Transitioning to electric construction vehicles and machinery

A study of Swedish and Norwegian experiences

Master's Thesis in the Master's Programme Design and Construction Project Management

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DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022
www.chalmers.se

MASTER'S THESIS ACEX30

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Abstract

Greenhouse gas emissions are increasing. As a result, global environmental goals have been developed to limit environmental impact. These goals form the basis of the goals, visions, and incentives established at a national level. Sweden intends to be a leader in the transition and has established laws, regulations, and incentives to steer the country in that direction. The provisions aim, among other things, at the electrification of vehicles, including construction and civil engineering machinery. However, there is uncertainty regarding how the transition should be carried out in practice and what it will entail.

The thesis is conducted in collaboration with Swedish and Norwegian representatives from the multinational construction company Veidekke. The thesis investigates the transition toward an electric worksite. More specifically, what conditions are necessary for a successful transition towards electric vehicles and machinery, how relevant actors view the transition in terms of responsibilities and change management, and the consequences of such transition. The thesis aims to provide a basis for decisions for actors who contemplate making the transition toward electric vehicles and machinery.

Through empirical research based on interviews with relevant actors both within and outside of the construction industry, an observation at a construction site that utilizes electric machinery, and executive summaries of reports and studies that map theoretical and practical needs and consequences of a transition towards electric construction sites, it is found that the implementation of electric machinery is complex and requires substantial logistical, technical, and contractual consideration. Moreover, it is concluded that there are ambiguities regarding the economic, logistical, and technical feasibility that need to be addressed before a large-scale transition is advantageous. Finally, based on the findings, recommendations for future research are formulated.

Key words: Electrification of vehicles, Construction machinery, Construction vehicles, Charging, Construction Procurement, Change Management, Sustainability.

Omställningen till elektriska bygg- och anläggningsfordon
En studie av svenska och norska erfarenheter

Examensarbete inom masterprogrammet Organisering och Ledning i Bygg och Fastighetssektorn

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Sammanfattning

Utsläppen av växthusgaser ökar. Globala miljömål har tillkommit för att begränsa miljöpåverkan. Dessa målutgör grunden till de mål, visioner och incitament som upprättas på en nationell nivå. Sverige har för avsikt att vara ledande när det kommer till omställningen och har upprättat lagar, bestämmelser och incitament som avser styra landet i den riktningen. Bestämmelserna tar bland annat sikte på elektrifiering av fordon, inklusive bygg- och anläggningsmaskiner. Det råder dock osäkerhet när det kommer till hur omställningen ska gå till i praktiken och vad den får för konsekvenser.

Denna avhandling är genomförd i samarbete med såväl svenska som norska representanter från det multinationella byggföretaget Veidekke. Avhandlingen avser undersöka omställningen mot en elektrifierad byggarbetsplats. Mer specifikt, vilka förutsättningar som är nödvändiga, hur relevanta aktörer ser på omställningen med avseende på ansvarsområden och förändringsledning men även vad en sådan omställning får för konsekvenser. Avhandlingen avser utgöra stöd vid beslutsfattande för de aktörer som överväger att göra omställningen mot elektrifierade bygg- och anläggningsmaskiner.

Genom empirisk forskning baserad på intervjuer med relevanta aktörer såväl inom branschen som utanför, genom en observation på en byggarbetsplats där elektriska maskiner används, genom att analysera studier och rapporter som avhandlar teoretiska och faktiska behov och konsekvenser av omställningen mot elektriska bygg- och anläggningsmaskiner framkommer att omställningen är komplex och att betydande logistiska, tekniska och kontraktuella överväganden behöver göras. Samtidigt så råder det oklarheter gällande den ekonomiska, logistiska och tekniska genomförbarheten, vilket måste överkommas innan en storskalig omställning är attraktiv. Framtida forskningsområden är formulerade baserade på resultaten i slutsatsen.

Nyckelord: Elektrifiering av fordon, Elektrifiering av bygg- och anläggningsfordon, laddning, Byggupphandling, Förändringsledning, Hållbarhet.

Preface

In the spring of 2022, we enjoyed writing our master thesis on an exciting and highly relevant topic. The thesis constitutes 30 credits and is written at the Architecture and Civil Engineering institution on the department of Construction Management at Chalmers University of Technology.

We would like to send our sincere gratitude to our supervisor and examiner at Chalmers, Mikael Viklund Tallgren. We would also like to show appreciation to Lucas Isebäck and Anders Holmqvist for providing us with the opportunity to write for Veidekke and to all the interviewees who participated. Lastly, we want to thank Veidekke in Norway for their hospitality, letting us observe their meeting, and showing us around the construction site.

Jonathan Kristiansson & Mohammed Musallam

Gothenburg, June 2022

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NOTATIONS

Battery-type	Completely disconnected from an external power source
Boverket	The Swedish National National Borade of Housing, Building and planing
Bymiljøetaten	Norwegian Agency for Urban Environment
Climate neutral	Net-zero emissions of greenhouse gases into the atmosphere and the emissions should not contribute to the greenhouse effect
CO_2-Equivalent	A unit that weighs emissions of different greenhouse gases to the global warming effect that emissions of one ton of CO_2 will have over 100 years
Electrical Vehicle	Vehicle with a fully or partially electric powertrain
Elektrifierings plan	Electrification Plan
Energimyndigheten	Swedish Energy Agency
Fossil-free construction sites	The construction takes place without any polluting emissions to air
Fossil-free vehicle	Vehicle that run on alternative non-fossil fuels, such as electricity, biofuel or hydrogen
Fossilfritt Göteborg	Fossil-Free Gothenburg
Fossilfritt Sverige	Fossil-Free Sweden
HVO-diesel 100	Biodiesel consisting of Hydrotreated Vegetable Oil
Hybrid Electric Vehicle	Vehicle powered by an electric powertrain in combination with an internal combustion engine
Hybrid Vehicle	Vehicle powered by two or more distinct types of power
Konkurrensverket	The Swedish Competition Authority
Lagen om offentlig upphandling, (LOU)	The Swedish Public Procurement Act
Miljö- och klimat programmet	The Environment and Climate Programme
Naturvårdsverket	The Swedish Environmental Protection Agency

Off-highway/-road vehicles	Vehicles that that is intended for use on steep or uneven ground or used for construction
Regeringskansliet	Government Offices of Sweden
Sveriges Miljömål	Sweden's Environmental Objectives
Tethered-battery-type	Possible to be both disconnected and connected to external electric power source
Tethered-type	Constant physical connection to external electric source
Trafikverket	The Swedish Transport Administration
Upphandlingsmyndigheten	The Swedish Procurement Authority

ABBREVIATIONS

BEV	Battery Electric Vehicle
EM	Electric motor
EV	Electric vehicle
ICE	Internal combustion engine
PHEV	Plug-in Hybrid Electric Vehicle
SOC	State of charge
SOH	State of Health
SOP	State of Power

1 Introduction

In this chapter, a background to the topic is presented. Thereafter, the aim and research questions are stated as well as the delimitations. To conclude, the outline of the report is presented.

1.1 Background

In 2015, the World Heads of State of Government adopted 17 Global Goals, 169 Milestones, and Agenda 2030. By 2030, participating countries are committed to leading the development and the world towards a sustainable and just future (Regeringskansliet, 2016). Moreover, an agreement was entered to limit the temperature increase to 1.5 degrees Celsius (Fossilfritt Sverige, 2018). For the temperature increase to be limited to below 1.5 degrees, emissions must be reduced to zero before the second half of the century (Göteborgs Stad, 2021a). The civil engineering industry is an industry with a significant environmental impact. The industry is responsible for 39 % of the global carbon emissions and 30 % of the global greenhouse gas emissions (World Green Building Council, 2019). In 2019, the Construction and Real Estate sector in Sweden accounted for about 21 % of emissions (Boverket, 2021b). Transportation constitutes a large part of the climate impact on a construction site (Ingelhag & Högberg, 2021), where work machinery are a significant emitter of greenhouse gases (Ribberink et al., 2021). The construction sector is estimated, with existing technology, to be able to halve its climate impact. However, the goal in the construction sector in Sweden is to achieve net-zero greenhouse gas emissions by 2045 (Fossilfritt Sverige, 2018). Electrification and electrical construction equipment are a step toward achieving the environmental objectives (Bernholdsson et al., 2020). Electric vehicles have the potential to reduce greenhouse gas emissions and thus contribute to a reduced environmental impact (Beltrami et al., 2021; Kouridis & Vlachokostas, 2022; Kumar et al., 2021). As a result, national Governments are expressing an increasing interest in electric vehicles (Kouridis & Vlachokostas, 2022). However, the pace of the adoption of electric vehicles depends on whether it is feasible (Kumar et al., 2021). Moreover, there is currently uncertainty regarding the adoption of electric vehicles (Wang et al., 2020). To speed up, ease, and incentivise the transition towards electrification of vehicles in Sweden, goals, laws, regulations, initiatives, plans, programs, and requirements have been enforced on a national and regional level.

Sweden's environmental goals constitute the ecological dimension of Agenda 2030 and relate to areas of hazardous substances, sustainable urban development, waste, air pollution, climate, and biodiversity (Göteborgs Stad, 2021a; Sveriges Miljömål, 2020). The Swedish government has decided upon a law called The Climate Law, which is part of a framework that includes climate goals and a climate policy council. The Climate Law fortifies that Sweden should have zero emissions of greenhouse gases by 2045 and negative emissions thereafter (Fossilfritt Sverige, 2018). The Swedish government has also decided upon a Duty to Reduce, which entails a 70 % reduction of greenhouse gas emissions from domestic transport until the year 2030 (Energimyndigheten, 2021b; Eneroth & Lindholm, 2021).

Cities have a crucial role in achieving the globally and nationally set environmental goals (Göteborgs Stad, 2021b). Some initiatives aim to take climate action (Fossilfritt Sverige, 2018). For example, the City of Gothenburg's Environment and Climate Program 2021-2030 aims to transform the city into an ecologically sustainable city by 2030, a long-term strategy to reduce the climate impact of travel and transport (Göteborgs Stad, 2021b). Moreover, Gothenburg has adopted the goal that the city's vehicle fleet and local transportation system should be fossil-free by 2023 and 2030, respectively, where Business Region Gothenburg has been commissioned to develop an electrification plan. The electrification plan includes goals, vision, plan, and proposals on how the goals can be met regarding energy supply, charging of heavy vehicles, the city's fleet of vehicles, and construction works purchased by the city (Göteborgs Stad, 2021a). Moreover, Gothenburg, Stockholm, and Malmö have agreed on environmental requirements that apply to all procurements of the Swedish Transport Administration contracts. The common environmental requirements concern, among other things, fuels, heavy and light vehicles, and construction machinery (Trafikverket, 2018).

1.2 Aim & Research Questions

The purpose of the work is to investigate what relevant actors both within and outside of the industry believe are essential to consider when implementing electric construction vehicles. Moreover, to map the experiences and conclusions from previous projects and studies that investigate the adoption of electric construction vehicles. Furthermore, to illustrate what such adoption would entail and how it can be enabled. More specifically, the work aims to answer the following questions:

- How do stakeholders experience the transition toward electric construction vehicles?
- What does the transition towards electric construction vehicles entail?
- How can the transition towards electric construction vehicles be facilitated?

1.3 Delimitations

This study focuses on implementing electric vehicles and machinery within the construction industry that reside and operate at the construction site. Furthermore, this study delimits the manufacturing and the end-of-life of the batteries and the vehicles and machinery. Though the production of electricity and the expansion of the electricity grid is mentioned in terms of the increasing demand following the electrification of vehicles, it is not elaborated on in detail. Moreover, the thesis consists of national and international articles and studies. The results and discussions are, however, formulated concerning Swedish conditions.

1.4 Outline of the Report

Chapter 1	*Introduction:* This chapter presents a background to the study. Furthermore, the chapter presents the aim, research questions, and delimitations.
Chapter 2	*Frame of Reference:* This chapter provides information regarding the concepts elaborated on in the study. Furthermore, three reports based on Swedish and Norwegian experiences concerning electrification of construction vehicles and machinery are compiled and presented
Chapter 3	*Method:* This chapter describes the methodology. Furthermore, ethical consideration as well as reflection on chosen methodology.
Chapter 4	*Interviews & Observation:* This chapter presents the relevant outcomes from the interviews and observation.
Chapter 5	*Discussion & Analysis:* This chapter presents a discussion and analysis of the results.
Chapter 6	*Conclusion:* This chapter presents the conclusion answering the study's research questions. Furthermore, recommendations for future research are presented.

2 Frame of Reference

This chapter presents the study's frame of reference. In addition, the chapter aims to provide information about the concepts which form the basis for the study's discussion and analysis.

2.1 Procurement Methods

To carry out a construction project, an agreement is needed between the actors involved to avoid risks that involve ambiguities and misunderstandings that contribute to problems during the construction process (Byggföretagen, 2021). In Sweden, there are two primary forms of contracting, turnkey contracting and execution contracting, which can affect the client's transparency of design and construction as different provisions and regulations are tailored and govern the agreed partners (Boverket, 2021a; Bygg & teknik, 2017). In addition, the contract form is an essential tool in the Swedish construction industry, where different assessment criteria are considered (Höök, 2021). A turnkey contract is a contract in which the contractor is responsible for the whole project stretching from the design to the delivery of the project. An executory contract is where the client is responsible for the design. The contractor is responsible for executing the contract, but not for the functionalities (Boverket, 2021a; Robert Deli, 2017). Boverket (2021a) points out that more effort and knowledge from the client is required to run an executory contract.

An increasingly popular form of contract is the Collaboration contract. Collaboration contracts aim to increase collaboration by sharing a common goal and purpose (Forbes & Ahmed, 2011; Lahdenperä, 2012; Larsson & Sobis, 2013). Moreover, to share the project's financial gains and losses among all involved actors (Forbes & Ahmed, 2011; Lahdenperä, 2012). The incentives for collaboration contracts increase when the ambiguities in processes become manageable and apparent demand for collaboration arises (Larsson & Sobis, 2013; Lindberg, 2009). Furthermore, it is stated that collaboration's arguments are moral, ideological, economic, and cognitive. Regardless of the form of the contract, it is essential to ensure continuity and keep track of the project's overall goals (Boverket, 2021a; Bygg & teknik, 2017). Collaboration requirements will also be placed on the governance and management, which is favorable for the partners involved (Larsson & Sobis, 2013).

2.1.1 Public procurement

The Swedish Public Procurement Act (LOU) is applied in procurement by an authority when procuring goods, services, and construction contracts (Sveriges Riksdag, n.d.). Public procurement is a regulatory process to ensure open market competition (Konkurrensverket, n.d.) and efficient use of finances (Upphandlingsmyndigheten, n.d.).

The selection of suppliers must be made on a business basis, where a supplier must compete on the same terms to offer the best product/service (Konkurrensverket, n.d.). LOU is based on five basic principles that should be considered in the assessment criteria:

- Non-discrimination
- Equal treatment
- Proportionality
- Openness
- Mutual recognition

(Upphandlingsmyndigheten, n.d.)

2.2 Change Management

Change is a complex process (Anyieni, 2016). Crawford & Nahmias (2010) argues that change can involve many projects and, in some cases, an entire organization. In addition, organizational change can occur at different levels requiring different change strategies and methodologies (Anyieni, 2016).

Change refers to applying an approach based on what is required to move to a future stage, focusing on how the change takes place (By, 2005). Change is an ever-present characteristic of organizational life, both at an operational and strategic level (By, 2005), having varying degrees of complexity (Ponti, 2011). Independent of industry, an organization changes due to internal or external influences (By, 2005; Higgs & Rowland, 2005; Stowell, 2020). However, dealing with change is more problematic in traditional industries for various reasons, such as reluctance to learn new methods and techniques (Dainty et al., 2007). Adapting new laws, regulations, and visions from authorities have been seen as an external driving force for adaptation and organizational change (By, 2005). Organizations must constantly embrace new operating methods (Sullivan et al., 2010) and implement new technologies to be competitive and survive (Anyieni, 2016). Organizational changes are recognized as a trend with benefits (Crawford & Nahmias, 2010) but have an impact on the organizations (Anyieni, 2016; Moran & Brightman, 2000) and their employees (Flott, 2013; Anyieni, 2016; Moran & Brightman, 2000).

According to Moran & Brightman (2000), Change Management can be defined as: *"The process of continually renewing an organization's direction, structure, and capabilities to serve the ever-changing needs of external and internal customers"* (p. 66). In addition, Change Management can be defined as an approach to covering the transition of every new organizational change to gain organizational benefits (Asana, 2021). Despite that organizational change is accepted due to necessity, it is considered unpredictable and can contribute to a crisis. A crisis may indicate a lack of knowledge in implementing and managing organizational change (Higgs & Rowland, 2005). Furthermore, Higgs & Rowland (2005) stated that organizational change could affect the organization's performance in different ways, so organizational change cannot be separated from organizational strategy. Moran & Brightman (2000) agreed that sudden changes could cause crisis in organizations and be a reason behind reduced product quality and loss of production. Moving from resistance to acceptance usually entails going through the emotions of mistrust, anger, and loss, resulting in a need to be provided with accurate information and support (Flott, 2013).

Anyieni (2016) states that the will to change is related to understanding why the change takes place and its benefits. Clear, effective communication tends to contribute to less resilience, which increases the tendency to undergo a change and adaptation (Dainty et al., 2007). It is argued that the lack of clarity in communication, lack of clear goals, lack of employee involvement, and the lack of organizational capabilities and structures are barriers to change. In addition, inertia can be derived from the fact that there are not enough adapted regulations (Ali et al., 2019) and standardization to support change (Dainty et al., 2007). Ali et al. (2019) also state that the organization's lack of rules and regulations could be a reason behind the failure to implement organizational change (Ali et al., 2019).

2.3 The concept of Sustainability

A commonly and widely adopted definition of sustainable development is the one stated by the World Commission on Environment and Development: *"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Keeble, 1988, p. 16.). Similarly, business sustainability can be defined as: *"adopting business strategies and activities that meet the need of the enterprise and its stakeholders today while protecting, sustaining, and enhancing the human and natural resources that will be needed in the future*" (Labuschagne et al., 2005, p. 373). There is ambiguity in what sustainability entails (Labuschagne et al., 2005; Ruggerio, 2021), and it is difficult to express it in concrete terms (Labuschagne et al., 2005). Therefore, how one defines sustainability is, to a large extent, a question of ideology and context (Ruggerio, 2021). Sustainability is, however, commonly seen as a system of interrelated dimensions consisting of Environmental/Ecological, Economic, and Social (Mies & Gold, 2021; Ruggerio, 2021) that should not be considered inseparable parts of a whole (Yılmaz & Bakış, 2015).

2.3.1 Social, Economic & Environmental Sustainability

Social sustainability is argued to be an essential aspect. The focus is on fundamental rights and freedom, including equality and intergenerational balance (Yılmaz & Bakış, 2015). In organizations, the social dimension of sustainability can be described as the organization's impact on the social system (Mies & Gold, 2021) and the company's relationship with its stakeholders (Labuschagne et al., 2005). Internally, the focus lies on health, rights, equity, and well-being. Externally, the focus lies on contributions to economic activities on a macro-level (Labuschagne et al., 2005).

Economic sustainability entails a steady flow of private investments where resources are used and managed efficiently. Moreover, the assessment of economic efficiency is made considering social criteria rather than organizational profitableness by, amongst other things:

- Creating new merchandising opportunities
- Creating new markets
- Decreasing resource and energy use in production, thus lowering the costs

(Yılmaz & Bakış, 2015)

The environmental aspect of sustainability considers the impacts that humans make on the environment (Morelli, 2011). Morelli (2011) further defines environmental sustainability as: *"meeting the resource and service needs of current and future generations without compromising the health of the ecosystems that provide them*" (p. 6). A second definition is: *"the ability to maintain things or qualities that are valued in the physical environment"* (Sutton, 2004, p. 1). Such resources and qualities are air, water, land, and mineral & energy resources (Labuschagne et al., 2005)*,* where sustainability is achieved by protecting and conserving natural resources (Yılmaz & Bakış, 2015).

2.4 Sustainability in Construction

Sustainable construction can be described simply as sustainable development implemented in the construction industry. Sustainable construction entails that the industry steps away from its traditional focus areas of the economy, durability, and utility (Baloi, 2003). Furthermore, to meet environmental challenges and deliver economic improvements while also considering cultural and social demands (Bal et al., 2013). The construction industry significantly impacts the environment and climate (Baloi, 2003; Yılmaz & Bakış, 2015). According to Yılmaz & Bakış (2015), the environmental problems caused by construction can be significantly reduced. Sustainability is becoming increasingly considered in construction contexts (Bal et al., 2013; Baloi, 2003; Yılmaz & Bakış, 2015), and the construction industry is under pressure to do so (Baloi, 2003).

The sector has the potential to increase economic sustainability. However, it is argued that the construction industry cannot support environmental sustainability, partly due to inefficient use of resources and partly due to its economic inefficiency (Yılmaz & Bakış, 2015). Moreover, the construction industry tends to stick to tested methods, limiting innovation (Sullivan et al., 2010). Leading sustainability-focused change requires various approaches (Scott & Esteves, 2017; Washington, 2015). To successfully transition to sustainability, the overall mindset of the organization must change. It includes the transformation of norms and values related to the environment and socio-economic well-being, seeing all involved stakeholders as units linked to the organization's success (Moran & Brightman, 2001).

Construction is complex (Zavadskas et al., 2018), dynamic and risky (Bal et al., 2013; Segerstedt & Olofsson, 2010). Baloi (2003) further states that implementing sustainability in construction has been difficult. To achieve the most efficient and sustainable solution, many options must be analyzed (Zavadskas et al., 2018), and economic and sustainability objectives must be balanced (Baloi, 2003). The potential benefits of adopting sustainable construction practices are improved staff working conditions and protection of the environment. However, barriers in terms of lack of knowledge and awareness regarding environmental aspects and insufficient legislation, commitment, communication, and change management need to be overcome (Baloi, 2003). Hence, the leader's role in finding necessary measures to induce change towards sustainability is essential (Moran & Brightman, 2001) to ensure a smooth implementation (Burnes, 2004). By advocating trust, transparency, and open communication between management and staff in an organization (Washington, 2015; Moran & Brightman, 2001) and by advocating social gains, sustainability can be achieved (Ali et al., 2019).

