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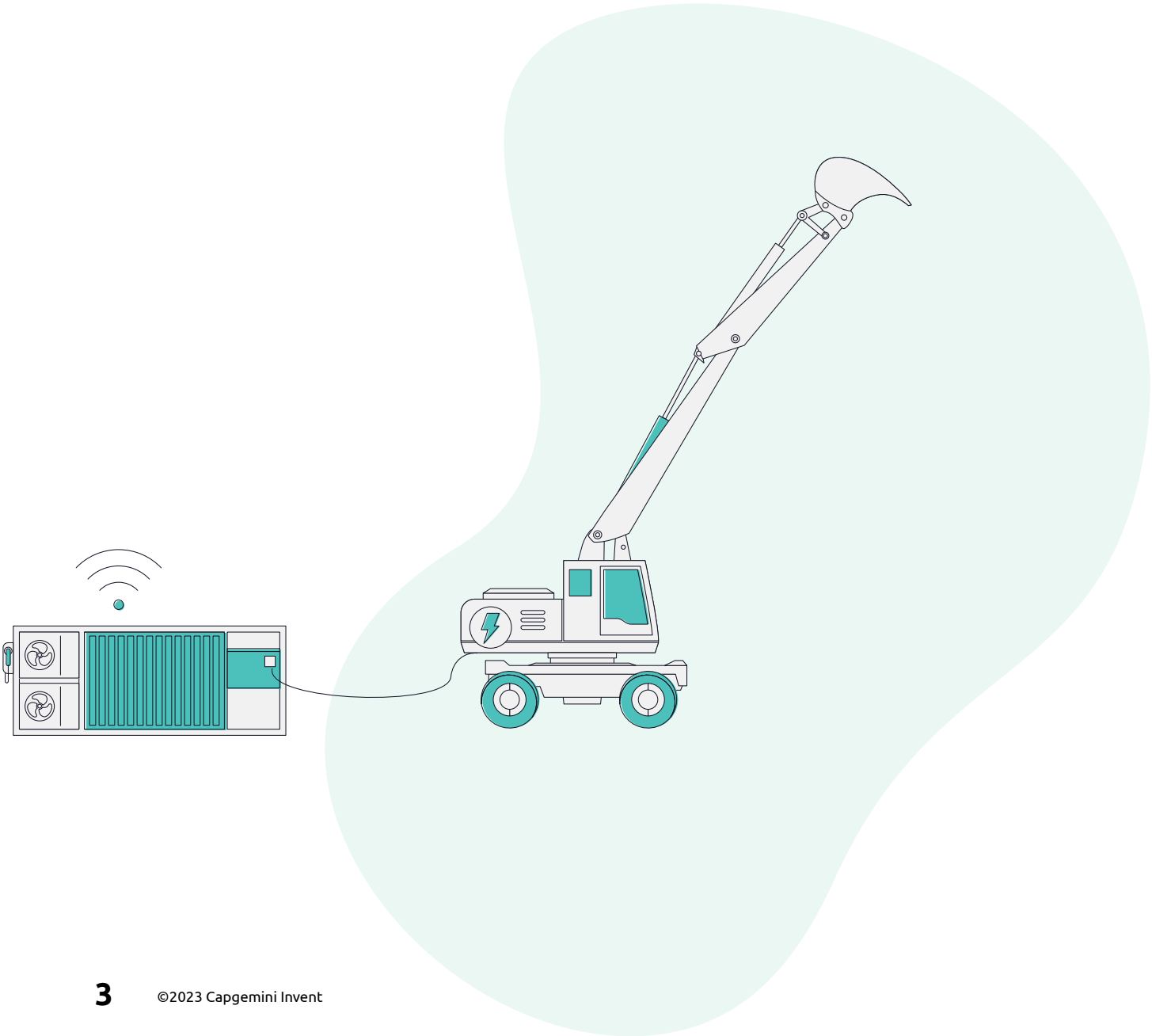
HOW TO SUCCEED WITH

Zero emission construction sites

Learnings from Norway

CONTENTS



ABOUT THIS REPORT

This report is a result of a study carried out by Capgemini Invent. The study is based on interviews with a wide range of industry stakeholders and extensive research into existing reports, publications and news articles. The challenges and recommendations presented in this report should not be seen as the direct opinions of the stakeholders interviewed. Nonetheless, Capgemini Invent would like to thank the following organizations for their participation in interviews and for sharing their insights.

SELECTED INTERVIEW PARTICIPANTS

ANEO, Oslo, Mangrossistenes Forening, NCC, NyeVeier, RG Rental Group, Capgemini, NASTA, ICLEI Local Governments for Sustainability Europe, Braathen Landskapsentreprenør AS, kvist, CONTUR, Trondheim Kommune, EBA

In addition to these, other governmental and private stakeholders operating in the construction industry and its research domain have been interviewed.

This study was conducted between April and September 2023, and challenges and recommendations are based on the current status at the time of writing.

EXECUTIVE SUMMARY

The construction industry is acknowledged as a significant contributor to global warming and is considered a top offender in terms of local emissions. This has lead many nations and cities to explore the transition to zero-emission construction, whereof Norway has emerged as an early adopter primarily through the increased application of electric zero-emission construction machinery.

Photo: Aneo Build

Embracing early adoption means taking risks by experimenting with new and evolving technologies—sometimes succeeding, sometimes learning from failures. By capitalizing on the experiences and insights from the Norwegian market, this report is designed to support other countries as they navigate the landscape of new zero-emission technologies and practices. The perspectives provided in this report is drawn from interviews with key industry stakeholders supplemented with existing academic and industry publications. The output is a report presenting key barriers to realizing zero-emission construction, actions to be taken to overcome these challenges, and opportunities arising in view of tangible stories and first-hand experiences.

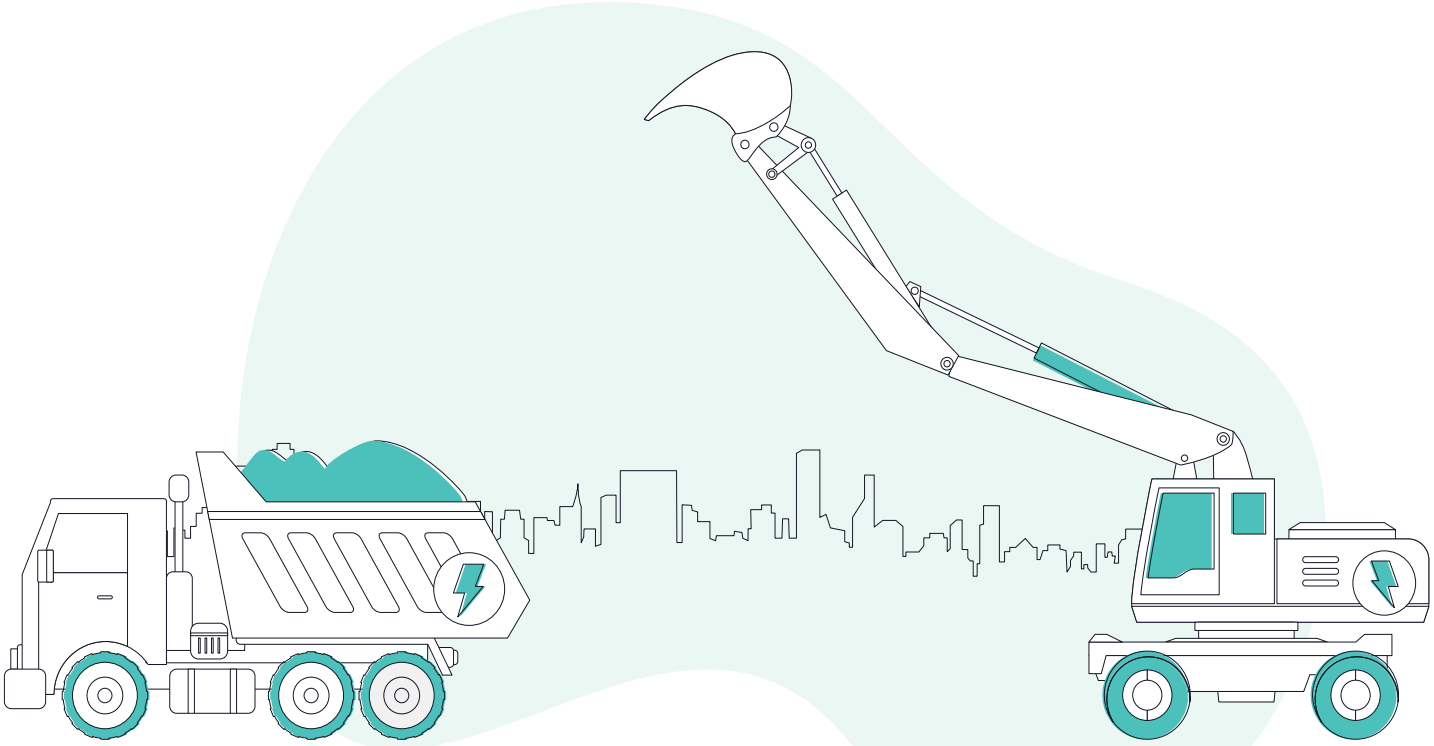
The key challenges identified are interlinked and heavily dependent on each other, and they all boil down to five key barriers that must be addressed in order to accelerate the adoption of zero-emission construction sites: additional costs and willingness to pay, absence of stable and predictive incentives, lack of standardized requirements and regulations, limited accessibility to zero-emission machinery, and increased demand for electricity and infrastructure challenges, incl. charging and electricity supply. At the heart of all these challenges lies the need for interaction between governmental regulators and market participants to ensure predictability in the market, joint efforts to drive change, and an opportunity to capitalize on the new opportunities at hand.

Firstly, regulatory authorities must set requirements and direction to ensure predictability and reduce risk for market participants. This includes regulations to ensure market push, supported by incentives to facilitate market pull.

Secondly, the industry must collaborate to deliver on the requirements and realize the ambitions. This includes upskilling, knowledge sharing, and innovation across the value chain, including joining forces to create a sizable demand for zero-emission construction machinery to increase the attractiveness of high-scale production.

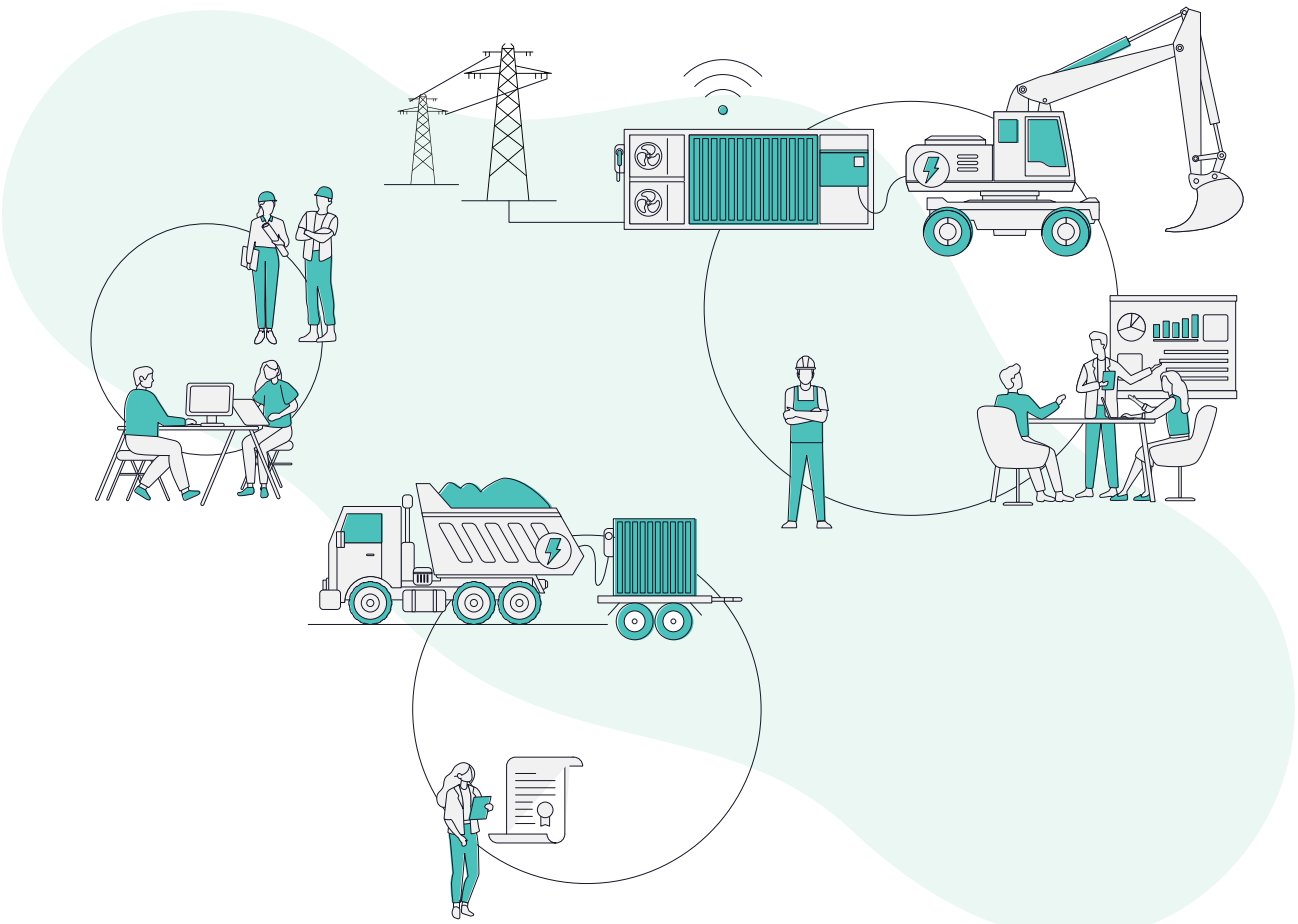
Lastly, the industry must think transition and restructuring, extending beyond mere electrification, and capitalize on the opportunities arising from digitalization, data, and connectivity. This includes reaping the benefits of being a first mover, utilize digitalization for improved optimization, and unlock the potential of new revenue streams from data monetization.

