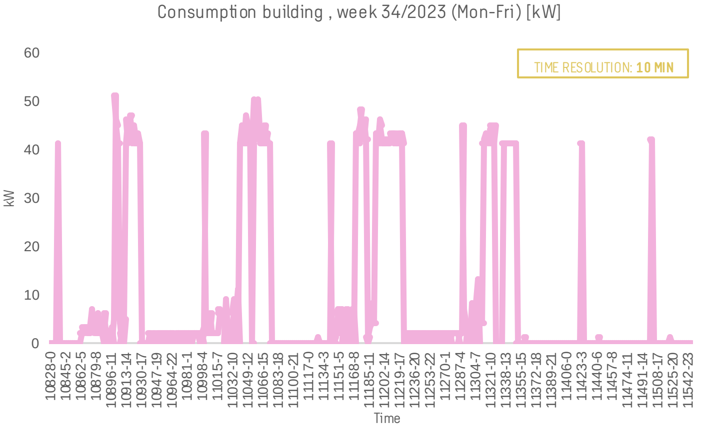
This power spike was recorded at 15:50 and lasted for half an hour. It seems unusual for the construction barracks to have such peaks and may indicate that some form of charging infrastructure was connected to the same circuit. This information has not been made available during the project period.

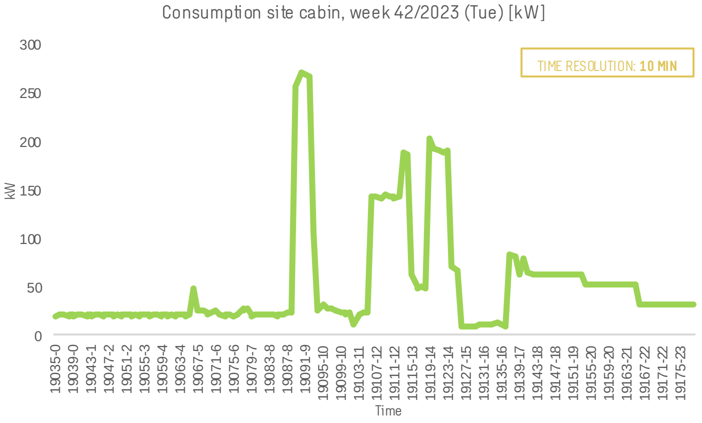
Building

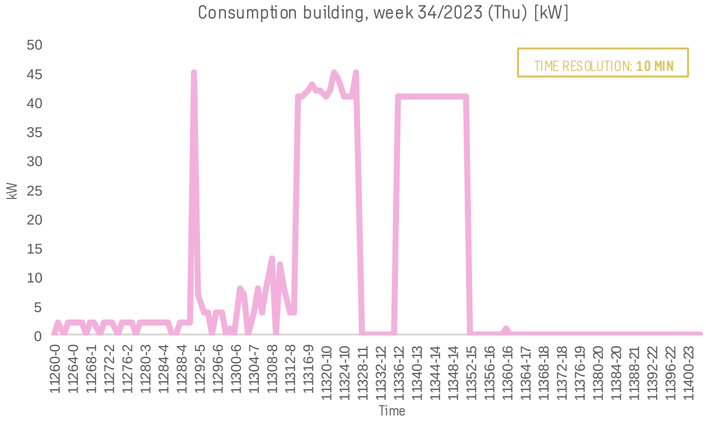
- Maximum power: 51 kW

The highest recorded power for the building occurred several times, especially in August (weeks 31-34). Some peaks were recorded during lunchtime (11-12), but a significant number also took place outside these times (09-10 and 14-16).Below are diagrams for selected weeks and days for the construction barracks and building.









Stovner bad | Power Consumption

Circuit Meters: Power-Specific Consumption Points

Here we see the maximum power [kW] for the circuits with **BoostPoint** and **Hummingbird**. The data is gathered from circuit meters with a 10-minute time resolution.

BoostPoint

- Maximum power: 168 kW

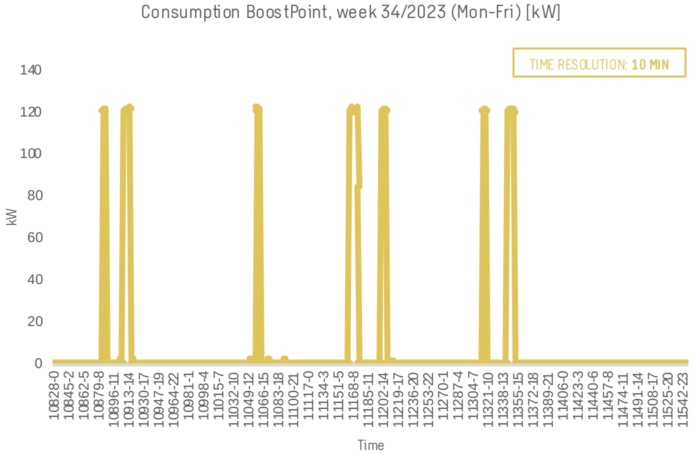
The highest power peaks recorded for BoostPoint occurred several times during the construction project: in weeks 23-25, 28, and 40-42. Most of the 168 kW peaks occurred between 16:30 and 19:30, with a few instances around 09:00 and 14:00.

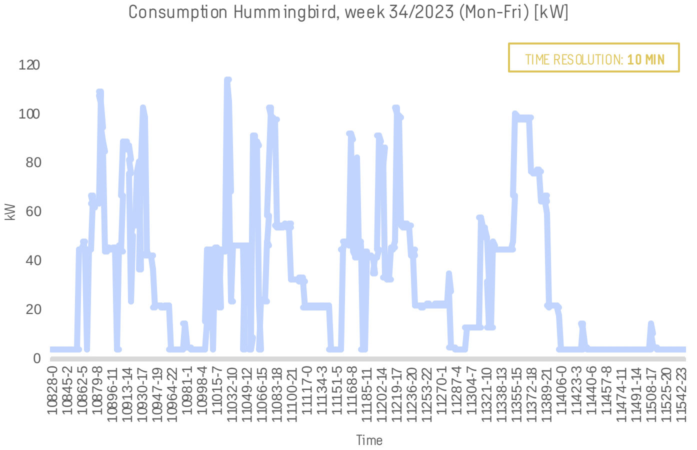
For comparison, BoostPoint has the capability to charge electric vehicles quickly and efficiently, with a maximum capacity of 360 kW per cable.

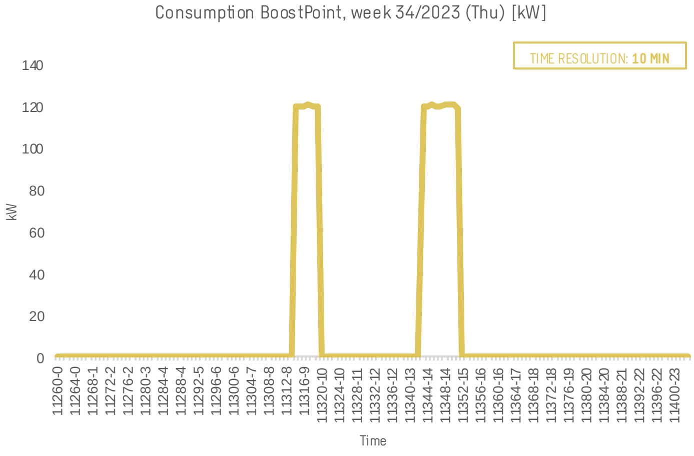
Hummingbird

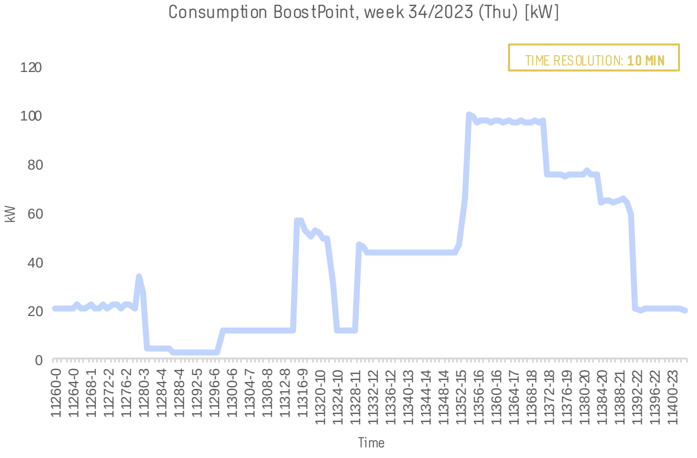
- Maximum power: 114 kW

The maximum power for Hummingbird occurred on three different days, all in August 2023. The peak lasted the longest on Wednesday, August 30, 2023 (from 14:40-15:00), while the other peaks occurred between 09:00-10:00 and 14:00-15:00 on the respective days.







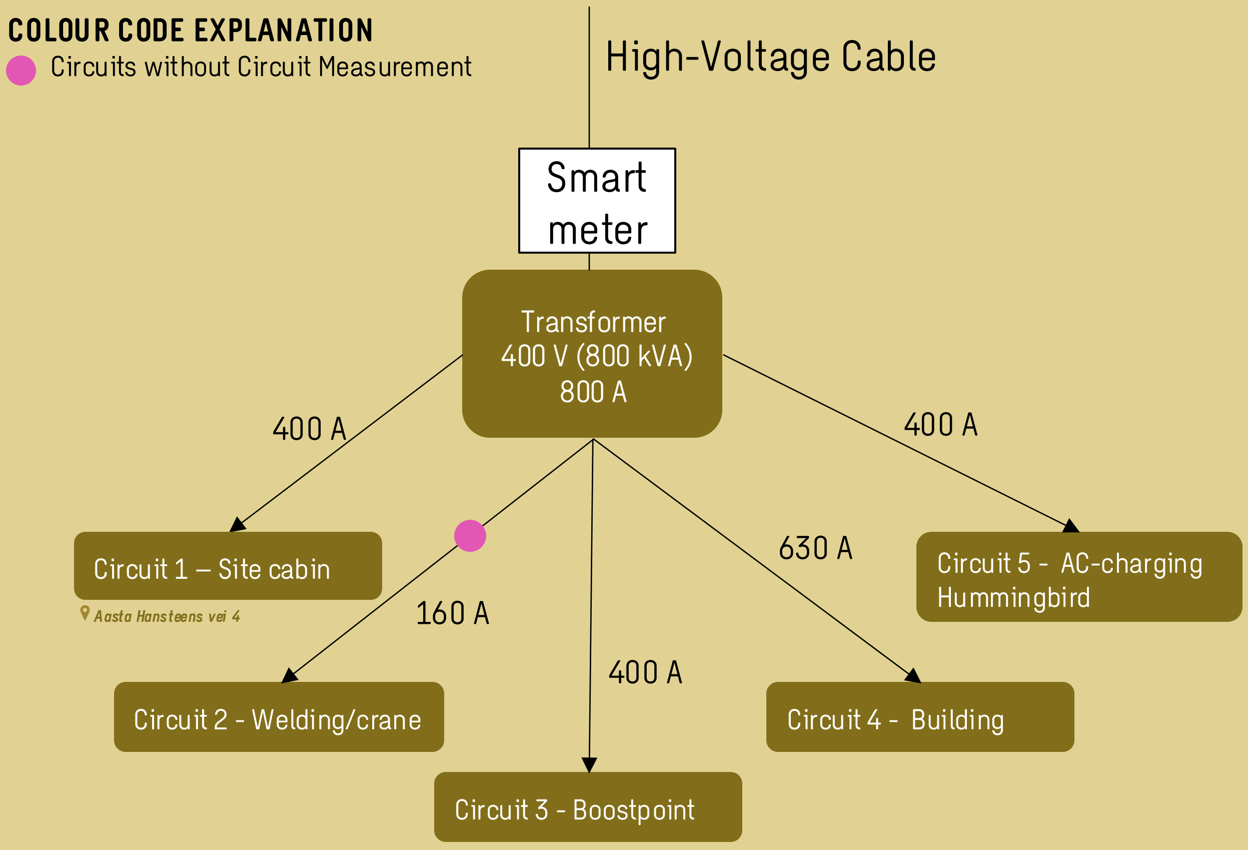


Reservations Regarding the Power Peaks

During the data analysis, Sweco became aware that there is some noise in the dataset. Without being able to further confirm the accuracy of the data for the project, the decision was made to exclude parts of the final delivery that require such data. As a result, the following sections under ***Power Consumption*** for the Stovner Bad project will not consider smart energy meter data for 2023 as part of the basis for estimating the project's peak power. Instead, the total circuit-measured consumption for 2023 will be used as the "final" power consumption.

This comes with limitations on the results:

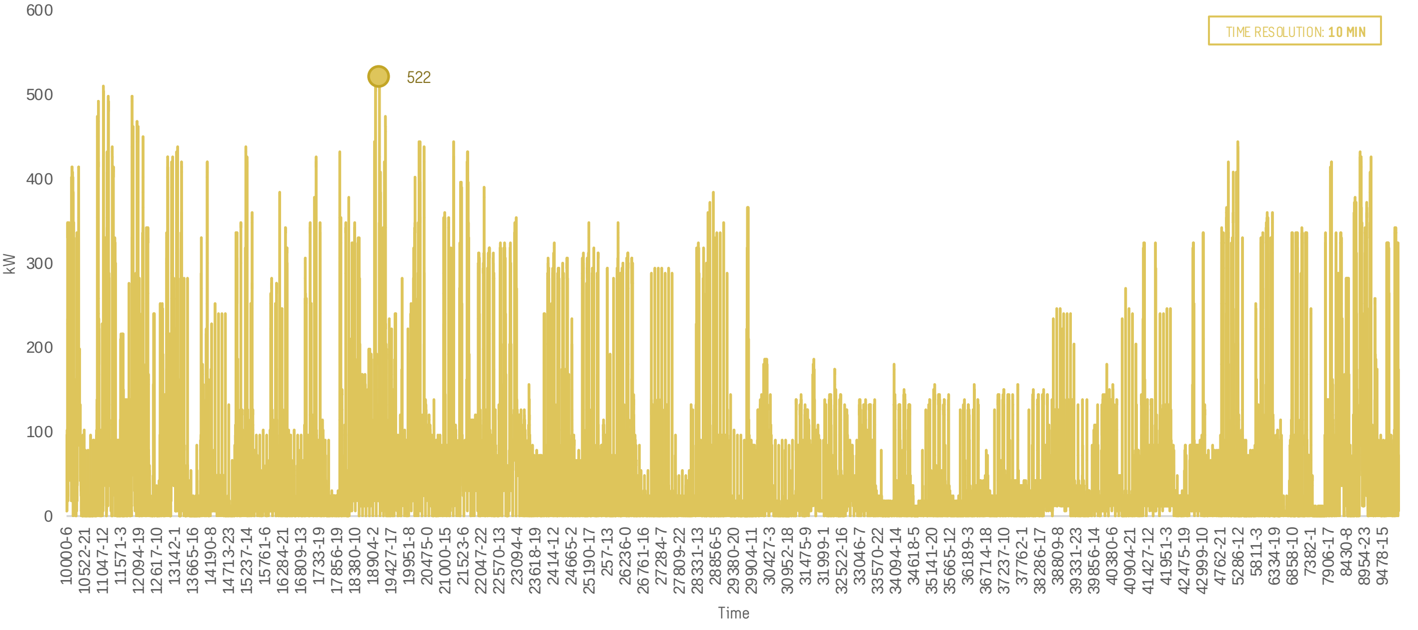
- The actual power consumption at Stovner will be higher than the reported total circuit-measured consumption, as this does not account for Circuit 2 – Welding/Crane, as well as any other electrical consumption that was not logged by the circuits mentioned in the power setup. The latter would have been captured with smart meter data.
- In reality, both power peak and potentially energy quantities in the project are likely underestimated.