2.4.1 Stakeholder Identification & Engagement

A construction company does not execute the project on its own. Instead, most of the production work is carried out by other stakeholders (Segerstedt & Olofsson, 2010). Stakeholders can be defined as: *"any group or individual who can be affected or is affected by the achievement of the organization's objectives"* (Freeman & McVea, 2001, p. 4). Familiar stakeholders in construction are, amongst others: consultants, clients, engineers, subcontractors, managers, local government, coordinators, directors, suppliers, and subcontractors. The absence of stakeholders can lead to a neglect of issues relating to sustainability. Stakeholder identification and engagement are therefore critical activities that should occur early. By engaging appropriate stakeholders, increased project quality and economic sustainability can be attained and simultaneously reduce the environmental impact. Furthermore, stakeholders can affect the organization's functioning, development, and goals (Bal et al., 2013). Freeman & McVea (2001) describes two postures for managing stakeholders: buffering and bridging. Buffering entails an amplifying of barriers between internal and external stakeholders. It is argued that excluding important stakeholders always is a losing strategy.

2.5 Construction Logistics

Logistics is critical to consider in construction since it directly influences project performance indicators such as reliability, cost, and production speed (Sullivan et al., 2010). Coordinated construction logistics are highlighted as a necessary rational tool to improve efficiency in the industry (Hedborg Bengtsson, 2019). Moreover, logistics are interesting to consider to reduce construction projects' social and environmental impact. Limited storage space, congested roads, and disruption of residents and businesses need to be considered, especially for sites located in cities and urban areas. Each construction project is complex (Hedborg Bengtsson, 2019) and unique in the working environment, nature of work, and client policies (Sullivan et al., 2010). Sullivan et al., (2010) argue that the preconstruction phase, where the context of the project is defined, is vital for a successful project. Moreover, good communication is essential to ensure the consistent functioning of processes.

2.5.1 Construction electricity

The electricity provided to a site can be permanent or temporary. In construction, temporary power grid connections are commonly used. In contrast to permanent configurations, temporary electric configurations require agility and flexibility to cope with different power ranges and distributions. Furthermore, temporary electric configurations must be moveable and adaptable to the project's progression. Thus, it is vital to know when and where equipment is relocated. In addition, several factors require attention when planning for electrics on site: Waterproofing sensitive electrical components and equipment, health and safety when working with and installing electrical components and equipment. Managing temporary electrics requires electric specialists (Sullivan et al., 2010).

2.6 Construction Vehicles & Machinery

Electrification and hybridization of vehicles are not new phenomena (Mol et al., 2010). However, heavy vehicles, primarily off-highway vehicles, have fallen behind and are still in the conceptual and prototype phase. This is mainly due to uncertainties about performance and acceptability (Beltrami et al., 2021) and technological and economic aspects (Mol et al., 2010), which further complicates selling the concept (WSP, 2017). Some can be derived from the project orientation that characterizes the construction industry, leading to high-cost awareness and an unwillingness to invest in unproven concepts and technology (WSP, 2017). Furthermore, access to infrastructure that caters to electricity can limit the applicability of electric vehicles (EVs) if the project is isolated. Additionally, vehicles and machinery are often provided and owned by small (WSP, 2017) or lease and rental companies (Mol et al., 2010), which can further complicate and reduce interest as they often have small financial margins (Mol et al., 2010; WSP, 2017). There are, however, initiatives that target sustainability within the construction industry, and the transition towards an electrified machine fleet is underway (Berg et al., 2015; WSP, 2017).

2.6.1 Types & Configurations

Construction vehicles and mobile work machinery are often targeted for defined tasks in off-road conditions. Mol et al., (2010) state that different powertrain technologies are available when speaking of electrification of heavy-duty vehicles in general: All-Electric Powertrains, Hybrid Electric Powertrains, and Plug-in Hybrid electric powertrains. The use and advantages of each powertrain vary with the type of vehicle and are of usage. What characterizes an all-electric powertrain is that the energy storage system and the traction drive are electric. In addition, an All-Electric Powertrain features benefits regarding efficiency, as it has a more energy-efficient motor (Mol et al., 2010). There are three main configurations:

- Tethered-type: Tethered-type configurations are common in underground applications, where air pollution is a concern and the vehicle is in a fixed position for longer durations. The charging is continuous and does not result in any limitations in terms of operational time.
- Battery-type: The battery-type configuration is interesting from a flexibility perspective but faces limited operational time relating to the battery capacity. In addition, there is also a correlation between the weight of battery-type configurations and operational time. The most extended operational runtime can be attained for excavators when keeping the weight under approximately 10 000 kg.
- Tethered-battery-type: The tethered-battery-type configuration combines the flexibility of the battery-type configuration and the option of continuous charging as the Tethered-type configuration.

(Beltrami et al., 2021)

Vehicles with a Battery-type configuration can be called Battery Electric Vehicle (BEV). Hybrid Electric Vehicles (HEV) are most common for on-road applications and suited for driving patterns that include frequent deceleration and acceleration (Mol et al., 2010). Hybrid electric powertrains differ from all-electric powertrains by having two sources of power.

The power sources typically consist of a petroleum-fueled combustion engine and a supplementary electric motor. The supplementary power source allows for many benefits compared to a traditional petroleum system: Extra power when performing demanding operations, allowing downsizing of the combustion engine, thus improving the efficiency and still meeting the power demand (Beltrami et al., 2021; Mol et al., 2010). A Plug-In Hybrid Electric Vehicle (PHEV) combines technologies of all-electric and HEVs. PHEVs are intended to operate primarily on electric power while still having a conventional combustion engine that can assist with power and range (Mol et al., 2010).

2.6.2 Characteristics

Achieving satisfactory energy availability and power performance is particularly challenging in construction contexts (Berg et al., 2015). While the focus lies on traction for passenger cars, the focus varies largely for off-road vehicles and machinery depending on the area of usage and what type of power requirements are needed for accessory features such as hydraulic systems. Furthermore, off-road construction vehicles and machinery have more complex load profiles (Beltrami et al., 2021). The average operating power lies within the 50-80 % maximum range, and the number of continuous operating hours is significantly higher (Mol et al., 2010), reaching up to eight hours (Beltrami et al., 2021). The difference can be expressed as a difference in duty cycles, where the term cycle is synonymous with the period under which the machinery operates. The fundamental characteristics of electrical motors (EMs), in contrast to conventional Internal Combustion Engines (ICEs), are that they can provide the maximum amount of power throughout the velocity range (Beltrami et al., 2021). Beltrami et al., (2021) compared excavators with an ICE and an EM in terms of both continuous and peak power to operating weight. The results indicate that the continuous power-to operating weight ratio is similar for the EM as the ICE, though slightly higher for the former. For the peak power-to-weight ratio, the EM is significantly higher than the ICE.

2.6.3 Charging

As electrification progresses, the need to charge batteries and thus also the need for charging infrastructure increases. Increased electrification of heavy-duty vehicles operating in urban environments can strain the electrical networks, suggesting that optimizing the vehicles and their use is essential and where the focus should be directed. Energy efficiency is highly relevant for electric vehicles and machinery in general, more so than for conventional ICE, considering the already restricted operational runtime (Beltrami et al., 2021) and the 10-30 times longer charging duration when compared to refueling traditional ICE vehicles and machinery (Energimyndigheten, 2021a). When addressing the need for charging, it is also essential to consider the type of power configuration that the machinery has. In the study of Berg et al., (2015), three scenarios based on different charging strategies as well as different storage systems and technologies (configurations) for BEV and PHEV haulers and dumpers are evaluated: Charging while being operated (Cycle), charging during lunch breaks and night (Lunch and night) & charging strictly during the night (Night).

The strategies were evaluated based on three primary parameters: Weight & Volume, Part & Lifetime Cost, and Environmental Cost of the storage system. Concerning Environmental cost of BEVs, all scenarios are better than a diesel version (Berg et al., 2015). See Table 2.1 & 2.2.

Table 2.1. *Vehicle configurations, charging strategy and charging duration. Own table, adapted from (Berg et al., 2015).*

Charging strategy	Charging duration [sec]
Cycle	30-100
Lunch & Night	2,400
Night	57,600

Table 2.2. *Optimal charging strategy depending on vehicle configuration and main area of consideration. Own table, compiled from (Berg et al., 2015).*

	Charging scenarios for optimal:		
	Weight & volume	**Part and lifetime cost**	**Environmental costs**
BEVs	Within cycle	Part cost: Within cycle Lifetime cost: During night	Combined charging: Night and/or at Lunch
PHEVs	Within cycle	Part cost: Within cycle Lifetime cost: Lunch & Night	Combined charging: Night and/or at Lunch

2.6.4 Considerations

Noise is an environmental problem on construction sites for those in its vicinity (Naturvårdsverket, n.d.). In congested areas and in areas with low speeds, BEVs and HEVs have the potential to reduce noise emissions (Energimyndigheten, 2021a; Sandberg et al., 2010; Verheijen & Jabben, 2010). Therefore, EVs are suitable in urban areas (Beltrami et al., 2021) and applicable where environmental consideration is required (Mol et al., 2010). However, silent vehicles can pose a danger as they may be more difficult to detect (Verheijen & Jabben, 2010). To prevent accidents involving pedestrians and bicycle users, various preventive measures can be taken using sensors and visual and auditory aids (Sandberg et al., 2010). Another environmental aspect associated with electric powertrain systems is that they contribute to fewer emissions (Mol et al., 2010) by reducing the consumption of fossil fuels (Energimyndigheten, 2021a). Energimyndigheten (2021a) further argues that reducing emissions leads to a better working environment.

Prices act as a barrier to further implementation (Mol et al., 2010). At present, the cost of battery-powered vehicles is significantly higher and highly dependent on the development of batteries. For instance, a battery-powered wheel loader can be up to three times as expensive as the corresponding diesel-powered wheel loader (WSP, 2017). However, a decrease in lifetime costs can be achieved using electric machinery because of less maintenance and better efficiency, thus contributing to competitive advantages (Mol et al., 2010). Ribberink et al. (2021) argue that so is the case for both small and large excavators, providing both economic and environmental benefits. Calculations indicate that small electric excavators have lower fuel, maintenance, and operational costs when compared to small diesel excavators.

Whereas the large electric excavator is moderately cheaper when looking at maintenance costs and more expensive fuel costs, which can be derived from higher charging costs. In theory, the total investment cost (purchase & installation) of charging infrastructure and the annual usage costs correlate to the charging power provided by the installed infrastructure (Ribberink et al., 2021). Therefore, smart charging and optimizing the vehicle's electrical outlets can become more common and relevant in conjunction with electricity prices becoming more volatile (Energimyndigheten, 2021a).

Whether it is advantageous from a practicality standpoint depends on whether the requirements are met to ensure its functionality for the duration of a working period regarding driving and recharging. Ribberink et al. (2021) state that the possibility of refueling and recharging construction machinery on-site must exist. However, the authors declare uncertainty about how electricity will be supplied to the site. Larger vehicles and machinery with intensive cycles may require that the logistics are well planned at the construction site, considering the operational driving time and the difficulties with charging infrastructure (Beltrami et al., 2021). The current battery technology limits the implementation of hybrid vehicles, as the necessary power cannot always be guaranteed (Mol et al., 2010).

Distribution and access to existing infrastructure that satisfies, among other utilities, electricity is a prerequisite when adopting EVs (WSP, 2017). Charging EVs may offer greater flexibility than conventional refueling stations (Energimyndigheten, 2021a). On the other hand, inadequate charging infrastructure reduces convenience and flexibility (Kumar et al., 2021). Moreover, Energimyndigheten (2021) states that it is difficult to expand the charging infrastructure due to, among other things, electricity network limitations. Kumar et al. (2021) further argue that the fear of depleting the energy storage before reaching the destination is one of the main barriers to the adoption of EVs.

In addition, there are a limited number of configurations available for electrified construction vehicles and machinery. Availability is reflected in the prices of electrified vehicles. In the long term, the conditions for electrification and hybridization of the construction sector are good. By 2050, most vehicles and machinery in the construction sector are expected to be either hybridized or electrified (Energimyndigheten, 2021a). However, it is challenging to sell the concept of electrification because there is a lack of essential data, driving cycles for different machinery and activities, to make accurate analyses, calculations, and comparisons. Furthermore, reliability is a priority and can act as an obstacle to the implementation of new technologies. Nevertheless, the transition towards a fully or partially electrified machine fleet is already underway. This can be explained by the pursuit of reduced fuel costs and gaining a competitive advantage by having an environmental profile (WSP, 2017).

2.7 Executive summaries

Previously covered theories are exemplified in a broad perspective in a report on:

Section 2.7.1	Emission-free Construction Site
Section 2.7.2	Feasibility study Electric Worksite
Section 2.7.3	Emission-free Construction Machinery, Recommendations for Procurement Requirements

2.7.1 Emission-free Construction Site

In this section, the report covering the project Emission-free Construction site is compiled.

2.7.1.1 Prerequisites

Olav Vs Gate is a street located in the center of Oslo. The street was adapted to pedestrians and renovated. The project was a pilot project for an emission-free construction site where a major focus was on machinery. The contractor was procured by the Norwegian Agency for Urban Environment, Bysmiljøetaten, through an open tender competition. The tender was evaluated based on cost and quality criteria. The project was carried out as a main contract (execution contract) during the period September 2010 - December 2020. The report consists of two primary chapters:

- Planning
- Project execution

(Bymiljøetaten, 2020).

2.7.1.2 Results

This section presents the main take-aways from the market dialogue during the planning phase. Furthermore, five main areas of results connected to the project execution are summarized: Charging, Functionality, Environment & Health, Economy, and Encountered Problems.

The market dialogue resulted in the following:

- Due to increased interest, there are longer delivery times and a limited supply of electrical machinery and vehicles on the market which led to traditional diesel vehicles having to be converted. The machinery suppliers were open to converting machinery but wanted guarantees that the machines would be used.
- The limited supply combined with the fact that few contractors had their own electrical machinery and vehicles resulted in Norwegian Agency for Urban Environment both investing in and renting electrical machinery and vehicles.
- Many machineries risked being unused during the project period, something the Norwegian Agency for Urban Environment solved by offering service license agreements, which made subletting possible.

- Lack of knowledge about the division of responsibilities. The contractor wanted the customer to take responsibility for access to electricity and take the electricity bill. Usually, fuel is included when renting traditional vehicles and machinery. In this project, the conditions were different because of electrification. There was uncertainty as to whether the electricity in the area would be sufficient, which posed a risk to the contractors in terms of time and cost. To escape the risk, the contractors insisted that the developer should be responsible for the electricity supply, thus facilitating the tendering process. Having EVs requires charging infrastructure. In Olav Vs gate, electricity was supplied through underground cables and distributed via electrical cabinets. The electrical cabinets were moved continuously to ensure an efficient charge
- Lack of experience in what it is like to work with electrical machinery and vehicles.

(Bymiljøetaten, 2020).

Machinery was occasionally forgotten to be charged, which could be attributed to a lack of experience. Consequently, the machinery ran out of charge early in the day. Even when the machines were charged correctly during lunch and work breaks, they did not last a full working day. It was essential to minimize the distance between the machinery and the charging stations from a battery capacity perspective. The location of the charging stations was also crucial for the project's progression and operation (Bymiljøetaten, 2020). The range, performance, and capacity of the machinery utilized in the project are illustrated in Table 2.3. For specifications of operating and charging conditions, see Table A1 in Appendix A.

Table 2.3. *Compilation of the electrified machinery used in the emission-free construction site, Olav Vs gate. Own table, compiled from Bymiljøetaten (2020).*

Machinery	**Excavator 8 tons**	**Excavator 16 tons**	**Excavator 25 tons**	**Wheel Loader**
Type	Cable and battery	Cable and battery	Battery	Battery
Engine power [kW]	40	75	122	22
Battery capacity [kWh]	100	Not specified	300	33
Battery operation time:				
Manufacturer	4 hours	30-40 minutes	6-8 hours	3-5 hours
Contractor	8 hours	Not specified	6-8 hours	2-4 hours
Charging time:				
Manufacturer	2.5-9 hours	1 hour	5-7 hours	6-7 hours
Contractor	7-9 hours	Not specified	5-7 hours	8 hours
Fast chargning	Yes	No	Yes	No

The contractor stated that the emission-free excavators have a capacity equivalent to that of fossil-fueled if they are charged and suitable for the task at hand. Re-flattening was, however, necessary since the electric wheel loaders had a lower capacity than traditional ones. Consequently, a HVO-diesel wheel loader was used as a supplement when the electric machinery was insufficient. The electric machinery and vehicles were, however, perceived as more reactive and comfortable to drive (Bymiljøetaten, 2020).

Electric machinery and vehicles were perceived as quieter, thus contributing to better communication and increased safety at the workplace. Furthermore, the implementation of electric machinery and vehicles improved the air quality, resulting in reduced fatigue and thus better work safety and environment for the employees. The efforts made to achieve an emission-free construction phase contributed to reducing emissions by 52 % compared to if the project had instead been implemented fossil-free. Compared to if the project was carried out with fossil fuels, the corresponding percentage is 99 %. The project saved approximately 37,000 liters of diesel, whose related emissions represent about 100 tons of CO_2-equivalents. Had the project instead only used HVO fuel, the savings would have been approximately 1.5 tons of CO_2-equivalents (Bymiljøetaten, 2020). See Figure 2.1.

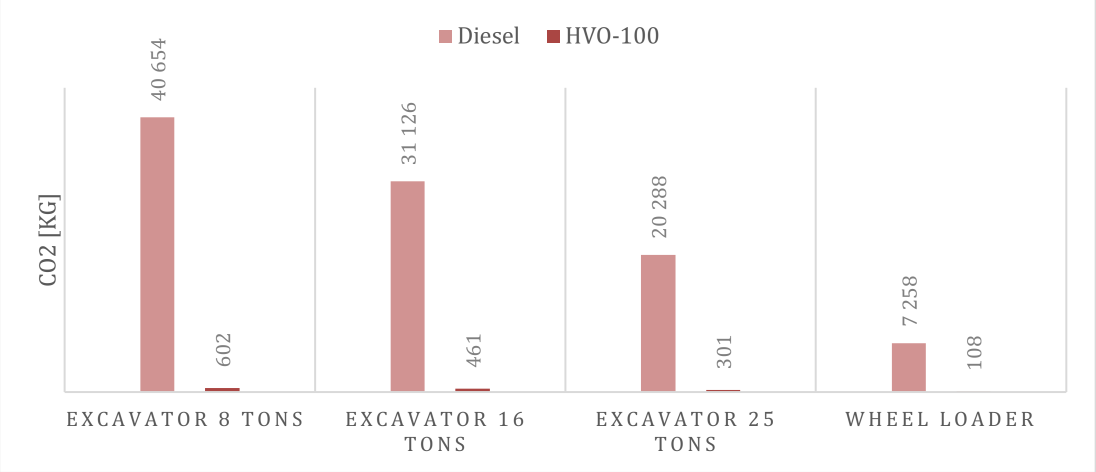

Figure 2.1. *Total CO_2 savings per machinery category when operating on electricity compared to diesel and HVO-100 as fuel. Own figure, compiled from* Bymiljøetaten (2020).

The project was consequently 8.69 % more expensive, which could be attributed partly to additional costs due to more expensive machine rent and other expenses, which amounted to 5.1 MNOK. Consequently, the construction cost of the project rose to 63.9 MNOK. Furthermore, the project was prompted by preparatory work corresponding to a cost of 3.9 MNOK. However, this cost was not allocated to the project, but the developer. Hence, additional costs resulting from the transition amounted to 9 MNOK, see Figure 2.2. In addition, there have been overheads because of deviations from the original emission-free conditions (Bymiljøetaten, 2020).

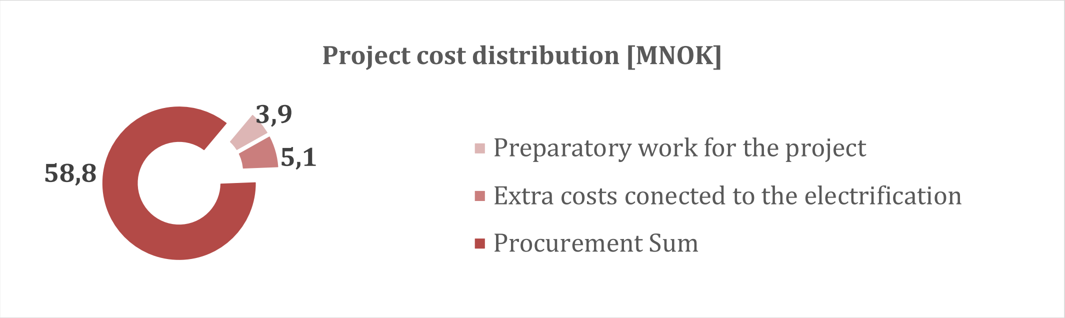

Figure 2.2. *Project cost distribution [MNOK]. Own figure, compiled from* Bymiljøetaten (2020).

The cost of electricity was initially high because the electricity was priced as temporary construction electricity. During the latter stage of the project, permanent electricity was established, which entailed a kWh-cost reduction of about 58 %. The project consumed electricity at a cost of approximately 219,000 NOK. Furthermore, there were additional costs for the electricity connection to the grid, upgrading the transformer station, extra temporary cables, and rental of building cabinets during the construction period at the expense of 451,000 NOK. The total electricity related costs amounted to 670,000 NOK. For Diesel and HVO-100, it was assumed that there would be no additional costs. It was estimated that diesel as a fuel would cost 221,718 NOK while the HVO-100 would cost 480,338 NOK (Bymiljøetaten, 2020). See Figure 2.3.

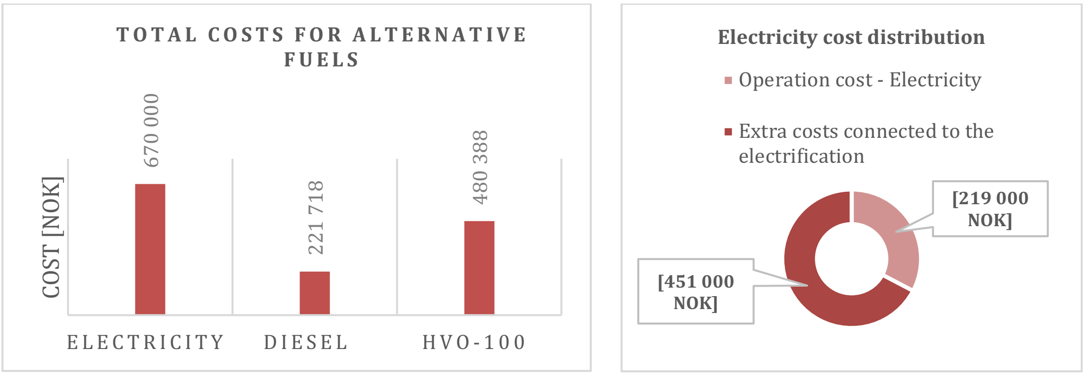

***Figure 2.3**. Cost comparison of the three primary energy sources (left). Distribution of the electricity costs (right). Own figure, compiled from* Bymiljøetaten (2020).