Despite the increasing adoption of zero-emission practices in Norway, there is still a large variation in maturity across Europe and the finish line is far from reached. The true acceleration of zero-emission construction will only materialize once the market begins to perceive and fully embrace the opportunities presented by this transition. At that point, forward-looking and proactive players are expected to secure a prominent market position.



INTRODUCTION

In the pursuit of a sustainable future, the urgency to establish a new standard for construction sites has emerged, driven by the need to decarbonize energy consumption to meet Paris Agreement targets. Among the multitude of industries contributing to greenhouse gas emissions, the construction sector emerges as a significant player, accounting for 23% of the world's CO2 emissions (1). A closer examination of the numbers reveals that 5.5% of these emissions arise directly from construction sites activities, primarily caused by burning fossil fuels to power machinery and equipment (1). This has led several European governments to establish ambitions and goals to accelerate the transition from conventional to clean construction sites.



→ Defining zero-emission construction sites

Various terms are used for construction practices that systematically manage and reduce emissions. In this report, the definition that is used - zero-emission construction sites – refers to a construction site without airborne emissions from fuel combustion within the system boundary (2). This implies the use of energy sources that do not lead to local emissions of CO2 or NOx. In this report, the focus has been on electricity as the primary energy source, however, to gain a comprehensive perspective, other sources such as hydrogen are relevant to include.

Emissions

	Fossil (diesel)	Fossil-free	Zero-emission
CO2 from engine		 [1]	
SOx/Nox from engine			
Particulate Matter (PM) from engine			
Noise from engine			

[1]Biofuel engines emit CO2 at levels close to regular diesel engines, but the absorption of CO2 during sustainable biofuel production offsets emissions, potentially resulting in a climate-neutral impact

Figure 1: Illustration of emissions and pollution from various fuel options (3)

The term zero-emission construction is interchangeable with other similar names such as emission free construction. To avoid confusion, this report refers to zero-emission.

→ Environmental impact of construction activities

The construction sector has a significant global and local impact, contributing to nearly a quarter of global greenhouse gas emissions (1). For construction projects, there are two major components of CO2 emissions, namely direct and indirect emissions. Direct emissions, also called operational CO2 emissions, primarily stem from on-site energy consumption and construction activities. Indirect emissions, on the other hand, are produced in other parts of the value chain, such as the extraction of construction materials, production, transportation, demolition, and other non-building-related activities (4).

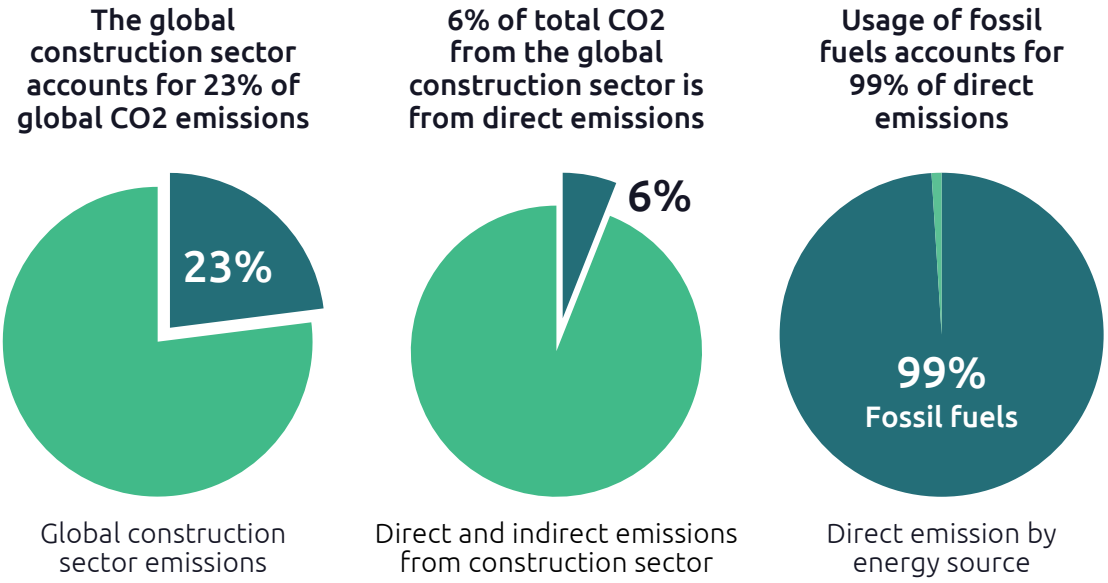


Figure 2: Global construction sector emissions breakdown (5)

Besides CO2 emissions, construction activities also create other climate effects such as airborne particles, noise, and waterborne pollution (2). These environmental effects can be categorized into two main groups:

- **Immediate impacts**: such as noise, air pollution (NOx, SOx, PM2.5, PM5, PM10), vibrations, and exhaust. Affecting the local environment and machine operators' working conditions.
- **Long-term impacts:** such as changes to land masses, effects on biological ecosystems, and impacts on animal habitats.

The focus of this report are direct emissions, more specifically the direct emissions from construction machinery. This focus is not sufficient to minimize the overall environmental footprint of the construction sector, however, it constitutes an essential component of the overall solution.

In London, construction machinery is estimated to account for 7.5% of the city's NOx emissions, 8% of large particle matter PM10, and 14.5% of fine particle matter PM 2.5 (46). Additionally, the construction site machinery contributes greatly to noise pollution, which all has adverse health effects for those affected.

→ Norway's ambitions are clear: by 2030, all construction sites in the largest cities must be zero-emission

In 2021, several large Norwegian municipalities entered an agreement named "Storbyerklæringen" (Urban Declaration). In this declaration, the cities commit to ensuring that their municipals construction activities are zero-emission by 2025. Moreover, the goal is for the whole construction industry within these cities, including both the public and private sectors, to comply with the zero-emission construction objective by 2030 (6). The ambition of the declaration is to showcase a collective commitment to reduce greenhouse gas emissions in urban areas, enhance air quality, and promote sustainable solutions.

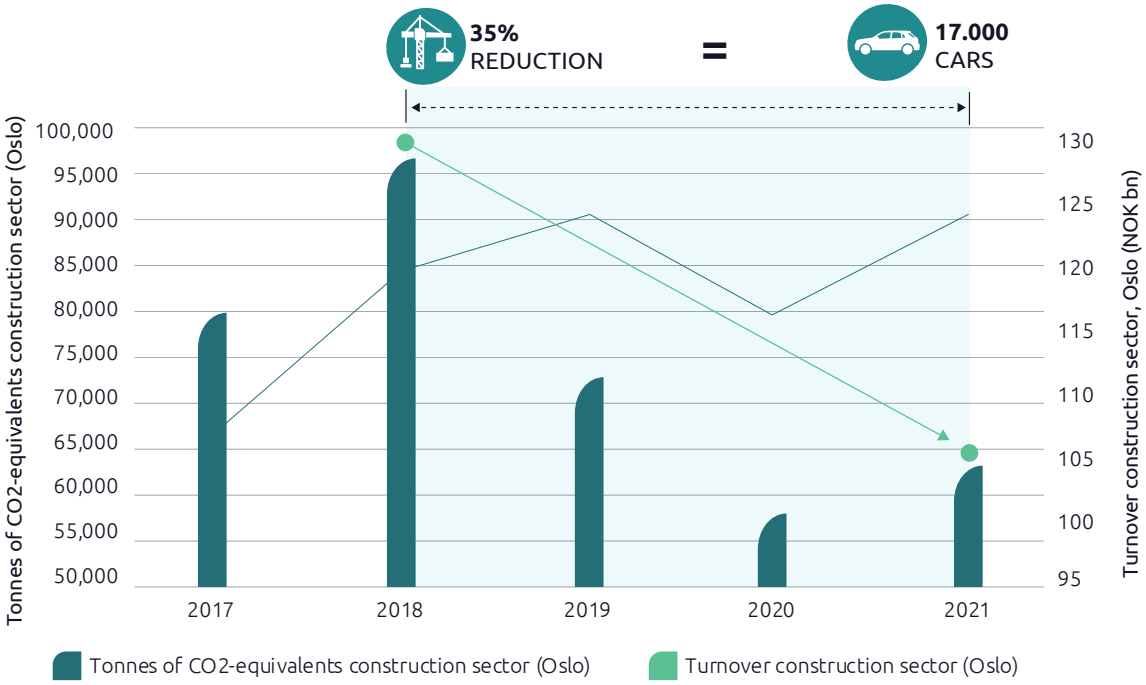


Figure 3: Relationship between construction industry emissions (tonnes/CO2) and turnover (bnNOK) in Oslo, Norway between 2017 and 2021 (8) (9)

Since the declaration was signed, the cities have witnessed a transformation of construction sites where the municipality is the client (7). To illustrate this, using Oslo as an example, 55% of the energy use on the construction sites are currently zero emission, whereas the remaining energy use is fossil free[1]. The city's work towards reducing emission in the construction sector can further be substantiated by its reduction in emissions from mobile combustion in the construction sector despite increased industry activity (Figure 3). As the figure shows, Oslo have reduced emissions from construction by 35%, from 98k tons in 2018 to 64k tons in 2021. This reduction is equivalent to removing 17.000 fossil-fueled cars from Norwegian roads[2]. Put differently, Oslo has embarked on its journey towards emission reduction from the construction sector, consistent with the broader Norwegian construction sector as illustrated in figure 4.

Figure 4: Relationship between construction industry emissions (tCO2e/mNOK) and turnover (mNOK) in Norway between 2017 and 2021 (8) (9)

[1]Presented on Dialogkonferanse om fornybar og utslippsfri utbygging av fornybar energi, Fornybar Norge 2023.
[2]Assuming a typical diesel car emits approximately 2.68 kilograms of CO2 per liter of diesel fuel burned, travels around 15,000 kilometers annually with a fuel efficiency of about 6 liters per 100 kilometers (15 km per liter). This is approximately equivalent to 2.01 metric tons of CO2 per year.

→ Ambitions vary between the European countries, and a significant proportion have yet to establish clear objectives targeting the construction sector

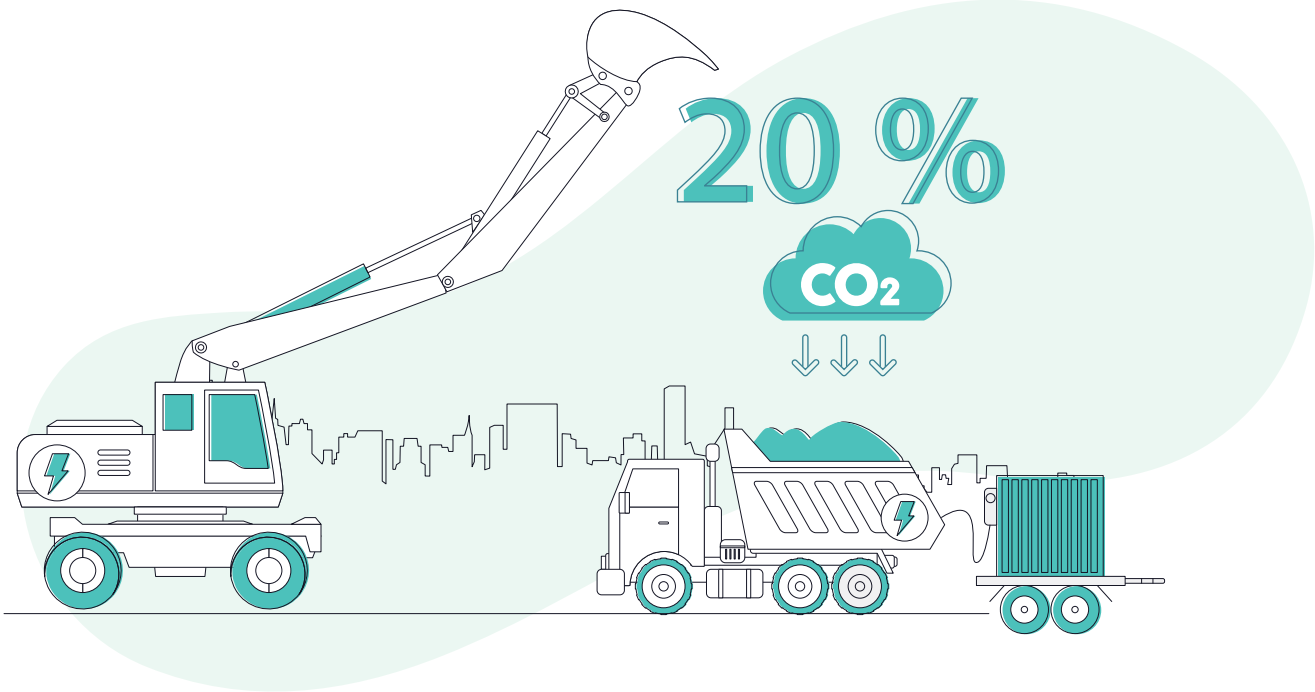
Aligned with the European Union's commitment to reduce greenhouse gas emissions, several European countries are working strategically towards the establishment of zero-emission construction sites. Finland, for instance, has set ambitious targets through its own Green Deal. The country is aiming at 100% fossil-free construction sites by 2025, with 20% of these utilizing electricity, biogas, or hydrogen as energy sources (10). The target is set to rise to 50% by 2030, signifying an escalating commitment to sustainable development.