Stovner bad | Power Peak [kW]

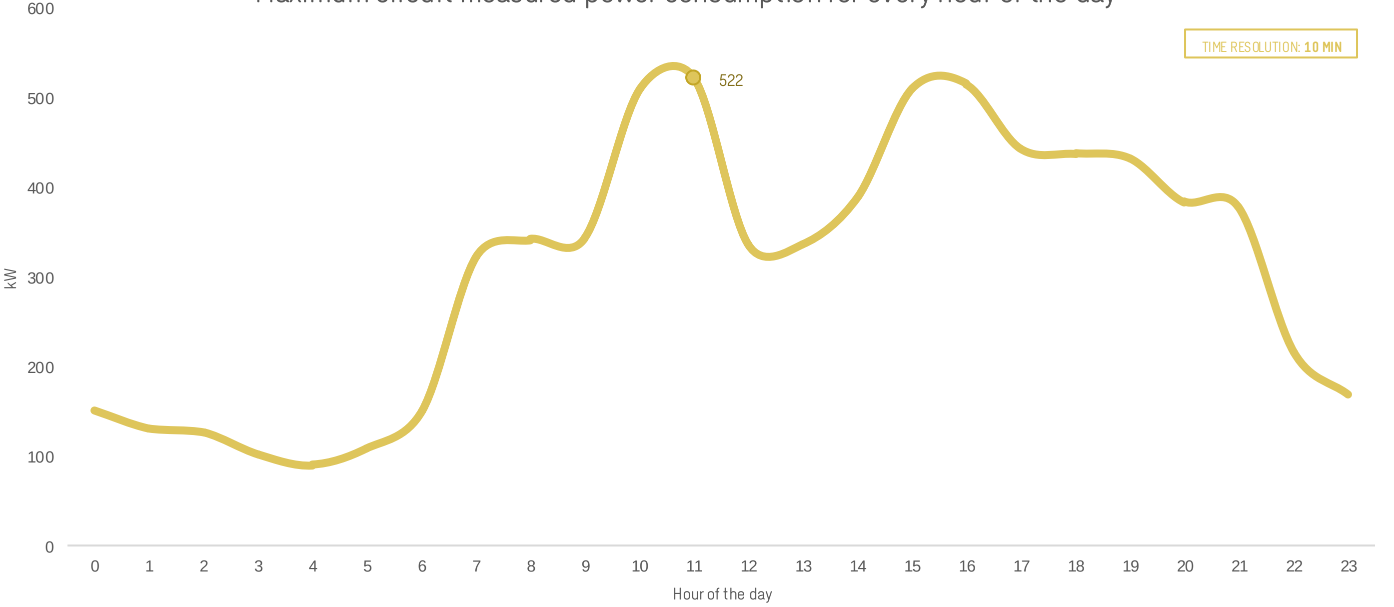
Power of the Entire Construction Project

Maximum circuit measured power consumption in the construction project



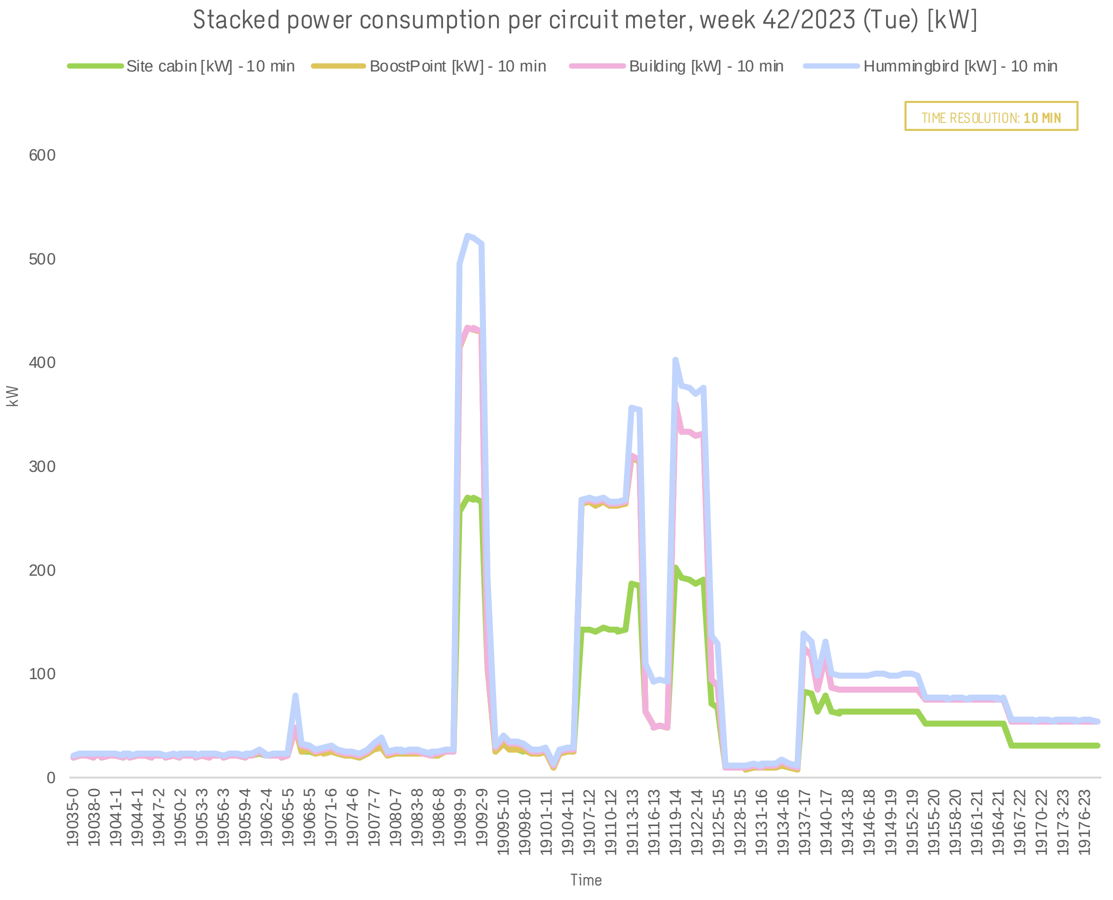
The highest peak power for the electrical consumption at the construction site was measured at 522 kW, recorded on Tuesday at 11:10, during week 42 in October 2023. The diagram above shows the power consumption for the entire construction period, while the one below displays the maximum hourly power peaks recorded for the project. The project's highest peak at 11:00 is highlighted here, along with high power levels observed between 15:00 and 17:00.

Maximum circuit measured power consumption for every hour of the day



Stovner bad | Power Peak [kW]

Day with the highest recorded peak power



Hours in a day	Hourly average peak for the construction project
0	30
1	25
2	23
3	21
4	19
5	18
6	19
7	27
8	32
9	33
10	62
11	98
12	46
13	44
14	51
15	75
16	98
17	48
18	55
19	66
20	55
21	48
22	42
23	36

The peak power of 522 kW on the day in question comes from various sources. The construction barracks contributed 270 kW, BoostPoint contributed 162 kW, the building did not contribute any power, and Hummingbird contributed 90 kW. This means the peak power is distributed as follows: 52% from the construction barracks, 31% from BoostPoint, 0% from the building, and 17% from Hummingbird. It's worth noting that charging with BoostPoint and Hummingbird accounts for 48% of the peak power.

It is likely that there is additional power consumption in the project that is not captured by these circuit measurements. The percentages above are based solely on the available circuit data, and there is some uncertainty regarding these figures.

The project's peak power represents a 433% increase compared to the average power recorded at 11:00 throughout the project's execution period.

Stovner bad | Cause of Power Peak

The historical activities carried out at the construction site are numerous, and the progress plan gives us an indication of potential activities that may have caused high power demand.

From the main progress plan for the project, it appears that groundwork was the ongoing construction phase on October 17, 2023. It cannot be ruled out that charging of other machines and vehicles, not listed in the machinery list at the relevant time, may have contributed to the power peak.

Activities on October 17, 2023:

Groundwork

- Pre-excavation
- Sheet piling
- Piling
- Mass filling
- Demolition/filling of underpass on Fossumveien (fiber relocation and district heating)
- Concrete work: In-situ concrete – bottom slab part 1 for insulation, reinforcement, earthwork, water/sewage, and pouring started on October 16

From the machinery list for October, it appears that the following electric construction machines were in use:

2023	October	Electrical [kWh]	Excavator	Hitatchi EL, ZE210-6
2023	October	Electrical [kWh]	Excavator	Volvo EE230
2023	October	Electrical [kWh]	Excavator	Hitatchi
2023	October	Electrical [kWh]	Excavator	Volvo EE230
2023	October	Electrical [kWh]	Wheel loader	Cramo
2023	October	Electrical [kWh]	Crane	Tower crane

If the electric tower crane is excluded (which was supposed to have its own dedicated circuit measurement and is therefore not included in the calculated peak power), five electric construction machines (excavators and one wheel loader) remain that may require charging during the workday.

5 Sophies Minde

Enerhaugen Arkitekter

Sophies Minde | Information

Renovation

Potential Demolition – Ground Work – Structural Work – Facade – Interior Work – Exterior Work

Sophies Minde building at Carl Berner place in Oslo is undergoing a total renovation. It will continue to house a kindergarten, as well as offices and district functions for Bydel Grünerløkka. A health center, maternity care, Oslohjelpa, and a community hall for district residents will be established. A total of 13,000 m² will be renovated. Additionally, the outdoor area will be upgraded, with approximately 7,100 m² of outdoor play space being developed. The project aims to achieve "Excellent" certification under BREEAM-NOR and is being carried out as a zero-emission construction site.

The project began in August 2023 with setup, drainage, water and sewage (VA), and structural demolition. It is scheduled for completion in mid-2026. The main contractor for the project is Vedal Entreprenør.

The construction project aims to be carried out as a zero-emission site. The construction site is supplied with an available power capacity of around 2,000 kW. Heating and drying of the building are handled by electricity through the use of fan heaters and other heating elements. District heating has not been used. Additionally, a charging container provided by Aneo with two CCS2 charging points (BoostPoint from Nordic Booster) has been in use, primarily for charging excavators. There has also been a battery container—a Hummingbird from Nordic Booster—on-site, equipped with CCS2, Type 2, and industrial plugs. The construction site also has one tower crane and 20 construction barracks, which will increase to 42 by mid-2024 (thus not part of the analysis period for this report).

The project has not utilized extra energy meters beyond the smart energy meters except for those in the charging container. There are two smart energy meters on-site.

Sweco has received the following relevant data and information from the project:

- Monthly machine overview including accumulated consumption

- Smart energy meter data with hourly resolution [kWh/h] for 2 meters.

- Measurement of two CCS2 charging points for fast charging of machines, with 1-minute resolution from August 2023

- Grid capacity: 2,450 kVA total transformer capacity. Two existing transformers and one temporary transformer, equivalent to around 2,000 kW

- 20 construction barracks

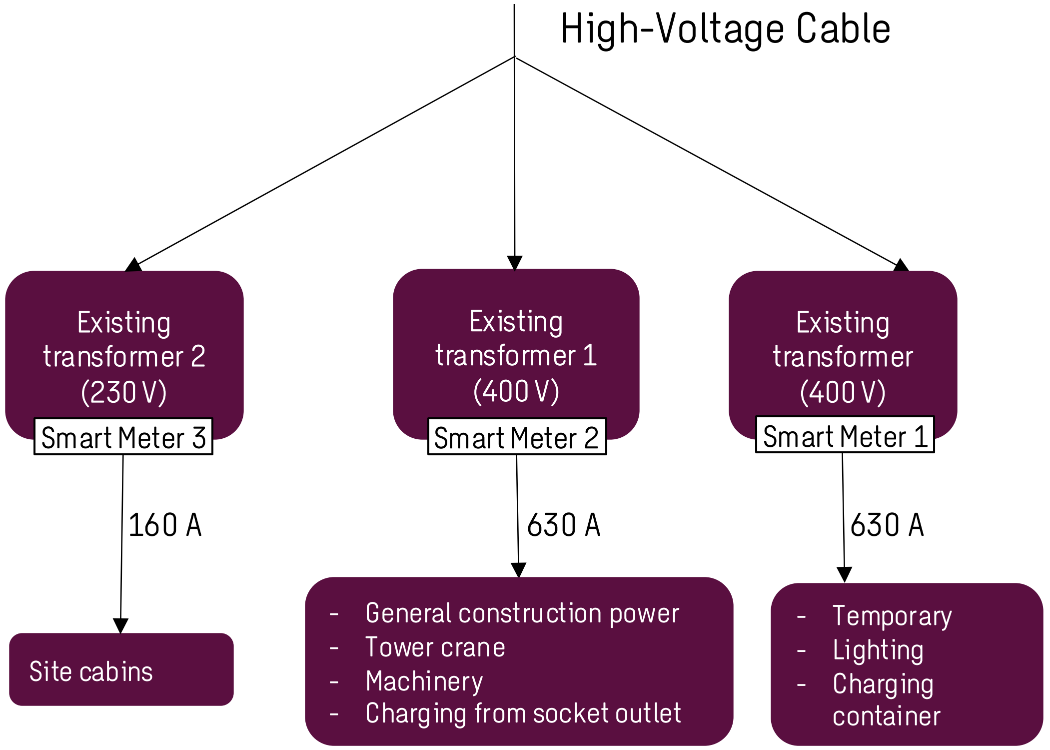
ANALYSIS PERIOD: Aug. 2023- Mar. 2024

Key figures for logged part of the construction period:

- Maximum power consumption: 397 kWh/h (16:00 Thursday, week 1 in January 2024)
- Average hourly power consumption: 117 kW
- Average monthly consumption: 74,802 kWh
- Average daily consumption: 2,375 kWh
- Total energy consumption: 448,810 kWh
- Zero-emission share of energy use during the constructi phase: 100%
- Zero-emission share of energy consumption for machinery: 100%

Sophies Minde | Information

Power Setup

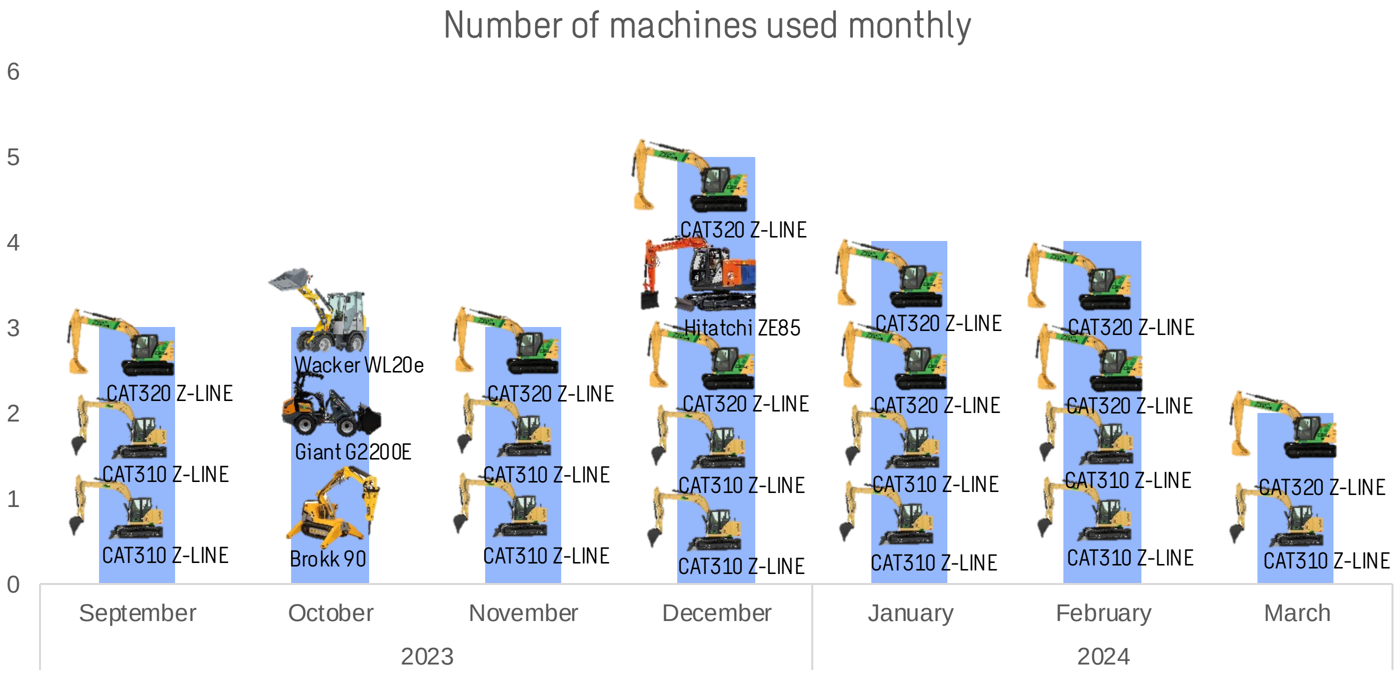


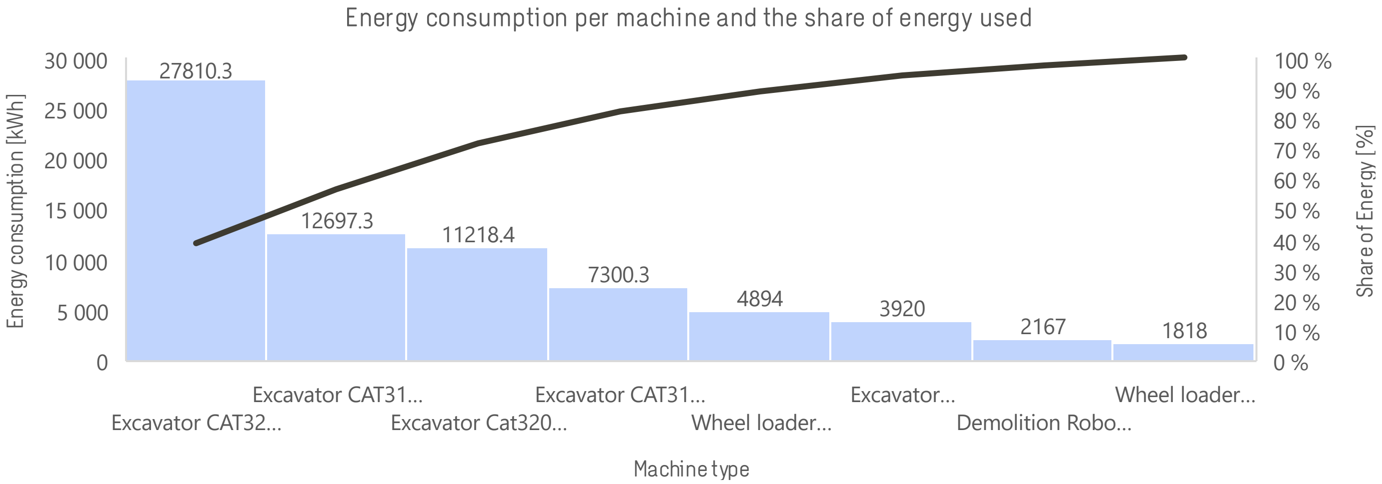
During the analysis period (October 1, 2023, to March 31, 2024), three existing transformers have been in operation. Based on information from the construction site, around 800-900 kW of power is available. Each transformer has an smart energy meter. There is no circuit-measured consumption, except for the consumption from the two fast-charging points (CCS2) in the charging container provided by Aneo.

Starting from May 31, the existing transformer (with Smart Meter 1) will be replaced by a new transformer with larger capacity. This is due to the introduction of an electric drilling rig. The new transformer, which is not included in the analysis above, will have a capacity of around 1,550-1,650 kW and is intended to supply the charging container with two CCS charging points, as well as support well drilling and compressor operations for well drilling.