The encountered problems during the project are summarized and categorized into three categories: Weather and Climate, Charging, and Technical. See Table 2.4.

***Table 2.4.** Compilation of the encountered problems with the selected electrical machinery used in the project. Compiled from* Bymiljøetaten (2020).

Problem Area	**Description**
Weather and Climate	Colder weather led to challenges linked to the functionality of the machinery as they were sometimes difficult to start and sometimes even required restarting
Charging	• Error codes • Blown fuses • Power blackout • Water in the power cable • Disconnection of the cable due to human error
Technical	• Hydraulic oil leakage • Battery cooling did not work • The machinery stopped for unexplained reasons

2.7.1.3 Conclusions

The conclusions from Olav Vs Gate are summarized and categorized into five categories: Procurement, Machinery, Electricity, Charging, and Costs. See Table 2.5.

Table 2.5. *Conclusions of the project. Own table, compiled from* Bymiljøetaten (2020).

Area	**Description**
Procurement	• The environment should constitute at least 20% of the construction procurement criteria. • At least half of the environmental criteria must relate to emissions from the construction site. • Suppliers should receive points for using emission-free machines and vehicles and reducing the need for transport.
Machinery	• The lease agreement arranged by the City Environment Agency offered flexibility and optimization of resource use for the contractors. • Some operations proved to be impossible to perform with zero-emission technology. • Machinery directly connected by cable should have better procedures to prevent delays and damage.
Electrical considerations	• The developer should map the grid accessesion possibilities at an early stage • It is crucial to initiate contact with the network companies at an early stage to ensure the availability of electricity and a realistic timeline and cost estimation. • The developer should consider implementing alternative temporary energy solutions.
Charging	• Charging routines and usage routines are central to the machinery lasting a full working day. • More detailed planning should be carried out, where the machinery should be used for what they are suitable for • The optimal temperature for charging the machinery is in the range of -1 to +15 degrees Celsius. At warmer temperatures, error messages occurred and at colder temperatures, the capacity of the batteries was reduced.
Costs	• Additional costs occur when machinery needs to be converted. • All costs relating to the switch to electric machinery are expected to decrease following the increase in production • Increased demand can lead to more competition among machine suppliers and thus lower the prices. • More experience and knowledge from similar pilot projects will gradually reduce costs and the need for own dedicated project resources.

2.7.2 Feasibility study, Electric Worksite

In this section, the report covering the Feasibility study Electric Worksite is compiled.

2.7.2.1 Prerequisites

The project aimed to create conditions for cooperation, knowledge exchange, and dialogue regarding the use of electrical construction machinery. The projects were located in an urban environment in the Gothenburg area and took place in 2020/2021. The project was divided into two main work packages. In short, the goal of the packages was to develop project descriptions for test- and demo projects which are carried out using electric machinery (Bernholdsson et al., 2020).

2.7.2.2 Results

Initially, a mapping of machinery used in both small and large contracts is presented, followed by the possibilities of replacing conventional machinery with electrical machinery. Thereafter, the energy demand for different degrees of electrification and the financial results are presented.

The study maps the number and size of machinery in 22 small construction projects and 3 large construction projects. See Figures 2.4 & 2.5.

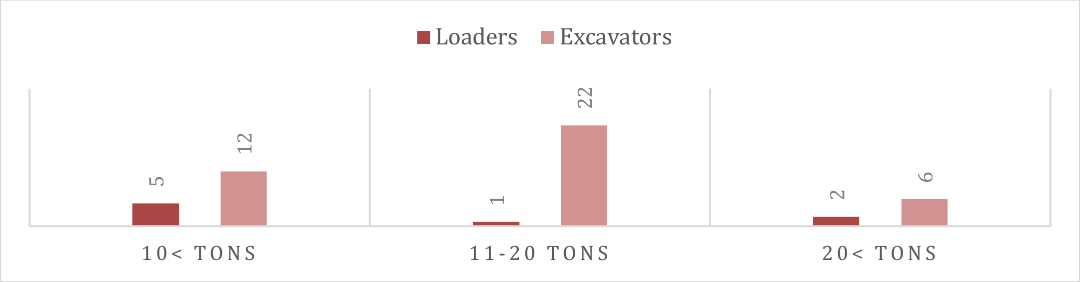

Figure 2.4. *The number and size of machinery in the 22 smaller construction projects. Own figure, compiled from Bernholdsson et al. (2020).*

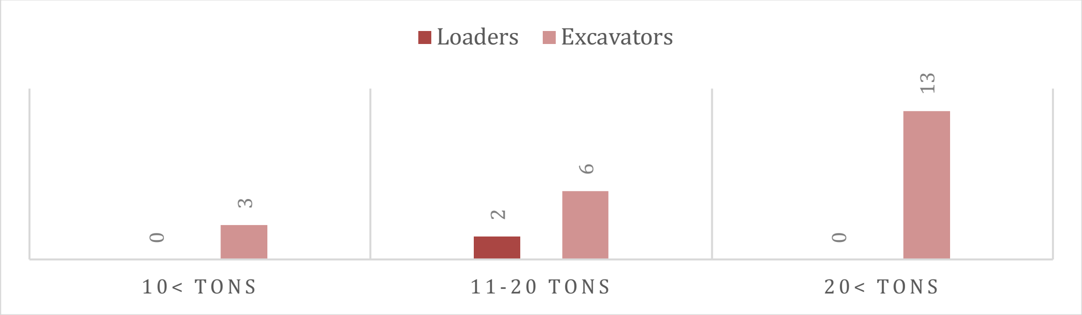

Figure 2.5. *The number and size of machinery in the 3 larger construction projects. Own figure, compiled from Bernholdsson et al. (2020).*

The analyzed machines under 10 tons (compact machinery) have engine power within 18.5-85 kW. Machines between 11-20 tons (medium machinery) have engine power within 75-137 kW, and machines above 20 tons (large machines) have engine power within 107-226 kW. The machinery is mainly medium-sized for the 22 small projects, while the three larger contracts primarily use large machinery. The compact machinery is further categorized into compact excavators and compact loaders.

A theoretical analysis concluded that a commercially available compact excavator could replace 2 out of 12 compact excavators intended for construction. The corresponding number for the compact loaders was 2 out of 3 (Bernholdsson et al., 2020). See Figure 2.6. Similar data is not produced for the medium-sized or the large machinery.

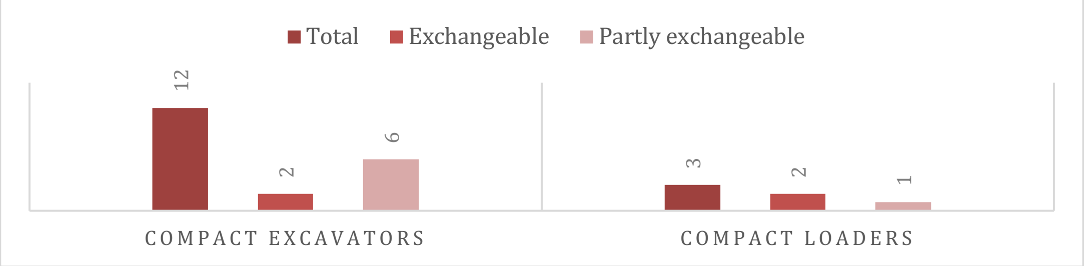

Figure 2.6. *The total number of compact machinery in the small and large contracts and the number of compact machinery that are wholly or partly exchangeable with electrical variants that are currently commercially available. Own figure, compiled from Bernholdsson et al. (2020).*

The local network is heavily loaded during the morning and evening hours and certain parts of the year. The capacity of the local electricity grid may therefore become an obstacle to the electrification of machinery. As a result, the estimated daily energy consumption that the study presents is based on assumptions about energy consumption, working hours, and energy use. The premises resulted in estimated daily energy needs, which then formed the basis for three scenarios on which the study's analysis is based: Low, Medium, and Max. In addition, three charging strategies were considered. The strategies entail different charging durations which occur during other times of the day (Bernholdsson et al., 2020). Details of the scenarios and the three charging strategies can be found in Table 2.6 & 2.7. See also Table A2 in Appendix A.

Table 2.6. *Percentage of energy consumption, active hours and type of workload for the three scenarios (Low, Medium & Max).* Own table, compiled from Bernholdsson et al. (2020).

Scenario	Percentage of max (8h use) Energy consumption / Active hours	Workload
Low	20 / 1.6	Moderate
Medium	50 / 4	Mix of moderate and intensive
Max	80 / 6.4	Intensive

Table 2.7. *Total number and distribution of charging hours for the three charging strategies. Own table, compiled from* Bernholdsson et al. (2020).

Chargin Strategy	Time of day	Precentage of total daily charge	Total charging hours
1	Night	100	12
2	Night Forenoon Afternoon	50 25 25	12 0.5 0.5
3	Night Forenoon Lunch Afternoon	40 15 30 15	12 0.5 1 0.5

The energy demand in the smaller contracts varied greatly. The daily energy needs for the 22 smaller contracts and the different scenarios are below. Assumptions for the estimations are found in Table A2. See Appendix A.

- Scenario Low (14-343 kWh)
- Scenario Medium (54-1,160 kWh)
- Scenario Max (115-2,340 kWh)

For most smaller contracts and scenario Low, the energy demand was less than 150 kW. Eight contracts exceeded the 150 kW limit for scenario Medium, and one contract exceeded 450 kW. For scenario Max, all but five contracts exceeded 150 kW, and five exceeded 450 kW. The charging strategies that require the highest power output are in descending order 2, 3, and 1 (Bernholdsson et al., 2020). See Figure 2.7.

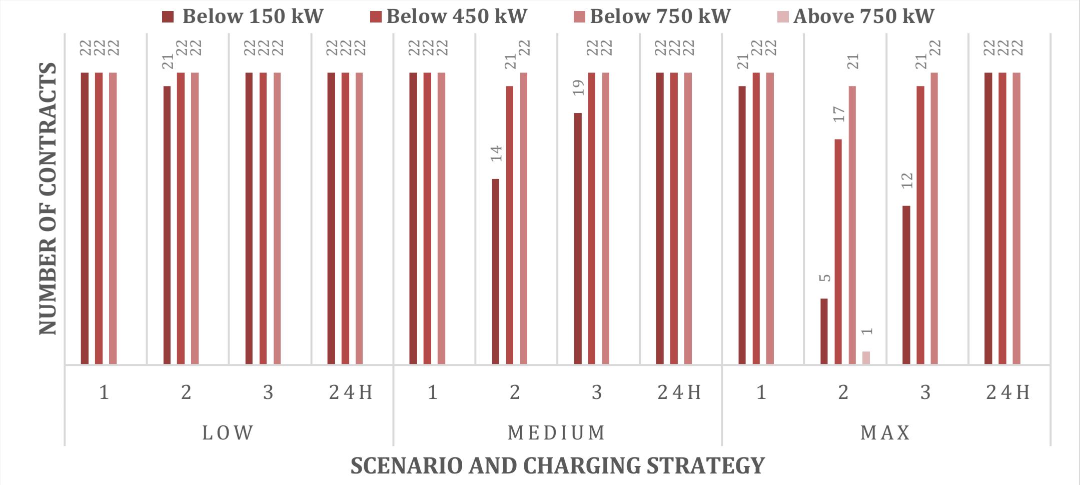

Figure 2.7. *The number of small contracts that are below and above the power output limits for the different charging strategies and scenarios. Own figure, compiled from Bernholdsson et al. (2020).*

The report delimits the theoretically necessary power outputs to only one of the three large contracts, as they use similar machinery and thus have identical daily energy requirements. The daily energy needs for the three large contracts and the different scenarios are below. Assumptions for the estimations are found in Table A2. See Appendix A.

- Scenario Low (459-563 kWh)
- Scenario Medium (1,661-1,893 kWh)
- Scenario Max (3,478-3,807 kWh)

Only Strategy 1 and scenario Low managed a power output of 150 kW for the studied large contract. For Strategy 2, over 150 kW was required for Scenario Low and well above 750 kW for both Scenario Medium and Max. For Strategy 3, the Low, Medium, and Max scenarios were above 150, 450, and 750 kW. Considering the average daily power, it exceeds 150 kW only for Scenario Max (Bernholdsson et al., 2020). See Table 2.8.

Table 2.8. *Scenarios and strategies that would entail large contracts to be below or above the output limits. Own table, compiled from Bernholdsson et al. (2020).*

Scenario	**Strategy**	**Below**			**Above**	**Below**
		150 [kW]	**450 [kW]**	**750 [kW]**	**750 [kW]**	**150 [kW] daily average**
Low	1	YES	YES	YES	NO	YES
	2	NO	YES	NO	NO	
	3	NO	YES	YES	NO	
Medium	1	NO	YES	YES	NO	YES
	2	NO	NO	NO	YES	
	3	NO	NO	YES	NO	
Max	1	NO	YES	YES	NO	NO
	2	NO	NO	NO	YES	
	3	NO	NO	NO	YES	

Four cost items are analyzed: Investment cost – Powertrain & Battery, Cost – Fuel & Energy, Total cost over the lifetime (including investment and operation costs, excluding charging fees), and Charging fees and cost of electricity network connection. See Table 2.9.

Table 2.9. *Cost items. Own table, compiled from Bernholdsson et al. (2020).*
**Assumptions presented in Table A2, see Appendix A.*
***Calculations presented in Table A3, see Appendix A.*

Investment cost – Powertrain & Battery
• The investment cost of battery-powered machinery with a capacity to last a full working day is just over four times as expensive as the corresponding diesel variant. However, for battery-powered machinery with a capacity to last only half a day, the factor amounts to approximately two. The higher costs can be derived from the price of the battery. *
Cost – Fuel & Energy
• The cost of fuel and energy is expressed as SEK/kWh work performed. • The kWh-cost of electricity is about four times lower than diesel. *
Total cost over the lifetime (including investment and operation costs, excluding charging fees)
• Provided that the machinery can handle the entire estimated service life, the battery-powered machinery that can last an entire day without charging will be approximately 700,000 SEK less expensive than their diesel-powered counterparts. Machinery with a battery that can last half a day will be 1,000,000 SEK less expensive. * • The point of profit depends on how much the machine is used. For the battery that lasts all day, profit occurs at just over 6,000 hours. For the battery that lasts half a day, profit occurs at about 3,000 hours.
Charging fees and cost of electricity network connection
• The study mentions seven different connection options to construction sites: 1. Establishing new connections in conjunction with new construction 2. Connect to already existing charging stations 3. Mobile energy storage systems in the form of batteries 4. Use of the existing cable cabinet (150 kW) 5. Use of existing substation (450 kW) 6. Use of temporary mobile substation (750 kW) 7. Connection to lighting poles • The cost of network connection, expressed in SEK/kWh and SEK/installation/kWh, on a construction site differs depending on the chosen connection option and for how long the connection is used. For the investment in battery operation to be profitable, the cost of night chargers must not exceed 1.7 SEK/kWh and 2.4 SEK/kWh for fast chargers. * • For night charging and a power of 50 kW, the cost will be 150,000 SEK. For fast charging, where the charging needs are covered during a break of 30 minutes, a power of 120 kW is needed, and the cost amounts to 720,000 SEK). Both night and fast charging are within the limits that apply to a battery-powered machine's investment to be profitable. However, the cost does not consider the network connection cost itself. * & ** • For the existing cable cabinet and existing substation (options 4 & 5), the price varies according to Figure 2.8. * & ** • If a new connection is established in a temporary substation (option 6), the cost varies according to Figure 2.9. * & **

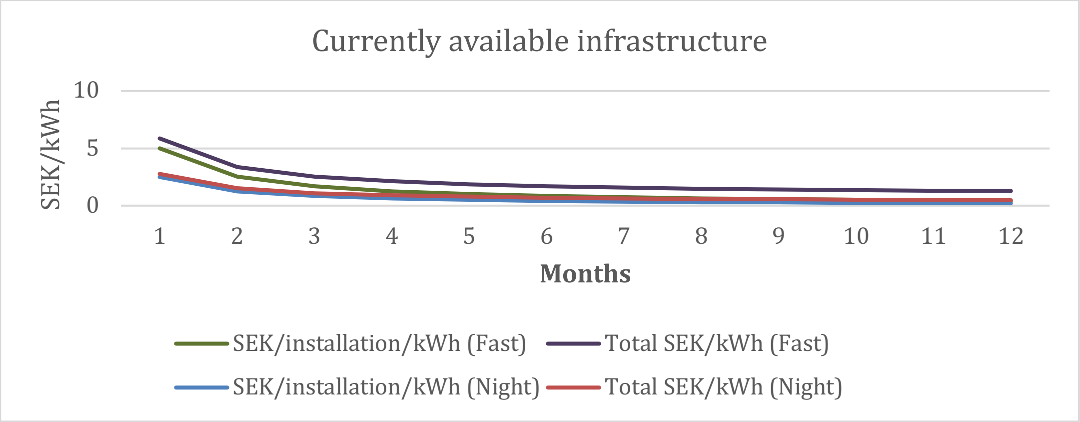

Figure 2.8. *Variation of prices when using currently available infrastructure for fast charging and charging during the night. Own figure, compiled from* Bernholdsson et al. (2020).

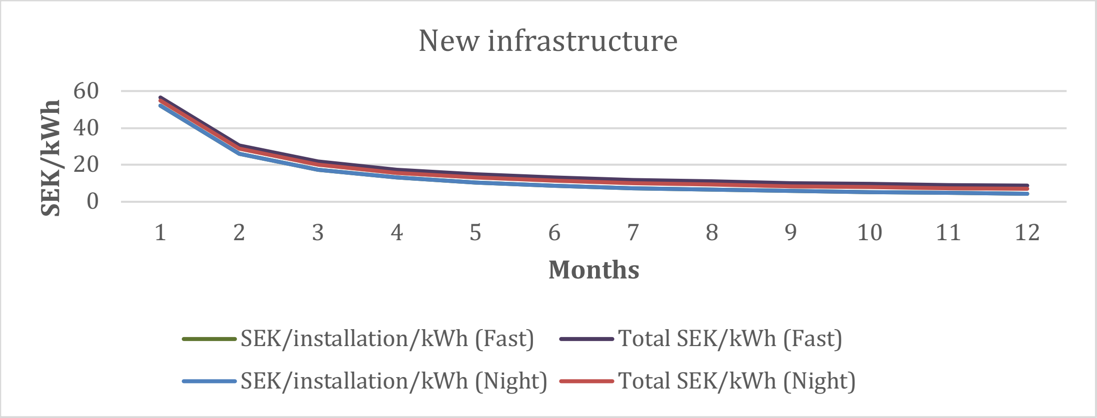

Figure 2.9. *Variation of prices when establishing new infrastructure for fast charging and charging during the night. Own calculation and figure, compiled from* Bernholdsson et al. (2020).

2.7.2.3 Conclusions

The study's conclusions are summarized and categorized into three main categories: Demand & Exchangeability, Connection, Power supply & Charging strategy. See Table 2.10.

Table 2.10. *Conclusions of the feasibility study. Own table, compiled from* Bernholdsson et al. (2020).

Area	**Description**
Demand & Exchangability	• There are operations carried out by conventional diesel-powered machinery that electric variants can entirely or partly replace. However, these machinery are of smaller size, which does not reflect the market demand.
Connection	• Electrical cabinets may be sufficient for small contracts. • For large contracts that entail new construction, taking advantage of the connection to the new building is an attractive solution. • A high-power output can be ensured using mobile substations.
Power supply & charging strategy	• In large contracts, the choice of charging strategy has a significant impact on the power demand. • Cable-powered machinery would reduce local power output but could cause power quality problems in the local grid. • Energy storage in batteries can be used to even out the power output.

2.7.3 Emission-free Construction Machinery, Recommendations for Procurement Requirements

In this section, the report covering the project Emission-free Construction Machinery, Recommendations for Procurement Requirements is compiled.

2.7.3.1 Prerequisites

The project aimed to develop recommendations for procurement requirements for public actors in Gothenburg that can accelerate the construction sector's transition towards emission-free construction equipment. The project, which was launched in 2019, was conducted in three segments:

- Current situation analysis & climate calculations
- Market dialogue
- Procurement requirements

(Almér et al., 2020).

2.7.3.2 Results

In this section, the results from the current situation analysis, market dialogue, and climate calculations will be presented. The results are categorized into nine categories. See Table 2.11.

Table 2.11. *Summary of the current situation analysis, the market dialogue, and the climate calculations. Own table, compiled from Almér et al., 2020 & Snarset, 2020a, 2020b, 2020c, and Appendix C2 in Almér et al. (2020).*

Form of contract
• Clients use execution contracts more often than turnkey contracts. Only half of the clients have been involved in collaborative projects.
Planning
• Electricity infrastructure must be established before the start of construction. Such establishments can take upwards of six months to finalize. Consequently, longer lead times are needed for tenders and contract writing. • It is essential to apply more extended framework agreement periods to increase the incentives by reducing the risk of investing in new technologies. • Using cable-powered machinery or having a battery storage container on-site could solve the issues with limited operational time for battery-powered machinery.
Knowledge & Development
• Lack of knowledge regarding emission-free work machines regarding price and availability, resale value, and battery life are barriers to increased demand. • Collaboration is vital to speed up development. If the demand for emission-free machinery increases, the availability of machinery will follow. • Clients need more expertise to promote environmentally friendly technology.
Responsibility
• The City of Gothenburg should be responsible for electricity and charging infrastructure. Furthermore, the city should carry out more pilot projects. • Large companies have better economic conditions and should therefore lead the development. • Rental companies should invest more in emission-free machinery since they have greater control over the rate of occupancy.
Setting requirements
• Most actors consider the Common Environmental Requirements for Contractors ineffective. • Requirements are considered to drive development. • The setting and follow up of concrete goals and requirements, and a common forum for knowledge sharing are mentioned as critical factors for increased implementation. • The City of Gothenburg should set the same requirements at the regional level, there should be a long-term perspective and the market situation should be considered. • The requirements need to be technically feasible and preferably published well in advance. • Environmental consideration should carry more weight in procurement.
Follow-up of requirements
• Follow-up of environmental requirements is not done to any great extent, which leads to uncertainty about their effectiveness and legitimacy. • Monitoring the requirements is important to counteract distorted competition and should be carried out systematically in a way that is easy to implement.

Future recommendations

- An adaptability of the requirements to better suit different actors and circumstances.
- An increased soft-value implementation.
- The requirements are increased successfully, and the new requirements balance or replace old requirements to not affect the ability to leave a tender offer.
- The use of a bonus system to increase the incentives.
- To allow for machinery to be delivered to the project after the project start.
- Include other alternative fuels.