Overview of ambitions and targets in selected European countries	TARGETED GOALS			
	Emission reduction by 2030 (in %, compared to 1990) (country level)	Net zero/Climate neutral/Zero emissions (country level)	Fossil free (construction level)	Net zero/Climate neutral/Zero emissions (construction level)
Norway	55%	2050	2025	2050
Sweden	63%	2045	N/A	2045
Denmark	70%	2045	2030	2045
Finland	60%	2035	2025	2035
Iceland	55%	2040	N/A	2040
Italy	55%	2050	N/A	2050
France	40%	2050	N/A	2050
Germany	65%	2045	N/A	2045
Netherlands	49%	2050	N/A	2050
Belgium	35%	2050	N/A	2050
UK	68%	2050	N/A	2050

Figure 5: Summary illustrating difference in targeted goals in selected European countries

In Sweden, where the construction sector is responsible for approximately 20% of the country's climate emissions, a collective effort involving multiple industry groups and numerous stakeholders aims for net-zero emissions by 2045 (12). Specific cities, like Malmö and Uppsala, are targeting a fossil-free construction industry by 2030 (13) (14), whereas Stockholm has a 2040 target (15). In other parts of Europe, for instance Iceland, Reykjavik's Climate Action Plan outlines objectives for 2021-2025, including the goal of being entirely fossil-free by 2025. A crucial part of this strategy is mandating fossil-free energy sources for all city-commissioned construction projects. The city aims to have most of the work equipment at construction sites powered by sustainable energy, using this as a measure of the plan's effectiveness (16).

While numerous European nations and cities have established concrete goals for construction sites free of fossil fuels and emissions, many major European countries still lack such specific targets, as illustrated in figure 5. Generally, the construction sector aligns with national goals for net-zero emissions, instead of formulating its own ambitious, industry-specific targets that could hasten the achievement of net-zero greenhouse gas emissions within the sector. Going forward, additional European nations need to outline bolder objectives for their construction sectors to render the aim of achieving climate-neutral construction more feasible.



→ The ecosystem in the construction sector

The ecosystem in the construction industry is complex, fragmented, and involves various stakeholders that interact and collaborate to shape the landscape of projects. Each stakeholder's unique role and contribution is essential in ensuring successful planning, execution, and sustainable development of construction endeavors. Moreover, the stakeholders specifically related for zero-emission construction the main stakeholder groups include (17):

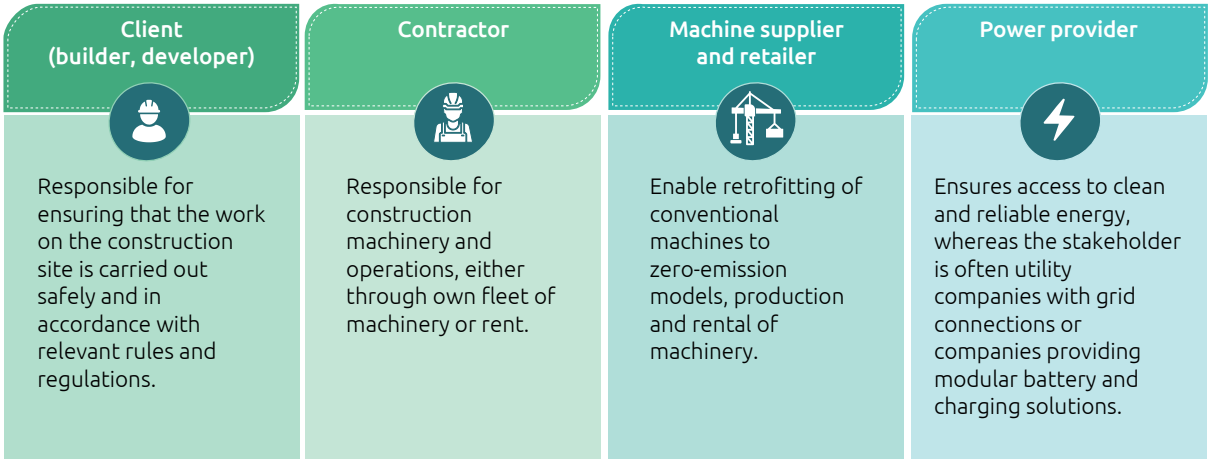


Figure 6: Overview of key stakeholders related to zero-emission construction

→ Primary drivers of zero-emission construction sites: Regulations, Incentives, and Technological development

Several drivers have contributed to the increasing adoption of environmentally friendly practices, whereas the following three drivers are significant factors having a determining role in shaping the future of zero-emission construction sites[1]:

1 REGULATIONS

Governments and local authorities are implementing stricter regulations and policies with the goal of reducing emissions and promote sustainable practices. This has led to the push for zero-emissions construction sites, including demands from contractors for zero-emission machinery, documentation of environmental requirements, and other sustainability measures.

2 INCENTIVES

Support schemes, state subsidies and other financial incentives stimulate market actors, lowering the barrier of investment in new electric machinery and infrastructure. Support schemes covering additional cost of new machinery or state subsidies which moderates fluctuating electricity prices, among others, contributes to reduced investment risk and ensures predictability. In addition to providing direct support to cover the extra expenses involved in the electric transition, the reduction of switching costs serves as an additional incentive to facilitate a smooth transition. This includes, among other things, higher taxation on CO2 emissions and higher fuel prices.

3 TECHNOLOGICAL DEVELOPMENT

Technological development facilitates electrification of construction sites, considering high scale production of electric construction machinery, improved battery technology, and charging solutions. The market for zero-emission construction machinery is still in its early stages causing the purchase price of these machines to be more expensive than conventional alternatives. However, the additional cost of switching to zero-emissions machinery is expected to decrease over time and in line with technological advancements and serial production.

In addition to incentives, regulations, and technological development, there are several other factors affecting the pace and adoption of zero-emission construction practices. Some of these are the general market conditions, including inflation and access to financing, access to renewable energy and grid, innovation pace, and the construction sectors' willingness to change.

[1] Capgemini Invent Research

→ Additional characteristics influencing the transition to zero-emission construction

In addition to the market drivers for zero-emission construction, there are characteristics and trends within the industry that both impede and promote the transition to zero-emission operations.

In many countries, the construction sector is fragmented with a few large companies working alongside numerous smaller sub-contractors. This can hinder the transition to zero-emission for several reasons. One being that comprehensive emission oversight demands data, which is harder in a complex, fragmented sector. Another being that introducing new technology and ways of working necessitates communication and collaboration to ensure compatibility across actors.

Besides fragmentation, **the industry is characterized as capital-intensive**. The transition to zero-emission construction presupposes new and, in many cases, large investments, especially in the construction equipment fleet. Seeing that machinery has an expected lifetime of 3-8 years and that zero-emission machinery is perceived as new and untested, large investments in new machinery is still seen as a financial risk. Combined with global factors, such as inflation and unpredictable interest rates, the industry is facing increased cost pressure, as well as a need to maintain flexibility and reduce tied-up capital. The result is reluctancy among players to go all in on zero-emission construction.

In contrast to fragmentation, which can potentially slow down the transition to zero-emission construction, **the industry is increasingly deploying digital tools to enhance both efficiency and sustainability.** New areas of technology that are becoming increasingly widespread are the use of 5G, Digital Twins, and IoT-enabled machinery, among others. Despite historically lagging in digitalization compared to adjacent industries (18), the enhanced adoption of new technologies and solutions serves as a foundation for and simplifies the navigation process to zero-emission construction practices. Some examples on how digitalization can support in the transition is that it enables a higher degree of tracking and reporting, making it a vital instrument to meet the increasingly stricter reporting standards, and allows for better optimization of the new and connected machine fleet.

The move towards zero-emission operations is therefore in the middle of a period of upheaval in the construction industry. Many players might be reluctant to take on what might be perceived as a nuisance amidst. However, compelling evidence suggests that achieving zero-emission construction is not only feasible in the long-run, but also represents new opportunities for the sector. This report provides such evidence, with a particular emphasis on insights drawn from Norway.

Photo: Aneo Build

→ Where are we now? Zero-emission construction maturity across Europe

The status of zero-emission construction in Europe varies across countries and regions. While many European nations are actively striving to reduce emissions from the construction sector and advocate sustainable practices, the level of progress differs. Despite the difference in maturity and development, a prevalent characteristic among the most advanced markets is the presence of governmental regulations and financial incentives. Moreover, it is essential to note that the progress and status will vary widely across nations due to other factors such as policy priorities, technological readiness, machine availability, and local industry conditions.

An international market analysis conducted by Aneo Build and Capgemini Invent in October 2022 assessed both progress and potential for electrification in the construction sector across selected European countries. The report reveals that the Nordic countries, as well as the Netherlands and Germany, excel as leading performers within the sample.

These countries exhibit a significant level of strength in incentives and regulations, indicated by publicly stated goals and supporting incentives that target reduction of greenhouse gas emissions within the construction sector. Considering incentives, the parameters include both targeted support schemes (e.g., cost coverage of new electric machinery) and financial incentives to move away from fossil fuels and increase attractiveness of electricity (e.g., carbon taxes, change in price level of diesel relative to electricity).

Photo: DepositPhotos

The Dutch government actively promotes the shift to clean and zero-emission construction equipment through subsidy programs. This support extends to purchasing new machinery, retrofitting existing equipment for lower emissions, and funding innovation projects (47).

The top performing countries on electrification readiness include Norway, Island, and Sweden. Shared characteristics for these countries are high access to renewable energy, reliable power grids, and attractive market conditions considering size, growth, and the importance of construction sector in the national economy. Lastly, the parameters include the country's share of EV and PHEVs in the national car fleet as an indication of the country's willingness to electrify.

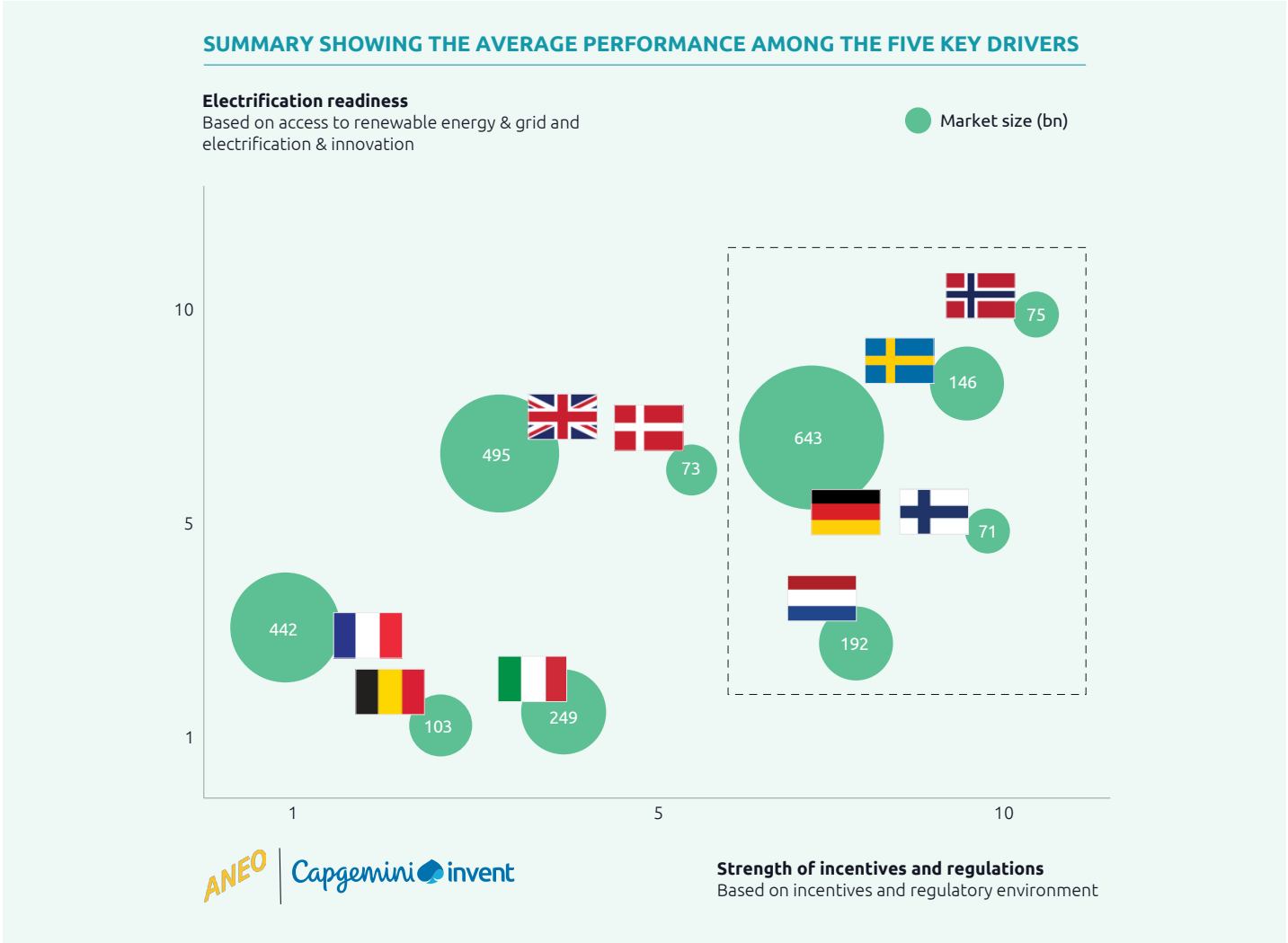


Figure 7: The assessment of the selected European countries is based on a quantitative and qualitative analysis across five criteria; incentives, regulations, access to renewable energy and grid, market conditions, and innovation performance and electrification willingness. Considering market size, the construction sector is defined as the broad construction industry covering transport, buildings, construction services, manufacturing, trading of construction products and extraction of materials, energy, water, and communication

The results from the analysis indicate a significant variance in the maturity and adoption of zero-emission practices across European countries. Despite these findings, there is evident activity and interest present across nations at all levels of maturity. The growing awareness and desire to act emphasize the urgency to accelerate the adoption of new and sustainable construction practices. Furthermore, a series of challenges must be addressed to succeed in the transition, achieve the Paris Agreement targets and notably, to support the ambitious goals of individual European countries. The scope of this study encompasses numerous challenges of this nature. Additionally, it outlines approaches to resolve these challenges by capitalizing on insights derived from the Norwegian construction sector and initiates a discussion surrounding the findings.