Sophies Minde | Information

List of Machines





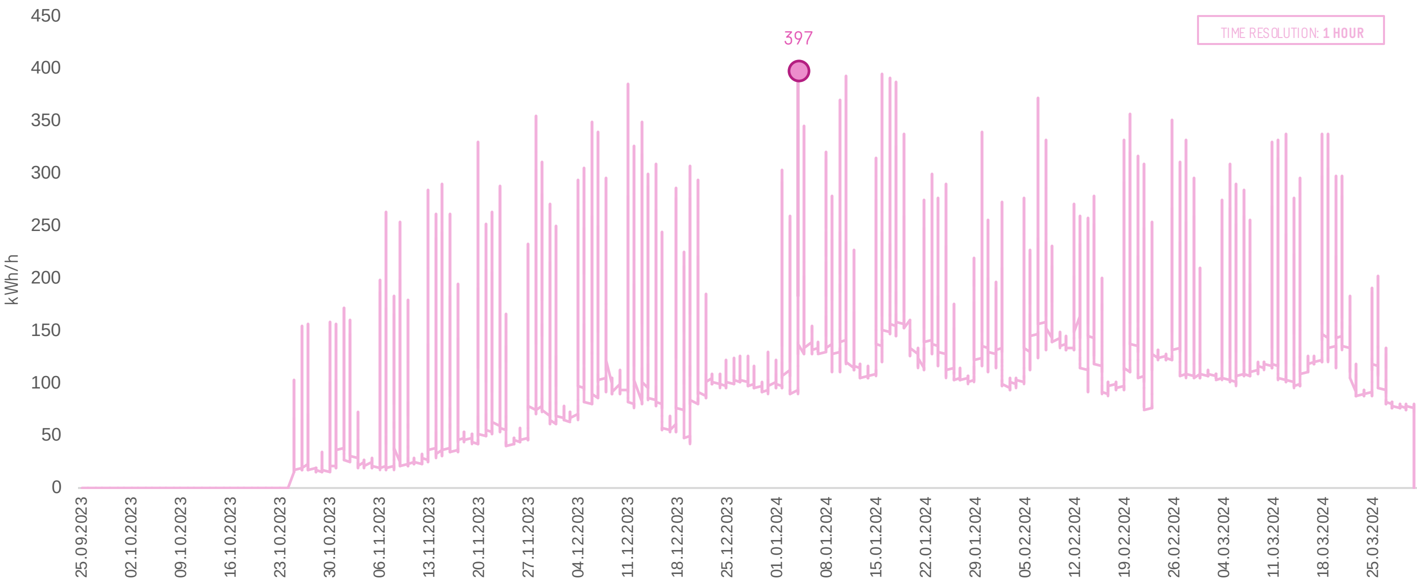
The diagram above provides an overview of the active construction machines used in the project. Throughout the period, the project has exclusively used electric machines.

The majority of machines in use, as shown above, have been within the excavator category. Excavators accounted for 88% of the energy consumption during the analyzed period. This is particularly true for the CAT 320 Z-line, which was in use for 6 out of the 7 months of the analysis period. A possible explanation for this is that Sophies Minde is a renovation project, with a large outdoor area that has required significant excavation work. In comparison, new construction projects typically have a greater need for lifting work with cranes, etc.

Sophies Minde | Power Peak [kW]

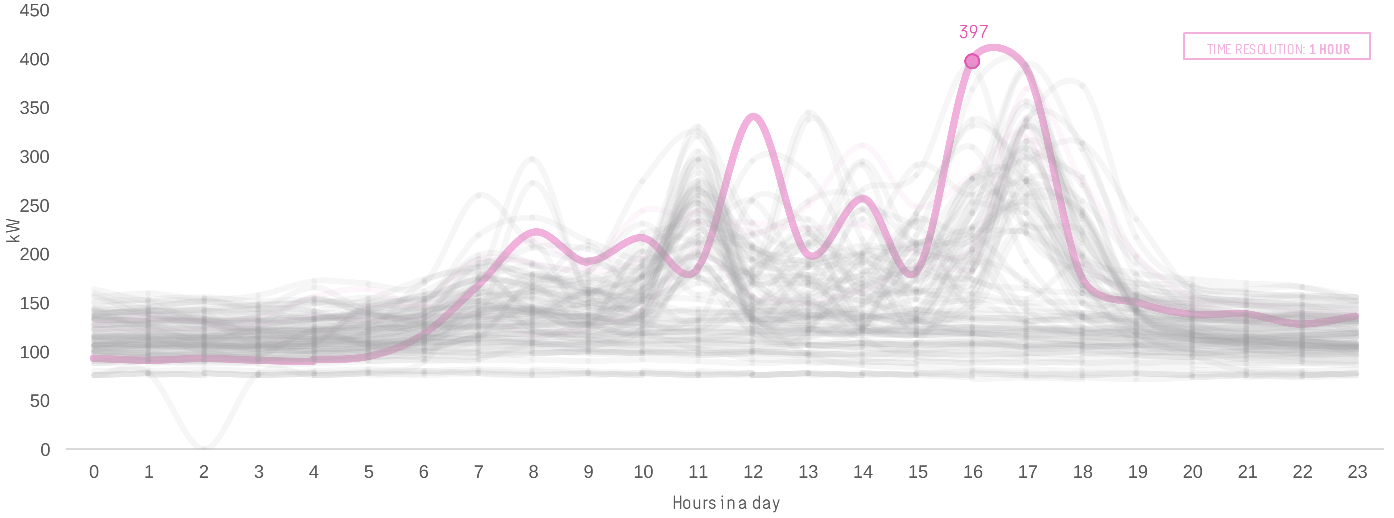
Power of the Entire Construction Project

Total power consumption from all smart meters on the construction site



The highest peak power for the electrical consumption at the construction site was measured at 397 kW, recorded on Thursday at 16:00 during week 1 in January 2024. The diagram above shows the power consumption for the entire construction period, while the one below displays daily consumption curves for 2024, highlighting the day with the highest peak power. The base load was around 20 kW at the start of the construction period, with peaks reaching up to 200 kW. The base load has gradually increased throughout the construction period and now stands at around 90 kW.

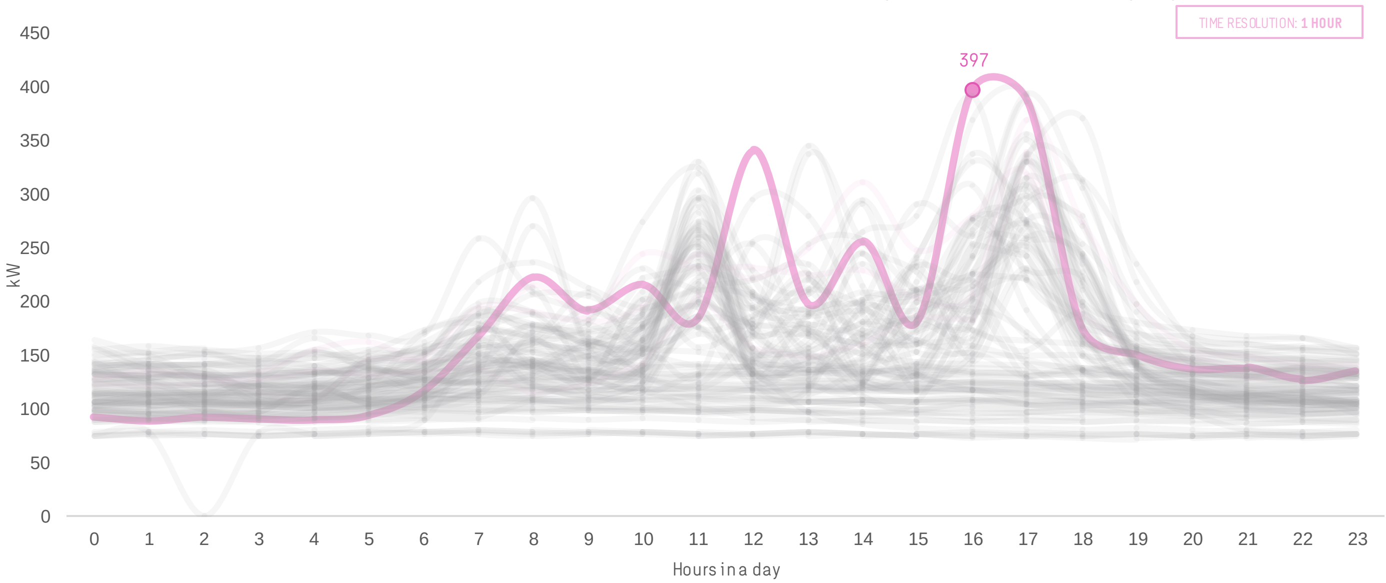
Daily power consumption curves in 2024 where the day with the highest power peak is highlighted



Sophies Minde | Power Peak [kW]

Day with the highest recorded peak power

Daily power consumption curves in 2024 where the day with the highest power peak is highlighted



Similar to the highest peak power recorded at 16:00 on Thursday during week 1 in January 2024, a significant proportion of peak power events occur around the same time or around 11:00. This is clearly linked to the frequent use of two fast chargers at these times, which is the main cause of the peak power.

In the table on the right, the average consumption for each hour of the year in the construction project has been calculated, covering the period from September 2023 to March 2024. Additionally, the average for each hour across all years is shown on the far right ("average of averages").

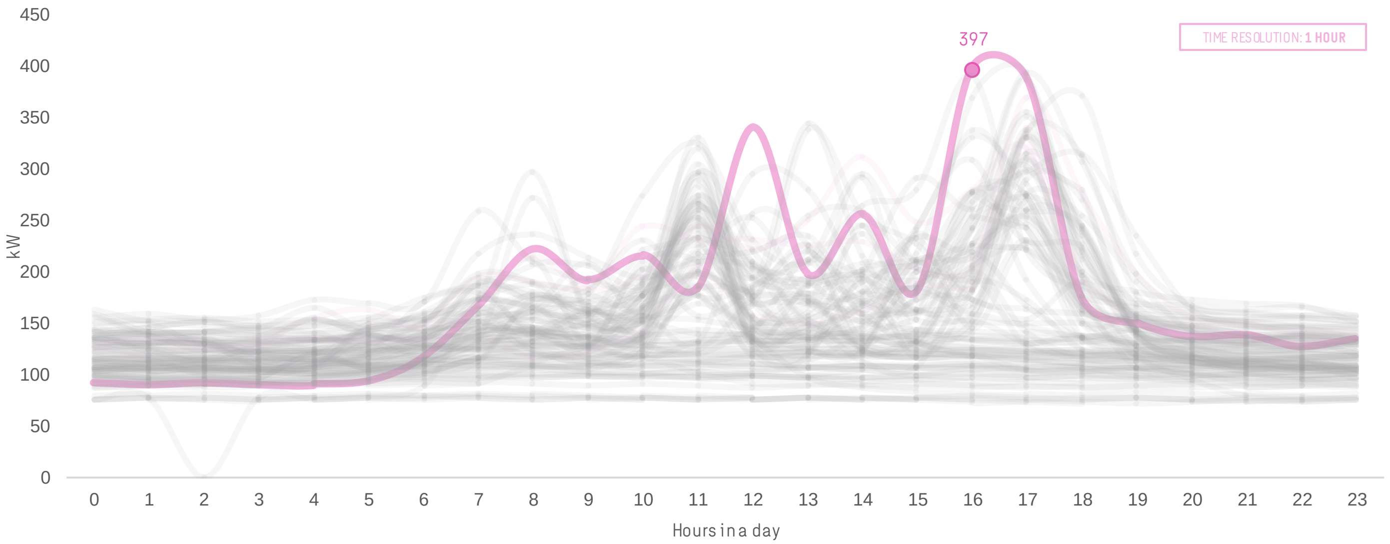
The highest peak that occurred on Wednesday at 16:00 during week 1 in January 2024 represents a 360% increase compared to the average power at 16:00 in 2023, a 123% increase compared to 2024, and a 200% increase compared to the overall average for that hour.

The table on the right clearly shows that the peak power events for this construction project typically occur either at 11:00 or between 16:00-18:00. The reason, as mentioned, is that two electric machines are fast-charged either during lunchtime or at the end of the workday.

Hours in a day	**Average hourly power for each year** 2023	2024	Average of average
0	40	117	78
1	40	117	78
2	41	114	78
3	41	114	78
4	44	117	80
5	44	119	82
6	46	124	85
7	56	140	98
8	60	145	102
9	64	138	101
10	65	148	106
11	94	188	141
12	82	154	118
13	73	154	114
14	75	155	115
15	77	154	116
16	86	178	132
17	102	204	153
18	90	162	126
19	63	132	98
20	51	123	87
21	46	120	83
22	43	118	81
23	41	117	79

Sophies Minde | Cause of Power Peak

Daily power consumption curves in 2024 where the day with the highest power peak is highlighted

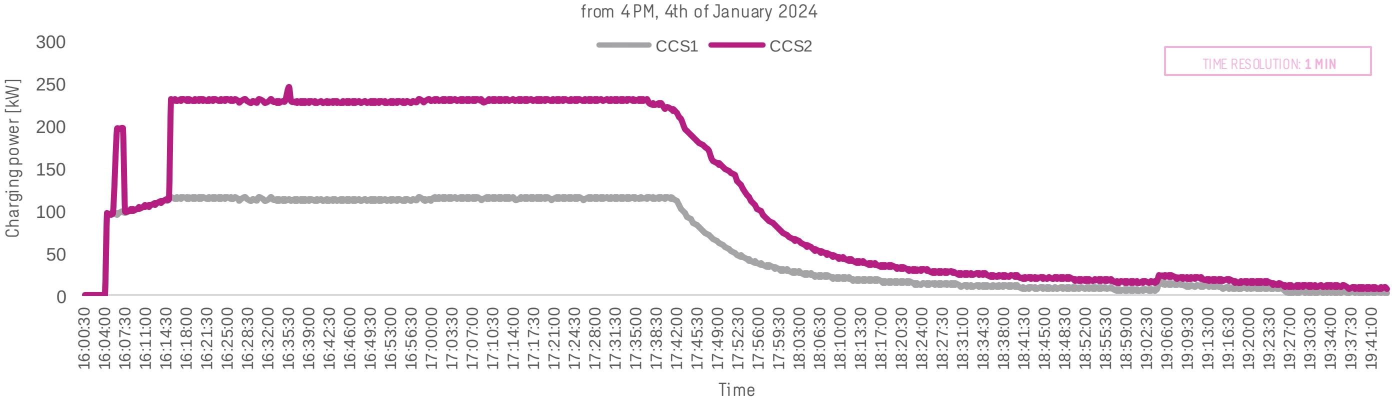


On the day with the highest peak power, it is evident that both fast chargers were in use simultaneously, as shown in the diagram below. Together, they reached a maximum power of 258 kW, with an average of 203 kW over the relevant hour, accounting for 51% of the highest peak power as an hourly average. The remaining power, after subtracting this, is 194 kW. With 20 construction barracks consuming around 30 kW, it is reasonable to assume that the remaining 164 kW was used for charging other excavators, as it is reported that there were four excavators on-site in January.

The two excavators that are not fast-charged can charge at a maximum of 80 kW. It has been reported from the construction site that six 18 kW heaters were in use for building heating during the winter, which accounts for a maximum of 108 kW. Additionally, some of the power went towards lighting and the site's single tower crane.

In summary, the two CAT 320 Z-line excavators being fast-charged simultaneously are the main cause of the peak power for this construction project.

Stacked simultaneous charging power CCS1 and CCS2 [kW]
from 4 PM, 4th of January 2024



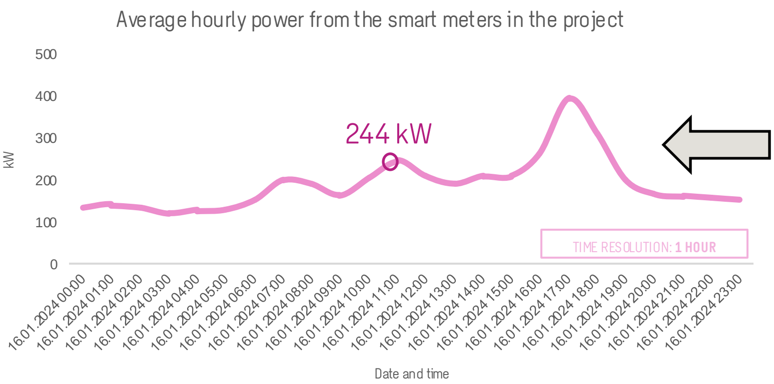
Sophies Minde | Cause of Power Peak

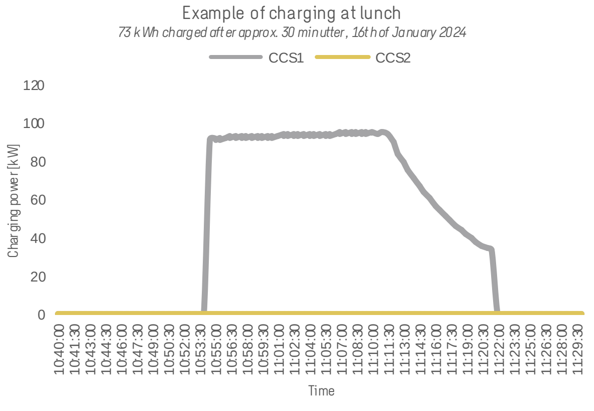
In this case, an easy solution to reduce the cause of the peak power is to distribute the charging over the evening and night, allowing the machines to be ready for the next day. Currently, the machines are plugged in at the end of the workday, and two uncontrolled charging sessions are initiated. The charging curves start around 16:00 and quickly reach 100 kW before tapering off after around 2 hours, each machine charging at 115 kW. Instead, the charging could be spread over the next 15 hours, which would allow each machine to charge at a rate of 20-50 kW, thereby reducing the peak power caused by this charging pattern by at least 60%.

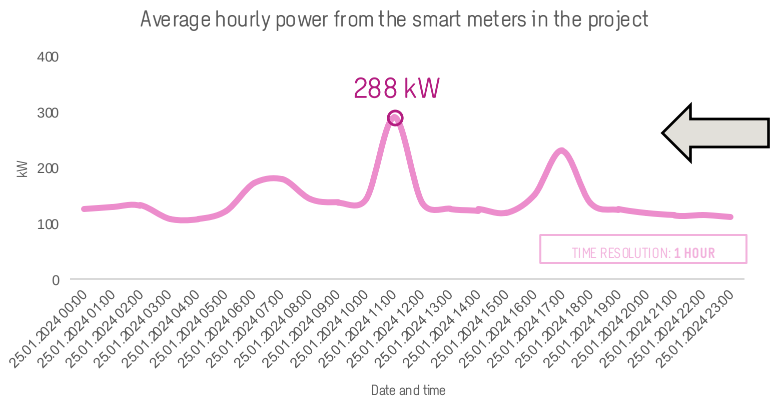
However, if the cause of the peak power in the evening is resolved, a new peak will occur in the middle of the day, which is more difficult to manage—lunchtime charging. The machines still need to be charged during the workday, especially for construction projects with multiple shifts.