Availability, Demand & Costs

- Zero-emission work machinery are currently available, however, to a limited extent. The delivery times varied but were at the most nine weeks.
- There are plans among suppliers to expand their range of electric vehicles. The price for some machines was as much as 70 % higher. The prices of batteries are expected to go down. The total cost of ownership is argued to be similar.

Climate Calculations

The climate calculations are based on data from a project at Tuve Centrum in 2016, where streets, bicycle lanes, and walkways were renovated using seven excavators all over 10 tons. The tender amount was approximately 14 MSEK

The total amount of consumed diesel in the project was 25,413 liters. As a result, the total emission of greenhouse gas equivalents amounted to 52 tons. The corresponding emission if zero-emission work machines had been used is 11.5 tons. See Figure 2.10.

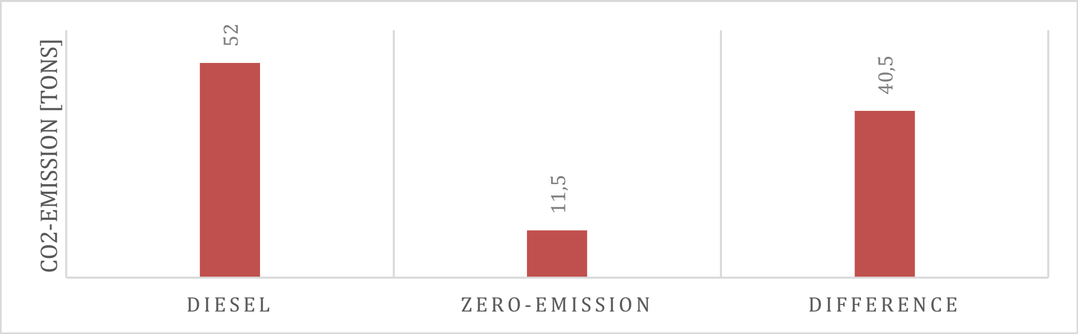

Figure 2.10. *Emissions from the diesel-powered machines compared to what the emissions would have been had zero-emission machines been used. Own figure, compiled from Snarset (2020b) in Almér et al. (2020).*

2.7.3.3 Conclusions

This section summarizes the study's conclusions. Furthermore, proposals and recommendations are given for tender evaluation, follow-up, and bonuses. See Table 2.12.

Table 2.12. *Suggested procurement requirements and recommendations. Own table, compiled from* Almér et al. (2020) *and* Snarset (2020c) in Almér et al. (2020).

Suggested procurement requirements	
A certain percentage of energy consumption shall be from emission-free work machinery	• The client indicates the percentage. • No specific machinery is required, making the requirement flexible.
100% emission-free for selected parts	• The requirement is directed toward isolated operations.
100% emission-free for selected work machinery	• The requirement is directed toward a specific type of machinery.
The tenderer specifies the size of emission reduction using emission-free work machinery	• The requirement includes that the tenderer submits an implementation description for how the project will be carried out with as large an emission reduction as possible. The description is then added to the contract. • The tender shall include a calculation in accordance with the template and instructions provided by the client and the assignment of the project is made based on a weighting between price and environment.
The tenderer is allowed to submit tenders with alternative designs with a higher emission reduction using emission-free work machinery	• The tenderer can submit alternative tenders where the level of use of zero-emission machinery is higher. • If the alternative offer is more expensive, the share of emission-free is weighed in. Emission-free options are rewarded with either price reductions to make evaluation prices comparable or quality points in relation to price points.
Recommendations	
Tender evaluation	Tender evaluation can be carried out according to different principles. For example: • The tender can be awarded to the tenderer with the most quality points. The quality points can be distributed by weighting the price and quality. • The points can also be distributed based on emission reduction, where the tenderer who can show the highest emission reduction is awarded the highest score. • The tenderer who has submitted the best offer from an economic perspective and at the same time meets the set mandatory requirements is awarded the contract.
Follow-up	Follow-up should be carried out systematically and may include: • A list of machinery, working hours for each machine • Invoices • On-site sampling and climate calculations made in accordance with the template provided by the client
Bonuses	The value of all bonuses in projects normally amounts to 0.5-1% of the contract value, within which range bonuses linked to emission-free work machinery should be accommodated.

3 Methodology

This chapter presents the methodology used in this report. Firstly, the research process and design are explained—secondly, the data collection and analysis. Thirdly, the ethical considerations and reflections on the chosen methodology.

3.1 Research Process & Design

Initially, a problem definition was made, and an approach was determined. After that, a research design was elected, and data collection was initiated. The data processing took place simultaneously with the data collection, acting as a continuous source of inspiration (Alvesson & Sköldberg, 2017). Lastly, the data was analyzed, and the report was concluded. The process is illustrated in Figure 3.1.

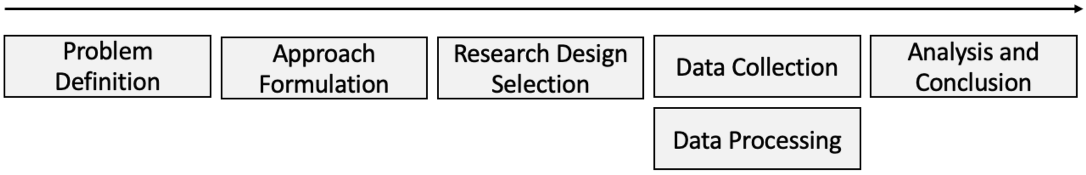

Figure 3.1. *Research process.*

The research took a qualitative approach. The qualitative data consisted of semi-structured interviews, a literature review, and an observation. Using a mixed research design yielded higher credibility, validity (Bryman, 2006), and a more robust understanding of the matter (Creswell & Plano Clark, 2017). Furthermore, it allowed for more efficient identification, determination, and prioritizing of information, thus improving the structure of the findings (Awuzie & McDermott, 2017; Bryman, 2006).

3.2 Data Collection & Analysis

The data was either primary or secondary. The primary data was gathered to answer the specific research questions and consisted of semi-structured interviews and observation. The secondary data was collected to support or contrast the primary data and had already been collected for other research purposes (Mohapatra et al., 2013). The secondary data includes a literature review of qualitative data based on relevant projects, case- and feasibility studies in Gothenburg and Norway. The collected data is visualized in Figure 3.2.

Qualitative data	
Primary data	Secondary data
Observation Interviews	Literatrue review

Figure 3.2. *Data collection of Primary and Secondary data.*

3.2.1 Literature Review

As part of the secondary data, a literature review was conducted. The literature review consisted of a preliminary and a primary review of scientific, academic, government, municipal, case, and project reports and studies. In the preliminary review, the summaries and conclusions were evaluated according to the research topic and acted as an inspiration for the primary literature review. The literature review was conducted using ScienceDirect, Chalmers Library, DiVA, ResearchGate, Scopus, and Google Scholar. Moreover, municipal and organizational web pages were used to find additional information. Moreover, the following keywords were used: Electrification of vehicles, Construction machinery, Construction vehicles, Charging, Construction Procurement, Change Management, and Sustainability.

As part of the primary data, in-depth interviews were conducted. In contrast to what Mohapatra et al. (2013) state regarding in-depth interviews typically conducted by one moderator, the interviews were conducted using two moderators. Dual moderators resulted in a simple division of labor where one ensured a smooth interaction while the other ensured that the main topics were addressed (Mohapatra et al., 2013). The structure of the interviews was semi-structured and tailored to each respondent group. The semi-structured approach entailed flexibility and a relaxed and informal atmosphere that facilitated discussions while still keeping to the topics essential to the research (Mohapatra et al., 2013), thus maximizing the outcomes (Awuzie & Mcdermott, 2017).

The selection of respondents was partly based on the findings in the preliminary and main literature review, in which they either took part or were mentioned. Respondents were also selected based on the outcomes of the already conducted interviews. The respondents feature a variety of competencies both within and outside of the construction industry to ensure that several perspectives are considered. The respondents are categorized into four groups: Researcher, Machinery & Services providers, City Representatives, Innovation & Environment, and Energy Distribution. See Table 3.1.

Table 3.1. *Selection of respondents. Respondent group & Respondent Role.*
**Company B represents a parent and an affiliated company.*

Respondent group		Respondent Role
A	Researcher	Battery Researcher
B	Machinery & Services providers	CEO – Company A Market – Company A Operations manager – Company B*
C	City Representatives	Politician Process leader – Organization A Process leader – Organization A
D	Innovation & Environment	Environmental coordinator – Organization B Environmental strategist – Real estate group A Environmental coordinator – Company C Innovation leader – Company B*
E	Energy Distribution	Project manager – Company D

The motivation behind interviewing the researcher was based on the need to investigate the possibilities and challenges related to the implementation of electrified vehicles and machinery in the construction industry. More specifically, what the battery-technical prerequisites are and what the future entails. Representatives from two Machinery & Service providers of different sizes were interviewed to understand better how the electrification process is looked upon from their perspective, how far they have gotten in their conversion, and what they see as the drivers and barriers. Company A is a smaller company located in Gothenburg. They offer vehicle and machinery-related services and retail. Company B is affiliated with a large contractor that operates globally. Company B offers a wide range of services beyond construction vehicles and machinery. A politician and two process leaders representing the City of Gothenburg were interviewed to understand the city's visions and how the city works towards achieving them. Furthermore, what the future has in store in terms of regulations, drivers, and barriers that may promote or hinder the transition towards electrification of society and the construction industry specifically. Representatives with insight into environmental and innovation issues were interviewed to understand the status of the electrification transition based on their experiences from their respective company/organization and pilot- and demonstration projects. Finally, an electricity distribution company representative was interviewed to understand how the company looks at the increasing electricity demand and who is responsible for its adequacy.

The respondents were contacted primarily using email and secondarily by phone. The scope and purpose of the interview, and general practicalities such as the expected interview duration, were communicated in advance to create a higher level of legitimacy (Awuzie & Mcdermott, 2017). Moreover, the interview guide was shared a few days prior to the interview to allow the respondents to prepare. Simultaneously, the concept of semi-structured interviews was explained. The respondents were also informed that they were free to talk about other matters if they found something was missing in the guide. All communication with the respondents and the interview guides was in Swedish. The interview guide is presented in Appendix B.

Prior to starting the interviews, the respondents decided whether they accepted the interview to be recorded or not. In addition, the respondents were informed of the purpose of the recordings and that the recordings are to be removed in conjunction with the report's completion. The analysis consisted of listening to the recordings and taking notes. The notes were categorized following the interview guide, and the main findings were then identified and compiled. If more than one respondent in the same Respondent Group was interviewed on the same occasion, the data was synthesized before the main findings were identified. Finally, the gatherings from the interviews were combined with the other primary and secondary data to answer the research questions.

3.2.2 Observation

In complement to the literature review and interviews, an observation was conducted. The observation consisted of participation in a meeting and a site visit to a project in Norway where electric machinery are being used. The purpose of the participation was to get a holistic perspective on how electrification has shaped itself in an ongoing project. The purpose was also to gain insight and an understanding of the participants in their natural environment (Mohapatra et al., 2013). Prior to the observation, an invitation was received with a description of the agenda for the meeting. The participants were simultaneously informed of the observation, meaning that the observers took the role of observers as participants (Mulhall, 2003). Eight participants were invited to the meeting, five of whom were present. The participants' roles are:

- Construction Leader
- Environmental Leader
- Environmental Advisor
- Project Manager

One of the meeting participants decided on the meeting agenda in advance, see appendix C. The duration of the meeting was 90 minutes. During the meeting, the observers were given the opportunity to ask questions, and notes were taken throughout the meeting. In addition, the meeting was recorded with the consent of the meeting participants. The recording was transcribed and constituted, along with the notes, the primary source of information gathered from the observation. The meeting participants were informed that the recordings would be deleted once the report was completed. At the end of the meeting, the construction site was visited for further observation. Pictures were taken at the site to support the observations during the meeting. The site visit lasted 60 minutes. A summary concluded the observation with the meeting organizer that lasted 30 minutes to ensure a correct interpretation of the meeting takeaways was made.

3.3 Ethical Considerations

Ethical aspects were primarily considered during the interview process and the observation to ensure that the interviews and observation took place without causing harm to the interviewees and observation participants. The interview respondents and the observation participants voluntarily agreed to participate. All respondents and observation participants were informed of the anonymization before the start of the interview and observation. The anonymization was done to ensure that the interviewee and the observation participants answered the question honestly and would not feel uncomfortable about the uncertainties surrounding the agreements, thus increasing the credibility. Moreover, the respondents are presented with the choice of allowing the interviews to be recorded. The respondents and the participants were also informed that the recordings would be deleted concerning GDPR.

The interview respondents who wished to review their contributions were offered the opportunity to do so. Similarly, the meeting host was also able to review the gatherings from the meeting and the photos taken during the site visit. To not jeopardize the anonymity of the meeting participants, the report does not specify each participant's contributions, as both the project name and the participant's roles were stated.

3.4 Reflections on Chosen Methodology

Using semi-structured interviews offered respondents the flexibility to elaborate on what they felt most comfortable with. However, this resulted in many alternated interview guides, which resulted in a more extensive and thus more time-consuming compilation and analysis of data. Moreover, digitally conducted interviews offered more flexibility. However, physical interviews may have entailed a more casual setting and more impressions, which could have enriched the discussion and analysis.

The meeting and site observation in Norway provided insights into the hardships and the benefits of using electric machinery from the perspective of several relevant actors. The observation was conducted physically, meaning that impressions of the meeting participants were easy to observe. In addition, the site visit provided a better understanding of the characteristics of a construction site that allow for the electrification of construction machinery. However, it is worth mentioning that one of the respondents that took part in the interview study also had a leading role in the meeting at which the observation took place. The respondent had expressed skepticism regarding the electrification of construction machinery, which may have skewed the direction and thus the observed outcomes.

4 Interviews & Observation

This chapter presents the study's findings in terms of primary data. The chapter is divided into sections, where each section contributes to answering the research questions:

Section 4.1	Respondent group A	Researcher
Section 4.2	Respondent group B	Machinery & Service providers
Section 4.3	Respondent group C	City Representatives
Section 4.4	Respondent group D	Innovation & Environment
Section 4.5	Respondent group E	Energy Distribution
Section 4.6	Observation	

4.1 Respondent Group A – Researcher

This section includes the results from the interview with the Researcher. The main findings are presented in Table 4.1.

- Researcher (R1)

Table 4.1. *Summary of the main takeaways from Respondent group A.*

Category	Main findings
Limitations	• The production speed of batteries and the dependency and accessibility of raw materials. • The battery capacity may not be sufficient for a full day of operating. • The battery's ability to store energy deteriorates over time.
Prerequisites & conditions	• EVs require a large amount of energy. Therefore, sufficient capacity must be ensured. • It's essential to have an available and well-thought-out charging infrastructure. • Whether EVs are adopted is up to the market to decide.
Economy & environment	• Historically, the cost of batteries has decreased. • Electrification of vehicles benefits the environment - no reason not to electrify. • Batteries have a value on the secondary market.

There is no reason not to electrify vehicles. That applies to vehicles within the construction industry more than passenger cars considering the high utilization rate. Following the high utilization rate, the battery's capacity must be enough to last a full day and perform all tasks that a traditional construction vehicle performs. If not, it might not be feasible to use electric vehicles. Larger batteries could serve as a solution, as construction vehicles are less sensitive to higher weights. More vehicles and battery swaps are two other possible solutions to the capacity problem, though significant economic consequences. Another option is expanding the infrastructure and using fast charging, though R1 expresses uncertainty about whether it is efficient enough. Infrastructure, such as intermediate storage, has the potential to store energy locally but can also be used as an energy buffer to relieve the electricity grid during power peaks. The storage itself can be optimized in different ways.

It can be energy or power-optimized. Power-optimized intermediate storage is something that would be advantageous from a construction perspective. Alternative options are to regenerate energy that can charge the battery while operating the vehicle or connect the vehicle to the grid via a cable.

When addressing EVs, State of Charge (SOC), State of power (SOP), and State of health (SOH) are three fundamental concepts. A battery, regardless of application, has a SOC that can be specified as a scale of 0-100 %, and the optimal power output and battery life can be attained when kept within the range of 20 – 80 %. Connecting the vehicle to the grid via a cable would entail a controlled SOC and thus optimal power and battery life. Battery life is expressed in the number of cycles, the number of discharges, and charges. Eight thousand deep cycles are a reasonable life for batteries today, a number which, according to R1, will not increase significantly in the future.

> *"The deeper discharges and charges you make, the fewer you can do."*
> *-Respondent 1*

> *"Fundamentally, the capacities of batteries will not increase very much."*
> *-Respondent 1*

There is ambiguity regarding whom the responsibility to advocate and adopt EVs lies. Instead, that decision is dependent on the demands of the market. However, subsidies from the State are available to push implementation. The speed of implementation of EVs is also dependent on the rate of battery production- the speed at which raw materials are produced, and the accessibility of these materials. As battery production expands, raw materials will be depleted, which can already be seen today. However, resource depletion can be avoided by reusing, recycling, and diversifying batteries to a greater extent. R1 does not doubt whether the electrification of vehicles is beneficial for the environment, though the choice of energy source does impact how much. In addition, improved efficiency and reduced noise and particulate emissions can be attained, which is beneficial for construction in urban environments. Political benefits such as fewer dependencies on fossil energy sources are not insignificant. When addressing the economics of EVs, the battery and its components and materials constitute a significant proportion. Except for short periods where the price increased due to lack of materials and components, the cost of batteries has fallen at a constant rate over the past ten years. In total, the cost has dropped by about 80 %. The price for the consumer is also decreasing, partly because of more actors entering the market. The point of profitability for passenger cars occurs after two to three years, which correlates to how much the car is used. For construction vehicles, the point of profitability should therefore occur earlier. Moreover, the secondary market for batteries is expanding, which can provide an income once the battery has served its purpose in construction contexts.

> *"There is no reason not to electrify almost all vehicles . . . the potential is huge…"*
> *-Respondent 1*

> *"The more you use a vehicle, the faster it can catch up."*
> *-Respondent 1*

4.2 Respondent Group B – Machinery & Service providers

This section includes the results from the interview with the Machinery & Service providers. The main findings are presented in Table 4.2.

- Market manager – Company A (R2)
- CEO – Company A (R3)
- Operations Manager – Company B (R4)

Table 4.2. *Summary of the main takeaways from Respondent group B.*

Category	Main findings
Prerequisites & conditions	• The most prominent driving force is the customer's requirements, which influence the company's direction. • The actor responsible for the charging infrastructure depend on the type of service offered. The responsibility of ensuring available electricity lies with the customer.
Demand & Functionality	• Large electric machinery is becoming increasingly more considered as its availability increases. • There is a distrust regarding the functionality of electric machinery. • The machinery must be fully functional to be sufficiently attractive. • Analyze vehicle data to anticipate maintenance and service needs and optimize operation.
Economy & Environment	• Electric machinery are more expensive to rent but less costly to operate. • Sustainable solutions can be attractive despite being more expensive. • The customer pays for the electricity consumption. • Investments in electric machinery benefit the contractor in the long run. • There are clear environmental benefits to electrifying construction vehicles.

A driving force that R4 mentions is the profitability requirements from the parent company. Furthermore, there are visions of climate-neutral by 2045, which involves all subsidiaries. The parent company of company B has made its interpretations of the global UN's goals to take sustainability into account and control and influence, where these goals are formulated with a focus on four categories of customer, efficiency, sustainability, and employees. R3 states that Company A has no internal goals or visions specifically linked to sustainability or conversion to electrification. Instead, R2 believes that the most prominent driving force is the customer's demands, which go in the company's direction. Company B is a managed organization with clear goals as a roadmap for the entire organization, but R4 claims that everyone at the individual/group level has free hands to choose approaches if these goals are achieved. Company B has developed a comprehensive climate plan and roadmap at the regional level, where three of the four focus areas concern electrification, energy optimization, and climate neutrality.

The aim is to offer climate-neutral solutions for workplaces by 2030. To achieve these goals, Company B aims to reduce its CO_2 footprint by 25 % by 2024 compared to the current situation. Unlike Company B, Company A does not know the state financial support that can be applied regarding the conversion to fossil-free vehicles and charging infrastructure. R3, on the other hand, pointed out that the subsidies they knew of mainly were directed at the contractor.

R4 states that Company B has come a long way but that the development is to some extent governed by suppliers and the prevailing market situation. Furthermore, R4 mentions that most of the heavy vehicles and machinery Company B provides are fossil-powered. According to R4, electric machinery and vehicles have come in recent years and will be considered to a greater extent in the future. R3 believes that Company A has not come as far in the conversion as only one machine in their possession is electrically powered. R4 claims that there has been a noticeable change in the market as more and more large electric machinery becomes available, even though the supply is still limited.

Furthermore, R4 claims that the demand for fossil-free and electric solutions increases. R4 understands that demand is not as great in all segments but that it is still sufficient for Company B to be able to invest in the products that come out. On the other hand, R4 claims it is also not justifiable to invest without seeing an apparent and broad demand. R2 has a positive attitude when it comes to electrified vehicles and machinery regarding the great interest of customers. This is something that R3 agrees with and believes that they will need to switch to electrified vehicles with the idea that development is progressing in the automotive industry. For Company B, it is about being part of the development and following the demand and supply in the market. R3 stated that Company A has not performed any analysis of future situations but instead tries to stay up to date on how the development is going. This is done, according to R2, to be able to predict what can affect diesel vehicles and act quickly when the development has progressed sufficiently.

The contract can be classified into different environmental certifications depending on what requirements are set by the customer and what type of contract it is, says R4. The requirements that govern the contractors and subcontractors shape the solutions that Company B provides. R2 and R3 have a similar view, namely that the requirements set by the customer are decisive. R4 points out that procurement is in many ways a competition. Vehicle provider A's image is that meeting the requirements is crucial to being a competitive player. R4 explains that the requirements can be formulated and set in different ways. The customer may, for example, require a specific fuel or set requirements that include a more electrified total solution. According to R4, the latter means that Company B must deliver a complete solution that provides a customized infrastructure, including charging posts, battery packs, batteries for electrical storage, solar cells, etc. Furthermore, R4 points out that no specific requirements are set in some cases, after which Company B instead strives to fulfill its own internal goals and visions through continuous internal measurements to follow up and steer towards sustainability.

"We are controlled by our customers who are controlled by a customer who in turn is controlled by public actors and authorities."