Access to zero-emission construction machinery is a direct factor that affects how far different countries are progressing in the transition towards zero-emission construction sites. Traditionally, availability of zero-emission machinery has been higher in the Nordics than elsewhere in Europe, contributing to lowering the barrier for piloting and adopting zero-emission machinery for the respective nations. Despite this, the share of electric machines relative to the total fleet is still very low.

Exemplified by Norway using statistics from Maskingrossisternes Forening (MGF), electric machines constitute less than 1% of the total construction fleet in 2022, illustrating that we are still in an early phase. It is, however, important to emphasize that this count also considers machine types available soly in fossil-driven versions.

Upon closer inspection of distinct machine types available in electric versions, however, there is a higher share of adoption. For instance, in 2022, there were sold 4.575 excavators in Norway, out of which 76 of these were electric. In other words, electric excavators accounted for 3.5% of excavators being sold. While these figures currently remain modest, electric machines has started making inroads into the total and is forecasted to rise as availability widens.

METHODOLOGY

The research objective of this study has been to map out the current market status, including main drivers and challenges, of zero-emission construction sites in Norway and Europe. Based on the insights obtained, the report aspires to recommend actions to accelerate the new standard of zero-emission construction sites, focusing on experiences and learnings from Norway and how these can be applied by other countries.

Photo: Aneo Build

The insight presented in this report is drawn from analysis of previous academic and industry studies, existing material produced by Capgemini Invent, sector specific articles and publications, and interviews with a wide array of stakeholders. Additionally, 17 interviews with corporate leaders, interest organization advisors, and experts directly involved in the transition to zero-emission construction were conducted. The interviews focused on market status for zero-emission construction sites, the dynamics of the ecosystem and value chain, challenges and opportunities, enablers, collaboration methods, and sharing of relevant experiences.

The challenges and recommendations identified are not to be seen as the direct opinions of the stakeholder interviews but are Capgemini Invent's views based on insights given through interviews and other sources at the time of writing.

CHALLENGES

By being a front-runner, Norway has actively seized opportunities for growth and acceleration in the transition towards zero-emission construction, accompanied by inherent challenges. By leveraging experiences from the Norwegian market, this chapter delves into the challenges identified along with emerging solutions fostered by the market in response to the new demands. Moreover, the challenges encountered are not exclusive to Norway and are reflective of broader trends, offering valuable insights to other countries.

1

ADDITIONAL COSTS AND LIMITED WILLINGNESS TO PAY.

The industry's cost-focus, including macroeconomic factors such as inflation and increased interest rates, magnifies the challenge of the extra cost associated with zero-emission practices.

2

ABSENCE OF STABLE AND PREDICTABLE INCENTIVES.

As long as zero-emission solutions cost more than their traditional fossil fuel-driven counterparts, many actors depend on incentive schemes to take the financial risk of investing in zero-emission solutions.

3

LACK OF STANDARDIZED REQUIREMENTS AND REGULATIONS.

Complying with new regulations usually demand additional effort, especially if requirements differ between actors as it multiplies the effort needed for compliance. In the absence of standardized requirements, the competitive advantage of investing extra effort to meet them remains uncertain, elevating the risk of commitment.

4

LIMITED ACCESSIBILITY OF ZERO-EMISSION MACHINERY.

While smaller zero-emission machines are gaining notable market share, while the production and availability of larger machinery is still restricted. This results in a limited number of machines being available in the market, as well as a restricted variety of machine types.

5

INFRASTRUCTURE CHALLENGES, INCLUDING CHARGING AND ELECTRICITY SUPPLY.

Transitioning to electric constriction machinery requires reliable energy supply, including sufficient infrastructure to deliver electricity where and when it is needed. Lack of information regarding available electricity on the construction site, limited capacity in the power grid, and lack of renewable energy are example of challenges arising in the light of electrifying the machine fleet.

1

ADDITIONAL COSTS AND LIMITED WILLINGNESS TO PAY

Zero-emission construction sites require new investments in machinery and equipment and introduce new operational costs.

A prevailing challenge for zero-emission construction is the additional costs associated with zero-emission equipment compared to conventional machinery. Firstly, the initial investment price of zero-emission machines is significantly higher than its conventional counterpart, meaning that either the acquisition or rental price will be higher. Secondly, supplementary needs such as batteries and mobile charging solutions and potential need for upgrading the grid infrastructure serves as relevant additional expenses. Furthermore, it is not solely the direct costs which constitute the challenge; factors such as inflation and interest rates also impact a company's willingness to invest. In this context, economic downturns, for instance, naturally curtail both the desire and ability to make investments and undertake change in cost levels.

> ***"Cost level affects everything we do and anything that has an additional cost becomes even more difficult to defend"***
> *(Client)*

> ***"The cost level is a general obstacle. To reduce the risk of investing in zero-emission equipment, the framework conditions for electrification must be predictable."***
> *(Tora L. G. Hansen, Head of Strategy and Business Development, Aneo Build)*

As mentioned above, investing in zero-emission machinery entails a significantly higher cost compared to their diesel driven equivalents. In 2023, depending on size and whether they are cable connected or battery driven, a zero-emission machine is on average two to three times more expensive than their traditional counterpart primarily driven by the high price of batteries and smaller economies of scale. Acquiring zero-emission machinery is not only more expensive, but it also poses a financial risk for the purchaser. This emerges from the analysis, of which over 60% of the respondents point out that the transition to zero-emission constitutes a high financial risk, especially in terms of financial profitability.

Challenge: *Additional costs and limited willingness to pay*

1 2 3 4 5

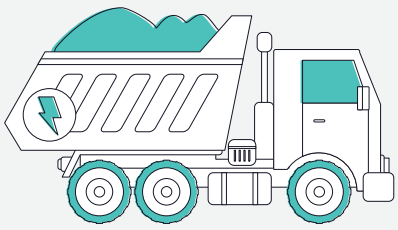
[1]The common conception that the total cost of ownership is lower for an electric machine compared to a conventional has been challenged. This is mainly due to the argument that zero-emission machinery has lower maintenance and fuel costs. This statement has recently been challenge due to the following reasons: (1) Battery replacement will be an important maintenance cost for zero-emission construction machines. Since batteries make up a significant portion of the total cost of the electric machine, the maintenance cost might prove to be substantial. (2) Shifting energy source results in new cost dependencies, where electricity scarcity and recent events such as Europe's energy crisis is expected to introduce a element of uncertainty considering afforfability of electricity.

However, when considering the costs that occur throughout the lifetime of the machinery, electric machinery is seen to be competitive on pricing over time. Despite the high initial investment costs, the electric alternative is seen to have lower operating costs over its lifetime (excl. other additional costs occurring in the transition phase)[1]. This is substantiated by comments from interviews who have observed a decrease in operational costs due to the transition from conventional to electric machinery.

Despite the associated costs and prevailing price levels, the market is witnessing an increasing number of players committed to execute zero-emission projects, even without substantial cost increases. An example is Braathen Landskapsentreprenør, who estimated that the use of zero-emission machinery resulted in a cost increase of between 5% and 10%. For further details on this project, please see case study.

CONCLUSIONS

Cost-focus, considered in the context of the prevailing economic conditions, magnifies the challenge of the extra cost associated with zero-emission practices as well the stakeholders willingness to invest.



Considering the prevailing price level and availability of zero-emission machines, survey respondents reported that the additional costs associated with realizing emission-free construction is up to 25% on building projects (e.g. apartment building) and between 25%-50% on larger construction projects (e.g. road and tunnel work).

Case study 1:

Zero-emission without significant additional costs

One actor who has fully embraced zero-emission projects is Braathen Landskapsentreprenør. The contractor has chosen to go for an all-in approach, arguing, and later experiencing, that this approach does not entail significant cost increase. Underscoring their willingness to commit to zero-emission construction is the Klosterenga park project which they executed completely emission free, being the first to complete this type of construction work only using zero-emission machinery (19). Despite substantial investment in new zero-emission equipment, the contractor discloses that the overall project expense did not experience any significant cost increase compared to using traditional diesel machines due to lower operational costs. An early estimate is that using zero-emission machinery resulted in 5-10% higher project costs than if the project had used diesel machines.

Photo: Braathen Landskapsentreprenør AS

One of Braathen Landskapsentreprenør's key messages is the importance of wholeheartedly adopting zero-emission practices. The contractor initially went for a mix of diesel and electrical machinery when approaching the use of zero-emission machinery but experienced that as long as diesel is available, it will be too easy to revert to old habits and choose these machines. In line with that, Braathen Landskapsentreprenør decided to sell all their diesel machines for infrastructure projects and went 100% electric in 2022. This shift required creative thinking, innovative project planning and, at some times, custom equipment development to fill market gaps. Overall, Braathen Landskapsentreprenør is pleased with their decision, showcasing that all-in on zero-emission projects is both feasible and cost effective.

Braathen Landskapsentreprenør's main learnings from the Kosterenga park project includes:

- The use of electric construction machinery leads to a quieter construction site than traditional operations, leading to remarkably few noise complaints.
- Had to be more creative in project planning to take new factors into consideration, such as limitation on availability of electricity.
- "Fuel"-cost were significantly lower than if diesel had been used.

Case study 2:

Risk-taking market actors increase access to zero-emission machinery

The risk associated with investments in zero-emission equipment has created opportunities in the rental market, where companies such as Rental Group have taken a position. Through large investments in the electric machine fleet, Rental Group will supply electric construction machines to the Scandinavian market.

Photo: Rental Group

Rental Group believe that the competitiveness of zero-emission machinery lies in the reduced total cost of operations, primary driven by fuel prices, coupled with lower CO2 emissions. In line with that, the company believe that these elements will be key drivers in pushing the market towards zero-emissions. In other words, by ensuring machine availability combined with a competitive comprehensive solution, the company aim to stimulate demand of electrical machines and implement sustainable solutions in the Scandinavian rental market.

Why did Rental Group decide to carry out the investment?

- Zero-emission construction machines are here to stay. As a large company, we have the resources and confidence to make a bet in the market aiming to stimulate demand and accelerate the share of zero-emission construction sites.
- We believe that zero-emission construction sites and the requirements for new solutions and technologies will grow rental penetration and we want to be a part of the transition.

2

ABSENCE OF STABLE AND PREDICTABLE INCENTIVES

Unpredictable incentives pose a challenge for actors, who need to rely on them in strategic decisions and project planning.

The transition to zero-emission operations demands significant upfront investments, due to e.g., acquirement of new machinery or development of new energy infrastructure. In this context, incentives represent a powerful instrument as they reduce the additional cost and risk associated with such undertakings. This research particularly underscores the problems caused by unpredictable support schemes. Due to factors like lengthy lead times for acquiring electrical machinery and tenders being submitted well in advance of project initiation, support schemes must be reliable for stakeholders to consider them in project calculations, investment evaluations, and other strategic activities. Changes or removal of incentives considered in project planning can impact the financial state of the actor significantly, not to mention the markets willingness to invest.

> ***"Norway's success are the incentive schemes we've had so far. These have been the major difference between us and the rest of Europe. In other European countries, contractors have to take the whole cost, while we in Norway have had schemes that support on this. But, Norway has recently started removing these, something I see as very problematic"***
> *(Sjur W. Helljesen, Nasta)*

> ***"Dedicated funding is needed at this early stage in the transition. (…) Funding is also needed to build capacity of public procurers and enable demand aggregation (…)."***
> *(Big Buyers, (48))*

Challenge: *Absence of stable and predictable incentives*

1 2 3 4 5

Norway's position as the frontrunner in zero-emission construction is often attributed to strong governmental incentives, coupled with regulations and requirements. Specifically, a study participant expressed that if it had not been for Enova and Oslo Municipality, Norway would not possess a single electric construction machine today. However, even though support schemes have been stable for a longer time, Norway has recently implemented changes in the arrangement. These alterations involve a shift from fixed structures to a competition-based approach, provoking reactions among market players arguing that the change exerts an adverse impact on market development. Further details can be found in in the case study *Market maturity and role of incentives*.

One does not have to look further than to the Netherlands to witness yet another instance underscoring the impact of reliable incentives and support schemes. The Netherlands enhance predictability through means like disclosing details related to annual budget, highest attainable funding, and a calculator/test application for applicants to forecast their eventual funding (20). This scheme set-up makes it easier and less risky for the applicant to predict final funding, fostering greater willingness to invest. As a result, some study participants predict the Netherlands to take over Norway's frontrunner position within the end of 2023 due to their extensive and stable incentive scheme.

KEY CONCLUSIONS

- *Incentives are needed to build procurement capacity and enable demand aggregation*
- *Lack of predictability creates uncertainty and makes it more challenging for industry players to commit resources and capital*
- *The industry is characterized by long lead times and timeframes. Actors must be sure that the incentives will remain throughout a project to consider them in project planning. If they change unpredictably this can have substantial financial consequences*

Enova, a state-owned Norwegian company, is actively contributing to Norway's transition to a low-emission society. The purpose of Enova is to accelerate technological development and innovation that can contribute to emission reductions (53). With support from Enova, new technology can be developed and improved so that it can be adopted more quickly and cost-effectively, eventually becoming preferred by the market without subsidies.

Case study 3:

Role of regulations and incentives in the Norwegian market

Regulations and incentives are seen as important drivers to increase the number of zero-emission machines.

In 2019, Oslo municipality started rewarding zero-emission machines in tenders. In the same year, the first zero-emission machines were purchased. Now, in 2023, Norway boasts nearly 30 times as many zero-emission construction machines, a trend projected to continue (figure 9). Enova has been essential to this growth and has supported zero-emission construction machines with more that 460 million NOK between 2017 and 2023 (21).

While direct causation between the increase of zero-emission machines in Norway and the implementation of incentives and regulations cannot be proven, most would agree that this correlation holds true. Noteworthy is the decline from anticipated sales of 200 zero-emission machines to the actual sales number being 86 in 2022 (MGF). The drop is clearly impacted by the pandemic, the conflict in Ukraine, and other variables leading to material shortage, heightened interest rates, and unfavorable exchange rates. These elements give rise to less favorable economic conditions and increased financial uncertainty, which in turn impact willingness and ability to invest.