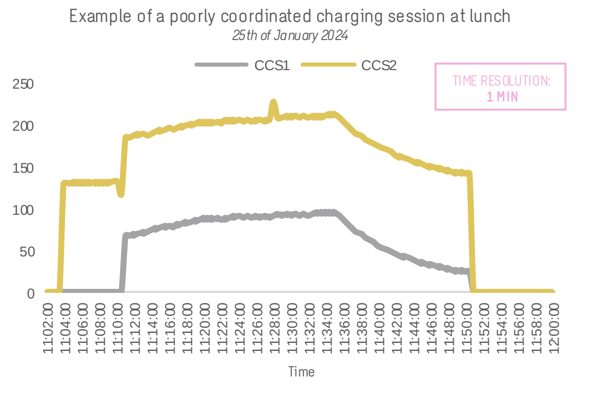
> Distributing the charging evenly throughout the evening/night is easy to achieve, but it requires that those who initiate the charging have the opportunity to provide information to the charging system about when the charging must be completed. So far, few in this market have implemented this functionality. **!**

Charging during lunchtime is a clear cause of power peaks in most construction projects with a high proportion of electric machines. Solving this peak power issue seems, in theory, easy to address by, e.g. changing routines related to lunch breaks to avoid simultaneous charging. Below, you can see how simultaneous charging during lunchtime increases the peak power. In the top diagrams, one machine is fast-charging, while two machines are charging simultaneously in the lower diagrams.



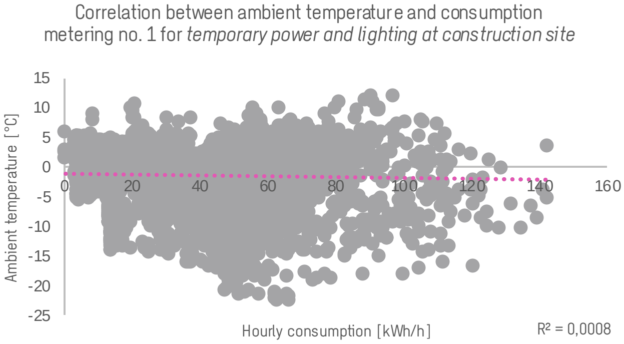


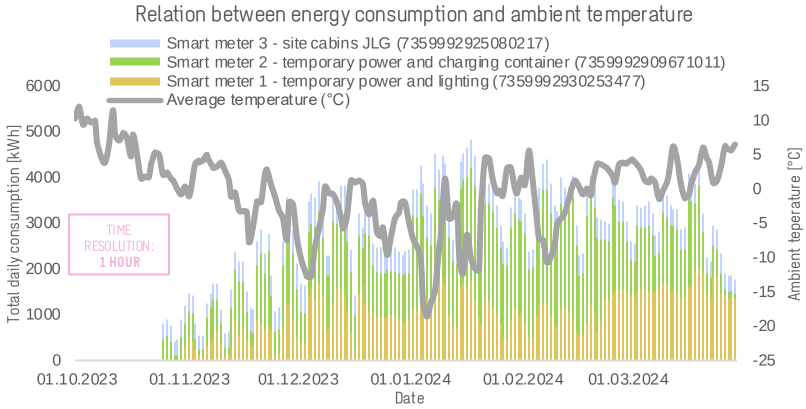


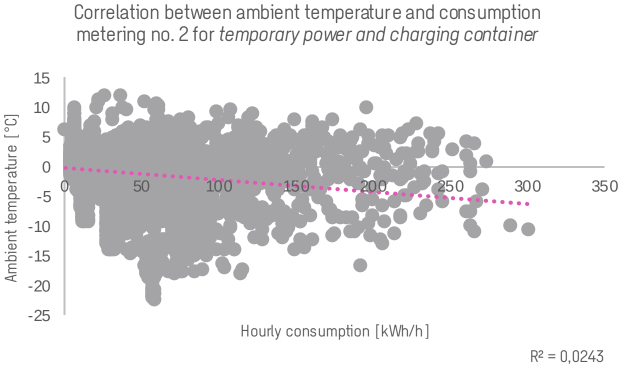


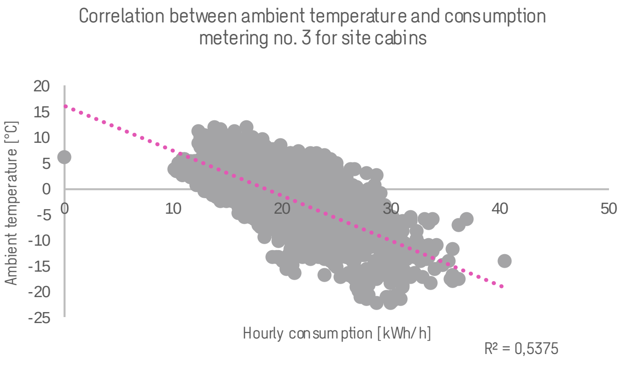
Sophies Minde | Temperature and Consumption

Correlation









As clearly shown in the figures to the left, which illustrate the relationship between outdoor temperature and smart meters, there is very little correlation between outdoor temperature and energy meter 1 and energy meter 2. The third smart meter, which is dedicated to measuring the site cabins, shows a very strong negative correlation.

To examine the relationship, a linear correlation factor has been calculated between the consumption per smart meter and outdoor temperature. The data is at an hourly resolution.

There is a negative correlation factor, also known as the correlation coefficient, between outdoor temperature and the consumption of each the energy meter. The correlation factor is a statistical measure that describes the strength and direction of a linear relationship between two variables. The value of the correlation coefficient ranges between -1 and 1.

A value of 1 represents a perfect positive linear relationship between the variables. A value of 0 indicates no linear relationship, and -1 represents a perfect negative linear relationship. Negative values, as seen here, indicate that as one variable decreases (in this case, temperature), the other increases, meaning consumption rises.

The correlation values between outdoor temperature and each of the different smart meters are as follows:

- **Energy meter-1** - Temporary power and lighting: -0.061848784. This indicates almost no relationship, a very weak negative correlation.
- **Energy meter-2** - Temporary power and charging container: -0.156035915. This indicates a weak negative correlation.
- **Energy meter-3** - Site cabins: -0.733119257. This indicates a strong negative correlation.

SUM of smart meters: -0.193808749. Overall, the influence of outdoor temperature on total consumption indicates a weak to moderate negative correlation. This means that as outdoor temperature decreases, consumption will rise slightly to moderately. Based on the available data, it appears that this correlation is primarily due to the heating of (1) the construction barracks and (2) the building heating. It is assumed that building heating and possibly drying are distributed across the other meters and account for the weak negative correlation for smart meter 1 and smart meter 2.

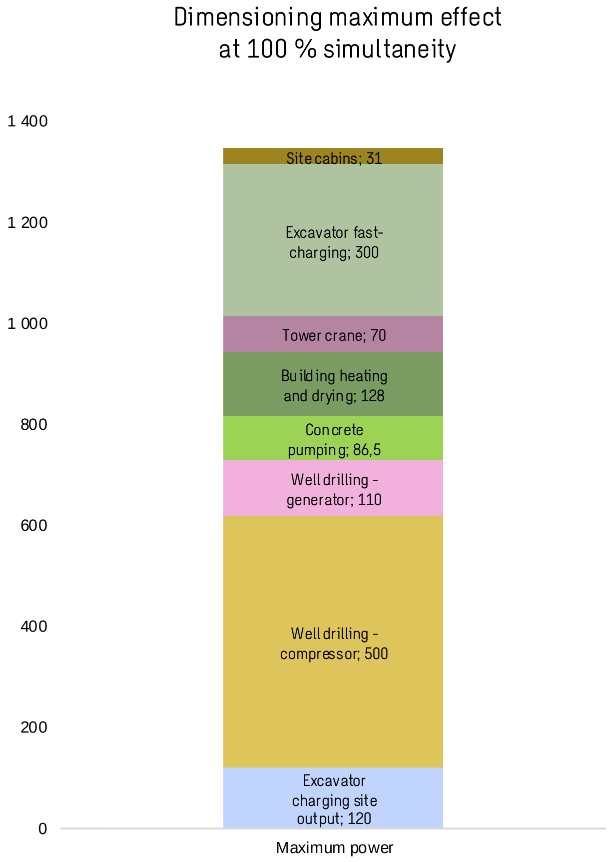
Sophies Minde | Power Consumption

100 % Electrical Construction Site

Sophies Minde has so far been a 100% electric and therefore zero-emission construction site. The highest recorded peak power to date has been 397 kW. This appears to be a relatively low peak power compared to the equipment present on-site, and this deserves attention. However, the electric drilling rig has not been in operation during the analysis period.

In January, the heaviest month on the construction site, there were 5 electric excavators in operation. The machines could charge simultaneously at 2 fast-charging points or industrial sockets. Full simultaneous charging would amount to around 420 kW. Additionally, there were 20 construction barracks consuming around 30 kW, 1 tower crane estimated at 70 kW, 8 fan heaters of 16 kW each for building heating, totaling 128 kW, concrete pumping at 86 kW, an electric generator supplying hydraulics to the drilling rig at 110 kW, and the compressor component of the drilling rig at 500 kW, which is used for drilling energy wells.

If all of this equipment were to consume maximum power simultaneously, the total peak power on-site could reach up to 1,350 kW. However, this does not all happen at the same time, even though it could at Sophies Minde, as the site has a grid capacity of 2,450 kVA.



(1) If these activities occur in the summer with an outdoor temperature of, for example, 22 °C, the power demand could be reduced by almost 35% to around 890 kW, as only about 5 kW would be drawn from the construction barracks, and there would be no need for building heating.

(2) Additionally, the machines do not necessarily operate simultaneously, nor do they always run at full capacity for their operations.

Below are two scenarios that could have occurred on the day with the maximum logged hourly consumption, helping to explain why the registered peak power so far has been so low. A key factor is that nominal capacity is not always reached. For example, the concrete pumping may have used only 50% of its nominal capacity (see scenario 1 below). Alternatively, it may not have been in use, while there may have been greater demand for building heating and machine charging (see scenario 2 below).

Factor in relation to nominal performance	Scenario 2	kW
1	Site cabins	31
0,8	Excavator fast-charging	240
0,3	Tower crane	21
0,6	Building heating and drying	76,8
0	Concrete pumping	0
0	Well drilling - generator	0
0	Well drilling - compressor	0
0,3	Excavator charging site output	36
	SUM	**405**

Factor in relation to nominal performance	Scenario 1	kW
1	Site cabins	31
0,8	Excavator fast-charging	240
0,3	Tower crane	21
0,5	Building heating and drying	64
0,5	Concrete pumping	43,25
0	Well drilling - generator	0
0	Well drilling - compressor	0
0	Excavator charging site output	0
	SUM	**400**

6 Construction Projects for Water and Sewage

Construction projects | Introduction

In this project, the goal has also been to analyze construction projects managed by the City of Oslo. However, due to a lack of detailed data, this part of the assignment has been deprioritized. Nevertheless, we will provide some information on a selection of construction projects. Special thanks to Synne Sidenius, formerly at the Water and Sewerage Department (WSD), now at UKE in Oslo Municipality, and Espen Hauge at WSD for kindly sharing data.

Construction projects for W&S

The construction projects we have analyzed are carried out by the Water and Sewerage Department (WSD) in Oslo Municipality. These projects specifically focus on pipeline renewal/renovation and are not representative of other types of construction projects. WSD typically has around 40-50 projects in progress at any given time. In 2023, they had more than 30 zero-emission machines and vehicles distributed across these projects.

Experience so far shows that the maximum power demand per zero-emission construction site is between 50-300 kW, depending on the type of project and how the setup and logistics are organized for each individual project.

Typical project execution for this type of work often follows this process:

Excavation/blasting/jackhammering → removal of old pipes → laying new pipes → backfilling with new materials → compaction and road construction → asphalting. Typically, no more than 20 meters is worked on at a time to avoid having an open trench for too long. Asphalting is done either at the very end or in larger segments to complete the project or create temporary roads so that normal traffic can resume.

Typical equipment used in these types of construction projects includes:

- Excavator
- Pipe-bursting machine
- Construction barracks
- Wheel loader
- Asphalt paver
- Milling machine (often mounted on an excavator)
- Drilling rigs (often mounted on an excavator) and compressor
- Sheet piling (often mounted on an excavator)
- Concrete pump
- Vibrating plate
- Roller

Excavators handle most of the work. In some cases, pipe-bursting machines are used, but excavators are also common for this type of project.

In this report, we have access to smart energy meter data for the following construction projects managed by WSD:

- Lybekkveien
- Danmarks gate
- Hovseterdalen Nodig
- Klosterenga
- Lindeberg pipe-bursting (Alnaparkv. and Prof. Birkelandsv.)
- Noreveien
- Ansgar Sørlies vei 75
- Silurveien 44

We only have access to the machinery list for the following projects:

- Danmarks gate
- Klosterenga
- Hovseterdalen

These are the projects that will be highlighted in this report. For the remaining projects, only key figures such as maximum hourly power, average hourly power, monthly consumption, and total energy consumption will be presented.

Construction projects | Hovseterdalen

W&S

The Water and Sewerage Department (WSD) in Oslo has renovated water and sewer pipes through Hovseterdalen as part of this project. Two sewer lines follow the route down Hovseterdalen Park and were renovated using a trenchless method. This is done by accessing a manhole and threading a new pipe through the existing one to the next manhole. This method was used on the sewer lines from V1 to V18. The water main running through the park was upsized from 150 mm to 300 mm. From V1 to K2, digging was done to connect to an existing pipe. From K2 to V18, the pipe was "burst." In practice, this means digging a trench 6 meters long and 3 meters wide at two manholes to pull the new pipe through the old one. This approach avoided having to excavate the entire pipe route and all the manholes. However, excavation was still required at all the connections on the water main and at every other manhole.

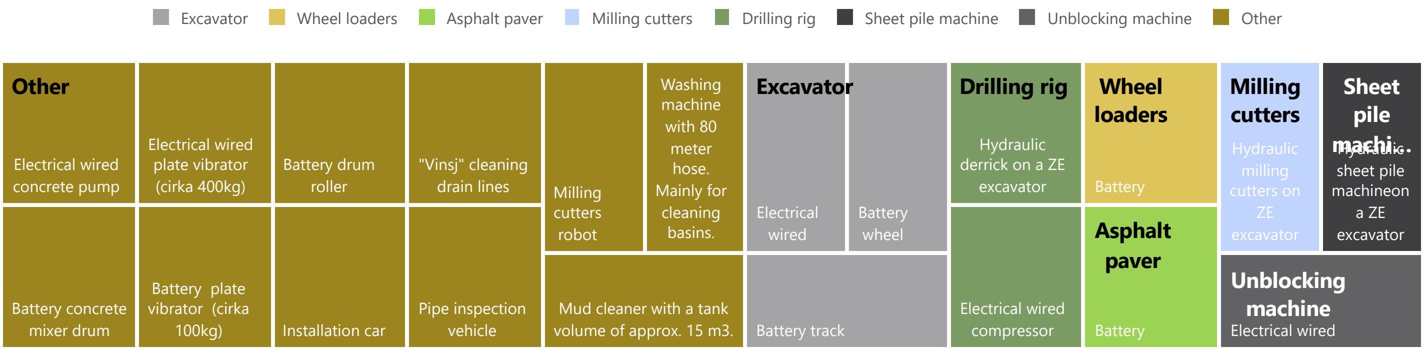
ANALYSIS PERIOD: November 2022 - March 2023
Key figures for logged part of the construction period:

- Maximum hourly power: 214 kW (February 23, 2023, at 12:00)
- Average hourly power: 33 kW
- Zero-emission machinery fleet: 100%
- Average daily consumption: 765 kWh
- Average monthly consumption: 18,216 kWh
- Total energy consumption: 91,080 kWh

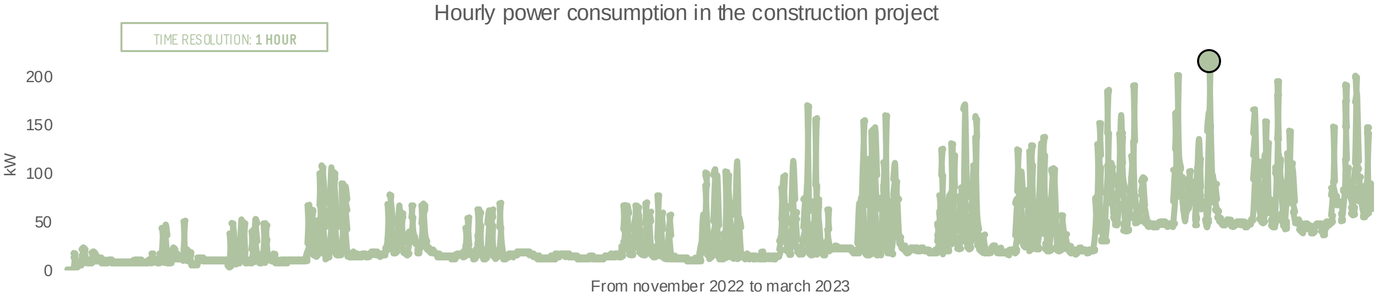
The base load in the project increases from the start towards the end, rising from around 10 kW at the beginning to about 50 kW towards the end. It is also during this later period that the highest peak power of 214 kW occurs. In the final phase, there is a difference of around 160 kW between the base load and the peak power. In the initial phase, this difference ranges between 60-100 kW.

Progress Plan
- February 9, 2023 – March 8, 2023: Excavate and replace the water main from V1 to K2.
- November 7, 2023 – March 8, 2023: CIPP renovation of both sewer lines from V1 to V18.
- February 9, 2023 – August 2, 2023: Stage 1: Pipe bursting of the water main and associated work from K2 to V10.
- July 5, 2023 – December 8, 2023: Stage 2: Pipe bursting of the water main and associated work from V10 to V18.
- December 15, 2023: Handover of completed facility..