-Respondent 3

Issues concerning functionality, including charging and operation, have been highlighted as major concerns by R2, R3, and R4. R4 adds that it is a challenge not only for those who supply the vehicles to the customer but also for the manufacturers of the vehicles. R3 expressed concern and distrust that the EVs might not function in the same way and under the same conditions as a traditional diesel vehicle. R2 was also skeptical and pointed out that the development has not gone far enough. Electrified machinery should be as functional as conventional machinery to be attractive on the market. R2 also points out that the machinery needs to meet the durability requirements, which R3 agrees with. The challenge that manufacturers face regarding battery capacity and the development and optimization of electric machinery is emphasized by R4. R4 further believes that there should be a focus on developing the batteries in terms of capacity, weight, user-friendliness, and easy battery replacement. R4 indicates that this is partly to avoid the unnecessary costs of acquiring more batteries and minimize the consequences of human errors such as forgetting to charge the batteries/machinery. The capacity must be sufficient to cover the daily needs, and at the same time, ensure that charging can take place in a way that does not mean that the work is interrupted. R3 reasons similarly and believes that it is not justifiable to procure several batteries, or machinery in some cases, to cover the same capacity that a traditional machinery can meet. Furthermore, R3 believes that the industry should place higher demands on the manufacturer, as technology development needs to go faster for the conversion to occur faster and be less demanding.

"If the machinery meets the functional requirements, there is no reason not to get it."

-Respondent 3

The percentage difference in the purchase price and the rental price for the traditional fossil-powered machinery compared to the electric-powered machinery is significant. Furthermore, electric machinery have become more attractive among customers following a clear shift in demand. This enables Company B to rent out the electrical machinery more often, which results in higher profitability, thus motivating the purchase of such machinery, according to R4. On the other hand, this does not apply to all of Company B's product categories. The percentage difference in the rental price for heavier machinery can still be much more extensive; therefore, Company B must consider whether customers are willing to pay or not before investing. R4 explains that business models need to be adapted and prices set concerning demand so that electric machinery can be profitable. The rental cost is adjusted according to the market, the form of contract, and rental period, R3 claims. Electric machinery are 50% more expensive to rent than traditional machinery due to a higher purchase price. At the same time, R2 and R4 believe that operation costs are lower, which benefits the customer over time. R2 believes that it is a common perception within the industry. R3 points out, with some uncertainty, that electrified machinery are 30-60 % cheaper to operate according to the manufacturer. At the same time, R2 points out that electricity operating costs are a quarter compared to diesel-powered machinery. Company A did not perform any investment analysis when acquiring its electrified vehicle. R3 believes a broader impact on electrified vehicles would result from a more transparent demonstration of operating cost savings. However, R3 and R4 believe that customers are prepared to pay a little more for fossil-free machinery.

R3 sees no indication that electrified machinery will continue to be more expensive than traditional ones but that demand and supply will eventually stabilize. R4 highlights that Company B, like other actors that provide services, will gradually replace its fossil-fueled vehicles with electrical counterparts as they become obsolete. Regarding the access to electricity, both Company A and Company B agree that access to electricity is a responsibility that lies with the customer. R4 pointed out that a direct connection to the electricity grid is not always possible. For example, if the project is remotely located, it may require alternative (off-grid) solutions to satisfy the electricity needs. The policy regarding the operating cost, both at Company A and Company B, is that the customer bears this cost. R2 clarifies that the customer is currently responsible for both tank infrastructure and fuel at the workplace, something that should apply even after the conversion to electricity, then in the form of electricity costs, charging infrastructure, and any overheads that affect the conversion.

On the other hand, Company B offers services and solutions for the customer to succeed in operating the machinery, but not the fuel/energy itself. Company A believes that the investment in electric machinery currently does not yield any profit but that it still benefits the company in the short and long term because the acquisition can be seen as an approach to gain experience and be competitive in future fossil-free pilot projects. R3, like R2, views the investment positively and as an internal driving force in a sustainable direction.

"Everyone is prepared to invest in sustainable solutions by taking on more costs today."

-Respondent 3

"We believe that if the machinery works as we hope, then we have gained some experience and can, in some cases, drive development – that is how we have reasoned internally."

-Respondent 2

R4 says that it is easy and common to get stuck in current limitations and restrictions. Instead, R4 emphasizes the importance of keeping up to date with the availability of machinery to develop new services and be able to offer solutions that minimize the customer's environmental footprint. Electric machinery require other types of solutions. Furthermore, R4 believes that by being innovative and providing such solutions, a value can be created for the company. R2 points out that exhaust fumes are a recurring problem that would diminish when using electric machinery. Furthermore, R4 believes that electric machinery have many other benefits that, in their entirety, can improve the working environment. For example, they are quieter, give rise to less vibration, and are more comfortable to drive. However, some factors can potentially degrade the working environment in connection with electrification, and that is if the machinery, instead of batteries, are powered by a power cable. Regarding follow-up, R2 stated that Company A could analyze vehicle data. Still, there is a lack of knowledge regarding machinery specifications and how they can access operational data. R4 also expressed an interest in taking part in operational data, however, mainly with business motives such as facilitating invoicing of the customer and anticipating maintenance and service needs more efficiently and thus maximizing the machinery's service life.

4.3 Respondent Group C – City Representatives

This section includes the results from the interview with the City Representatives. The main findings are presented in Table 4.3.

- Politician (R6)
- Process Leader – Organization A (R7)
- Process Leader – Organization A (R8)

Table 4.3. *Summary of the main takeaways from Respondent group C.*

Category	**Main findings**
Responsibility & Change management	• Cities / Authorities have an essential role in setting requirements. • A city-owned machinery pool could serve as a solution to facilitate the transition. • Single actors cannot drive development. Closer cooperation is needed. A single actor with coordination responsibility is, however, essential.
Obstacles & difficulties	• Initial costs & lack of proof of long-term economic feasibility. • Current working methods and business models will no longer work. • Insufficient charging infrastructure.
Drivers	• Improved health and environment. • Requirements and market demand.

There are various initiatives that the City of Gothenburg is and has been involved in when it comes to the transition towards a more sustainable society. R6 explains that Gothenburg has a governance model for how to work across the city and how they are followed up. The model involves planning, implementation, follow-up, and evaluation. In this model lies the so-called Environmental and Climate Programme, a programme in which Gothenburg organizes environmental and climate work to reach a 90 % reduction in carbon dioxide emissions by 2030. According to R7, electrification will be necessary to fulfill the goal, but the programme does not specify how or by whom the electrification ought to be carried out. Although Gothenburg has a goal that entails a fossil-free vehicle fleet by 2023, R6 emphasizes that the transition requires more consideration than just vehicles. For the construction sector, Organization A is working on an initiative where developers are allowed to give their opinion on what would be required in a sharp procurement to switch to electric machinery. The initiative stems, according to R6, from the difficulty of the conversion of machinery.

> *"It is precisely for working machinery that we see that it is most difficult to achieve the goals. It limps a little on our work machinery, but we focus on it in the new environment and climate program."*
>
> *-Respondent 6*

R7 says that the city has implemented initiatives to investigate the possibilities of shifting towards electrification. This has been done in various ways, including through the Electric Worksite project, where electrical machinery were tested, and the Emission-free Construction Machinery – Recommendations for Procurement Requirements project, where the city and other actors worked to develop adapted procurement requirements to promote continued implementation. R6 believes that Gothenburg has a vital role in setting requirements but at the same time that there are some limitations. For example, ambitious demands may be placed on fossil-free vehicles from which deviations then are made due to lack of availability/accessibility. R7 has a similar opinion, saying that making demands is one thing but also that one must consider the market's maturity. R7 and R8 further state that the city, considering the technology-neutral stance that the city takes, cannot be the party that decides which technology to use.

Furthermore, R7 believes that it is not up to individual actors to drive the transition, but it is about collaboration and that everyone is engaged. R8 agrees, adding that more coordination and support are needed in partnership with relevant actors and stakeholders, at least initially, to ensure trust between the actors and that the requirements set are closely anchored with the market. However, R8 also stresses the importance of having someone with a mandate responsible for the coordination.

> *"At the end of the day, there has to be a mandate. Therefore, an actor, such as Organization A, which has a coordination responsibility in work towards electrification, is central to driving the development."*
>
> *-Respondent 8*

Following new technology comes new follow-up methods, which stress that it is crucial to ensure that these are uniform and predictable, partly for the City of Gothenburg as a developer with a responsibility to evaluate their work with regulations and partly for individual entrepreneurs, R7 argues. R8 agrees and interjects that it is important to standardize and digitize follow-up processes to track and document, among other things, energy consumption on site. At the same time, R8 mentions that it is currently an unexplored area and that more tests need to be carried out before a functioning working process is established. Still, setting such requirements acts as an incentive, speeds up the transition, and increases demand, R8 states. Although such standardized requirements have been developed in the three cities of Stockholm, Gothenburg, and Malmö in the form of Common Environmental Requirements, these are not specified for electrification. R7 and R8 agree that it is difficult to follow up on the requirements, depending on how they are set, which R7 considers essential to ensure fair competition.

> *"We have an important role, to act as pioneers, to make demands in that we are a large buyer, but it requires some development and partners."*
>
> *-Respondent 6*

> *"You are careful on both sides. As a city and the ordering organization, we are careful about setting too tough demands. We need to understand what the market can deliver so that there is a kind of equilibrium there."*
>
> *-Respondent 7*

Availability and cost of machinery are two critical aspects necessary to consider. R6 points out that politicians are aware that the transition is costly at first. The initial cost is currently difficult to justify as there is not much evidence to show the outcome. Hence, there is a risk associated with investing in new technology, says R6, R7, and R8, though R6 is confident that the technology development will reduce costs with time. There are also concerns regarding the procurement- and offer process, as the prices are the decisive factor in most cases. There are ambitions that environmental and climate perspectives should also be considered. As a result, alternative technologies, which may have a higher economic cost, would be considered because of their ecological benefits, R6 argues. R6, R7, and R8 state that there is financial support for actors to apply for, which aims to reduce investment costs for machinery and vehicles and establish charging infrastructure. In addition, discussions are taking place at the political level to introduce additional incentives to reduce carbon dioxide in favor of fossil-free vehicles, R6 adds. In Oslo, a machinery pool has been established, where contractors rent machinery instead of buying them themselves. Entrepreneurs' access to machinery is thus ensured, something R7 mentions as a potential solution to the risk and accessibility problems. R8 shares the view of a machinery pool that it has the potential to reduce the risks of the transition, at least initially before the demand is high enough to carry itself. According to R8, the pool can be owned by the city and other operators. It is also a question of competition, according to R7. If several operators join forces to establish a machinery pool, there is a risk of a monopoly situation, which is undesirable. Moreover, even if the city wants to procure certain types of machinery, they are not sure they are available. Finally, even if machinery are available, an investment might not be economically feasible. This view is shared among R6, R7, and R8. Moreover, having concrete requirements to predetermine the approach can limit the options, something that can obstruct the transition towards EVs in today's situation. Similar obstruction can also occur if the client, despite available technology, does not require it, R6 and R8 states. The latter, according to R6, is attributed to the city's inability to keep up with the technology development.

> *"Making such demands may also drive the market to transition, but my view is really that the market has in many cases overtaken politics . . . the demands of politics need to catch up."*
>
> *-Respondent 6*

Establishing the necessary infrastructure related to the transition is the central issue that needs to be addressed, according to R7. Despite the need for access to charging capabilities and sufficient network capacity, the role of responsibility has not yet been established, R7 states. However, R7 and R8 both believe that it largely depends on the situation and the involved actors. The difficulties and barriers can take many forms, which to a large extent can be derived from a change of value chains, roles, and division of responsibilities, R7 argues. R7 stresses that the change resulting from the electrification transition is a challenge for both the individual and the organization. The change can lead to insecurity and fear of the unknown, which should be addressed by having an open dialogue about roles and responsibilities.

Previous working methods and models will no longer work, so new knowledge will need to be collected to make correct adjustments. There has always been a reliance on existing business models, that there is an infrastructure that can supply machinery and vehicles with fuel, and that fuel tanks can be placed on the construction site. However, due to electrification, the work to establish infrastructure and business models must be modified, according to R7. So far, what has been done is to place a diesel tank on the construction site, which constitutes the entire energy system. In electrification, more elements are added to the system and more actors. Furthermore, the commitments and involvement of the existing actors are changing, says R8. In addition, R7 states that actors such as energy companies, electricity producers, property owners, and landowners will have more say in following the emerged needs and conditions. For example, even if the contractor brings a portable charging station or batteries, they still need to connect to the grid to be recharged. Consequently, additional actors need to be involved, R7 argues.

"To succeed in this, it is important to ensure that we have the appropriate tools to create transition security for all roles on a construction site, that this new [approach] will also work."

-Respondent 7

"It's no longer a question of a vehicle . . . there will be a lot of new parameters that we need to consider, and it messes up a little bit in the resource planning of the performing actors."

-Respondent 7

Electrification in the context of vehicles would lead to improved health following lower noise levels and reduced levels of harmful air pollutants. Furthermore, the lower noise levels could lead to the construction of new homes in places not currently considered to be buildable according to R6. According to R7, the transition toward electricity within the construction sector is driven by the desire to lower the emissions due to the competitive advantages it would entail and create a better working environment and contribute to reducing the global environmental impact.

"Most people who have tested on electric vehicles appreciate their driving characteristics. There are fewer vibrations, no exhaust fumes, simply a quieter workplace."

-Respondent 7

4.4 Respondent Group D – Innovation & Environment

This section includes the results from the interview with the Innovation & Environment group. The main findings are presented in Table 4.4.

- Innovation Leader – Company B (R5)
- Environmental Coordinator – Organization B (R9)
- Environmental Strategist – Real Estate Group A (R10)
- Environmental Coordinator – Company C (R11)

Table 4.4. *Summary of the main takeaways from Respondent group D.*

Category	Main findings
Incentives	• Electrification of machinery is an essential step toward achieving Gothenburg's vision. • There are divided opinions about what incentives and measures are required to drive development. • Sharing of the costs and machinery could drive the transition.
Procurement & Requirements	• Cooperation and foresight are necessary. • There are divided opinions about the responsibilities of the different activities. • LOU is a barrier. Costs should be weighed against the environmental benefits. • Follow-up of requirements must be possible. • The follow-up has become more extensive and requires new methods and techniques.
Prerequisites & Conditions	• Each project is unique in terms of contractual conditions. It is essential to start with clear and correct information. • The transition towards electrification has an impact on both time and logistics.

R10 stated that the electrification of machinery plays a vital role in achieving the goals defined in the City of Gothenburg's Environment and Climate Programme and the visions in the city's Electrification Plan. The goals set within the city are strongly governing and constitute a sufficient driving force to achieve the goals, according to R10. R9, on the other hand, believes that more incentives are needed for all actors involved. According to R9, the city is working on incentives in the form of a bonus system that rewards operators who use electrical machinery and vehicles. R11, who works in Oslo, states that the municipality of Oslo also has high ambitions to reduce emissions and that all projects in Oslo will be emission-free by 2030, including machinery and vehicles. The approach to achieving the goals differs from that in Gothenburg. The municipality of Oslo has given additional incentives in the form of distribution of points in procurement to the operators who own electrical machinery themselves. R11 is skeptical about Oslo's approach to driving development and believes that it is essential to consider the availability of machinery, which R9 and R10 agree with.

However, R10 argues that there is yet no electric machinery available to the needed extent. In addition, R11 believes that available electricity network capacity should be considered. Moreover, the use of incentives such as that in Oslo is impossible because it jeopardizes operators' existing business models. R10 has a similar view of Oslo's approach and does not see how it would work in practice.

> *"This cannot be done, as they [the incentives] go into the entrepreneur's business strategy. For example, if a contractor has a strategy to rent machinery, they should not interfere, as long as the contractor can deliver a product."*
>
> *-Respondent 11*

> *"To say 'You must get this [electrical machinery] as a company' cannot be done. So the only thing we can threaten is that you cannot do business with us unless you meet our requirements."*
>
> *-Respondent 10*

There are divided opinions about the potential and possibilities of electrification of machinery and vehicles used in construction. R5 and R10 believe that the technology is already available today and that the transition is just a matter of execution. R9 and R10 express that the potential for electrifying vehicles and machinery is excellent, linked to reduced climate impact and the possibilities of densifying cities because of lower noise and emission levels. R9 clarifies something that currently limits Gothenburg. According to R10, the City of Gothenburg considers that the electrification of machinery is possible from a capacity perspective. R11, on the other hand, does not understand how the electrification of vehicles and machinery should be done concerning the already lack of network capacity and expresses that it should instead look at other approaches that bring more significant climate benefits. R10 is of a similar opinion and says that although more significant potential can be achieved in different ways, electrification has been given greater scope in the discussions.

> *"The technology exists. It's not rocket science to start transitioning to electrified vehicles."*
>
> *-Respondent 10*

> *"What worries us the most is if all construction machinery goes over to electricity is if there is enough power available. It's not possible. I do not understand how they [the municipality of Oslo] think. I cannot believe this has had such an impact."*
>
> *-Respondent 11*

Respondents agree that the cost of investing in electrical machinery is a crucial factor. R5, R9, and R10 also express that more cooperation is needed between different actors. Partly to overcome the uncertainties that prevail today, according to R5, and partly to test and follow up on new solutions and ideas, says R10. The responsibility lies with all parties, according to R9. At the same time, the client has a special responsibility to lead the way, something that the City of Gothenburg has done by deciding to develop a collaboration platform where actors can discuss issues and solutions. Furthermore, R9 understands actors who currently do not dare to invest in machinery due to uncertainty about whether their costs will be covered. At the same time, R9 highlights that cost is also a matter for the municipality. Allocating the conversion cost entirely with the city is not an option R9 sees, at least not with the current price picture.

R10 believes that new ways are needed to overcome the doubts of actors and mentions that the City of Gothenburg is looking at establishing a machinery pool in which contractors in the city's projects can take part in limited or specific work. The need for such a solution in terms of the market and the city's ability to make demands on electrified machinery in procurement, R10 considers to be great. It would also give smaller companies that would otherwise not be able to afford to compete for tenders a chance. At the same time, R10 emphasizes that the solution in such cases would be short-term and aim to give operators time to change their fleet themselves and then be phased out. R11 does not share the same view but is still skeptical of the municipal machinery pool because it would harm market competition.

" They [companies] need incentives in the form of us as clients asking for them [electrical machinery] and that we are willing to be involved in paying for the extra costs."

-Respondent 9

" If it is the client who must pay in full the entire cost of exchanging machinery for another, it will not go fast. We do not have that much money as a municipality."

-Respondent 9

"Many feel a little hesitant, and we need to visualize and enable this [using electrical machinery] . . . we cannot climatically afford to wait for all actors to acquire electrified machines."

-Respondent 10

R10 believes that there is an exaggerated belief that it will happen just because you order things. Instead, the set of requirements should be anchored in what is available and what is technically and financially feasible, and at the same time, be at the forefront of development. Furthermore, close cooperation and good foresight are needed to signal which requirements are current and to ensure a good effect of the requirements. R9, on the other hand, considers that the responsibility lies with the client, partly to make demands and partly to bear the additional cost that arises. However, R9 also says that the contractor, if he comes up with a better way to carry out the contract in terms of environmental and climate impact, can present it to the city, which then gets to evaluate the benefit against the cost and possibly distribute more funds to enable the implementation. R11 expresses a wish that it would be the model also in Norway, that the entrepreneur can decide how to achieve the goals. However, R5 considers LOU to be a barrier to such innovation as, in many cases, it is the lowest price that applies.

Regarding contract forms, R9 sees that it is essential to increase the feeling of security. At the same time, R9 describes construction projects as unique from the perspective that they relate to specific construction and that they are time-limited where the machinery is only used for a short time, which means that the contractual conditions differ from other types of projects and commitments where the machines are used for a significantly more extended period. R9 believes that machinery does not necessarily have to be owned by the contractor and once again highlights the emission-free project in Norway and says that the clients themselves had to buy up the machinery that then the contractors could use. However, because the supply was so limited, conventional machinery were converted to electric power, a path that Gothenburg did not want to take.

“As a city, we must set the right type of requirements at the right time to create good conditions for the industry . . . I think it is a bit over the belief that it will work out if we just make demands.”

-Respondent 10

”It is possible to do so [rebuild machinery], but that is not the path we want to take. We want to be able to trade up the contract as usual.”

-Respondent 9

R11, who has experience in projects in Norway where electrical machinery has been used, highlights the importance of starting from correct and clear conditions to ensure that the project can be carried out smoothly and that the electrical machines work as intended. R9 points out that Norway has progressed further in the transition and thus has more knowledge about what conditions are required. One lesson R9 has learned from Norway: it is crucial to have a plan for how charging will be met before the procurement takes place. R10 also says that it is vital to contact the network owner. R11 has similar experiences regarding the uncertainties surrounding the connection and access to power at the tender stage. R11 believes that the responsibility for ensuring access to power should lie with the developer to escape the uncertainties. In addition, before the contractor arrives, the developer should map how much power is needed and upgrade the power if it turns out to be needed, with which R10 agrees. At the same time, R11 understands that the developer does not always have the proper knowledge and skills. According to R10, logistics and charging infrastructure are the contractor's responsibility, as is the cost of the electricity used. If the machinery are connected by cable, it places additional demands on well-thought-out logistics.

Regarding the cost of electricity, R11 believes that the estimate often is too low. In addition, the cost of electricity is not clearly described in the existing agreements, which can be derived from the contractor’s obligation to report what the contract will cost and the often limited budget of the developer. As a result, charging is often significantly more expensive than initially intended. This can be attributed, among other things, to the fact that fast charging takes place at the same time as the power peaks. Furthermore, charging itself can be both a challenge and a safety risk. There is no standardized charging system, and different equipment is required for different machinery. R11 does not see supplying the machinery with power via cables as an alternative concerning safety at the workplace. Another safety aspect is fire risk when handling electrical components, which becomes relevant to charging. R9 has similar opinions and states there is much unknown regarding logistical conditions.

” Who will ensure that this planning takes place? Who is going to make sure the electricity is drawn?“

-Respondent 11

” What do we need to know, how much extra will it cost, what do we need to have arranged in advance in the form of charging infrastructure . . . can the machinery be used in different ways?”

-Respondent 9

> *" We must constantly ensure that the procurement requirements that are in place are site-specific and relevant. It will never work if we put it in the lap of entrepreneurs."*
> *-Respondent 10*

R11 states that issues related to electricity are usually a problem. If neither available nor sufficient network capacity exists, the machinery may need to be transported away to be charged, which entails further logical efforts. In the case of insufficient availability, battery containers are often suggested. However, these are expensive and difficult to deal with for logistical reasons, R11 says. R10 also points out that the containers also need to be charged, which may ultimately mean that fossil-powered generators will be required. Therefore, R10 does not see the meaning of electric machinery but says that it might as well allow the machinery to be powered by bio-based fuels. According to R11, the transition towards electrified machinery has consequences for both working hours and project duration. As an example, R11 explains that the foundation is approximated to take 30% longer to complete using electric machinery, despite that machinery suppliers claim similar capacity compared to diesel-powered machinery. One consequence of this is that additional machinery and machinery operators are needed. Another example that R11 highlights are that transport vehicles that drive in and out of the workplace constitute a logistical load. To build at the same time and budget as before is therefore not possible. R5 partly shares the view that R11 has regarding the creation of charging infrastructure but does not see that it would be a significant obstacle.