As illustrated on the next page, the Norwegian government in collaboration with Oslo municipality, has been employing some of the most powerful tools, namely incentives and regulations, to drive the Norwegian construction sector towards zero-emission.

Challenge: *Absence of stable and predictable incentives*

1 2 3 4 5

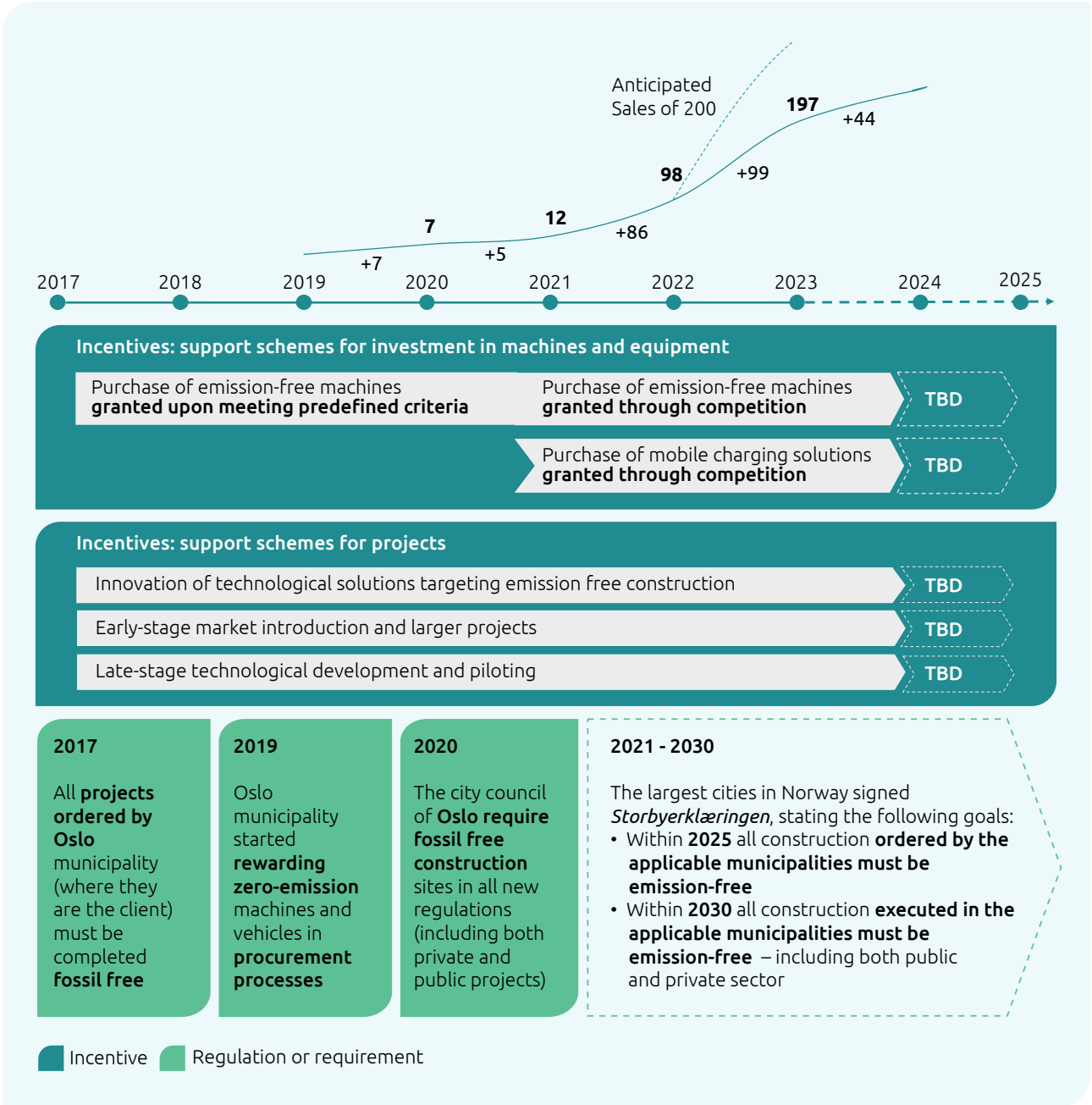


Figure 9: Timeline illustrating the presence of incentives and regulations targeting the Norwegian construction market

Case study 4:

Market maturity and role of incentives

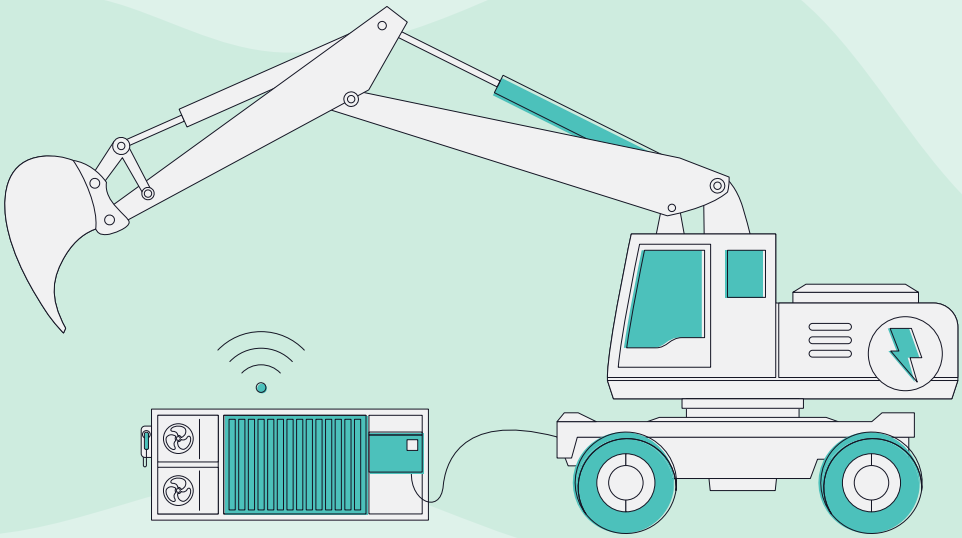
Unpredicted change or removal of incentives can create uncertainty in the market and make actors less willing to undertake risks.

The ramifications of unforeseen changes in incentives schemes are exemplified by recent changes in the Norwegian Enova support framework for purchasing zero-emission construction machinery.

Until April 2023, Enova sponsored the additional cost associated with purchasing zero-emission machines relative to a conventional machine by up to 50%, and in most cases 40%. In 2023, the incentive scheme changed from being fixed support to competition-based support. In the new incentive set-up, actors compete for shares of a limited "pot" based on 1) the projects estimated reduction in CO2-emissions and 2) for applying for the lowest founding amount.

The new incentive framework faced skepticism and opposition due to its perceived unpredictability and reduced favorability compared to the previous setup. Many stakeholders also view the changes as sudden and unexpected. Consequently, there is a growing apprehension amongst various stakeholders that this modification may slow down the transition to zero-emission construction.

Despite the market reactions following the change, there is an expectation that incentives schemes will change as the market matures. This is because incentives are there to enable market change and not fund the transition in the long-term. Such a change could be, for example, lowering the extent of financial support, remove the support, or, as in the Norwegian case, change from a fixed to competition-based set-up. Moreover, what the Norwegian reactions have illustrated is the importance of predictability in financial support schemes, of which actors such as Enova aim to ensure by providing clear application deadlines and a time frame for the different incentives.



3

LACK OF STANDARDIZED REQUIREMENTS AND REGULATIONS

Insufficient anchoring of regulations and requirements causes uncertainty.

Similar to Norway, various European countries have established ambitious emission reduction targets for the national construction industry. To ensure the accomplishment of these objectives, there is a need to anchor the goals and ambitions into standardized requirements. The anchoring includes aligning municipal objectives and award criteria within tender processes, as variation and inconsistency in these elements introduce uncertainty for the industry actors.

Today, where zero-emission construction traditionally incur an additional cost relative to conventional approaches, enforcement of regulations is by most seen as a necessity to steer industry actors towards sustainable practices. Moreover, this research highlights a crucial issue: the mere presence of ambitions and regulations is not enough. Many stakeholders point out challenges arising from inconsistent requirements exemplified by different criteria being used in tenders. The absence of such standardization complicates procurement processes, heightens risks in adopting new technologies, and hampers the coherence of market progression.

> ***"I believe it is possible to reach the Norwegian ambitions for zero-emission construction sites as long as we have anchored requirements from the national and local government, and incentives to support in the transition"***
> *(Kim Massey, Zero Emission Manager, Rental Group)*

> ***"We need commitment from the state and government, not just goals without requirements"***
> *(Sjur W. Helljesen, Nasta)*

> ***"It should be national requirements to accelerate the adoption of zero-emission practices, especially in the transition phase"***
> *(Tone Grøstad, MGF)*

> ***"Municipalities are enforcing different requirements in their tenders – decreasing the predictability for the entrepreneurs on what they need to deliver and focus on"***
> *(Sjur W. Helljesen, Nasta)*

As exemplified by the quotes above, industry actors are frustrated by incoherent tender requirements and the lack governmental interference to standardize these. Today, developers are in most cases free to set tender requirements and their respective weight as they please, resulting in great variations and lack of predictability on what is expected from the contractors. In regard to emissions, this entails that developers are free to choose the degree to which they want to include emission related requirements in their tenders. Due to this freedom, only 35% of Norwegian public procurement tenders in 2022 considered emission of greenhouse gases (22). As a result, the attractiveness and willingness of a contractor to fully commit to emission-free operations reduces as they are not sure of the competitive advantage this will provide them in the future.

KEY CONCLUSIONS

- *Lack of long-term commitment creates uncertainty and makes it more challenging for industry players to commit resources and capital*
- *Large variation in tender requirements and lack of standardization causes frustration among actors*

Case study 5:

The power of requirements

The world's first zero-emission construction site: Olav V Gate, Oslo, Norway (1)

In 2019, Oslo Municipality took a leading position in the transition towards zero-emission construction by incorporating emission criteria into a construction tender (23). Despite unavailability of necessary technology, contractors were required to utilize zero-emission machinery in order to stay competitive in the tender process.

Photo: Sørby Utleie

In response, the Norwegian machine supplier Nasta acted (1). The company successfully addressed the challenge by performing necessary machinery modifications in collaboration with its partner Hitachi. By doing so, they managed to ensure availability of zero-emission machinery by retrofitting conventional diesel machines to electrical machines.

Oslo Municipality's proactive approach demonstrates the potential of controversial benchmarks prior to market readiness, thereby catalyzing and promoting innovation through increased demand. Worth noticing is that before publication of the tender, Oslo Municipality engaged with several suppliers to inform them and gather information on the available technology. This prepared the market for the upcoming tender requirements, decreasing the risk of undertaking such an endeavor. Moreover, this case exemplifies the need to explore unknown territory and take action without waiting for a perfect blueprint.

Case study 6:

Lack of standardization in Norwegian tenders

So far Norwegian municipalities have emphasized environmental concerns differently in public procurement and tenders. Despite common ambitions, the attention and weight of environmental concern in tenders still vary greatly. As a result, some tenders will evaluate environmental footprint at a share of 0%, while others follow the recommendation to weight the category by 30%. Figure 10 illustrates how award criteria can differ across cities.

The variation in how much environmental efforts is being rewarded in tenders causes frustration among the market players. The reason is that inconsistent requirements cause uncertainty in market demand, increasing the investment risk needed to deliver on the criteria.

Moreover, starting in 2024, it is required to weight climate and environmental requirements at a minimum of 30% in all public procurements in Norway (24). While variation may persist within the climate and environmental requirements, this stipulation will establish a definitive benchmark for heighted environmental consideration in tenders. Simultaneously, it offers flexibility to explore solutions with minimum environmental impact.

Remodling of Åmli Municipality´s Gym	**Rehabilitation cold- and heating center**	**Tunnel and foundation work Majorstuen -Skøyen**	**Nordstrand secondary school, expansion**	**Transport and logistics hall Charlottenlund school**
Municipality: Åmli	Municipality: Haugesund	Municipality: Oslo	Municipality: Oslo	Municipality: Trondheim
Award criteria	Award criteria	Award criteria	Award criteria	Award criteria
100% Price	**60% Price** **40% Competence**	**60% Price** **20% Environment** **20% Quality**	**40% Price** **20% Environment** **20% Competence** **20% Understanding**	**60% Price** **20% Environment** **20% Execution**
Doffin reference: 2023-342113	Doffin reference: 2023-395519	Doffin reference: 22/569	Doffin reference: 22/3353	Doffin reference: 2023-33191

Figure 10: Overview of difference in award criteria across selected tenders in Norwegian cities

4

LIMITED ACCESSIBILITY TO ZERO-EMISSION MACHINERY

Limited access to zero-emission construction machinery is a barrier to reaching the ambitions of zero-emission construction sites.

Availability of electrical machinery is a prerequisite for realizing zero-emission construction sites. Beyond mere availability, these electric machines must be cost-effective and serve as credible substitutes for their fossil fuel-driven counterparts. This entails ability to execute analogous tasks, such as bearing equivalent loads and exerting comparable forces, all while avoiding significantly increased cost, time, or resource allocation.

> ***"Despite current availability, there are still various types of zero-emission machines that are needed. There has been a lot of focus on crawlers and excavators, but there is a lot of other equipment in need for electrification."***
> *(Kristin Fjellheim, Resource Manager, Sintef)*

> ***"Access to zero-emission construction machinery is a challenge. We need other big buyers besides Oslo to set requirements and criteria. More players are needed to change a market."***
> *(Marit Hepsø, Procurement department, City of Oslo)*

Currently, the availability of electric construction machines is contingent on its size, type, and power requirements. For smaller machines[1], the power demand is lower, and due to initiated serial production, the availability of these machines is increasing (25). However, the market situation is different for medium to heavy construction machinery. These machines have higher power requirement making it more demanding to produce their electric equivalent at a cost-effective price point.