Machine and equipment used on Hovseterdalen [100% emission-free]



Hourly power consumption in the construction project



Construction projects | Klosterenga

W&S

Klosterenga is a construction project that began in August 2021 and was completed in the spring of 2023. The project involved upgrading 66,000 m² of park, digging 1,500 meters of trenches, removing 10,000 tons of contaminated soil, and opening 450 meters of stream through the park. Twelve large concrete structures were to be built, and 5,000 m³ of materials were to be redistributed internally on the construction site.

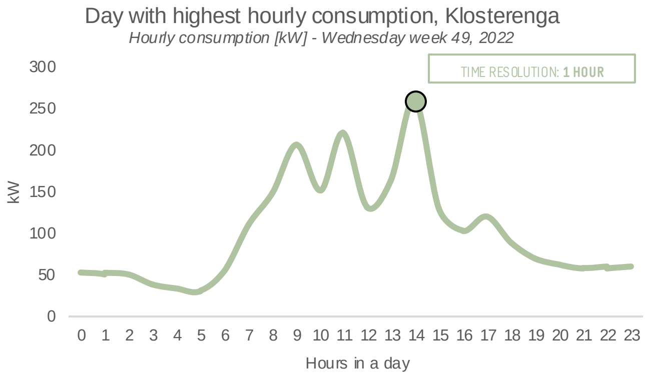
For this project, we had limited access to data. The analysis is based on energy meter data for the entire construction period and a simple machine list.

The maximum power peak was 260 kW, which occurred at 14:00 on December 1, 2022.

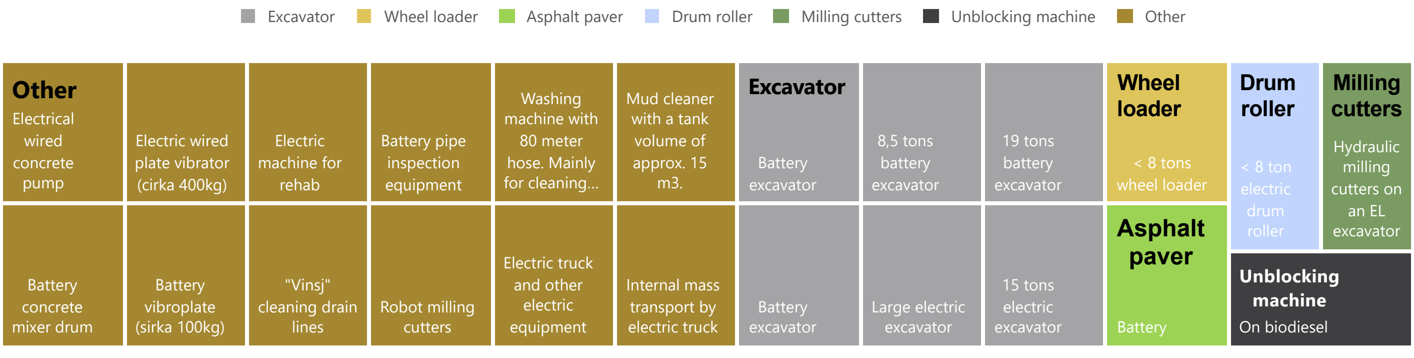
ANALYSIS PERIOD: August 2021 - March 2023

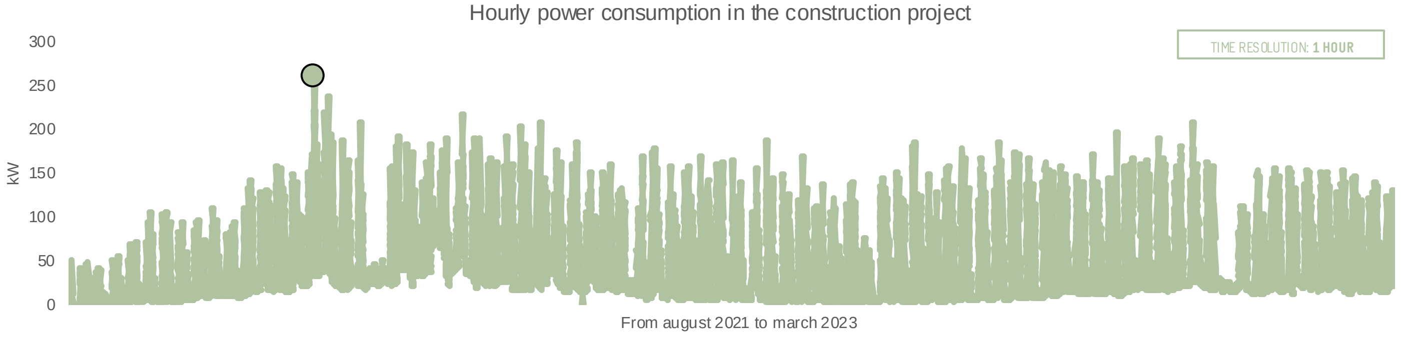
Key figures for logged part of the construction period:

- Maximum hourly power: 260 kW (December 1, 2022, at 14:00)
- Average hourly power: 39 kW
- Zero-emission machinery fleet: 96%
- Average daily consumption: 926 kWh
- Average monthly consumption: 26,382 kWh
- Total energy consumption: 527,655 kWh



Machine and equipment used on Klosterenga [100% emission free excl. unblocking machine]





Construction projects – Danmarks gate

W&S

Danmarks gate is a construction project managed by the Water and Sewerage Department (WSD) in Oslo. The project began in January 2021 and was completed in May 2022. There is limited information available regarding the project details, progress plan, and scope.

For this project, we had limited access to data. The analysis is based on energy meter data for the entire construction period and a simple machine list.

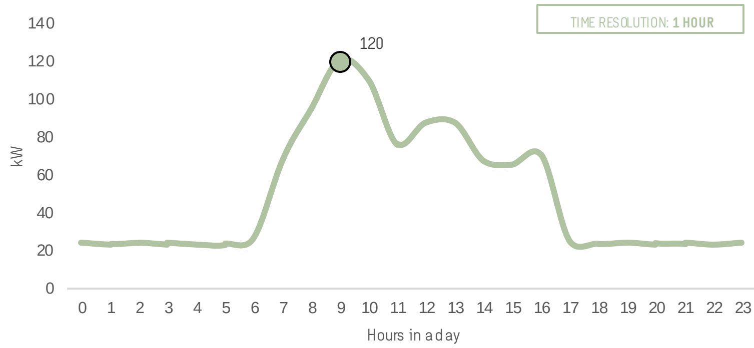
The maximum power peak was 120 kW, which occurred at 09:00 on December 12, 2021.

ANALYSIS PERIOD: January 2021 - May 2022

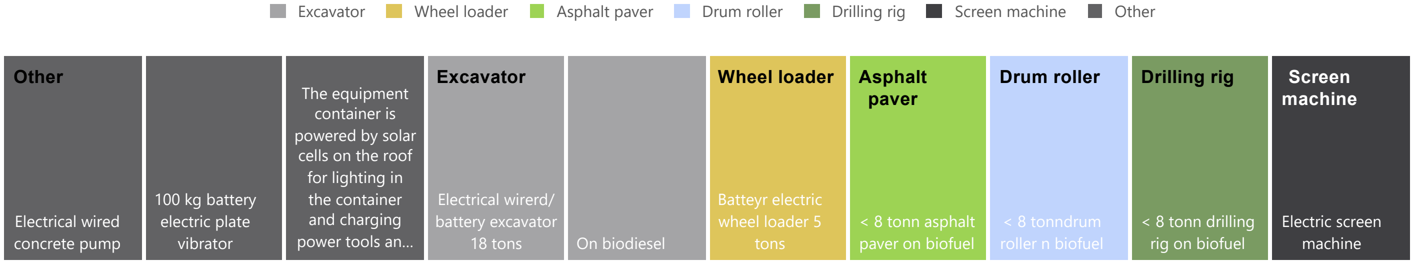
Key figures for the logged part of the construction period:

- Maximum hourly power: 120 kW (December 12, 2021, at 09:00)
- Average hourly power: 15 kW
- Zero-emission machinery fleet: 70%
- Average daily consumption: 369 kWh
- Average monthly consumption: 10,449 kWh
- Total energy consumption: 177,634 kWh

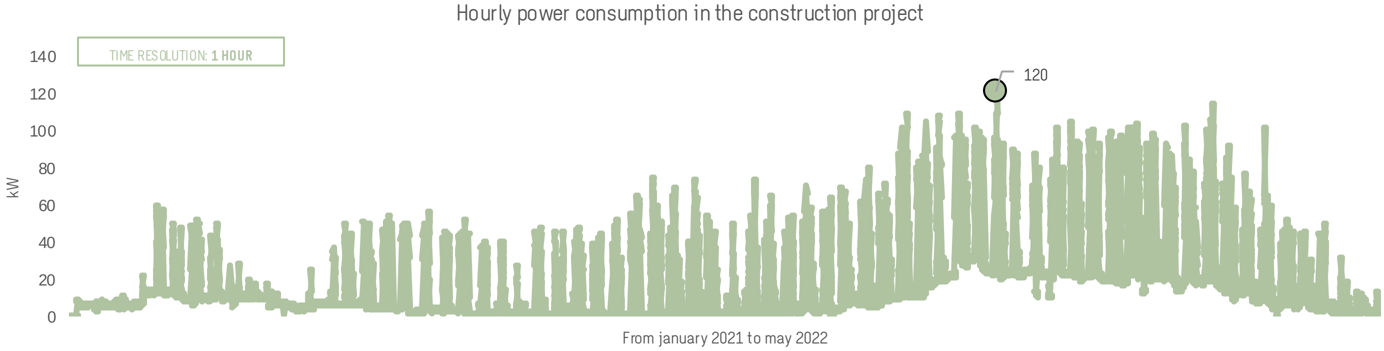
Day with highest hourly consumption, Danmarks gt.
Hourly consumption [kW] – Tuesday week 51, 2021



Machine and equipment used on Danmarks gate
[1 excavator, 1 asphalt paver, 1 drilling rig on biofuel and remaining on electricity]



Hourly power consumption in the construction project



Construction projects - Lybekkveien

W&S

Lybekkveien is a construction project involving W&S work for the residential area in Lybekkveien. The area has experienced several breaks and corrosion holes in the water mains. The project involves excavating approximately 460 meters of trench and includes 10 manhole groups, along with the need to reconnect 10 service lines for water and sewage. Power for the project has been drawn from an existing transformer located in the basement of a nearby building.

The project uses a Nasta excavator, a Zeron ZE160, which is a hybrid machine based on the Hitachi ZX160 model, operating with both cable and battery. The machine weighs 18 tons and has a motor capacity of 86 kW. It is recommended to use a 125 A connection, and the battery capacity is 44 kWh. Along with the excavator, Nasta Special Production has also provided a specially developed container with a 50-meter cable reel, which is useful for Zeron machines with the power outlet on the undercarriage, preventing the cable from getting in the way. The machine operator is also alerted when the cable is fully extended, and the machine automatically shuts down if the warning is ignored.

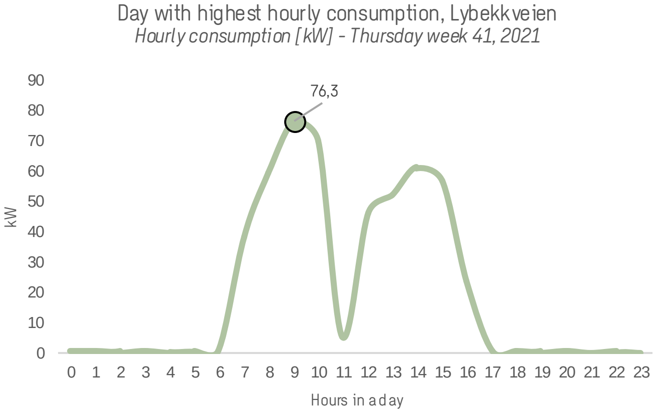
Cable from cable container with drum connected to the excavator in Lybekkveien. Screenshot from [youtubevideo] by Nasta.

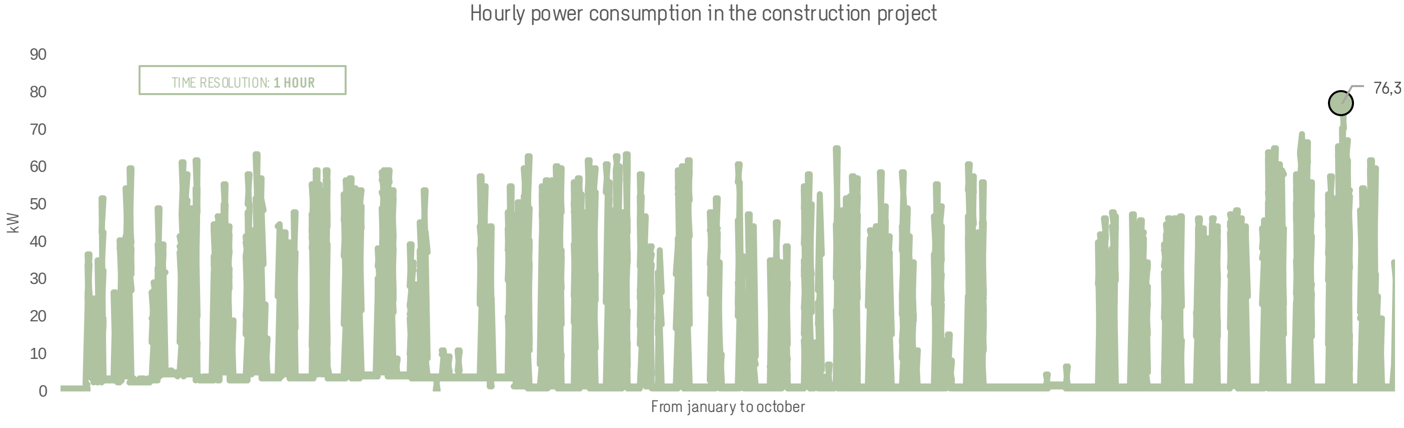
ANALYSIS PERIOD: January 2021 - October 2021

Key figures for the logged part of the construction period:

- Maximum hourly power: 76 kW (09:00, October 10)
- Average hourly power: 7.9 kW
- Zero-emission machinery fleet: 100%
- Average daily consumption: 185 kWh
- Average monthly consumption: 5,432 kWh
- Total energy consumption: 54,320 kWh

There has been limited information available about the project and when the various machines were in use, but the diagram below shows a recognizable usage pattern for the cable-electric excavator. The diagram illustrates the day with the highest hourly consumption, and it can be observed that the highest peaks occur before and after lunch, which is typical for a cable-electric excavator.





Summary of Key Figures for W&S Construction Projects

W&S

Construction projects from the W&S Agency	Lybekkveien	Danmarks gate	Hovseterdalen	Klosterenga	Lindeberg unblocking (Alnaparkv. 9 & Prof. Birkelandsv. 25	Noreveien	Ansgar Sørlies vei 75	Silurveien 44
Max. hourly power consumption [kW]	76	120	214	260	81	72	30	37
Dato og klokkeslett for makseffekt	10.10.2021 kl. 09	12.12.2021 kl. 09	23.02.2021 kl. 12	01.12.2022 kl. 14	2022-11-23 9:00	2023-2-3 11:00	2022-10-26 11:00	2022-11-29 11:00
Avg. hourly power consumption [kW]	8	15	33	39	9	7	7	7
Total energy consumption [kWh]	54 320	177 634	91 080	527 655	37 298	23 868	14 438	17 728
Avg. monthly energy consumption [kWh]	5 432	10 449	18 216	26 383	4 662	4 774	2 888	4 432
Avg. daily energy consumption [kWh]	185	369	765	926	101	178	172	179
Share of emission-free machines from machinery lists	100 %	70 %	100 %	96 %	No data available	No data available	No data available	No data available
Correlation factor ambient temperature and consumption	-0,021599124	-0,301747671	0,02361141	-0,191901553	0,015745191	-0,061238532	0,332516369	-0,035850786

The table above shows key figures for all construction projects where some data has been available. Data on the machinery fleet has only been available for Lybekkveien, Danmarks gate, Hovseterdalen, and Klosterenga. For the other projects, only energy meter data has been accessible. However, indications suggest that these projects also have a high proportion of zero-emission machines.

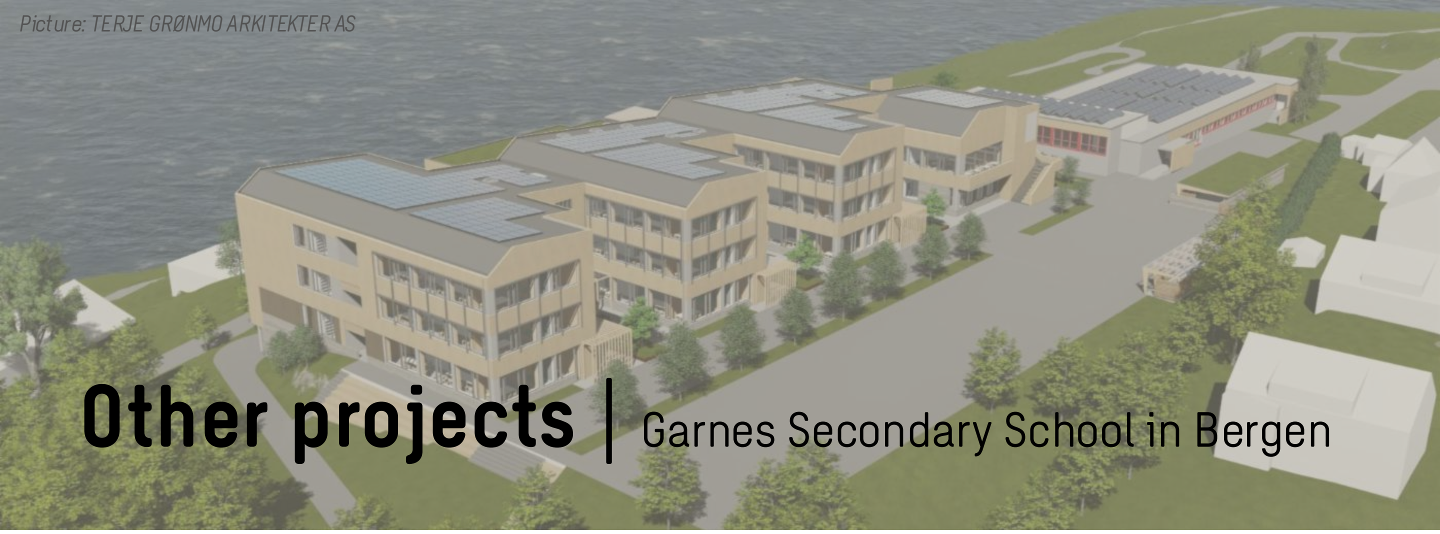
As shown, the maximum hourly power varies between 30-260 kW for this selection of WSD-specific construction projects. The highest power peaks for the different projects occur at 09:00, 11:00, 12:00, and 14:00.