> *"This is a trend we are seeing with electrical machinery, that they are time-consuming at the same time as it is an aspect that is not accounted for in the procurement . . . therefore, the transition may result in a need for a few extra months."*
> *-Respondent 11*

Regarding procurement requirements, R9 believes that follow-up of these must be possible, which means follow-up of the electrical machinery and those powered by fossil fuels to have something to compare with. R5 shares this view and adds that follow-up is vital to benefit future projects. Furthermore, R9 believes that there is no follow-up tradition regarding working machinery. Since work machinery are also not infrequently present in several workplaces, allocating costs is also a challenge that needs to be overcome. R11 shares this view, adding that it was previously enough to show that emission-free work machinery were in place but that the accounting requirements are now much more extensive. Contractors should actively take a position to follow up on the client's requirements, according to R10. To facilitate and improve data collection, new techniques and methods need to be developed. According to R5, R9, and R10, there is also a need to digitalize the industry. Furthermore, R5 and R9 argue for automating the collection of vehicle data. R5, R9, and R10 agree that cooperation with other actors is necessary to improve follow-up work.

4.5 Respondent Group E – Energy Distribution

This section includes the results from the interview with the Energy Distribution group. The main findings are presented in Table 4.5.

- Project Manager – Company D (R12)

Table 4.5. *Summary of the main takeaways from Respondent group E.*

Category	Main findings
Capacity, Conditions & Responsibility	• Sufficient network capacity is fundamental. • The availability and need for electricity vary from case to case. • Formally, the responsibility to ensure capacity lies with the network capacity. However, in practice, dialogue and cooperation are necessary. • Current regulations hinder the proactive expansion of network capacity. • Off-grid solutions can serve as solutions in case of limited network capacity. Preferable from a grid perspective.

R12 highlighted that Gothenburg has carried out and is implementing research projects that pave the way for the electrification transition in the construction industry and other industries and societal functions. A prerequisite that R12 considers being a conversion of construction sites towards electrification is the availability of machinery and that these are attractive both from an economic and a capacity perspective. Electrical machinery in the construction industry are not very common, although the transition is accelerating. R12 believes that there is some uncertainty about whether a complete transformation of the construction industry is possible in terms of network capacity. The electricity system in Sweden has historically been over-dimensioned and has worked well, with reasonable prices and high delivery reliability. Still, a particular network capacity cannot be guaranteed. The situation will be very different in the future as the energy demand will double, thus amplifying the uncertainties regarding capacity. Therefore, it is not possible to assume a specific capacity available at a particular location. In addition to network capacity, logistics in charging infrastructure can also become an issue.

Ensuring sufficient network capacity is fundamental for succeeding with the electrification of construction sites, R12 argues. Formally, the responsibility for ensuring sufficient network capacity lies with the network company due to their Obligation to Connect that prevails because of their monopoly position on the energy market. In practice, however, R12 believes that an early dialogue between developers and network companies is the key to ensuring sufficient capacity in the networks during construction. That applies to both temporary and permanent connections. Furthermore, the dialogue should eventuate in the forecasts and expansion of the electricity grid to meet the increased need. At the same time, R12 explains that the Income Regulation that covers the network companies has not considered the need to expand the electricity grid on "speculation" and thus does not provide financial margins to allow for investments. However, easing income regulation is something that R12 believes will be discussed more and more.

> *"It is impossible to say general rules such as a temporary connection takes two months, and a permanent connection takes six months. There are no such rules. That is why an early dialogue with the network companies is important."*
>
> *-Respondent 12*

Buildings have, upon completion, a power need. The question is how to match that need with the temporary need during the construction phase and possibly prepone the application to the network company and use the permanent accession. At the same time, R12 points out that it may well be that the need for power is greater during the construction phase than during the building's use phase and yet again emphasizes the importance of making case-by-case assessments. Aside from supplying machinery with power through a direct connection to the grid, battery storage can also be used, which R12 sees as a possible solution to the problem of insufficient network capacity. This is because battery storage allows charging during more advantageous periods of the day. Therefore, batteries will become more common and something that will be needed to maintain the grid's stability. However, battery storage is not something that the network companies are allowed to facilitate, considering their status in the energy market. When asked which solution is preferable, R12 refers to the power grid's ability to better cope with a low power output over a long period than with high power output over a short period.

> *"In general, you should always charge with as low power as possible for as long as possible. You do fast charging when you must when you are short on time."*
>
> *-Respondent 12*

4.6 Observation – Majorstuhjemme

This section includes the results from the observation at Majorstuhjemme. The observation consists of meeting participation and a site visit. The results are presented in subsections 4.6.1 and 4.6.2, respectively.

4.6.1 Meeting

This subsection includes the results from the observation of the meeting. The main findings have been categorized into four categories: General conditions & procurement requirements, Positive experiences, Negative experiences, and Areas of improvement. See Table 4.6.

Table 4.6. *Summary of the main takeaways from the meeting.*

General conditions & procurement requirements
• It is possible to apply for an exemption if implementation with electricity is not possible or practical from a propulsion perspective. However, the possibility of applying for an exemption does not apply from a cost perspective. • The tender requirement is "fossil-free". Therefore, the contractor is rewarded for electric machinery and receives minus or zero for diesel. • No extra time has been given to consider the use of electrical machinery.
Positive experiences
• The machinery connected via a cable works very well in static states, almost as well as traditional machinery provided that the machinery operator is experienced. • The electrical machinery supplied with electricity via a cable has a good range. However, it requires more planning. • The excavators work well on smaller jobs.
Negative experience
• Lack of knowledge regarding the use of electrical machinery. • The electric machinery is not used as originally intended. Insufficient operating time for the battery-powered machinery (2.5-4 h). • Minimum 1 hour charging time, not enough to charge the machinery only during breaks. Thus, it is only used for small jobs. • The load on individual electrical cabinets can sometimes be too large. • Limited network capacity. More than the theoretical capacity is needed due to losses in the cables. • The rent of the electric machinery is about three times as expensive as for the traditional machinery. • It is difficult to estimate costs. Limited availability and few suppliers on the market make electrical machinery expensive. It is also expensive to convert machinery to electric power. Expensive to operate machinery at power peaks. • Limited availability of electrical machinery causes delays. The propulsion has been critical. 6-12 months of extra time for an electrical approach in practice. • More significant risks because of more cables at the site. • Cables restrict the movement and placement of machinery. • There is a difference between the procurement requirements and the requirements in practice.

Areas of improvement

- Knowledge regarding the machinery.
- The pros and cons should be considered before future choices regarding methods and machinery.
- Better batteries. It is not reasonable to have insufficient machinery.
- Larger machinery with higher capacity than those currently available are needed for the larger jobs.
- When using electrical machinery, more careful planning is required, considering the order of execution, driving behavior, and cable placement.
- The requirements should be designed so that the contractors themselves get to choose the execution method to optimize the environmental benefits.
- More reward for emission-free technology and low emissions.
- There should be more focus on ‘effective’ measures. For example, minimize the number of material types used in the project.
- The developer should be the one which maps the electricity needs for the procurement.
- Establish framework agreements with suppliers of machinery to secure the asset.
- Batteries stationed close to the construction site can be a solution to avoid high electricity prices. These are, however, expensive and cost upwards 3,000,000 NOK.

4.6.2 Site Visit

This section includes the results from the observation during the site visit. The results consist of both self-taken and provided pictures as well as notes. The photographs and notes aim to contextualize, nuance, and add to the results in section 4.6.1. The site disposition is visualized in Figure 4.1.

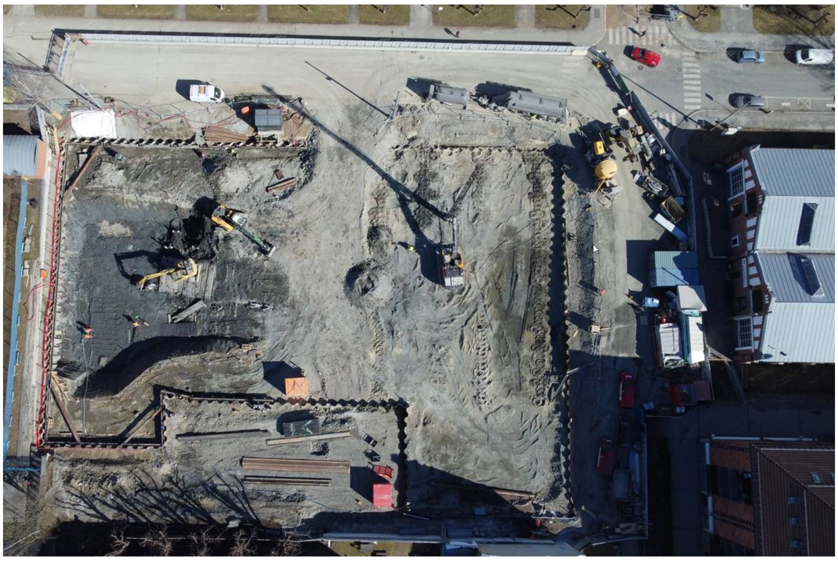

Figure 4.1. *Overview of the construction site, Majorstuhjemme. Photograph provided by Veidekke (Veidekke, 2022).*

The two electrical machineries consisted of one small and one larger excavator, see Figure 4.2. The small excavator was used moderately during the visit. The larger excavator was used to a more significant extent.

The operations consisted of digging and loading the trucks. See Figure 4.3. It was noticeable that they tried not to move the excavator more than necessary but instead to have the trucks adapt to the position of the excavator. The excavators only moved on flat surfaces during the visit.

Figure 4.2. *The two electrical machinery used in the project. 26-ton cable crawler excavator (Left), 10-ton battery crawler excavator (Right). Own photographs.*

Figure 4.3. *The cable crawler excavator loading a truck. Own photograph.*

The battery-powered excavator is charged via a cable via the temporary cabinets and substations. The cabinets were placed close to the excavator. The relocation of the cabinets is carried out by the actor who provided them. The large cable excavator was connected directly to the cabinets/substation via a cable. It is the driver's responsibility to move the cable if necessary. During the visit, the machinery driver moved the cable once. While the excavator was operated, the cable was lying on the ground next to it. See Figure 4.4.

Figure 4.4. *The cable from the excavator lying on the ground and connected to the substation. Own photograph.*

The noise at the workplace was relatively low. Several types of machinery operated simultaneously. However, the most noticeable noise came from the HVO-powered machinery and hand-held machinery, see Figure 4.5.

Figure 4.5. *The electric cable excavator, the HVO excavator, and a construction worker operating hand-held machinery. Own photograph.*

Majorstuhjemme has taken action to improve the safety at the construction site. Among other actions, sound signals and a rear-view camera are mandatory for all vehicles that reside within the site's boundaries, see Figure 4.6.

Figure 4.6. *Safety requirements are displayed at one of the gates to the construction site. Rearview cameras and audio signals are required for all vehicles that reside within the boundaries of the construction site (middle right of the sign). Own photograph.*

5 Discussion & Analysis

This chapter includes a discussion and an analysis based on the findings in the literature review, interviews, and observation. The chapter is divided into two primary sections: Driving Change & Change Management and Considerations – Potential and Limitations. Moreover, the following abbreviations are made:

Respondent Group		**Abbreviation**
A	Researcher	RGA
B	Machinery & Service Providers	RGB
C	City Representatives	RGC
D	Innovation & Environment	RGD
E	Energy Distribution	RGE

Executive Summary	**Abbreviation**
Emission-free Construction site	E1
Feasibility study, Electric worksite	E2
Emission-free construction Machinery, Recommendation for procurement requirements	E3

5.1 Driving Change & Change Management

This section presents aspects regarding attitude & commitment, procurement & requirements, and level & transfer of knowledge connected to the implementation of electric construction vehicles and machinery.

5.1.1 Attitude & commitment

Anyieni (2016) states that it is a comprehensive process to change an organization. By (2005) points out that it is an ever-occurring process within an organization which Sullivan et al. (2010) and Anyieni (2016) often argue is necessary for survival and to stay competitive, which goes hand in hand with the definition of Change Management by Moran & Brightman (2000). However, Moran & Brightman (2000) argue that sudden changes can cause a crisis to arise within the organization, something that, according to Dainty et al. (2007), may imply a lack of employee involvement. It is thus essential to consider the attitude of those affected by the change and respond with appropriate Change Management.

It can be concluded from the interview study that the attitude towards electrification differs among the participating actors. The attitude is generally positive for RGA & RGE, whose primary commitments are not directed at the construction industry. They express themselves in terms of opportunities, see the transition as possible and necessary, and believe that neither batteries nor the electricity grid will limit the scope of the transition. RGB is generally optimistic about the transition but also expresses some uncertainty about the economic consequences that the transition will entail. RGC, which primarily consists of actors outside the construction industry, sees the transition as more of a societal transition, of which the construction industry is a part. Moreover, RGC believe that the transition is possible but will involve great efforts and require significant changes to existing models and methods.

The attitude of RGD was of varying nature, with individual respondents expressing skepticism while others were positive about electrification.
The transition entail several actors being affected on a strategic and operational level, thus increasing the complexity, in accordance with what By (2005) states. However, high complexity combined with the construction industry's willingness to stick to proven methods, as stated by Sullivan et al. (2010), means it can be problematic to spark a significant change, as Dainty et al. (2007) describes. This desire can also be linked to the small economic and temporal margins that characterize the industry, an argument recurring in all interviews, in the observation, and in E1, E2, and E3, which reflects what Baloi (2003) expresses regarding the industry's great focus on economics. Those who expressed themselves skeptically felt no confidence in electrification as an economically justified method to achieve a more environmentally friendly construction and expressed frustration with the direction of the development. Construction professionals expressed the most uncertainty and distrust in the electrification of machinery. Partly due to the perceived decreased production capacity, as shown in the observation and stated by Moran & Brightman (2000) as a consequence of sudden changes. However, RGB, RGD and those participating in the observation were perceived as willing to test and use new technologies and methods, thus contradicting Sullivan et al. (2010).

The policymakers can decide on policy instruments and incentives to facilitate change and increase willingness to change. In the context of electric machinery, financial relief in procurement, bonus schemes, and the establishment of a machinery pool are three different types of incentives mentioned in the interviews with the RGC. At the same time, RGC points out, in accordance with what Baloi (2003) mentions regarding the balance between economics and sustainability objectives and what Zavadskas et al. (2018) state regarding the necessity to consider many options to find the most efficient solution, that such incentives impose a financial burden which must be weighed against what is reasonable. Moreover, that such incentives are short-term. In other words, the city cannot provide incentives in perpetuity, which should be seen as an incentive to commit to the transtion as soon as possible. In addition to providing incentives, RGD & RGC believes that the city has a crucial role in running pilot projects in collaboration with other industry actors to demonstrate the feasibility and drive development toward achieving the city's visions and goals. Showing that an action is possible constitutes a convincing argument, which motivates people to accept a change. However, an essential component regarding change management still seems to be missing, namely understanding why the change is taking place. More specifically, why the electrification of vehicles takes place when other methods are considered more effective, as highlighted in the RGD and during the observation. Therefore, the city has a great responsibility when it comes to communicating why the change is taking place, which they express being aware of during the interviews.

Furthermore, the city of Gothenburg considers itself to have an important role when it comes to making demands and procuring environmentally friendly alternatives, according to the interviews with RGC. Furthermore, they believe that individual actors cannot be responsible for driving development but that there must be a collaboration where everyone is engaged. Therefore, more coordination and support are required to develop trust between actors. Such cooperation has been initiated at a higher level between Sweden’s three major cities in the form of the Common Environmental Requirements.

It can be seen as an attempt to standardize goals linked to the environment, an aspect raised by Dainty et al. (2007), which can act as an obstacle to change in case of shortage. However, the impact and compliance with these environmental requirements are inadequate, as revealed in E3, attributed primarily to the lack of follow-up.

Furthermore, these requirements do not yet relate to electrification specifically, making the criterion "adapted regulations" to support change which Ali et al. (2019) state, in this regard towards electrification, are not met. Therefore, the purpose of the study E3 can be seen as an attempt to develop adapted regulations that complement the common environmental requirements, enabling the tenderer to specify how they wish to go about achieving the goals set by the client. If the bidder is allowed to decide for themselves, employee involvement would possibly increase within the organization. It could also lead to improved communication, and thus as Dainty et al. (2007) indicates, less resistance to change.

5.1.2 Procurement & Requirements

Traditional procurement methods, such as turnkey and execution contracts, entail a low level of collaboration and knowledge transfer. Such traditional contracts also place higher demands on the knowledge of the individual stakeholder. Moreover, E3 showed that clients primarily use execution contracts and that collaborative contracts have only been used by half of the clients surveyed. Something that emerges from the interviews with RGC & RGD is that the responsibility lies mainly with the client to set reasonable, clear, and measurable requirements. However, it is not always the client who possesses sufficient knowledge to make such judgments. In addition, the city of Gothenburg's technology-neutral role impacts their ability to require specific technologies, which suggests instead allowing the contractor to determine the approach to achieve environmental benefits, as expressed in the interview with RGD, the observation and E3. In this way, all participants in the procurement process would participate on equal terms, and efficient use of financial resources in accordance with LOU would be achieved.

Requirements set today are not considered effective and are not always complied with or followed up. One of the participants in the observation expressed verbatim that there is a difference between the requirement specified in the agreement and those applied in practice. Furthermore, that deviation from the requirements is allowed to ensure the project progression according to the timetable. Allowing deviations reduces the incentive to comply to requirements, and contradicts to what is brought up in E3 concerning the long-term perspective of requirements. Moreover, the lack of follow-up counteracts the requirement’s effectiveness and causes unfair conditions. This view is shared by RGC & RGD, who also emphasizes the importance of following-up to ensure gathering of knowledge for future projects. A lack of follow-up tradition within the industry, especially concerning vehicles and machinery, is according to RGD the main reason for this. At the same time, a technological shift from traditional vehicles to electric may entail that new methods, techniques, and routines need to be developed and that the old ones no longer will work. This is reflected in the interviews with RGB, where uncertainty regarding how follow-up of electric machinery should be done is expressed.

RGC & RGD expresses that new standardized methods are needed, which RGD advantageously believes can be digitized and automated. A difficulty associated with machinery is allocating time/costs to specific construction sites. Machinery often stay at several workplaces during periods, which must be overcome for the follow-up to work optimally. Distinguishing costs and allocated time between projects will also be crucial to follow up on the proposals for procurement requirements developed in E3.

The suggested procurement requirements described in E3 state that different data types should be reported depending on the requirements used. Since many contractors do not own their machinery and vehicles, this also becomes a problem for subcontractors who provide vehicles and services. The RGB interviews show an interest in accessing and analyzing vehicle data to a greater extent to streamline invoicing work and better follow up on the machines' service needs. In other words, contractors who rent vehicles and actors who rent out vehicles have a common goal, which could pave the way for deeper cooperation, which RGD highlights as necessary to follow up on the requirements successfully.

5.1.3 Level & Transfer of Knowledge

The importance of possessing proper knowledge to enforce a change successfully is emphasized by Higgs & Rowland (2005). However, in the interviews, executive summaries, and observation, the level and area of knowledge of the different actors vary. The interview with RGA showed that they have a good idea of what capacity batteries have and how they will develop in the future. The interviews with RGB showed that the level of knowledge regarding electrical machinery is relatively low, especially in the smaller Company A. The development direction is decided by the market and the client, to which RGB adapts. The interviews with RGC showed that the level of knowledge being discussed is about how electric vehicles affect the big picture with value chains and business models, that more actors are involved, and responsibilities are changing. The responses from RGD are varied, with some expressing themselves as if the effects of electrification of machinery are known in terms of the impact it would have on the environment and that the technology to get there already exists. On the other hand, others believe that the conditions for succeeding with a transition do not exist. Moreover, that such conditions will be a challenge to cater in the future. Therefore, achieving an even level of knowledge is desirable. Furthermore, it would lead to increased understanding, improved communication between the actors involved, and thus increased willingness and reduced reluctance to change, as Anyieni (2016) and Dainty et al. (2007) expresses.

Increased cooperation and improved communication and knowledge exchange can be achieved by making greater use of collaboration contracts, thus sharing a common goal and purpose, as stated by Forbes & Ahmed (2011) and Lahdenperä (2012). In addition, the barriers to change stated by Dainty et al. (2007) can be overcome. The City of Gothenburg believes that much is being done today to promote knowledge development, including through demonstration and pilot projects involving actors from different industries. Many conclusions were drawn from the executive summaries regarding knowledge development and knowledge exchange. In both E2 and E3, requests were expressed for joint forums where discussions could be held among different actors.

In connection with E2, such forums have already been established. Similar forums were also mentioned in the interview study with RGD, where it appeared as if the city has plans to develop a collaborative platform. For such a platform to be effective in terms of experience and knowledge exchange throughout the industry, it is essential to grant access to all who intends to undergo the transition. Otherwise, knowledge and lessons learned may be limited to those participating in the pilot and demonstration projects. This is especially true of companies of smaller size that do not necessarily have sufficient financial leeway to make unfounded decisions about expensive investments. However, in RGB, it emerged that Company A, a smaller company, has made its investment decision entirely on what others in the market are doing. This indicates that the transition can occur even if the knowledge is unavailable to all actors. However, at the same time, it is essential to let the market control the development. In this way, the transition can occur at the pace that the market allows.

5.1.4 Division of Responsibility

Regarding the division of responsibilities and roles, several sub-areas can be addressed. A sub-area recurring in the interviews is the responsibility to ensure that sufficient power and capacity are available in the grid to satisfy the project with sufficient power to supply the machinery powered by electricity. In reality, this means that the formal responsibility to ensure the functionality and sufficiency of the electricity network lies with the network companies. In the interviews, observation, and E1, there is a consensus about the client's responsibility to map the power requirement for the construction project. However, the interviews with RGD show an understanding that the client does not always possess the knowledge needed to ensure that sufficient capacity exists.

Connecting to the grid can be a lengthy process, requiring foresight that is not always possible in the construction industry, where lead times are often short. Hence, the decision-making process can become hasty. It is a conclusion that can be drawn from the interview with RGD and E1, where it was expressed that the power drawn to the project has not been enough but that the need has been underestimated. Similar experiences emerged at the time of observation, in which they expressed that the need could amount to double what had been estimated. It also links to a lack of knowledge, demonstrating the importance of cooperation between actors.