[1]Definition of construction machinery by size: small (8-16 tons), medium (16-23 tons), and large (>23 tons) (25).

As a results, coupled with concerns considering market demand, many of the medium and large machine types are still not available as an electric version. For those being available, most machines are a result of retailers taking matters into their own hands and building electrical machines themselves while waiting for serial production.

Moreover, the availability of zero-emission machinery is dependent on global demand. In Norway, there are approximately 300 heavy electrical construction machines available (MGF), making up a relatively small portion of the total construction machinery fleet. Furthermore, given Norway's dependency on import of construction machinery (26), the availability and price of these machines is directly contingent upon the global production and global demand. If global demand continues to be limited, chances are low that European manufacturers will initiate serial production in the near future. In such a case, the expected European demand for zero-emission machinery is likely to be covered by new market entrants seeking growth opportunities. An example is Chinees machine producers, which are already initiating serial production of heavy electrical construction machinery, aiming to accelerate technological advancements and achieve cost-effective production.

KEY CONCLUSIONS

- *The availability of zero-emission construction machinery constitutes a key barriers in the transition to zero-emission construction sites*
- *Limited availability is a consequence of limited global demand*
- *Limited European production unlocks opportunities for new and international market players to take a first mover position in the construction machinery market*

Zero-emission machinery are currently far more expensive than the conventional alternatives, with an additional cost being approximately three times higher than the price of a similar diesel machine (54)

Case study 7:

How retailers delivered to Norwegian demand

In response to the call for zero-emission construction machinery in Norway, Norwegian retailers have made sure to supply the necessary construction equipment despite the lack of production and only a few years ago, existence. Two of the industry players who have contributed to and had a fundamental impact in ensuring availability of zero-emission machinery in Norway are Pon and Nasta.

Photo: Nasta

As the demand for zero-emission construction machinery increased, Pon and Nasta proactively addressed the situation and managed to ensure provision of machinery by rebuilding conventional diesel machines to electric machines (27).

By converting conventional machines to electric ones, the Norwegian retailers managed to deliver what was required. This method of producing electric construction machinery is still the most common, however, as the adoption of electric machines increase, current methods are not sufficient to deliver on demand. Not only does this method entail high associated costs, but it is also not sustainable nor viable in the long run.

The relationship between production costs and market demand can be seen as a “chicken and egg situation”, as high market demand is necessary to initiate serial production thus achieve economies of scale and reduced production costs. On the other hand, market demand is highly dependent on the price, and prices must likely decrease for market demand to increase.

Case study 8:

Geographic presence affects availability of zero-emission machines

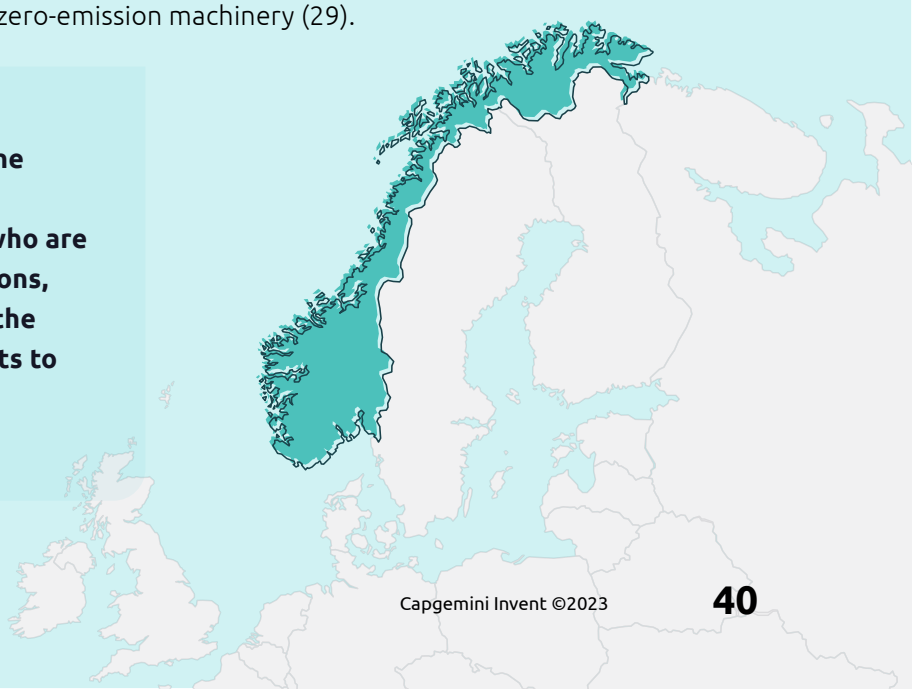
In Norway, most of the zero-emission machines are concentrated in the Oslo region and eastern Norway. This enhances the accessibility for zero-emission equipment for actors within this region, thereby creating a favorable environment for implementing regulations governing their utilization. However, this is not the case for other geographical parts of Norway. For instance, zero-emission project execution in Northern Norway is seen as considerably more challenging due to the scarcity of zero-emission machinery. This is illustrated by SINTEF's climate action analysis for the Storgata project in Tromsø, located in the North of Norway (28).

Tromsø Municipality's high environmental ambitions of having zero-emission construction sites by 2025 coupled with their desire for more sustainable practices led them to consider zero-emission machinery for the Storgata project in the city. However, the project mapping revealed a main challenge: there were virtually no zero-emission machines available in the area.

The background for limited availability of zero-emission machines is raised to be the low demand of machinery in the North of Norway, which leads to a significant financial risk for the actors considering investing. Additionally, it is further stated that the large price gaps for the use of zero-emission machinery relative to conventional, long delivery times, and availability of heavy construction machines increased the difficulty of carrying out the project as a zero-emission construction site.

Despite the challenging conditions in Northern Norway, the contractor managed to utilize two electric excavators, one electric wheel loader, and other smaller machinery in the project execution, representing one of the first major contracts in the north with demands for zero-emission machinery (29).

This project illustrates the importance of forward-looking actors who are willing to push for solutions, lowering the barrier for the next construction projects to become zero-emission.



5

INCREASED DEMAND FOR ELECTRICITY - INFRASTRUCTURE CHALLENGES, INCL. CHARGING AND ELECTRICITY SUPPLY

Reliable renewable energy supply, sufficient grid infrastructure, and availability of grid capacity details are fundamentals for the transition to zero-emission construction sites.

It is an indisputable fact that shifting toward zero-emission construction increases the demand for electricity, yielding several consequential challenges. Foremost, the shift necessitates that sufficient electricity is available, preferably being from renewables, and that sufficient information regarding the grid infrastructure is accessible. Furthermore, and closely related, it sets requirements to the energy infrastructure to ensure availability of electricity where and when it is needed.

> ***"Access to power and sufficient capacity is a key barrier and is highly dependent on geographical location and its power infrastructure"***
> *(Client)*

> ***"Electricity suppliers has become a key stakeholder in the execution of zero-emission construction sites. The dependency on their information makes it important to include them early in project planning."***
> *(Kristin Fjellheim, Resource Manager, Sintef)*

Energy availability across Europe varies due to factors like geographical diversity, renewable energy potential, resource endowment, technology and infrastructure, energy transition policies, imports, climate goals, and energy market integration. For instance, countries with abundant renewable energy sources and well-developed infrastructure have better energy availability. Norway serves as an exemplar in this regard, with its extensive hydropower capacity and established energy infrastructure. This is reflected in figure 11, illustrating the share of renewables in selected European countries electricity supply. On the other end, the average European country has a low degree of renewables in the power grid, decreasing some of the attractiveness of transitioning to electricity.

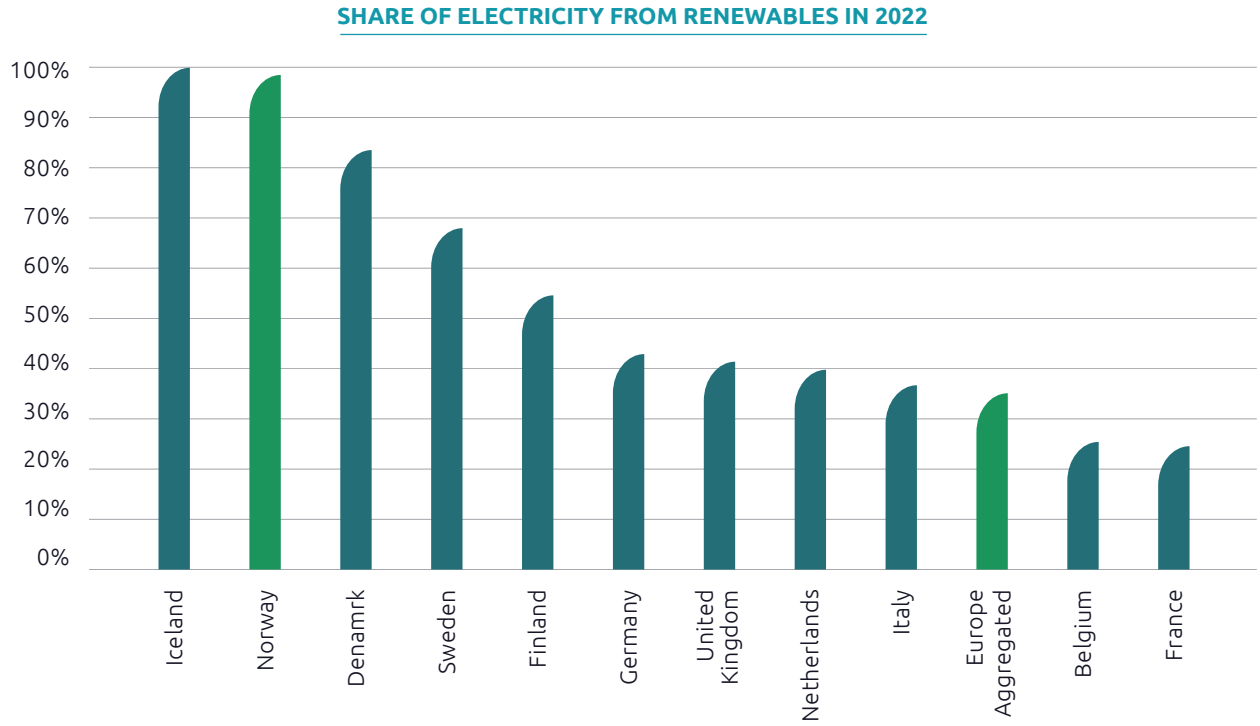
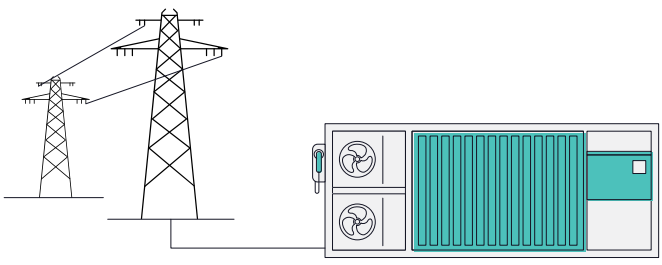


Figure 11: Share of electricity production from renewables in selected European countries, numbers from 2022 (30)

In addition to renewable energy, grid access, stability and capacity is essential for the adoption of zero-emission practices. Due to limitations in the power grid, both considering effect and location, coupled with the need for electricity where and when is needed, a market for mobile battery and charging solutions has emerged. In other words, the demand for electricity supply has been answered, providing necessary solutions to ensure sufficient power access. In addition to fostering flexibility, these solutions also address the challenge related to managing excessive peak demands and unnecessary wastes of energy. Unaddressed, these challenges pose new concerns to stakeholders such as procurers, project managers, and construction providers as it necessitates new thinking concerning efficient planning of site operations.



Furthermore, as electricity becomes a more integral part of the construction, the need for collaboration and communication between the client, contractor, and infrastructure providers becomes increasingly important. This aligns with the findings of the study, where a majority of the respondents emphasize important areas of knowledge moving forward being project planning, optimization, and alternative energy sources, including supply and charging.

KEY CONCLUSIONS

- *The introduction of new components related to power and energy access pose challenges for industry actors, especially related to lack of information on sufficient grid infrastructure, the operational need for electricity off the grid, and an increased focus on on-site logistics*
- *The need for energy management solutions has led to the emergence of new market entrants in the construction sector*
- *Respondents emphasize topics within energy and infrastructure as top priority for upskilling*

Contractors require data on energy availability to plan projects correctly. The dependency on such information is my many described as a bottleneck as it challenging to attain this information. And in some cases, contractors are forced to estimate available energy, risking financial consequences, as exemplified by the case study form Norway.

Case study 9:

Importance of sufficient energy planning

NCC Oslo's experiences from the Mortensrud infrastructure project demonstrates the importance information sharing and communication to ensure sufficient energy availability.

A Norwegian builder sent out a request for tender for project close to Oslo. When preparing their response to this tender, the Norwegian contractor, NCC Oslo, reached out to the local infrastructure provider to get data on electricity availability in the applicable area. The tender submission deadline was relatively tight, and NCC Oslo did not receive requested information in time to consider the information in their tender. They were therefore forced to base their calculations on estimations from earlier projects.

Photo: NCC

NCC Oslo's tender won, and they commenced work. Soon after initiating the project, the contractor realized that the available electricity was much scarcer than expected. For example, they could not use lights and heating ovens inside the barrack rigs simultaneously without the fuse tripping. As a result, NCC was forced to build a new transmission line from the high-voltage grid, in addition to a large range of additional technical solutions to ensure all regulatory requirements were filled. Not surprisingly this added up to a sizable cost. All allocated to the contractor, NCC Oslo.

This experience left NCC Oslo with valuable experiences that they will leverage to prevent the same line of events occurring again:

- There is great risk associated with "gambling" on the amount electricity available.
- In projects with large geographical extent, e.g., road projects, it is necessary to have available power throughout the "whole line", because machines use disproportionate amounts of energy moving back and forth to the charging station.
- We clearly see the benefit of having a professional partner in the supply of electricity and charging infrastructure in the tender and project phase. Besides ensuring communication, maintenance and as a result, stable electricity, this has proven to be both necessary and profitable.