Of the 8 projects, the peak power occurs at 09:00 for three projects, at 11:00 for three projects, while one project peaks at 12:00 and another at 14:00.

All peaks occur in the fall or winter. For most projects, there is almost no correlation between outdoor temperature and consumption. Danmarks gate shows the largest negative correlation (-0.30), followed by Klosterenga (-0.19), indicating a medium to weak increase in consumption as outdoor temperature decreases. This may be related to the number of barracks for the different projects, although this information is not available to the project. Ansgar Sørlies vei 75 stands out with a moderate increase in consumption as the temperature rises. The project cannot determine the cause of this, as there is little available information on the project's machines and equipment.

7 Other Construction Projects

Picture: TERJE GRØNMO ARKITEKTER AS



Other projects | Garnes Secondary School in Bergen

Sweco has also been granted access to data from the construction project for the new Garnes secondary school in Arna, outside Bergen, Norway. This project is of particular interest due to its ambitious target of achieving around 90% zero-emission construction. Skanska has shared data with Sweco and approved its publication in this report. Special thanks go to Jann Even Longva, project manager at Skanska, and Atle Skoge, site manager at Skanska, for their willingness to share data.

Introduction

Garnes secondary school is set to be demolished and replaced with a new building for 500 students, including a special unit for 20 students. The sports building will remain, but approximately 1,600 m² will be upgraded with a new steel pool, technical systems, facades, locker room facilities, and a swimming hall. The new building, approximately 9,300 m² gross floor area, will mainly be constructed with cross-laminated timber, except for the basement and elevator shafts, which will be built in concrete. The new building will have the same footprint as the existing school but will be one story higher. It will be certified according to BREEAM-NOR Very Good and will follow the passive house standard. Energy wells will supply the building with heating. There will be three 2x CCS charging points, with six available in total.

Project Schedule:
- November 2022: Start of demolition
- January 2023: Start of groundwork
- May 2023: Concrete work
- October 2023: Cross-laminated timber
- Feb-May 2024: Building envelope completed
- Nov-March 2024/25: Mechanical completion
- June 2025: Handover

The project received key components of its electrical setup from Eviny, including a battery with a gross usable capacity of 281 kWh. The battery can deliver 225 kW and charge at a maximum of 140 kW. The battery container was on-site from December 2022 to May 2023. Additionally, at peak times, there were three charging containers, each with two CCS2 outlets. Each container could deliver 200 kW and distribute the power across two charging points. During the groundwork phase, for which we have limited consumption data, other power peaks likely occurred, with worst-case scenarios reaching 600-700 kW during full simultaneous charging, as well as some consumption from the construction barracks and other equipment. The project, overall, has a grid capacity of 800 kVA, which equals 640 kW, considering the power factor.

Of the machines used on-site, 70% were zero-emission, meaning electric. However, only 40% of the total energy used for machinery was zero-emission. The drilling rig used for boring the energy wells is the main reason for the relatively low percentage of zero-emission energy use, as it consumes a significant amount of energy. If the drilling rig had been electric, the zero-emission share of energy use for machinery would have been 79%.

Sweco has received the following relevant data and information from the project:

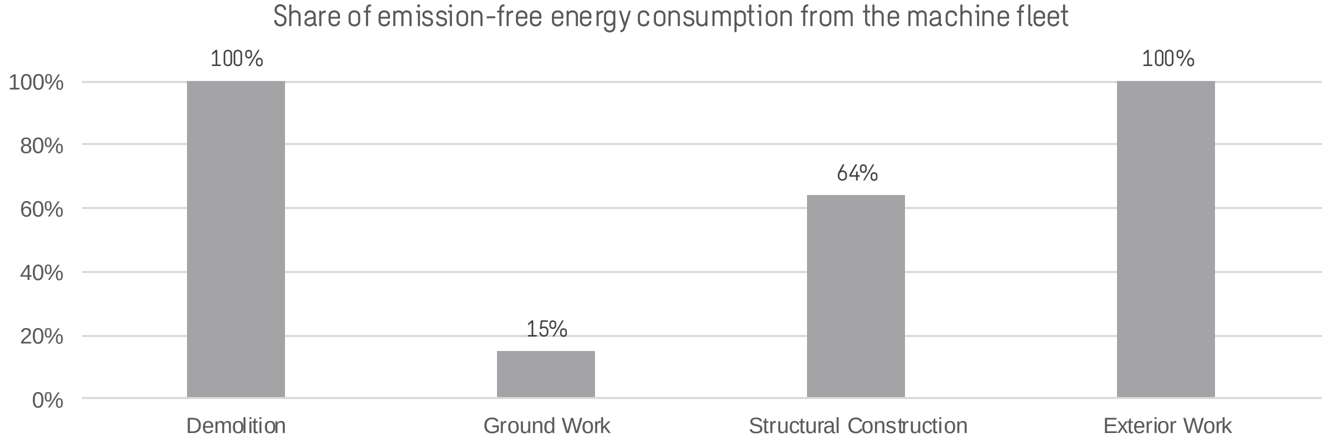
- Energy meter data with hourly resolution [kWh/h] for 3 energy meters
- Grid capacity: 800 kVA / 640 kW total transformer capacity
- Complete machinery overview and accumulated consumption through January 2024
- 30 construction barracks

ANALYSIS PERIOD: 06.2023-06.2024

Key figures for logged part of the construction period:

- Maximum hourly power consumption (energy meter): 467 kW (October 9, 2023, at 12:00)
- Average hourly power consumption (energy meter): 74 kW
- Average monthly consumption: 50,298 kWh
- Average daily consumption: 1,782 kWh
- Total energy consumption: 653,871 kWh
- Zero-emission share of energy use during the construction phase from the start to April 2024: 61% (87% if the drilling rig had been electric)
- Zero-emission share of energy consumption for machinery from the start to April 2024: 40% (79% if the drilling rig had been electric)

Other projects | Garnes Secondary School in Bergen

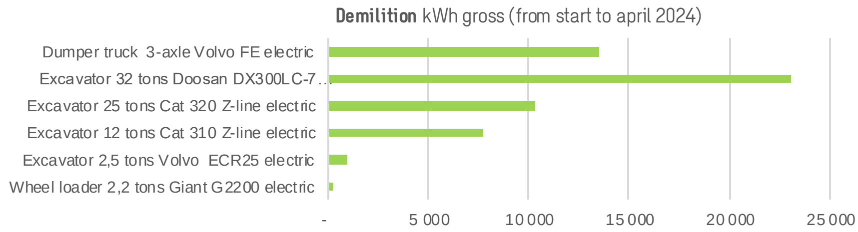


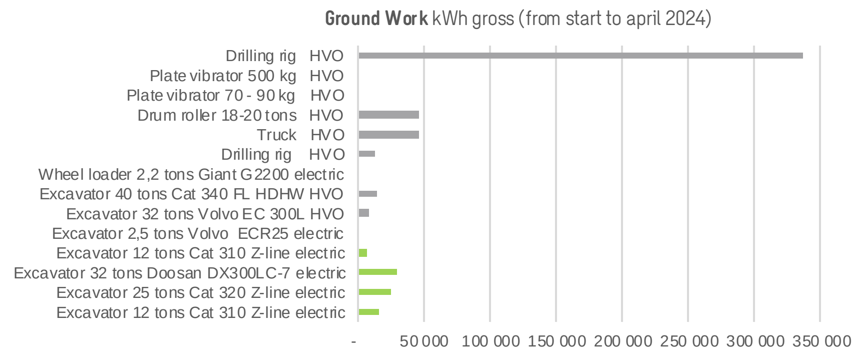
Data has been received on the energy consumption of machinery, categorized by energy source, from the start of the construction project through April 2024.

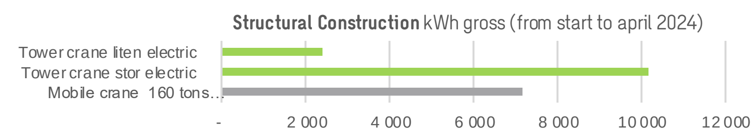
The data shows that the demolition phase was carried out 100% emission-free. The same applies to the outdoor works, while the superstructure phase had a 64% emission-free share due to the use of a mobile crane. This category of machinery currently has limited availability in emission-free versions.

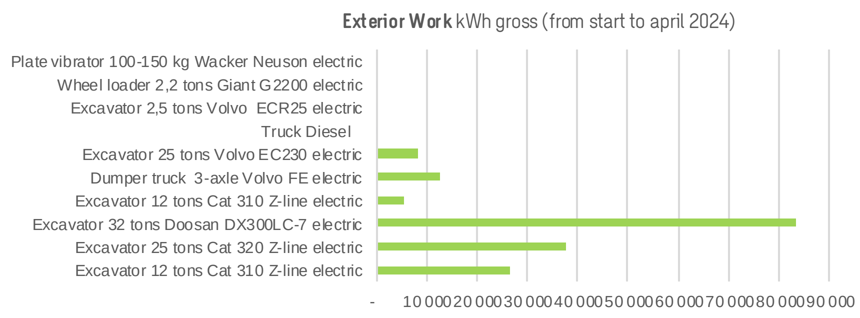
In the groundwork phase, only 15% of the energy consumption for machinery on the construction site was emission-free. The relatively low level of emission-free energy use in this phase is primarily due to the lack of an available emission-free drilling rig at the time. The project uses this rig to create energy wells. As also observed at Tøyenbadet, these drilling rigs are very energy-intensive. If the drilling rig had been electric, this phase of construction would have had an emission-free share of around 65-70%.

For the project as a whole, the emission-free share has so far been 40%. If the drilling rig had been electric, the emission-free share would have been 79%.







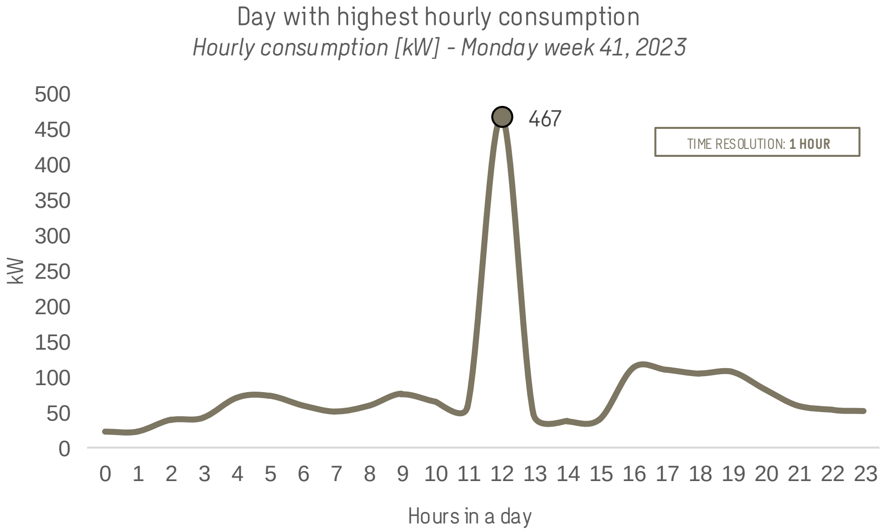


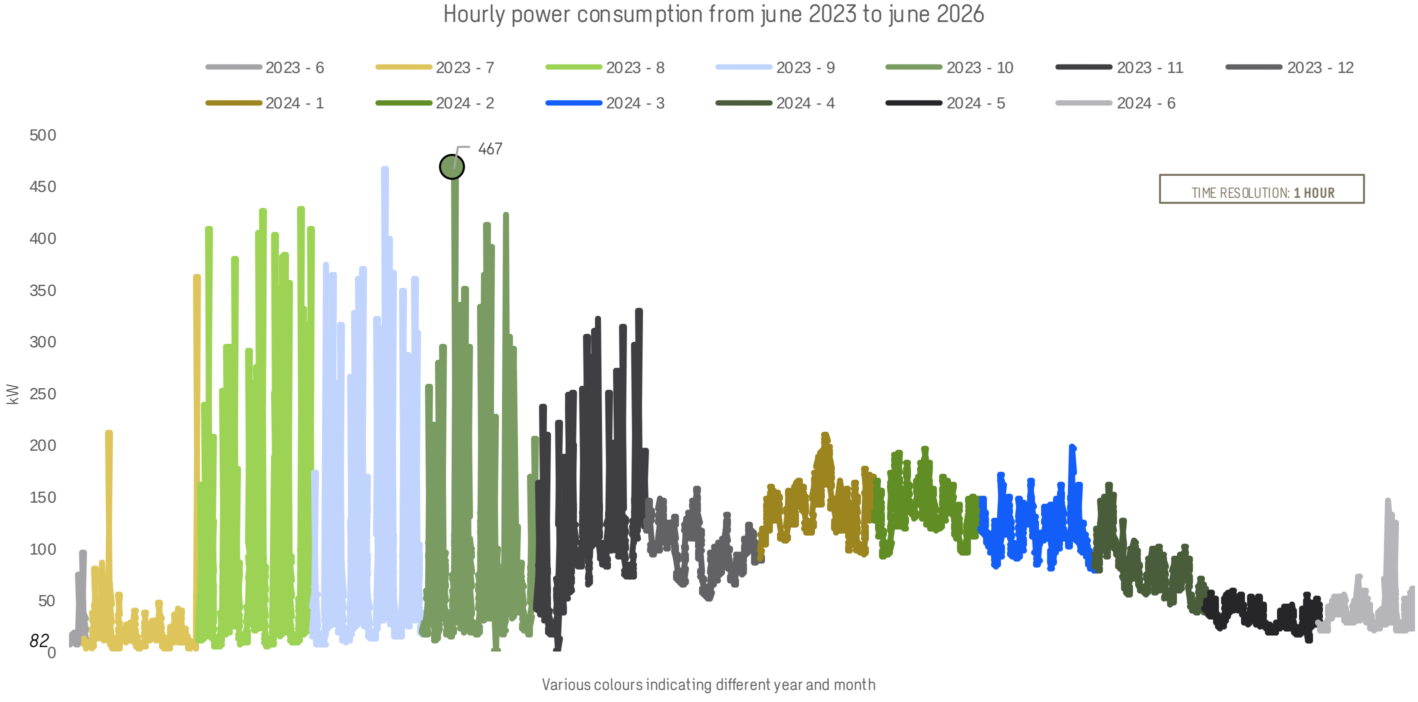
Other projects | Garnes Secondary School in Bergen

The highest recorded power peak drawn from the grid occurred on October 9 at 12:00 in 2023, as shown in the diagram below. The lower diagram shows the total hourly consumption for the entire analysis period, indicating when the highest power peak occurs.

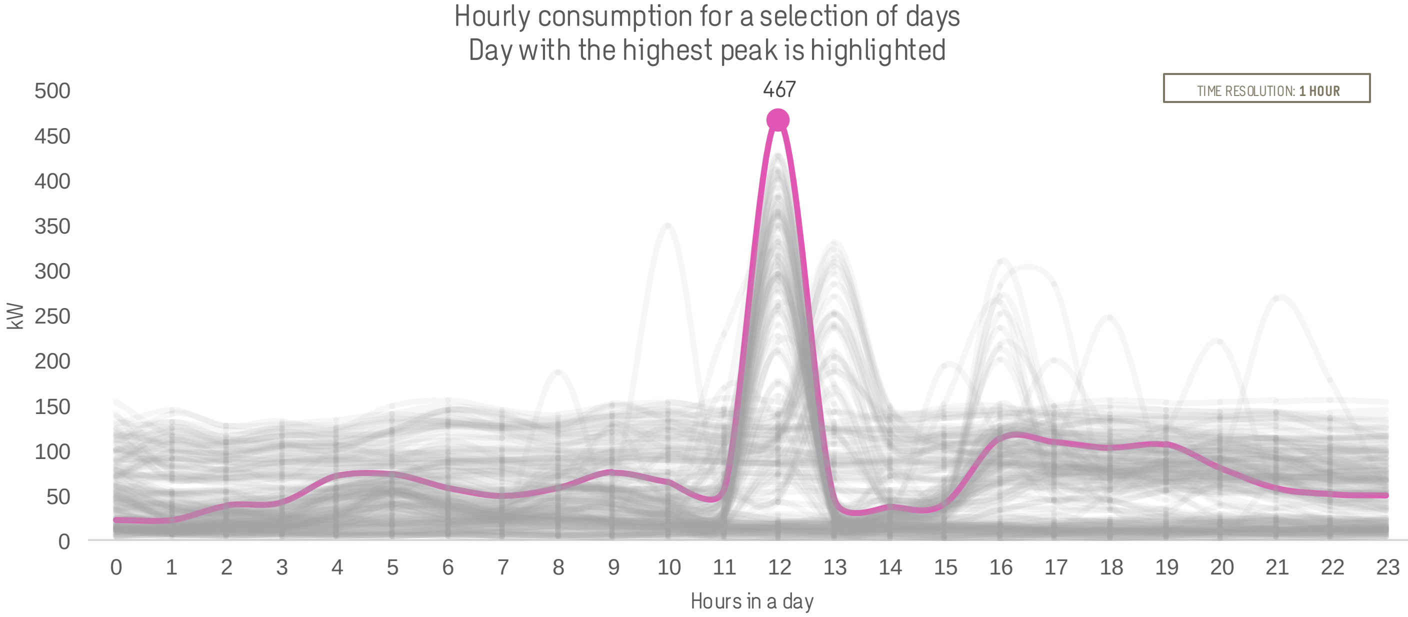
The cause of the power peak is the charging of electric machinery. The baseline consumption for the day in question is approximately 50 kW, meaning the difference between the peak load and the baseline is around 400 kW.