At the same time, RGE expresses that the time needed to establish a connection cannot be generally determined, but that it depends on a case-by-case basis. In other words, it may not be as easy as saying that a specific actor should be responsible for providing/assessing that enough power to the construction site exists. An interesting aspect raised during the interview with RGE was the so-called income regulation, which prevents the network companies from thinking proactively about expanding network capacity. In practice, this means that electrification, including in the construction industry, is opposed by the current legislation, which prevents the actor who will undoubtedly have a crucial role in the future in ensuring power availability. Long lead times are thus something that should be used as a rule, and how long these should be determined in consultation between the actors involved, but in E3, they concluded that up to 6 months might be needed.

However, the client is not responsible for the charging infrastructure. Instead, it is catered for by other actors, although E3 shows that there are wishes that so would be the case. One idea could have been that the grid companies cater to battery storage. However, it was something that RGE considered an impossibility given their position in the market. Another possibility would be for the city to provide batteries, possibly connected with the eventual machinery pool. However, questions about how it would work in practice concerrning the city of Gothenburg's technology-neutrality and distribution of costs need to be investigated.

5.2 Considerations - Potential & Limitations

This section presents necessary charging, safety, environmental, economic, and functionality & capacity considerations associated with the implementation of electric construction vehicles and machinery.

5.2.1 Charging Considerations

The choice of charging infrastructure is governed by what the location where the project takes place allows. E2 mentions several different connection options. What is appropriate to use cannot be determined without first mapping the needs and available capacity. In cases where existing capacity in nearby lampposts, electrical cabinets, or substations is present, temporary connections can be made. In cases where capacity is not sufficient, other temporary infrastructure such as batteries and temporary substations may become relevant. Batteries will become increasingly common, and that will have a significant role in the transition, it appears in the interview with RGE. Furthermore, the interview with RGA shows that short routes for electricity are preferable, which speaks for more temporary and mobile solutions. It is additionally confirmed during the observation, that electrical losses in the cables were highlighted as a reason why more power than planned was needed. Moreover, Tethered-type configuration place higher demands on the driver's consciousness as the connection cable needs to be moved when the machinery changes position. Hence, additional consideration is needed for planning to ensure the flow of the construction process, as stated by Hedborg Bengtsson (2019), Sullivan et al. (2010), and in the interviews with RGD.

The choice of charging strategy depends on several different factors. According to Berg et al. (2015), different charging strategies are attractive depending on which parameter is valued the most; weight/volume, economic cost, or environmental cost. However, during the observation, the choice of strategy is, in reality, controlled by the propulsion, where the charge is carried out when there is time and when it has minimal impact on the propulsion, which is during breaks and breaks most of the time. Such charging strategies mean that fast charging is required, which demands more from the power grid. It is not sure that the electricity grid is sufficient to enable fast charging, but rather something that needs to be investigated. However, even when such fast chargers are used, it is not guaranteed that it is sufficient to ensure a satisfactory charge, as was evident during the observation.

E2 analyzed four different charging strategies in terms of which strategy would entail the lowest power requirement. Evidently, a constant connection is preferable. From a capacity perspective, it was concluded that large projects would be able to be supplied with a standard 150 kW socket for scenario Low and Medium. At the same time, with the high use rate of construction vehicles as Mol et al. (2010) and Beltrami et al. (2010), it is not realistic to assume that the energy use in scenario Low is representative in practice. For smaller projects, however, all strategies and scenarios remain below the limit of 150 kW. This demonstrates what has previously been mentioned regarding the need to make case-to-case assessments.

The strategy of constant connection is followed by strategy one, strategy three, and strategy two. In other words, it is preferable to charge vehicles with battery-type configurations at a slow rate during the night to minimize the output requirement, which is also advocated in the interview with RGE. Moreover, such strategy entails lower lifetime costs, according to Berg et al. (2015). On the other hand, such a charging strategy would require a large battery, thus being more expensive, as shown in E2. Another aspect worth considering is what was highlighted during the interview with the RGA, namely that it is desirable to avoid complete clocking and recharging concerning battery life. A strategy that allows batteries to stay within 20-80 % SOC would be optimal, but it can be difficult if the battery's capacity is not sufficient. By being connected to the grid constantly, using a tethered-type configuration, the question of optimal SOC can be eliminated.

5.2.2 Safety Considerations

As a result of electrification, more electronic components are added, including electrical cabinets, cables, and batteries, thus increasing the risk of accidents linked to electronics and power. Handling electronics on the construction site is something that, according to Sullivan et al. (2010), should be done by specialists, indicating that the need for such personnel will be more significant following the increased electrification of construction sites. The observation showed that the handling of electrical cabinets in the same way as before is carried out by the operator who provides the electrical cabinets. In addition, the machinery operator carries out the relocation of the cable connected to the machinery. To reduce the need to move and manage cables and power, the construction and use of vehicles should be carefully planned.

5.2.3 Environmental Considerations

Both E1 and E3 demonstrate an apparent reduction in emissions in the use phase of electric machines compared to diesel machinery. However, the approach in the summaries differs. E1 calculates the actual emissions due to the emission exemption requirement and puts it in relation to hypothetical diesel use. E3 does a similar analysis but instead calculates the potential of electrification of construction vehicles by considering the actual use of diesel in a project. However, it is worth considering that the actual production of the vehicles is not included, so there is no empirical estimate of how the emissions/environmental impact of battery electric vehicles stack up against diesel vehicles from a life-cycle perspective. Although, RGA argues that battery vehicles are always better than diesel vehicles from an environmental perspective.

In E1, input data for CO2 equivalent emissions per kWh for diesel and electricity has been used. In E3, similar input data has been used but with Swedish conditions regarding fuel reduction obligations and Swedish electricity production. To illustrate the potential based on theoretical and empirical data, and to make the results in E1 more representative of the Swedish transition and thus more comparable to E3, the environmental benefits of E1 have been recalculated using input from E3. The hourly diesel emissions correspond to the average hourly consumption of the machinery used in E1 multiplied by the emission factor for diesel stated in Appendix C2 in Almer et al. (2020), where the reduction obligation is considered. The emissions for electricity correspond to the emissions per hour for an average weighted engine power of the machinery used in E1 multiplied by the emission factor for the Swedish electricity mix. The assumptions and basis for the calculations can be found in Appendix A, Table A4. The environmental benefits following electrification of construction machinery, more specifically the difference in emissions of CO2-equivalents, are illustrated in Figure 5.1 as a function of operating time.

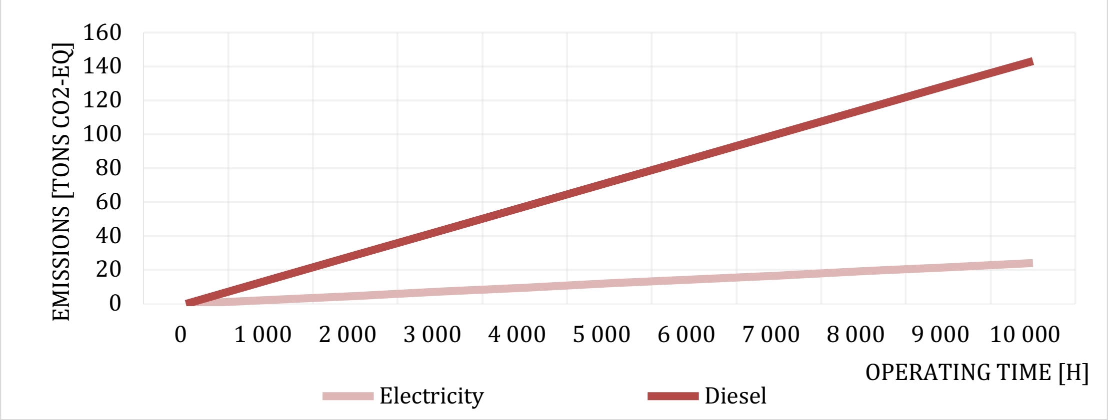

Figure 5.1. *Comparison of average emissions of CO_2-Equivalents from construction machinery in relation to operating time when using electricity and diesel as an energy source. Own calculation and figure. Compiled from Bymiljøetaten (2020) and Appendix C.2 in Almer et al. (2020).*

The results show that the longer a project lasts, the greater the benefits of switching to electric vehicles from an emissions perspective are. However, it should also be considered that the benefits of switching to electricity operation depend on the rate of the fuel reduction duty. More recently, the duty has been a topic for discussion, whether it should be sharpened or mitigated. Would the duty be mitigated, an increase of environmental benefits by electrifying machinery would be attained.

In line with what is stated by Morelli (2011), Sutton (2004), Yılmaz & Bakış (2015), and Mies & Gold (2021) regarding the interplay of environment and economy, both E1 and E3 made efforts to weigh the environmental benefits against the economical. Again, to make E1 and E3 more comparable, the environmental benefits of E1 were recalculated to Swedish conditions by considering the duty to reduce and by converting the currency to SEK, see Table A5. In E3, the environmental benefits expressed as the size of the savings of CO_2-equivalent in tons are divided by the project sum in MSEK, which amounts to a quota of 2.9. The corresponding quota for E1 amounts to 1.13. It is worth mentioning that the project sum for E1 includes additional costs, which correspond to 9 % of the projected contract sum.

The calculations of E1 include the category "others", in which the corresponding emissions are assumed to come entirely from diesel. The theoretical potential is thus higher than that in practice. However, it is not fully comparable in that E1 considers more parameters and that the project sum also includes project-specific overheads. Hence, a realistic quota is more likely somewhere in-between 1.13 and 2.9.

The question of what quota other sustainable solutions could result in would be interesting to consider. Both interview respondents and observation participants voiced opinions that the focus on electric vehicles to minimize the environmental impact of construction is misdirected. More specifically, it is argued that construction production accounts for only a small part of a building's total impact and that the building materials account for the vast majority. The fact that these views were expressed by actors representing contracting companies reflects the outcome of the market dialogue and proposals for procurement requirements that emerge in E3, stating that the preferable way to reach sustainability is to allow the contractor to choose the method themselves. On the other hand, as stated by Yılmaz & Bakış (2015) and Baloi (2003), the construction industry is under pressure to reduce its environmental impact. Thus, all possible measures ought to be considered.

A hope that reduced noise levels following the electrification of construction vehicles and thus lower noise and emission levels will allow further densification of the cities emerges during the interviews with RGC & RGD. RGC & RGD thus share a similar view as Energimyndigheten (2021), Sandberg et al. (2010), Verheijen & Jabben (2010), Beltrami et al. (2021) and Mol et al. (2010). However, in line with what is stated by Naturvårdsverket (n.d), one respondent in RGD with experience in electric construction machinery, argued that despite electrical vehicles being quieter, the noise from the construction site remains a problem. The respondent argues that the primary source of noise originates from the operations carried out by the vehicles, which was confirmed during the site visit at Majorstuhjemme. However, only one of the two electrical machinery was active during the visit, which may have given an unfair picture of their noise contribution. Considering that both Majorstuhjemme and E1 were procured as Emission-free, which can be considered one of the stricter and ambitious forms of procurement requirements that promote the use of electric vehicles, close-to-optimal conditions to achieve low noise levels were present. Nevertheless, a continuous flow of diesel trucks entered and exited the construction site at Majorstuhjemme, which affected the noise experience. Similarly, traditional machinery and tools were also used in E1, which may thus mean that the desired noise reduction was not achieved in that project either. Therefore, although it can be argued that the noise reduction potential can be achieved once the maturity level has increased, the current noise reduction does not reflect the theoretical potential.

Despite the noise levels being marginally lower, measures to account for safety hazards concerning quieter vehicles, in line with what Sandberg et al. (2010) state, had been taken at Majorstuhjemme. For example, both audible signal and rear-view cameras were mandatory on all vehicles at the construction site. Such measures are likely to be necessary as part of the need to embrace and implement new technology and operating methods described by Sullivan et al. (2010) and Anyieni (2016) and, as Labuschagne et al. (2005) state, reach social sustainability by internally focus on ensuring the health and well-being of employees.

5.2.4 Economic considerations

The interviews showed that some actors invest in electric vehicles despite not having evidence to show that it is profitable. It emerged in the interview with RGB that Company A relies entirely on the situation in the market regarding demand. At the same time, lack of availability on the market is mentioned in the interviews with RGB and RGD, E1, E2, and E3, and during the observation. Although just two Machinery and Service companies participated in the interviews with RGB, their answers were coherent, thus indicating that little has happened regarding the availability of machinery since the time of the executive summaries. The available machinery are mainly of smaller size, which works in some respects, but E2 and the observation revealed that the need for larger machinery cannot yet be satisfied. This confirms what Beltrami et al. (2021) state regarding off-highway vehicles falling behind in the development. Larger machinery can be converted from diesel to electricity as in E1, but it is a costly measure and a path the City of Gothenburg does not want to take, according to RGD. In other words, the availability of machinery can currently limit the scope and cost of electrification of machinery.

Nevertheless, in the interview with RGB and E2, and E3, it is stated that the market is changing. Still, the costs are significantly higher compared to traditional machinery. WSP (2017) states that the cost of electric machinery can be 300 % higher, which is reflected in Majorstuhjemme and in E2. Similarly, but not to the same extent, the higher cost is reflected in E3, where the investment costs were as much as 70 % higher. Thus, E3 reflects what both WSP (2017) and Energimyndigheten (2021) state regarding the higher price, and the price is affiliated with the availability on the market. Getting down to a level equivalent to the investment cost of diesel machinery will require significant technological improvements or discoveries that lead to reduced cost of batteries, which is the component of the electric machinery that represents the highest cost, as shown in E2. The interview with RGA revealed that battery costs decreased substantially in the last decade but also that it now has begun leveling out. Therefore, it is unlikely that the investment cost of battery electric vehicles will be significantly reduced, in contrast to what is expressed in E3.

The long-term economic consequences of a shift towards increased electrification were analysed in E2 and briefly mentioned in E3. E2 concluded that the point where the investment of battery-electric machinery with half-day capacity is profitable occurs after two years. The corresponding profit point for battery-electric machinery with full-day capacity is four years. After ten years, the accumulated savings are 1,000,000 SEK and 700,000 SEK, respectively. However, the analysis is theoretical and calculated based on assumptions of moderate energy consumption. Compared to the energy consumption in the large contracts, also analysed in E2, the assumptions correspond to a medium-sized machine and an energy consumption comparable to scenario Medium. Considering that E2 revealed that it is primarily large machines and more intensive energy consumption scenario that are relevant in large projects, a cost analysis based on those parameters would have been more telling and useful from a construction company's perspective.

Moreover, in contrast to Berg et al. (2015), who concluded that charging during the night, thus having a battery that lasts a full day, is preferable from a lifetime cost perspective, E2 concludes that a battery-electric vehicle with half-day capacity is preferable. Berg et al. (2015) and E2 do, however, take different parameters into account, whereas Berg et al. (2015) focus more on the battery and E2 on the machinery. Considering the scope of this report, the analysis by E2 is more relevant. However, the lifetime cost of the battery should also be weighed to get a complete picture of lifetime costs.

However, it can be more costly than expected to use electrical machinery in practice, something that showed in E1. Furthermore, it is worth mentioning that since this analysis is dependent on several variables, such as fuel and electricity costs, it is sensitive to cost changes. Unlike what E2 showed, a partaking actor in E3 expressed that there is no difference in the cost between zero-emission and diesel machinery in terms of the total cost during the ownership period. However, it does not specify which configuration is meant by emission-free in this context, thus making it difficult to put the statement in relation to E2. Consideration should also be given to the additional infrastructure and grid connection needed to supply electrical machinery with power, which also entails a cost. Thus, the choice and cost of establishing infrastructure vary from project to project depending on the conditions that prevail there. Access to power is a crucial factor. If power is available near the project site, the cost of establishing a functioning charging infrastructure can be relatively low. On the other hand, if it is required to establish new infrastructure in the form of, for example, a temporary substation, the cost can be significantly higher, as shown in E2.

In connection with the lifetime cost analysis, E2 also concluded a maximum allowed cost for chargers based on the cost savings and the assumed service life of ten years. However, these maximum costs are calculated with conflicting assumptions regarding daily energy consumption. The cost of the drivetrain is an estimation based on daily energy consumption of 240 kWh/day, while the costs behind the "budget" for the charger cost are based on a consumption of 180 kWh/day (420,000 kWh divided by 14,000 h, multiplied by 6h/day). To make E2 comparable to E1, the average daily consumption per machine in E1 was calculated by dividing the total energy consumption and the number of days the machinery were used (6h/day), see Table A6 in Appendix A. As a result, the energy consumption amounted to approximately 300 kWh/day, which is 25 % higher than that assumed in E2 for estimating the cost of the driveline. In addition, the average engine power of the three excavators and the wheel loader used was 65 kW (22-122 kWh), which is 35% lower than that assumed in E2 for the estimate of the cost of the driveline. Whether these differences in daily energy consumption and engine power significantly affect the cost of the driveline, lifetime costs, and thus when profit occurs is unclear but should nevertheless be considered.

Furthermore, E2 performed cost calculations for existing infrastructure. Similar calculations were not made for new infrastructures. However, the information in the report enabled the authors of this study to calculate the costs of new infrastructure. All the calculations were made with an estimated monthly consumption of 4,800 kWh. The estimation is very low compared to the theoretical consumption of the three large projects calculated in E2, where the daily use amounts to 459-3,807 kWh. Consequently, the costs in E2 are not representative of large contracts. Although, the relationship between existing and new infrastructure costs is still telling.

Furthermore, E2 states that the infrastructure had to be used a lot and for long periods to be economically feasible, which the calculations in Table A4 clearly illustrate. For example, investing in and installing new infrastructure for projects lasting one month is, according to the theoretical calculation, almost three times as expensive as for a project lasting three months. However, E2 pointed out that increasing connections and infrastructure utilization rates can become problematic since construction projects are often limited concerning location and duration. At the same time, it is not sure that it is logistically possible considering the capacity of the electricity network, as shown in E2 and implied during the interview with RGE.

Out of the analyzed summaries, only E1 shows the total costs of an emission-free project implemented in practice. The extra costs can be derived from the difficulty of entirely replacing conventional machinery. Additional costs were also mentioned during the observation. Moreover, a desire for bonuses and financial aids that award contractors for implementing emission-free technology was brought up. Such bonuses and aids were also mentioned in E3 to make electric machinery more attractive.

RGD expressed an understanding that pilot and demonstration projects are more expensive and that contractors need incentives in the form of financial support, the extra costs are difficult to justify on the client's part. Furthermore, significantly higher costs are not sustainable in the long run, according to RGD, indicating that eventual financial aid and bonuses will neither be substantial nor long-term. In fact, it was concluded in E3 that eventual bonuses connected to emission-free technology should be accommodated within the same 0.5-1% interval as other bonuses. Considering the additional 9% in E1, 0.5-1% is not significant. However, the 9% can be expected to decrease following gained experiences and knowledge transfer, thus making the bonuses balanced.

5.2.5 Functionality & Capacity Considerations

Beltrami et al. (2021) pointed out that construction vehicles differ from conventional vehicles in terms of performance and how they are used. Moreover, the power of EMs is better or similar at worst compared to ICEs. However, according to the interviews with RGB & RGD, observation, and E1 & E2, the capacity of electric machinery is not yet sufficient to replace conventional machinery entirely. In RGB, it was stated that electric machinery function only under certain conditions due to the limited battery capacity. Furthermore, it was stated in the interview with RGD and E1 that a traditional machinery was acquired to be on standby to ensure the schedule was kept. This indicates that the efficiency of electric machinery is subpar, which confirms what Berg et al. (2015) state regarding the difficulty of achieving satisfactory energy availability and power performance in construction contexts. On the other hand, the observation indicated that though the overall performance is inferior, electric machinery are not far off traditional machinery in terms of efficiency if they are designated for simpler tasks.

The observation revealed that the battery-electric machinery had a limited operating time of approximately 2.5-4 hours, and only one hour was set aside for charging. Moreover, charging during breaks was not always enough, which resulted in complications. Complications in conjunction with charging were also encountered in E1. However, some of the complications could be derived from human error, thus not giving a fair indication of the capacity and potential of electric machinery. Moreover, as seen in E1, battery-electric machinery with a significantly greater operational time is available. Hence, the problems concerning short operational time can be avoided by choosing machinery with greater capacity. Regarding battery capacity, RGB expresses that the focus of manufacturers should be on developing the batteries. Strictly regarding the development potential of batteries, however, RGA expresses that no significant improvement in battery capacity will occur. Limited battery life will thus need to be considered in the future. A way of overcoming an insufficient battery capacity is to instead use tethered type or tethered-battery type configurations. The former was used at Majorstuhjemme and the latter in E1.

6 Conclusion

This chapter presents the final conclusions and answers the study's three research questions. Furthermore, recommendations for future research are presented.

6.1 How do stakeholders experience the transition to electric construction vehicles?

City representatives and innovation and environmental actors see the transition as necessary to achieve the climate goals set at the national and regional levels. However, some challenges need to be overcome before a complete transition is possible. One such challenge is the limited supply of electrical machinery, which can certainly be overcome by converting existing machinery. However, it is a measure that is not considered feasible in the long run. Furthermore, the city expresses that they have limited opportunities to control and enforce the transition on others, considering the prevailing legality and the city's technology neutrality stance. The city representatives also understand that the transition will be a significant effort at first and see pilot and demonstration projects as a tool to facilitate and increase the pace of the transition and contribute to increased collaboration and knowledge development. The need for increased collaboration is also something that the energy company has highlighted. On the other hand, it appears that cooperation and preparatory work that gives rise to construction projects is limited by current legislation. Otherwise, optimism is expressed when it comes to ensuring the increased energy demand in the future.

There is no reason not to switch to electrified construction vehicles from the researcher's perspective. However, it is highlighted that the development of battery capacity has reached its peak and that a limited battery capacity is an aspect that will need to be considered in the future. For machinery and service providers, the transition is primarily a matter of the market demands and adapting accordingly. The supply and cost of machinery are seen as an obstacle to adapting at a faster pace. There is also uncertainty about the capacity and predation of the machinery. However, the general consensus is that development and the current market are striving for electrification.

Construction companies see the transition as an opportunity to meet a market need and gain a competitive advantage. At the same time, there seems to be a lack of understanding among some actors as to why the electrification of machinery has been given so much space compared to other methods that have more significant environmental potential. Similar to the machinery suppliers, they express uncertainty and distrust about the performance of the machinery, and since no extra time or financial means are given to support the transition, electric machinery are a risk you do not want to take. Furthermore, it is expressed that the existing requirements are not effective, that they are not followed up and that they are not designed in a good way, and that they are not long-term. Instead, they express the desire to, in addition to the common environmental requirements, be able to control/design the requirements themselves without being guided by requirements for a specific technology/method.