Case study 7:

Ensuring reliable electricity and cost control through mobile charging solutions

The rise of electric construction machinery, coupled with challenges related to power infrastructure and availability of electricity, have created a market for charging solutions where the Norwegian company Aneo Build is positioned.

Electrification of the construction industry has two key challenges related to power supply: (1) availability, (2) pricing. Firstly, the energy needs to be available when we need it and where we need it. Secondly, charging solutions introduce a new operating cost considering the battery, and element of uncertainty due to fluctuations in electricity prices. These factors introduce risk for the market participants, so how do companies like Aneo Build help to solve such challenges?

- Mobile charging solutions: flexible charging which reduce dependency on grid infrastructure, pressure on grid through peak shaving, and allows for boost charging.
- Optimization and flexibility in pricing: utilizing the electricity grid in periods of low demand allows to optimize the power outlet and thus price, allowing for better cost control and to provide fixed and/or spot prices.

Employing mobile charging solutions is seen as essential to tackle the energy requirements needed in the construction sector. In line with that, investments in and development of mobile charging solutions for the construction industry are financially supported by Enova in Norway.

Photo: Aneo Build

The challenges at hand are interlinked

The challenges above were discussed separately for the sake of structure, however in reality these challenges are intertwined and heavily dependent. For instance, the need for predictable incentives stems from zero-emission operations being more expensive than traditional methods. This is again a consequence of scares availability of zero-emission machines, due to limited global demand, which again can be linked to the high price. Followingly, it is evident that solving these challenges by nature require a holistic approach. One should therefore not aim to solve them singularly or in a sequential matter, but rather through systems thinking by understanding and taking advantage of the dependencies.

In addition to the challenges being internally linked, they must also be seen in relation to sector specific characteristics and overarching megatrends. For instance, the construction sector is, as previously discussed, often described as fragmented. This can result in duplicated effort, actors deploying incompatible tools, and lost opportunities to learn from others. All of which can impede the transition to zero-emission construction. Additionally, the industry is quite capital-intensive, increasing the financial risk of making the necessary large investments. Another factor that might hamper the transition is low digital maturity, as digital technology can support the adoption of zero-emission practices.

However, despite the intricacy of the current challenges, one does see positive development within almost all of them. Study participants are for instance positive to Oslo reaching their ambitions and give strong regulations and forward-looking market players much of the credit for this. In addition, availability of electric machines is increasing, and with more and more countries joining the transition to zero-emission, we might see serial production and lower machines costs in the near future. Furthermore, the industry is increasingly deploying digital tools, increasing their digital maturity, and followingly becoming more equipped to reap the benefits presented by the transition. In other words, as illustrated by Norwegian experiences, the challenges should not be considered as showstoppers, but rather hurdles that we need to overcome through new ways of working and innovative solutions.

RECOMMENDATIONS

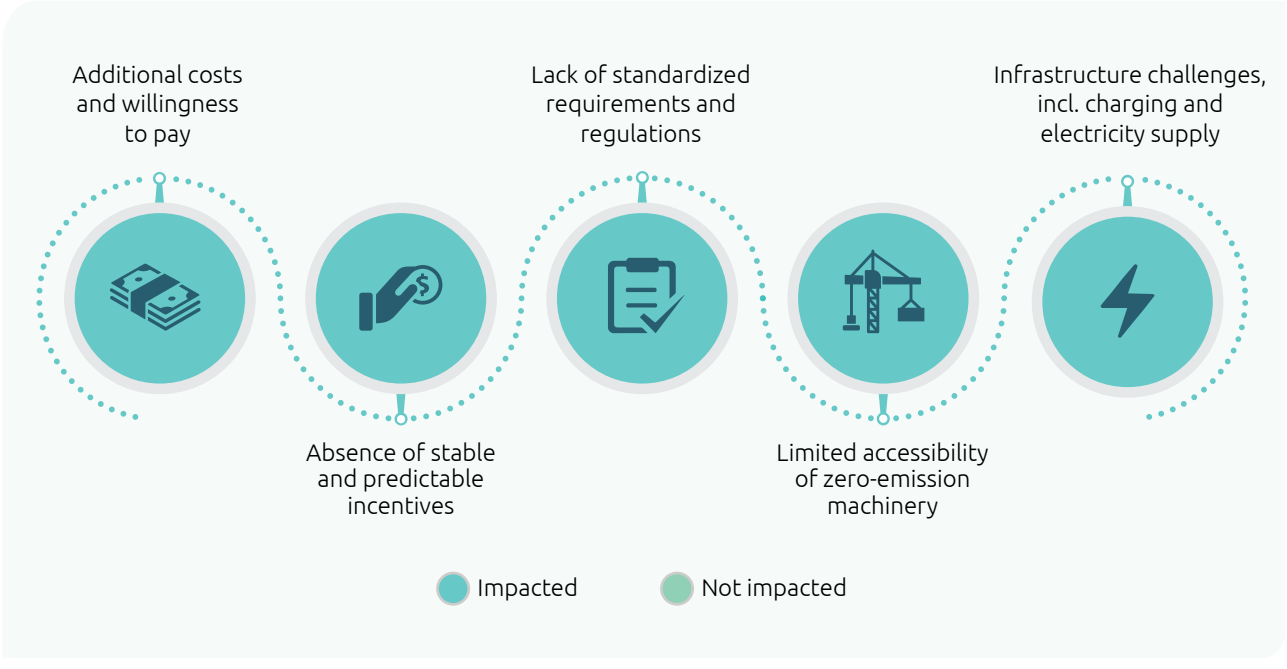
The following section of the report presents eight actionable recommendations within three main categories aiming to support the acceleration of zero-emission construction sites in Europe. The recommendations are based on lessons from the Norwegian market and are intended to target countries with diverse level of maturity considering zero-emission construction sites. The recommendations are interconnected, with the potential to enhance individual effects through mutual reinforcement.

Authorities and municipalities	**Predictability:** Regulatory authorities must set requirements and direction to ensure predictability and reduce risk.	1. **Regulations:** regulations ensure market push and signal lasting changes.
		2. **Incentives:** incentives ensure market pull and support realization of ambitions.
Construction market players	**Joint effort:** The industry must collaborate to deliver on the requirements and realize the ambitions.	3. **Upskilling across the entire value chain:** knowledge sharing remove stereotypy, biased perceptions, and facilitate behavioral change.
		4. **Fostering collaboration and innovation:** effective dialog and interaction among key stakeholders enhance feasibility of zero-emission practices.
		5. **Ensure sizable demand to facilitate high-scale production:** there must be sufficient demand before large-scale production of electrical construction equipment can be expected.
Moving past requirements	**Opportunities beyond compliance:** Industry players must think transition and restructuring, extending beyond mere electrification, and capitalize on the opportunities arising from digitalization, data, and connectivity.	6. **Reap the benefits of being a first mover or early adopter:** forward-looking players can capitalize on being early adopters, for example to capture market shares and talent.
		7. **Digitalization:** utilize digitalization and increased connectivity to optimize and implement new value adding technology.
		8. **Data monetization:** increased availability of data unlocks the potential of new revenue streams.

PREDICTABILITY

Regulatory authorities are responsible for setting the market direction, while execution rests in the hands of the market. It is a prerequisite and necessity that clear goals and frameworks are established, as this facilitates towards common ambitions and help reduce risk. In an extensive transition that requires large investments, such as the transition to zero-emission construction, it is essential to have predictability in requirements and incentives to provide security regarding future direction and market demand. In other words, to accelerate the adoption of zero-emission practices, strong political support and dedicated funding for pilot programs are crucial to establish normalization.

The recommendation is not only aimed at governmental authorities, but also municipalities as they have an essential role in the adoption of zero-emission construction sites.



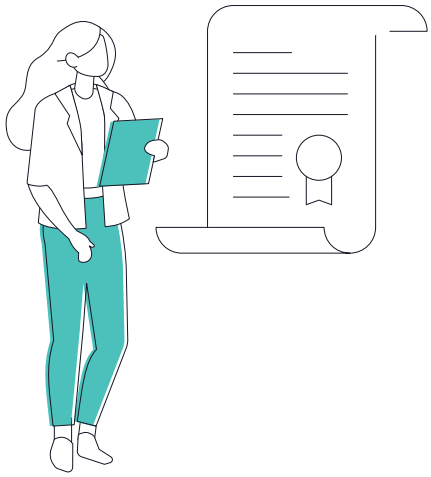
1

REGULATIONS ENSURE MARKET PUSH AND SIGNAL LASTING CHANGE

Stated ambitions sets direction while requirements signal lasting change. For example, a requirement such as "from 2030, all construction sites must be zero-emission" will not only prepare and encourage market change, but also provide predictability that the investments and adjustments needed for the transition will be both necessary and profitable in the long run.

While standardized requirements are crucial for achieving zero-emission construction, there are preceding steps that should be taken to ensure the market is sufficiently prepared. This includes gradually increasing the expectations of the market, for instance by setting criteria and rewarding environmental measures and actions in tenders.

Requirements are a powerful tool, not only to push the market, but also to reduce risk. As the shift towards zero-emission practices relies on market actors taking risks through investments in new technology and machinery, there arise a critical need for sufficient assurance concerning future demand. For instance, contractors want assurance that builders will request zero-emission machines before taking the investment decision and manufacturers must ascertain the existence of market demand before embarking on large-scale production. In other words, by signaling an inevitable picture of the future market situation, regulatory authorities can mitigate a large part of this risk.



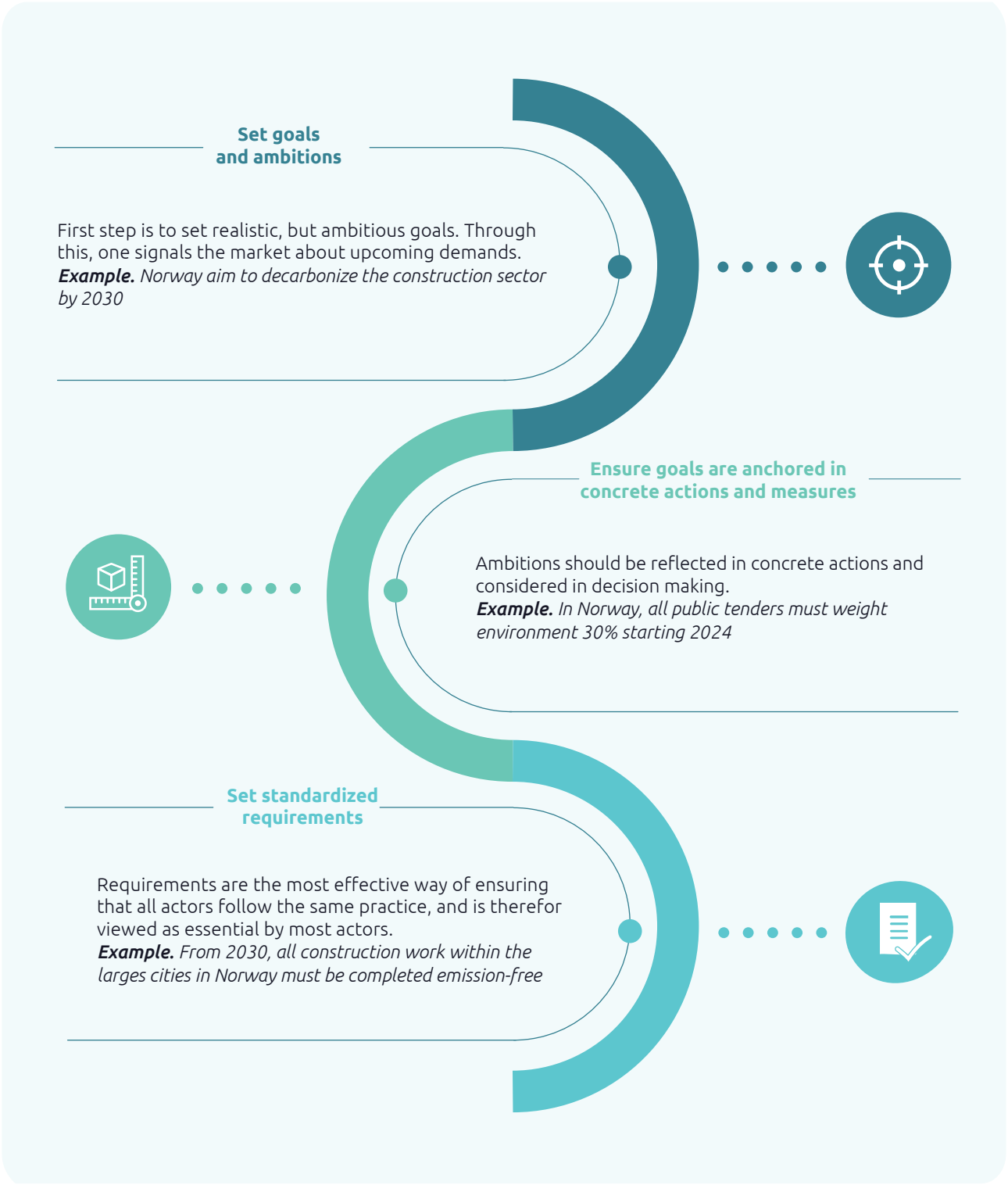


Figure 12: The connection between ambitions, regulations, and requirements

2

INCENTIVES ENSURE MARKET PULL AND SUPPORT REALIZATION OF AMBITIONS

Support schemes and other financial incentives are essential to reduce investment risk and account for the costs accrued in the transition towards realization of governmental requirements. Incentives can take various forms where this report is primarily centered around support schemes. However, it is worth noting that there are several alternative methods to stimulate the industry. For instance, other types of incentives that foster sustainable transition may involve CO2 taxation and green loans.

Moreover, incentives work as a pull factor, whereas support schemes are an effective tool to initiate market maturation and facilitate testing of zero-emission construction practices and is in some cases seen as a prerequisite for actors to be able to afford adhering to new regulations.