There is also an observed increase in consumption starting at 16:00 on the same day, which then decreases back to baseline after 20:00. This increase is also likely due to machinery charging.





Other projects | Garnes Secondary School in Bergen



The diagram above shows the hourly consumption per day for all days in 2023. The pink line is highlighted to mark the day when the highest power peak occurred.

Similar to the highest power peak, which occurred at 12:00 on Monday, week 41 in 2023, most power peaks happen around the same time. From the diagram, we also see that some peaks occur at 13:00 and between 16:00 and 17:00. These power peaks are linked to the simultaneous fast charging of machinery.

The table on the right calculates the average consumption for each hour of the year during the construction project (from June 2023 to June 2024). Additionally, the average for each hour across the years is displayed on the far right as the "average of averages." We observe an increasing baseline hourly consumption, while the highest power peaks occurred in 2023, during demolition and groundwork. The highest peaks typically happen around lunchtime due to the fast charging of construction machinery.

The highest peak recorded at 12:00 on Monday, week 41 in 2023, represents an increase of 215% compared to the average power registered at 12:00 in 2023, 386% compared to 2024, and 282% compared to the average of both years.

Hours in a day	Hourly average peak for the construction project 2023	2024	Average of average
0	50	84	67
1	44	83	64
2	43	82	63
3	45	84	64
4	50	85	68
5	56	86	71
6	54	88	71
7	51	89	70
8	55	93	74
9	56	98	77
10	54	99	77
11	57	98	77
12	148	96	122
13	68	94	81
14	49	95	72
15	51	96	74
16	76	95	86
17	70	91	80
18	66	87	77
19	64	86	75
20	64	85	75
21	61	84	73
22	57	84	70
23	54	84	69

8 Results

8.1 Grid capacity as a Limiting Factor

Results | Grid capacity as a Limiting Factor

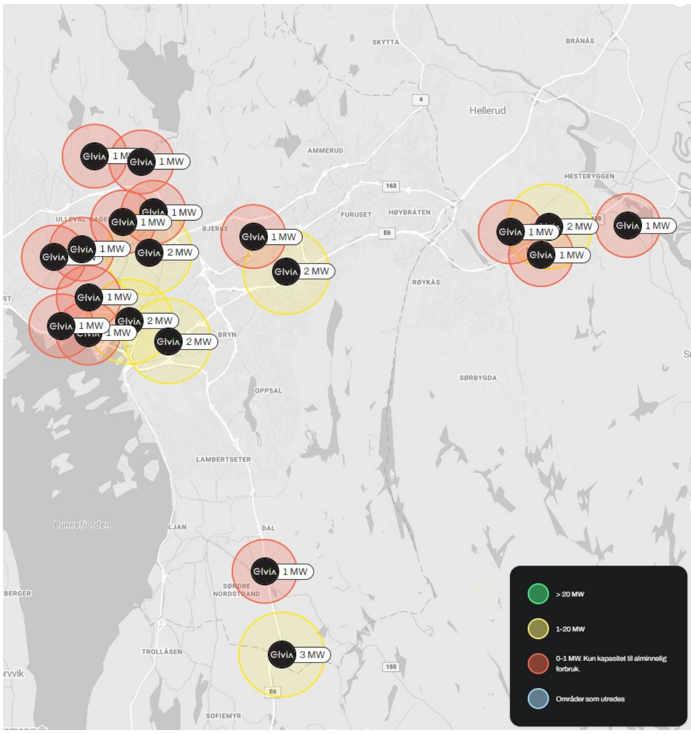
This report has examined the construction projects for the new Tøyenbadet, Stovner Bad, Sophies Minde, and a selection of historical construction projects. In these cases, power availability has not been a limiting factor in achieving the level of zero-emission construction attained.

At Tøyenbadet, the available grid capacity is around 640 kW, with the highest recorded power peak so far being 510 kW.

However, the project is not fully emission-free. If it were, and particularly if it had been fully electric, power availability could have been a limiting factor. Nevertheless, solutions, as outlined in this report, could mitigate this. With a starting point of 640 kW, the project could have achieved a 100% zero-emission construction site using certain measures. In addition to using heat pumps for the construction barracks and building heating/drying, there would need to be a more strategic approach to smart charging logistics. By doing so, the project could have stayed within the power limit. For example, without smart charging logistics, power availability could have been a limiting factor, potentially causing a peak of around 930 kW if all machines were charging at 11:00. This could have been resolved with a stationary battery bank with a minimum of 290 kWh usable energy and a discharge rate of 1C (290 kW).

Although power availability was not a limiting factor in this specific construction project, it will vary significantly from project to project, depending on the available capacity in the area. Therefore, it is crucial that the municipality takes an active role in the overall planning of future construction projects and assesses the power needs well in advance of starting construction.

The assessment of the existing knowledge base indicates that future power peaks could reach up to 1,000 kW or more with full electrification of large construction projects. However, with proper planning and measures, this power demand can be reduced.



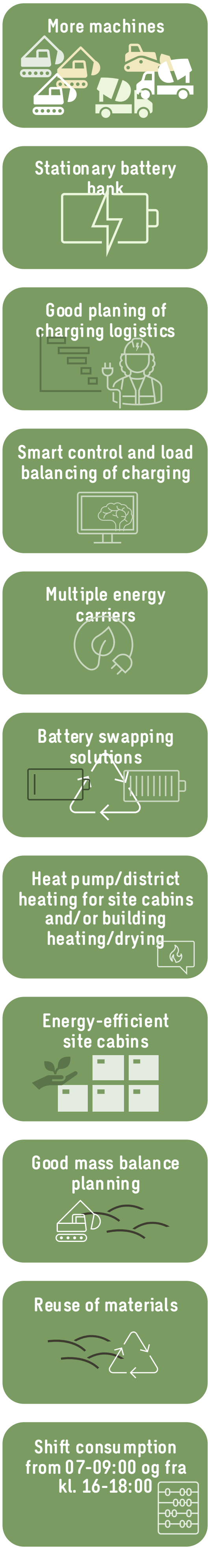
Available capacity for parts of Oslo retrieved from wattapp.no

8.2 Proposed Measures to Avoid Unwanted Power Peaks

Results | Proposed Measures to Avoid Unwanted Power Peaks

There are several measures that can be implemented to minimize undesirable power peaks. Some will be more rational from an economic standpoint than others.

1. **More machines**: This would allow energy consumption to be distributed across multiple battery-electric machines, enabling rotation and charging. Although potentially more expensive, it could be a viable alternative alongside a stationary battery bank. The overall cost-effectiveness of the options needs to be further assessed.
2. **Stationary battery bank**: A relatively simple solution to reduce power peaks through peak-shaving.
3. **Good planning of charging logistics**: This can be an effective and rational measure but requires more from those planning and operating the construction sites. It may also necessitate new routines and breaking with traditional work patterns on a construction site.
4. **Smart control and load balancing of charging:** This can be a cost-effective measure, but it requires the contractor to choose the right technological solutions. In principle, smart general control of the entire construction site can be achieved most effectively by identifying flexible loads, setting them up with contactors connected to a smart control system. This requires some physical equipment on-site and the establishment of a top system with smart algorithms to continuously minimize simultaneous power use.
5. **Multiple energy carriers**: Distributing energy consumption across more energy carriers than just electricity will help minimize power peaks.
6. **Battery swapping solutions**: This would, in effect, be similar to using multiple construction machines. However, battery swapping solutions for construction machines are not yet technologically mature.
7. **Heat pump/district heating for construction barracks and/or building drying/heating**: This would reduce the demand for electric power. District heating would provide the largest reduction but may not be as readily available everywhere as heat pump solutions.
8. **Energy-efficient construction barracks**: This measure would generally reduce power demand throughout the construction project. In addition to energy-efficient barracks, good routines and management of energy use in the barracks are important to avoid, for example, window ventilation while heaters are running, or reducing power consumption in the barracks during short periods of high demand.
9. **Good mass balance planning:** Minimizing excavation through proper planning can be an effective measure to reduce unnecessary movement of materials and transportation.
10. **Reuse of materials**: This could contribute by reducing the need for machine use.
11. **Shifting consumption from 07:00-09:00 and 16:00-18:00**: These are periods of high demand on the power grid. Measures include distributing charging loads for electric machines and striving for smart control of loads.



8.3 Requirements for the knowledge of the Contractor

Results | Requirements for the knowledge of the Contractor

The results from the survey conducted for the mentioned projects highlight a knowledge gap that must be addressed in the further work on contract requirements. To successfully facilitate seamless and automatic data collection from zero-emission construction sites, a commonly defined language and understanding are necessary. Strong prior knowledge is crucial for planning the most rational construction projects using electric machinery. It is considered appropriate to require that contractors, at a minimum, be familiar with SN/TS 3770:2023. Zero-emission construction sites and areas.

Power setup, circuit listings, and routines: Contractors should be required to clearly justify how they plan to set up the power infrastructure on the construction site and how they will ensure, throughout the project, that they have control over which circuits supply power to various consumption points. There are clear shortcomings related to logging and routines for monitoring energy consumption.

As part of the power setup, the contractor should describe their metering configuration and specify which circuits will have energy meters, as well as how data collection will be ensured and how they will implement routines for logging changes in energy use on the various measured circuits. They must clearly describe the equipment they plan to use, including the sizing of the power setup, the use of charging containers, and which machines they intend to charge there. They should also explain their choice of machinery, such as whether they are using wired, hybrid, or battery-electric machines, etc.

Furthermore, contractors should demonstrate how they will implement measures to minimize power peaks. There are several logistical and planning measures, as well as technical measures, such as smart load control or stationary batteries, that can be employed to reduce power peaks on a zero-emission construction site. It should be required that contractors show how they plan to reduce power peaks during the different phases of the construction project as part of the execution plan.

For example, contractors could be required to demonstrate which flexible loads/resources they have in the construction project and how they plan to manage them, as well as estimate how much power smart management can reduce peak demand by.

8.4 Recommended Requirements

Results | Recommended Requirements

To gain insights into the energy and power consumption of construction sites, as well as the causes of power peaks, detailed data is required. This requires (1) sufficient time resolution for the measurement data and (2) a detailed link between machines/processes and charging/consumption. In addition, there must be a sufficient number of energy meters installed on the construction site to differentiate what contributes to the overall consumption.

On a zero-emission construction site, there may be multiple energy carriers: electricity, thermal energy in the form of hot water from the district heating network, and hydrogen. Other fossil-free energy carriers, such as biogas, are by definition not emission-free and will not be discussed further here.

There will be specific requirements for the different energy carriers, but the most relevant in this context is electricity, as it can impact the operational patterns of construction sites and the need for electricity delivered from the grid. According to Sweco, the recommended requirements can be summarized in four categories:

Requirements for energy measurement

1. Requirements for metering setup
2. Requirements for time resolution of energy data
3. Requirements for data collection from energy meters

Requirements for charging systems

1. Requirements for communication between chargers and battery-electric machines
2. Requirements for communication between chargers and charging platforms

Requirements for machinery

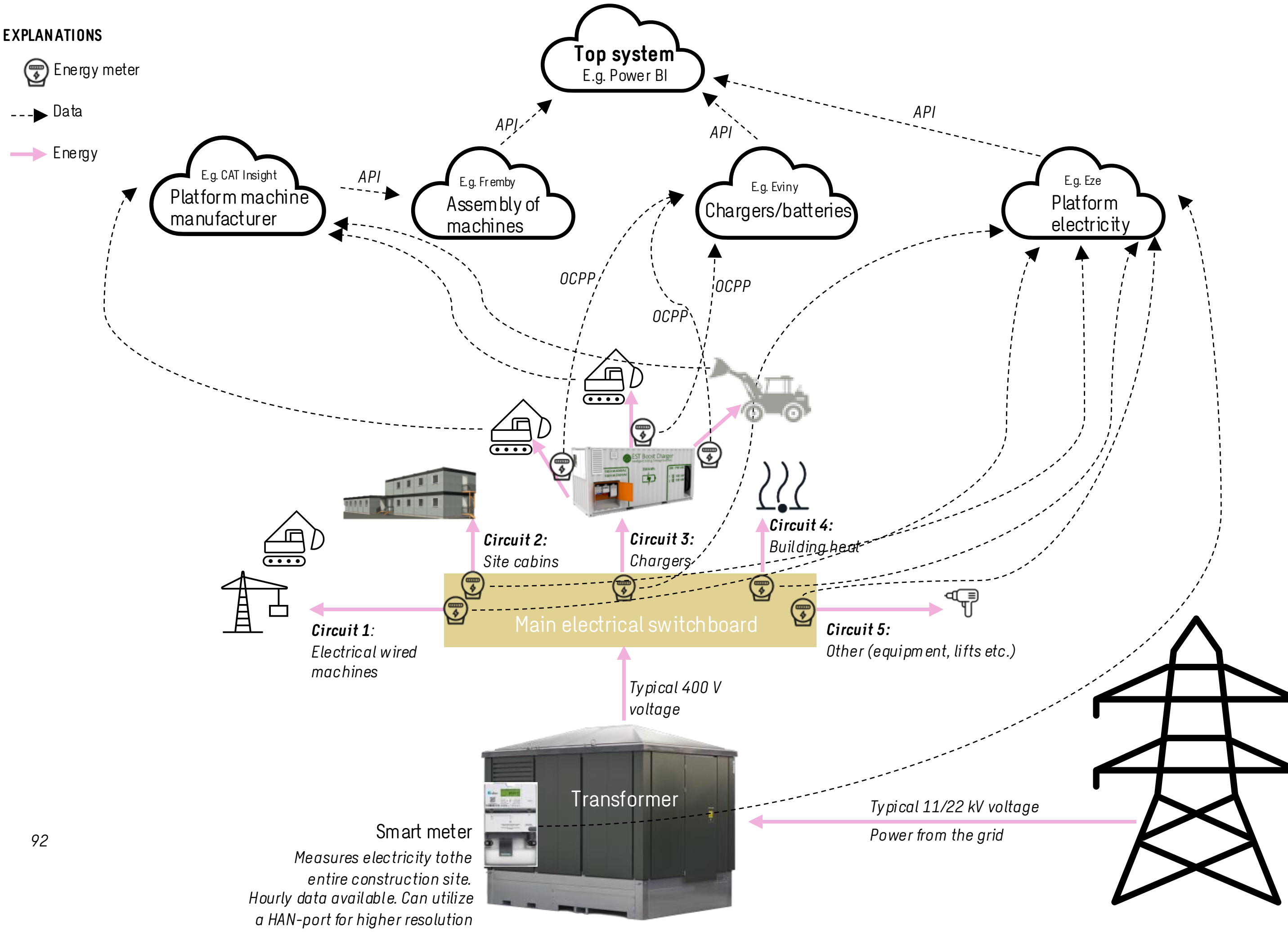
1. Requirements for data collection from machines

Requirements for communication between data platforms

1. Requirements for standardized data between platforms

These requirements concern the automatic collection of energy and power data to monitor and respond retrospectively. This can be compared to an Energy Monitoring System (EMS) for buildings. Ideally, this should be combined with the same functionality as a Building Management System (BMS) to also manage consumption in real-time. Recommending detailed requirements for this was not part of the project's scope, but it is considered reasonable to either require or, at a minimum, use as an award criterion, that the provider demonstrates how they plan to manage consumption and what reduction in power demand this could lead to.

PRINCIPAL ILLUSTRATION METER STRUCTURE AND FLOW OF ENERGY AND DATA



Results | Recommended Requirements

Requirements for energy measurement

Within the overarching requirement for energy measurement, the requirements are categorized as follows:

1. Requirements for metering setup
2. Requirements for time resolution of energy data
3. Requirements for data collection from energy meters

1. Requirements for Metering Setup

Purpose of the requirement: Ensure the ability to differentiate between consumption points to identify the causes of power peaks.

Recommended requirements:

- Equipment is connected to the HAN port of the energy meter to transmit data to the electricity platform.
- MID-certified energy meters should be installed on each circuit in the main distribution board. The circuits must be designed appropriately to differentiate between consumption points. For construction projects, at a minimum, there should be one energy meter per circuit for the construction barracks, chargers, building heating, wired machines, and other equipment on separate circuits.

2. Requirements for Time Resolution of Energy Data

Purpose of the requirement: Ensure that energy data has the highest possible time resolution to detect the highest power peaks. Typically, energy consumption is measured hourly via the energy meter, which only provides the average power [kW] over one hour.

Recommended requirement:

The time resolution of energy data should be a maximum of 10 minutes and should be logged throughout the project period.