6.2 What does the transition to electric construction vehicles entail?

A shift towards electrified machinery entails extensive changes in techniques and working methods both within and outside the construction industry, with economic, technical, logistical, and environmental consequences. With it, an increased need for cooperation and knowledge exchange arises. The purchase cost and the rent tend to be significantly more expensive for electrical machinery than traditional ones, opposite to what applies to the operating cost, which in practice and theory, is cheaper. However, it must be expected that additional costs will arise due to the electrification of machinery, as new needs emerge that have not existed before, such as electricity subscription and charging infrastructure costs. The study has shown that transition requires more prolonged and more extensive planning to ensure that the right conditions exist and thus avoid any unforeseen problems that may otherwise entail complications and high costs.

Furthermore, in connection with the implementation of electrical machinery, it is essential to identify and involve relevant actors at an early stage. For example, to ensure adequate electricity grid capacity and availability of machinery. Electrical machinery currently have comparatively lower operational capacity than traditional machinery, which in practice means that adaptations regarding the operations that the machinery intend to perform are needed. In addition, extensive planning of the loading of the machinery is required to ensure their operability. Electric machinery entail that more resources in the form of time and financial means will be necessary to complete the project.

6.3 How can the transition to electric construction vehicles be facilitated?

The lack of supply of electric vehicles combined with the higher prices makes it difficult for all actors to be able to participate in the transition. By establishing a machinery pool, as in Oslo, the availability of the city's projects can be ensured and high investment costs linked to machinery for the individual actors avoided. Furthermore, acquiring charging infrastructure entails a significant expense, which could be met in connection with a machinery pool. Moreover, the use of interoperability contracts would promote cost and risk diversification. Sharing the risks and costs and using each other's competencies is essential to achieving efficient processes and projects. Furthermore, such contracts would ensure that the level of knowledge regarding electrical machinery is higher among all the actors involved.

More time needs to be allocated for planning, design, and execution to meet the right conditions for projects to be carried out with electric vehicles. Partly to identify and involve relevant actors at an early stage, and partly so that the actors dare to make the transition. In addition, increased focus on logistical issues related to, among other things, cable management and charging of vehicles and machinery is required in connection with it becoming part of the daily routine. This management must be carefully planned and executed to not slow down the project’s progress. Furthermore, safety becomes an issue to consider due to an increased amount of electrical components and the fact that electric vehicles are quieter and thus more challenging to detect than traditional vehicles.

Ensuring that sufficient power is available in the electricity networks is the responsibility of the electricity companies per the connection obligation. At the same time, utilities are prevented from proactively upgrading capacity. Therefore, mapping the need for power for the construction project is within the client's scope of work. However, the client does not always possess the knowledge needed to make correct assessments, leading to the need being underestimated. In practice, significantly more power is required than initially estimated. Therefore, these companies should be involved in estimating the energy demand at an early stage.

The question of who should be responsible for both charging and charging infrastructure is less ambiguous. Although it has been expressed that the responsibility for providing infrastructure should lie with the client, it is with the contractor who executes the contract that the responsibility for ensuring that infrastructure is located on the site lie. The scope of the infrastructure can be more or less extensive depending on the needs of the workplace. To choose the right type of infrastructure, it is necessary to make assessments of the demand based on which vehicles will be used and thus the need for charging. Furthermore, the capacity prevailing in the network at the current location also guides the choice of the appropriate infrastructure and strategy. A solid mapping process is thus necessary for each project.

To succeed in driving a change process, an understanding and knowledge must exist, which places high demands on actors who consider themselves to have a leading role in coming up with how and why they intend to proceed. With a starting point in the construction industry, which is considered conservative, trying to push through a change without providing the basis on which actors can stand and make decisions is counterproductive. More pilot and demonstration projects such as those already carried out by the City of Gothenburg would help raise knowledge and understanding. However, to further enhance the potential of such projects, it is of great importance that other actors not involved in these projects also benefit from the experiences and lessons learned. A collaboration platform is a valuable initiative which should be invested in even more to build up the necessary understanding and comprehend the required conditions and consequences resulting from the transition.

6.4 Future research

The discussion and analysis covered many aspects of the transition to electric construction vehicles. However, it also eventuated in a few topics which could be relevant to future research.

The city takes a technology-neutral stance which limits what it can do and require without compromising actors' business models. Therefore, it would be interesting to analyze what conditions and changes are necessary to establish and manage a city-owned machinery pool considering the current legislation.

Furthermore, there is a need to map the energy demand at an early stage to ensure that sufficient conditions are present in time for the start of the project. Therefore, it would be of interest to analyze how relevant actors can be involved at an early stage and how the mapping of energy demand should be carried out systematically and become standardized. In addition, it would be of interest to research how the current legislation, which hinders energy companies from working proactively, can be altered to accommodate the increased need for planning.

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8 Appendix

- Appendix A – Figures & Tables
- Appendix B – Interview Guide
- Appendix C – Observation

8.1 Appendix A – Figures & Tables

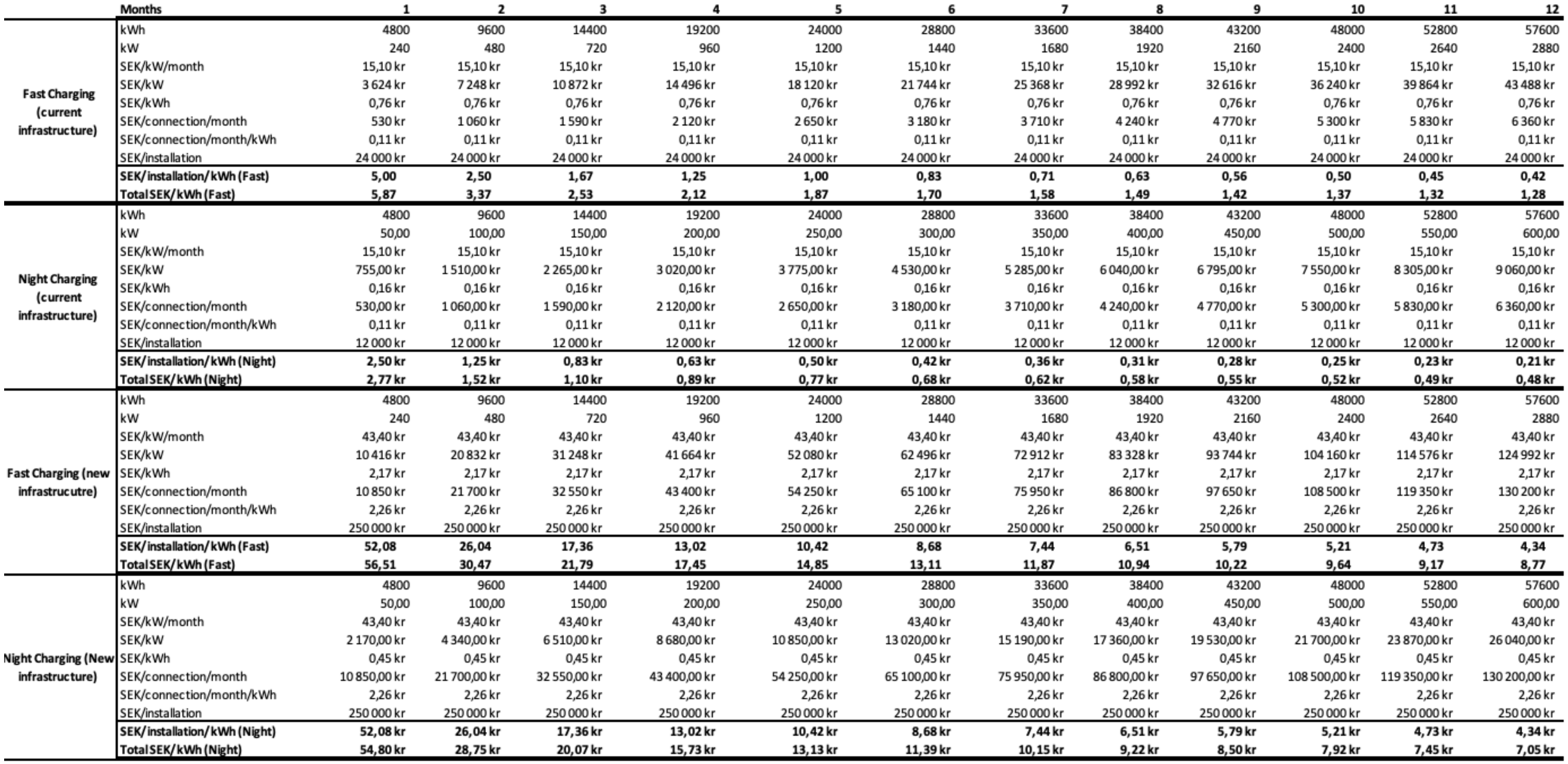
***Table A1**: Compilation of operating and charging conditions. Compiled from (Bymiljøetaten, 2020).*

Machinery	**Operating & charging conditions**
Excavator 8 tons	Operation time • Cable ensures continuous operation • 4 hours: Continuous battery operation • 8 hours: Non-continuous battery operation, 45 minutes charging during breaks. Charging time • 7-9 hours: 11kW (400V 16A) • 2.5-9 hours: (63-16A) Fast charging • 44kW (400V 63A)
Excavator 16 tons	Operation time • Cable ensures continuous operation • 30-40 minutes: Continuous battery operation Charging time • 1 hour: 63A
Excavator 25 tons	Operation time • 6-8 hours: Non-continuous battery operation, charging during breaks Fast charging • 2 hours: 400V 250A
Wheel Loader	Operation time • 3-5 hours: Intensive-normal workload

Table A2*: Summary of the assumptions made in the study categorised into segments. Compiled from* Bernholdsson et al. (2020).
*Two cables for fast chargers
**10 kV fixed subscriptions with a power factor of 0.95.

Diesel consumption for the different scenarios and machinery types	
Wheel excavators, l/h/tons	0.5(Low), 0.75(Medium), 1.0(High)
Crawler excavators, l/h/tons	0.75(Low), 1.0(Medium), 1.25(High)
Wheel loaders, l/h/tons	0.75(Low), 1.0(Medium), 1.25(High)
Energy, Efficiency ratio, and weight ratio	
Energy in diesel	9.8 kWh/l
Efficiency ICE (diesel)	30%
Efficiency EM	90%
Energy density battery	130 Wh/kg
Battery / Machine weight	25%
Daily energy need	
Small contracts	All machines are used every day. Each day is 8h.
Large contracts	All machines are used every day. Each day is 8.5h.
Costs & Costs calculations	
Fuel/Energy	Diesel: 4.13 SEK/kWh (incl taxes) Electricty: 1.05 SEK/kWh (incl taxes)
Powertrain costs	Maximum power: 100 kW Daily energy consumption: 240 kWh/day
Machinery lifetime costs	Machinery use: 6 h/day (180 kWh/day). Estimated lifespan: 10 years / 14,000 operating hours / 420,000 kWh.
Charger investment cost	3,000 SEK/kW Estimated lifespan: 420,000 kWh (as for the machine) Charger cost equation: [needed kW] x 3,000[SEK/kW] / [lifespan kWh]. • 700,000 SEK / 420,000 kWh =1,7 SEK/kWh(half-day) • 1,000,000 SEK /420,000 kWh =2,4 SEK/kWh(full-day)
Existing cable cabinet	Installation: 12,000 SEK / Cable* 530 SEK/month 15.1 SEK/month/kW 15.3 Cents/kWh
Existing substation	Installation: 12,000 SEK / Cable* 530 SEK/month 15.1 SEK/month/kW 15.3 Cents/kWh
New temporary substation	Installation: 250,000 SEK (+ additional costs associated with ground preparation) 10,000 SEK/month (rent) 850 SEK/month (subscription)** 43.4 SEK/month/kW** 3.2 Cents/kWh**

***Table A3**. Costs of currently available charging infrastructure and temporary charging infrastructure per month. Compiled from Bernholdsson et al., (2020)*



	Months	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Fast Charging (current infrastructure)	kWh	4800	9600	14400	19200	24000	28800	33600	38400	43200	48000	52800	57600
	kW	240	480	720	960	1200	1440	1680	1920	2160	2400	2640	2880
	SEK/kW/month	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr
	SEK/kW	3 624 kr	7 248 kr	10 872 kr	14 496 kr	18 120 kr	21 744 kr	25 368 kr	28 992 kr	32 616 kr	36 240 kr	39 864 kr	43 488 kr
	SEK/kWh	0,76 kr	0,76 kr	0,76 kr	0,76 kr	0,76 kr	0,76 kr	0,76 kr	0,76 kr	0,76 kr	0,76 kr	0,76 kr	0,76 kr
	SEK/connection/month	530 kr	1 060 kr	1 590 kr	2 120 kr	2 650 kr	3 180 kr	3 710 kr	4 240 kr	4 770 kr	5 300 kr	5 830 kr	6 360 kr
	SEK/connection/month/kWh	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr
	SEK/installation	24 000 kr	24 000 kr	24 000 kr	24 000 kr	24 000 kr	24 000 kr	24 000 kr	24 000 kr	24 000 kr	24 000 kr	24 000 kr	24 000 kr
	SEK/installation/kWh (Fast)	**5,00**	**2,50**	**1,67**	**1,25**	**1,00**	**0,83**	**0,71**	**0,63**	**0,56**	**0,50**	**0,45**	**0,42**
	Total SEK/kWh (Fast)	**5,87**	**3,37**	**2,53**	**2,12**	**1,87**	**1,70**	**1,58**	**1,49**	**1,42**	**1,37**	**1,32**	**1,28**
Night Charging (current infrastructure)	kWh	4800	9600	14400	19200	24000	28800	33600	38400	43200	48000	52800	57600
	kW	50,00	100,00	150,00	200,00	250,00	300,00	350,00	400,00	450,00	500,00	550,00	600,00
	SEK/kW/month	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr	15,10 kr
	SEK/kW	755,00 kr	1 510,00 kr	2 265,00 kr	3 020,00 kr	3 775,00 kr	4 530,00 kr	5 285,00 kr	6 040,00 kr	6 795,00 kr	7 550,00 kr	8 305,00 kr	9 060,00 kr
	SEK/kWh	0,16 kr	0,16 kr	0,16 kr	0,16 kr	0,16 kr	0,16 kr	0,16 kr	0,16 kr	0,16 kr	0,16 kr	0,16 kr	0,16 kr
	SEK/connection/month	530,00 kr	1 060,00 kr	1 590,00 kr	2 120,00 kr	2 650,00 kr	3 180,00 kr	3 710,00 kr	4 240,00 kr	4 770,00 kr	5 300,00 kr	5 830,00 kr	6 360,00 kr
	SEK/connection/month/kWh	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr	0,11 kr
	SEK/installation	12 000 kr	12 000 kr	12 000 kr	12 000 kr	12 000 kr	12 000 kr	12 000 kr	12 000 kr	12 000 kr	12 000 kr	12 000 kr	12 000 kr
	SEK/installation/kWh (Night)	**2,50 kr**	**1,25 kr**	**0,83 kr**	**0,63 kr**	**0,50 kr**	**0,42 kr**	**0,36 kr**	**0,31 kr**	**0,28 kr**	**0,25 kr**	**0,23 kr**	**0,21 kr**
	Total SEK/kWh (Night)	**2,77 kr**	**1,52 kr**	**1,10 kr**	**0,89 kr**	**0,77 kr**	**0,68 kr**	**0,62 kr**	**0,58 kr**	**0,55 kr**	**0,52 kr**	**0,49 kr**	**0,48 kr**
Fast Charging (new infrastrucutre)	kWh	4800	9600	14400	19200	24000	28800	33600	38400	43200	48000	52800	57600
	kW	240	480	720	960	1200	1440	1680	1920	2160	2400	2640	2880
	SEK/kW/month	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr
	SEK/kW	10 416 kr	20 832 kr	31 248 kr	41 664 kr	52 080 kr	62 496 kr	72 912 kr	83 328 kr	93 744 kr	104 160 kr	114 576 kr	124 992 kr
	SEK/kWh	2,17 kr	2,17 kr	2,17 kr	2,17 kr	2,17 kr	2,17 kr	2,17 kr	2,17 kr	2,17 kr	2,17 kr	2,17 kr	2,17 kr
	SEK/connection/month	10 850 kr	21 700 kr	32 550 kr	43 400 kr	54 250 kr	65 100 kr	75 950 kr	86 800 kr	97 650 kr	108 500 kr	119 350 kr	130 200 kr
	SEK/connection/month/kWh	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr
	SEK/installation	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr
	SEK/installation/kWh (Fast)	**52,08**	**26,04**	**17,36**	**13,02**	**10,42**	**8,68**	**7,44**	**6,51**	**5,79**	**5,21**	**4,73**	**4,34**
	Total SEK/kWh (Fast)	**56,51**	**30,47**	**21,79**	**17,45**	**14,85**	**13,11**	**11,87**	**10,94**	**10,22**	**9,64**	**9,17**	**8,77**
Night Charging (New infrastructure)	kWh	4800	9600	14400	19200	24000	28800	33600	38400	43200	48000	52800	57600
	kW	50,00	100,00	150,00	200,00	250,00	300,00	350,00	400,00	450,00	500,00	550,00	600,00
	SEK/kW/month	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr	43,40 kr
	SEK/kW	2 170,00 kr	4 340,00 kr	6 510,00 kr	8 680,00 kr	10 850,00 kr	13 020,00 kr	15 190,00 kr	17 360,00 kr	19 530,00 kr	21 700,00 kr	23 870,00 kr	26 040,00 kr
	SEK/kWh	0,45 kr	0,45 kr	0,45 kr	0,45 kr	0,45 kr	0,45 kr	0,45 kr	0,45 kr	0,45 kr	0,45 kr	0,45 kr	0,45 kr
	SEK/connection/month	10 850,00 kr	21 700,00 kr	32 550,00 kr	43 400,00 kr	54 250,00 kr	65 100,00 kr	75 950,00 kr	86 800,00 kr	97 650,00 kr	108 500,00 kr	119 350,00 kr	130 200,00 kr
	SEK/connection/month/kWh	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr	2,26 kr
	SEK/installation	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr	250 000 kr
	SEK/installation/kWh (Night)	**52,08 kr**	**26,04 kr**	**17,36 kr**	**13,02 kr**	**10,42 kr**	**8,68 kr**	**7,44 kr**	**6,51 kr**	**5,79 kr**	**5,21 kr**	**4,73 kr**	**4,34 kr**
	Total SEK/kWh (Night)	**54,80 kr**	**28,75 kr**	**20,07 kr**	**15,73 kr**	**13,13 kr**	**11,39 kr**	**10,15 kr**	**9,22 kr**	**8,50 kr**	**7,92 kr**	**7,45 kr**	**7,05 kr**

Table A4. *Emissions from electricity & diesel machinery. Own calculations, compiled from* Bymiljøetaten (2020), *and* Snarset (2020b) and Appendix C.2 in Almer et al. (2020).

** Snarset (2020b) in Almér et al. (2020).*

*** Appendix C2 in Almer et al. (2020).*

Machine	**Excavator 8 tons**	**Excavator 16 tons**	**Excavator 25 tons**	**Wheel Loader**	**Total**
Engine power [kW]	40	75	122	22	
Consumption/h [L]	5.24	9.14	20.0	3.5	9.47
Operation time [h]	2,873	1,261	375	768	5,277
Liter diesel [L]	15,057	11,528	7,514	2,688	36,787
Total [kWh]	114,920	94,575	45,750	16,896	272,141
Diesel emissions [tons CO_2-eq]	30.93	23.68	15.43	5.52	75.56
Electrical emissions [tons CO_2-eq]	5.38	4.43	2.14	0.79	12.74

Average wieted Engine power	51.57 [kW]
Emission factor - Diesel	2.05 [Co_2-eq /L] with a 21% reduction, according to the 2020 reduction obligation*
Emission factor - Electricity production	0.47 [kg CO_2/kWh]**
Average diesel consumption/hour	6.97 [L]

Operating time [h]	**Diesel [tons CO_2-eq]**	**Electricity [tons CO_2-eq]**
0	0	0
1,000	14.3	2.4
2,000	28.6	4.8
3,000	43.0	7.2
4,000	57.3	9.7
5,000	71.6	12.1
6,000	85.9	14.5
7,000	100.2	16.9
8,000	114.6	19.3
9,000	128.9	21.7
10,000	143.2	24.1

Table A5. *CO_2-savings per invested MSEK. Own calculations, complied from* Bymiljøetaten (2020).

** 1 NOK is equal to 1.07 SEK.*

Machine	**Emissions [tons CO_2-eq]**
Excavator 16 tons	31
Excavator 20 tons	24
Excavator 25 tons	15
Wheel Loader	6
Others	1
Total	**77**
Project cost	63.9 / 68.373 [MNOK] / [MSEK]*
CO_2-Savings per invested MSEK	1.1264 [Tons CO_2-eq/MSEK]

Table A6. *The average daily energy consumption (active). Own calculations, compiled from* Bymiljøetaten (2020).

Machinery	**Operation time [h]**	**Total [kWh]**
Excavator 16 tons	2,873	114,920
Excavator 20 tons	1,261	94,575
Excavator 25 tons	375	45,750
Wheel Loader	768	16,896
Total	**5277**	**272,141**
Full days of machinery activity (6h/day)		219.9 [Days]
Daily average consumption		309.4 [kWh/day]

8.2 Appendix B - Interview Guide

Table B1. *The interview guide.*

*Within and outside of the city/organization/company/group that the respondent(s) represent(s).

**Of the city/organization/company/group that the respondent(s) represent(s), but also their view on other's roles and responsibilities.

Drivers
• Goals & visions regarding the electrification transition • Potential & opportunities regarding the electrification transition • Incentives & drivers that exist/are needed to drive the electrification transition
Necessary Conditions
• Form of contract • Procurement requirements • Working methods • Charging infrastructure
Managing change & Responsilities
• Relevant involved actors • Managing change* • Roles and responsibilities**
Managing change & Responsilities
• Relevant involved actors • Managing change* • Roles and responsibilities**
Electricity & Network Capacity
• Present and future energy supply • Current and future network capacity • Measures to reduce the load on the network • Accession and legal relationships
Vehicle & Machinery
• Availability & demand • Fuctionality • Opportunitets & limitation • Economic, social and environmental consideration

Follow-up & Development
• Follow-up of goals, visions, requirements, performance. • Obstacles & difficulties • Improvement areas • Future prospects

8.3 Appendix C – Observation

Table C1. *The agenda of the observation of the emission-free construction site – Majorstuhjemme.*

Short presentation round and background behind the meeting
Emission-free construction site status
• What has worked • What has not worked
The process of emission-free machines
• What works • What is difficult to achieve and why • What is the rent cost – how was it reflected in the contract
Planning and implementation of emission-free construction site
• How should a zero-emission construction site be planned differently • How does the machines work in practice – difference emission-free versus conventional equipment (price, function, time)
Visit to the construction site

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