3. Requirements for Data Collection from Energy Meters

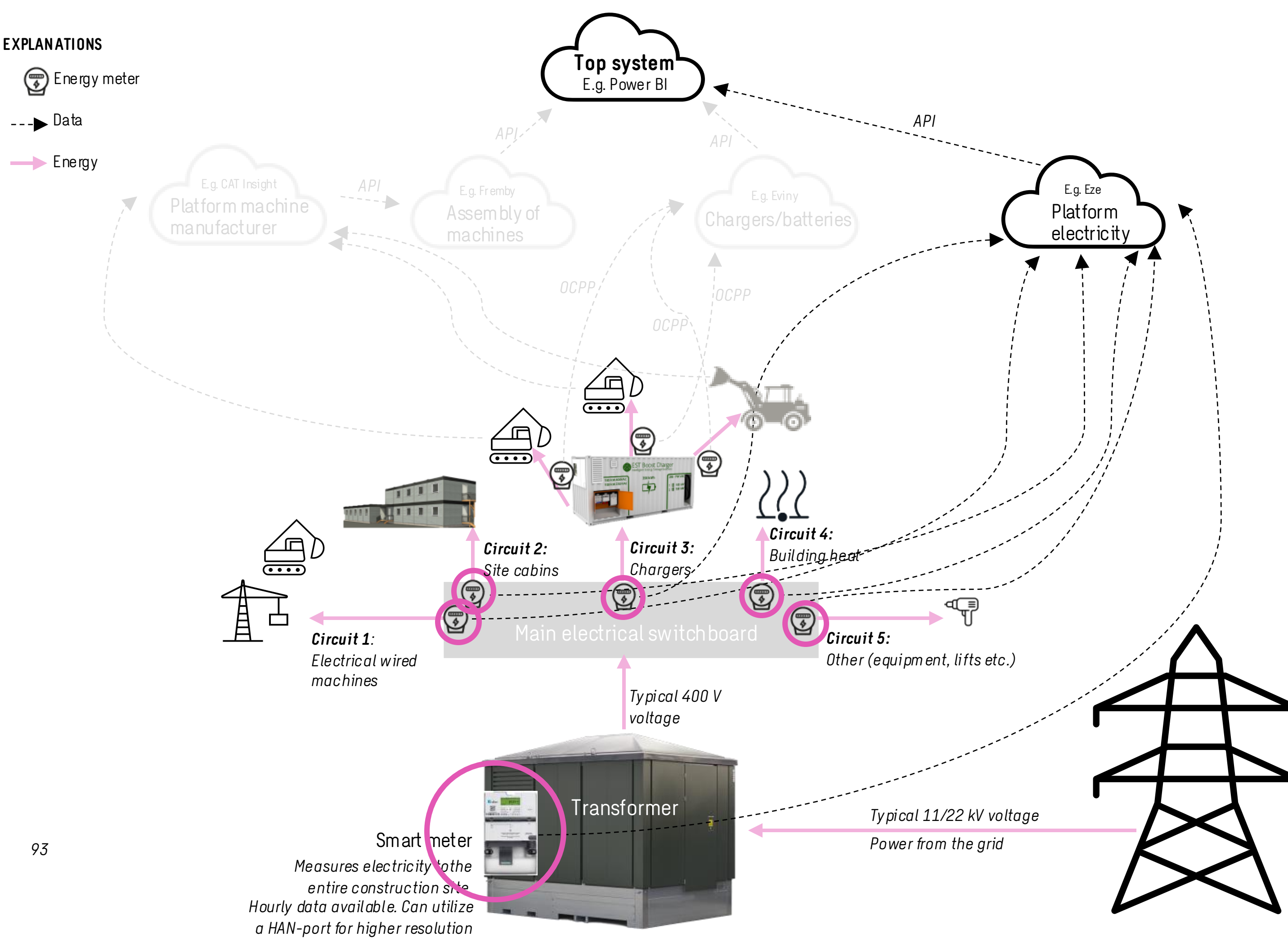
Purpose: Collect energy data on a platform to be able to transmit it to the top system for analysis and aggregation.

Recommended requirement:

Energy data must be transferable from energy meters to a cloud-based platform for electricity. This is done by using communication cards that can transmit data from the meter connected to an RTU (Remote Terminal Unit), which can forward data via the mobile network to the cloud-based platform for electricity.

This requirement is among the most costly, estimated at around NOK 1,200 per circuit meter, including 10-minute logging intervals. For a three-year construction project with five circuit meters, the total additional cost would be approximately NOK 50,000.total ekstrakostnad være på rundt 50 000 kr.

PRINCIPAL ILLUSTRATION METER STRUCTURE AND FLOW OF ENERGY AND DATA



Results | Recommended Requirements

Requirements for charging systems

Within the overarching requirement for the charging system, the requirements are categorized as follows:

1. Requirements for communication between chargers and battery-electric machines
2. Requirements for communication between chargers and the platform for chargers**

1. Requirements for Communication between Chargers and Battery-Electric Machines

Purpose: Ensure the functionality of the charger, enable load balancing, authentication, and secure standardized data transfer.

Recommended requirement:

- Communication between the charger and the vehicle/machine should use the ISO 15118 standard. It is advantageous if both the charging infrastructure and the machine comply with ISO 15118, parts 2 and 20, to enable plug-and-charge and bidirectional charging.

2. Requirements for Communication between Chargers and the Platform for Chargers

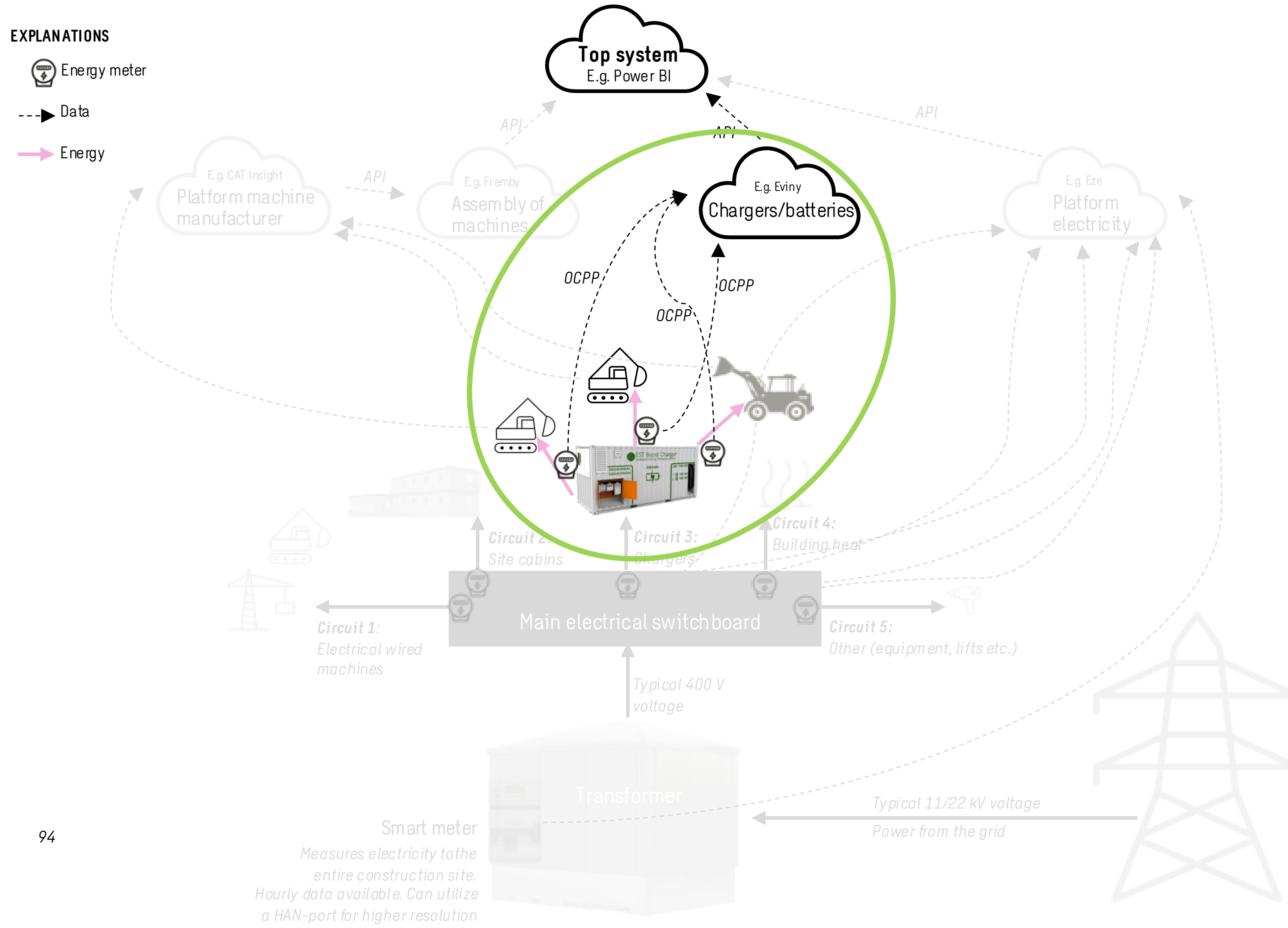
Purpose: Ensure communication between chargers and the platform for chargers to maintain well-functioning chargers, enable effective load balancing, and ensure secure and standardized data transfer.

Recommended requirement:

- Communication between chargers and the cloud-based platform should use the OCPP protocol version 1.6 or newer. It is advantageous if the protocol is OCPP 2.0.1 to ensure the latest functionality related to plug-and-charge and bidirectional charging.

This requirement will not be cost-increasing. Most chargers and electric machines are programmed to communicate using the ISO 15118 communication protocol. Requiring chargers and machines to communicate using ISO 15118-20 is currently not widespread, so this could potentially be added as a requirement in approximately two years.

PRINCIPAL ILLUSTRATION METER STRUCTURE AND FLOW OF ENERGY AND DATA



Results | Recommended Requirements

Requirements for machinery

Within the overarching requirement for machines, the requirements are categorized as follows:

1. Requirements for data collection from machines

1. Requirements for Data Collection from Machines

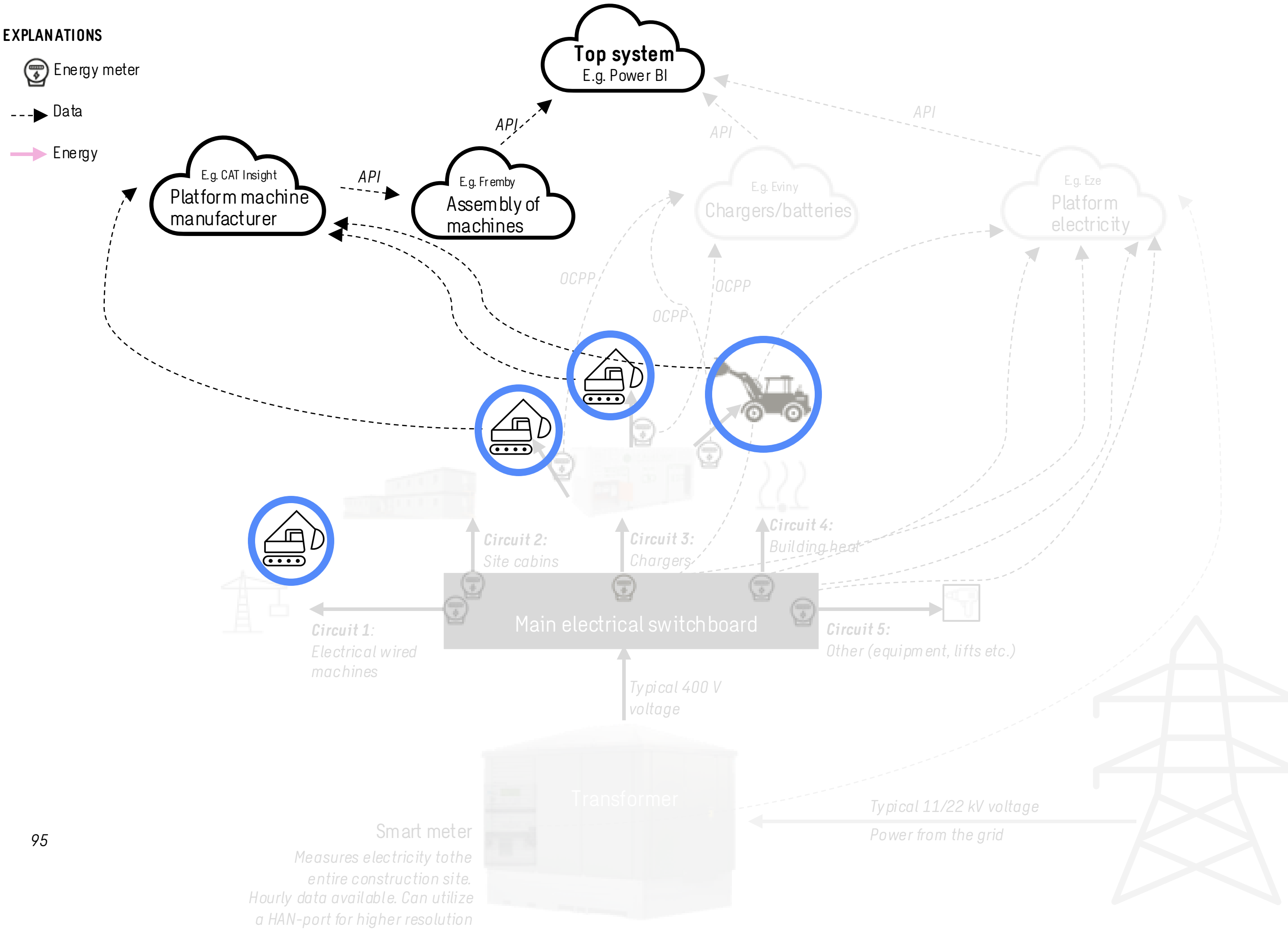
Purpose: Ensure data collection from machines to (1) establish a link between energy consumption and the specific machine that triggered the consumption, and (2) track which machines are present on the project at any given time. A monthly machine overview provides some insight but is considered relatively unreliable due to varying reporting routines.

Recommended requirement:

- Construction machines must comply with NS-EN ISO 6165 and ISO 22242, so the machine owner can receive data from the manufacturer through the interface defined by ISO/TS 15143-3. Proprietary formats for electric machines should be accepted until the standards are fully in place, as long as the data at a minimum provides information on operating hours, battery percentage, motor power, charging power, and GPS location.

This requirement may be challenging to formulate, but it should be written in a way that does not exclude proprietary solutions, given the current lack of standardization in data collection from electric machines. Since the City of Oslo has an agreement with Fremby, they could also help formulate good data collection requirements until standards are established. In principle, this requirement should not be particularly costly, as most new machines already transmit telematics data. The key is to ensure the data is routed to an additional destination besides the machine manufacturer.

PRINCIPAL ILLUSTRATION METER STRUCTURE AND FLOW OF ENERGY AND DATA



Results | Recommended Requirements

Requirements for communication between data platforms

Within the overarching requirement for machines, the requirements are categorized as follows:

1. Requirements for standardized data between platforms

1. Requirements for Standardized Data between Platforms

Purpose: Ensure that the various cloud-based platforms forward the desired data in the correct format to the top-level system using an API.

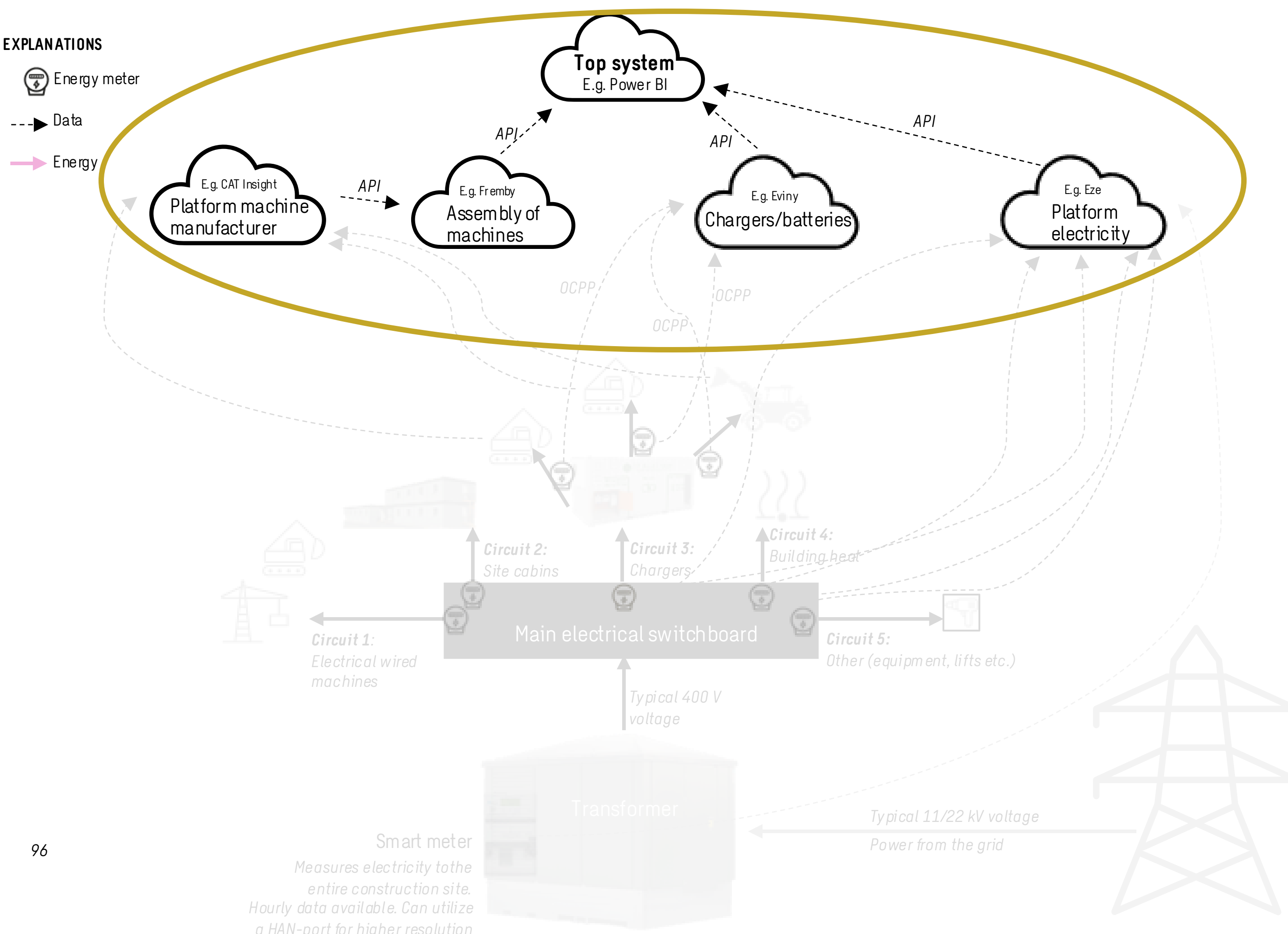
Recommended requirement:

- Data from cloud-based platforms must forward the required data to the top-level system of the project owner.

This requirement may be somewhat unclear in its current formulation. After the delivery of the first part of this report, the City of Oslo entered into an agreement with Fremby as a software provider to collect machine data from construction sites. Such a system, or potentially several others, could log and monitor essential data from machines, energy meters, smart energy meters, and other available data sources. This would make it easier to aggregate and observe energy and power consumption on construction sites, as well as to identify the causes of power peaks more effectively.

The system described here is, as of today, a monitoring system. To actively address power peaks, there will be a need for a control system that can manage the connection and disconnection of consumption in relation to the total aggregate consumption.

PRINCIPAL ILLUSTRATION METER STRUCTURE AND FLOW OF ENERGY AND DATA



SWECO