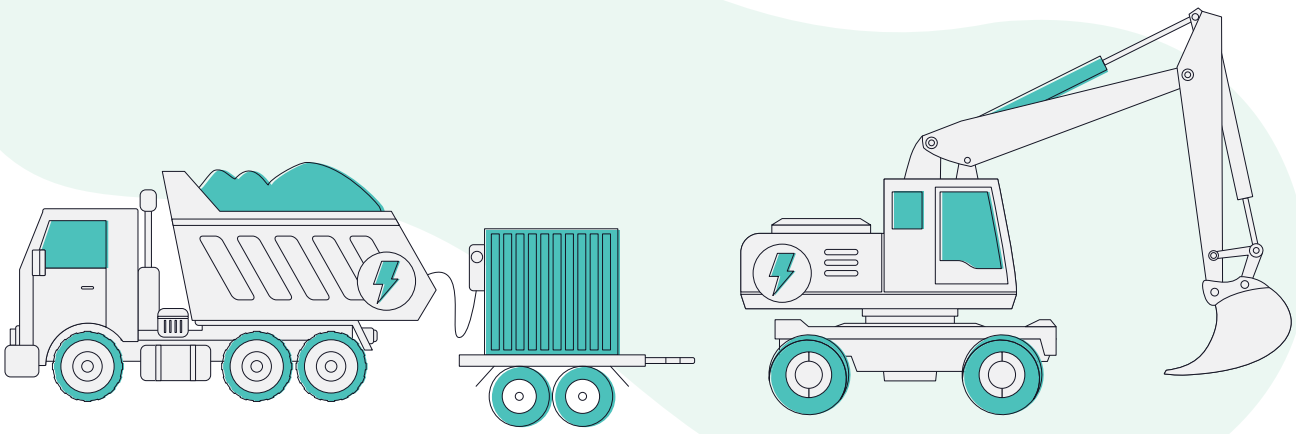
FOR INCENTIVES TO BE EFFECTIVE, PREDICTABILITY AND PRECISION IN TARGETING ARE ESSENTIAL

As support schemes are, by definition, used in unfavorable or risky markets, an actor must be able to trust the incentive. The actor must have predictability in terms of the size of the support and not least the duration of the support scheme. In addition, the support must hit its intended target accurately, meaning that it hits where the market needs it the most.

Followingly, this study has stressed the importance of support schemes to be stable and predictable to have their wanted effect; to facilitate the execution of zero-emission practices and simulate the demand for zero-emission machinery. Predictable and effective support schemes can be achieved through various methods as listed below.

Actions to make governmental support schemes predictable and effective:

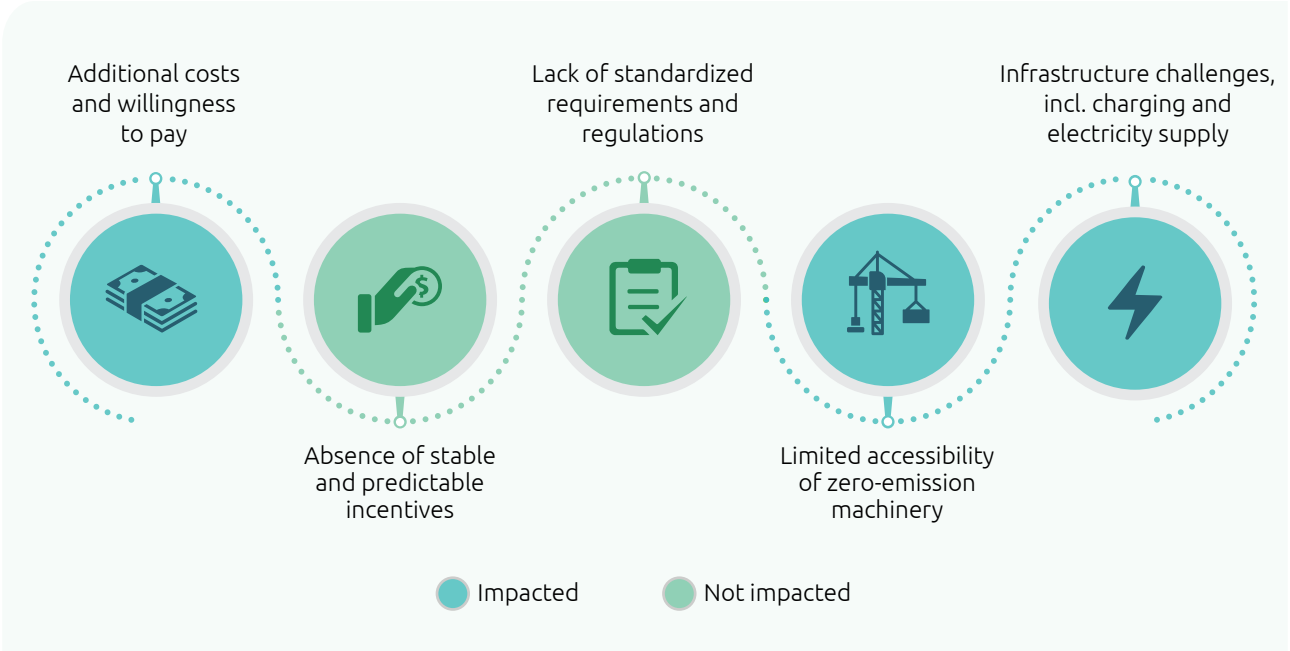
- Clearly stated criteria for receiving support
- Duration, timeframes, application deadlines are set and well communicated
- The total monetary pot that is to be distributed out is communicated. In case of rolling application, the remaining pot is communicated
- Application counseling or guidance is offered to potential applicants, to help the applicant predict chances of, and magnitude of, support
- The incentive hits where the market needs it; this is achieved through good and ongoing dialog with market actors



JOINT EFFORTS

The industry must collaborate to deliver on the ambitions and requirements set by the governmental authorities. Accordingly, stakeholders must come together to exchange knowledge, best practices, and assure sizable demand for zero-emission construction machinery. We need industry participants to collaborate within levels (municipalities to municipality, contractor to contractor) and across levels (contractor, power provider, manufacturer) to efficiently overcome challenges and accelerate the adoption of new and sustainable technologies in the construction industry. For a market in transition, the competition does not truly begin before the market is up and running. This, consequently, initiates new possibilities for partnership, collaboration, and not least, market opportunities.

> ***"What you gain from keeping your cards close to your chest is a temporary victory that will vanish rapidly. What you miss is that the industry as a whole is better equipped to meet upcoming requirements."***
> *(Svein Nilsplass, Area Manager Oslo, NCC Infrastructure)*



3

UPSKILLING ACROSS THE ENTIRE VALUE CHAIN

Photo: Aneo Build

Emphasizing awareness, education, and sharing of experiences related to zero-emission construction sites is crucial for succeeding in the transition. Knowledge sharing is not only important to enable smoother execution of emission-free initiatives, but is essential to remove stereotypy, biased perceptions, and facilitate behavioral change.

Several Norwegian players emphasize the importance of knowledge about the new zero-emission technologies and their use, not least the willingness to learn from each other and share experiences, to succeed in the transition.

To ensure upskilling across the entire value chain, some concrete actions are:

- **Demo-days:** organize days for demonstration of zero-emission machines and other relevant equipment to members across the value chain, allowing for machine operators and other stakeholders to personally test equipment and acquire fundamental knowledge about its use
- **Knowledge sharing:** engage in collaboration initiatives to share experiences, gain knowledge, and support the joint work. An example of such an initiative is the European Commission's Big Buyer initiative
- **Industry fairs:** engage in and take part of industrial fairs, whether for acquiring knowledge or exchanging experiences and setting examples
- **Industry organizations:** foster industry organizations capable of mitigating challenges through enhanced collaboration and a shared platform

In the Norwegian Oil and Gas sector, Offshore Norge, a robust industry organization, has alleviated prevailing challenges and stimulated innovation by fostering enhanced collaboration and a unified platform

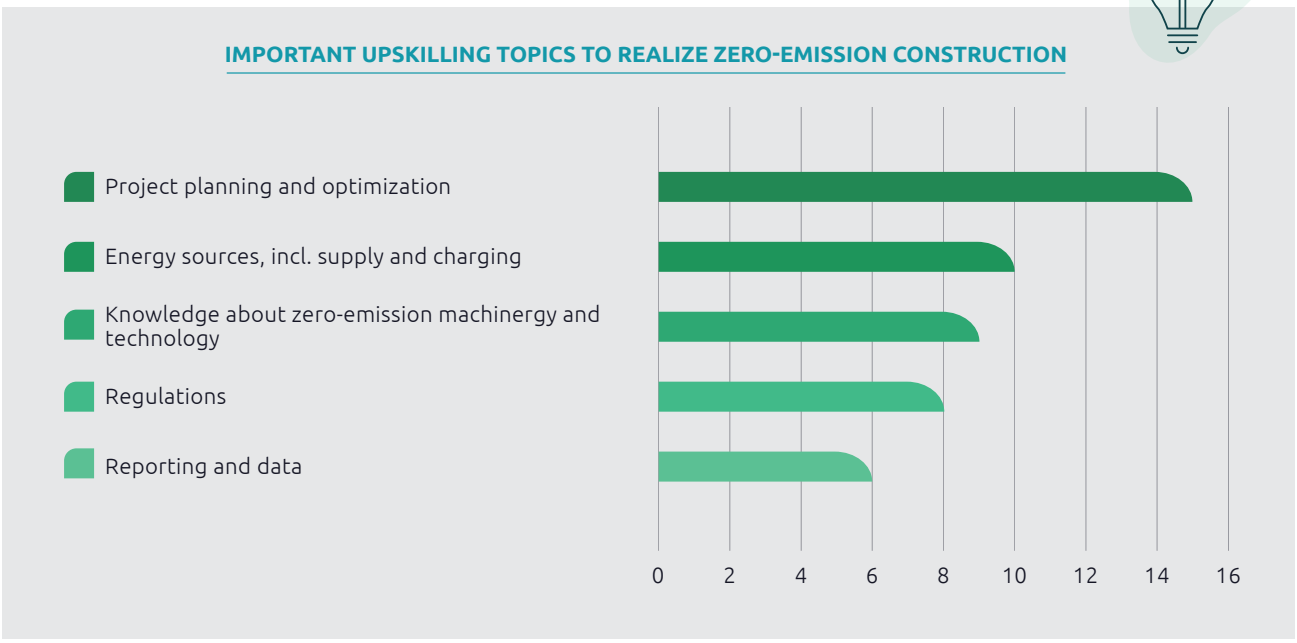


Figure 13: Results from market survey expressing participants ranking of key areas of expertise that needs to be strengthened to realize zero-emission construction

4

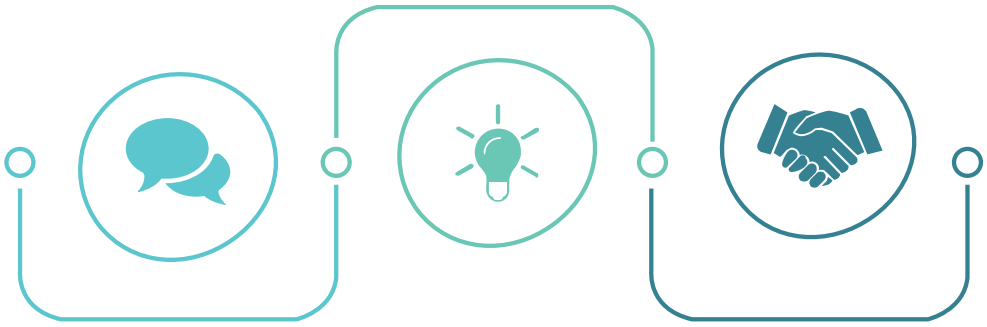
FOSTERING COLLABORATION AND INNOVATION

Effective dialog and interaction between stakeholders in the value chain are vital to enhance feasibility of and achieve zero-emission construction. This can be achieved by fostering collaboration throughout the entire value chain, involving not only those already engaged in partnerships but also embracing new market entrants. Not only will cooperation across actors contribute to knowledge transfer and skill development, but it will also reduce risk, ensure faster problem solving, and foster creativity and faster innovation.

As the zero-emission construction market is undergoing a transitional phase, the demand for innovative solutions and new approaches to work is evident. To maintain momentum and expedite progress in technological development, it is imperative to be open to sharing and leveraging each other's strengths, which, in turn, necessitates the adoption of new collaborative networks. The industry must harness potential and perceive opportunities across three levels: dialogue, open innovation, and ecosystem collaboration.

The power of a successful business ecosystem

Nestle's new business model to succeed in the coffee market with Nespresso and its single-use espresso capsule involved building a business ecosystem (50). Rather than creating the capsule AND a new coffee machine, Nestle patented its capsule technology and cultivated a network of machine manufacturers who produced compatible machines. In other words, Nestle created a model where the market met the demand for compatible coffee machines and in that way, facilitated the scaling and sale of Nespresso capsules. In this sense, it became an ecosystem with Nestle as orchestrator, appliance suppliers as partners etc.



Dialogue

New dependencies calls for the need of new dialogues

- Zero-emission construction triggers changes in the traditional value chain and increase dependency on certain actors, such as electricity companies
- Companies should reassess their routines and recognize the significance of strategically incorporating new actors during the early phase of the project
  - E.g. early mapping of necessary information related to infrastructure and electricity. It could be, for example, that the client surveys the availability of electricity on the construction site before calling for tenders

Open Innovation

Co-creation foster collaboration and accelerate innovation

- Partnered creation of new products, services, technologies, and solutions to foster creativity and accelerate innovation
- Includes joint development of tools and/or sharing of existing tools to support standardization
  - E.g. several actors release own guides for carbon calculations and climate accounting. By running parallel projects to create and establish such tools, the multiplicity causes both frustration and hinder progress toward establishing an industry standard

Ecosystem Collaboration

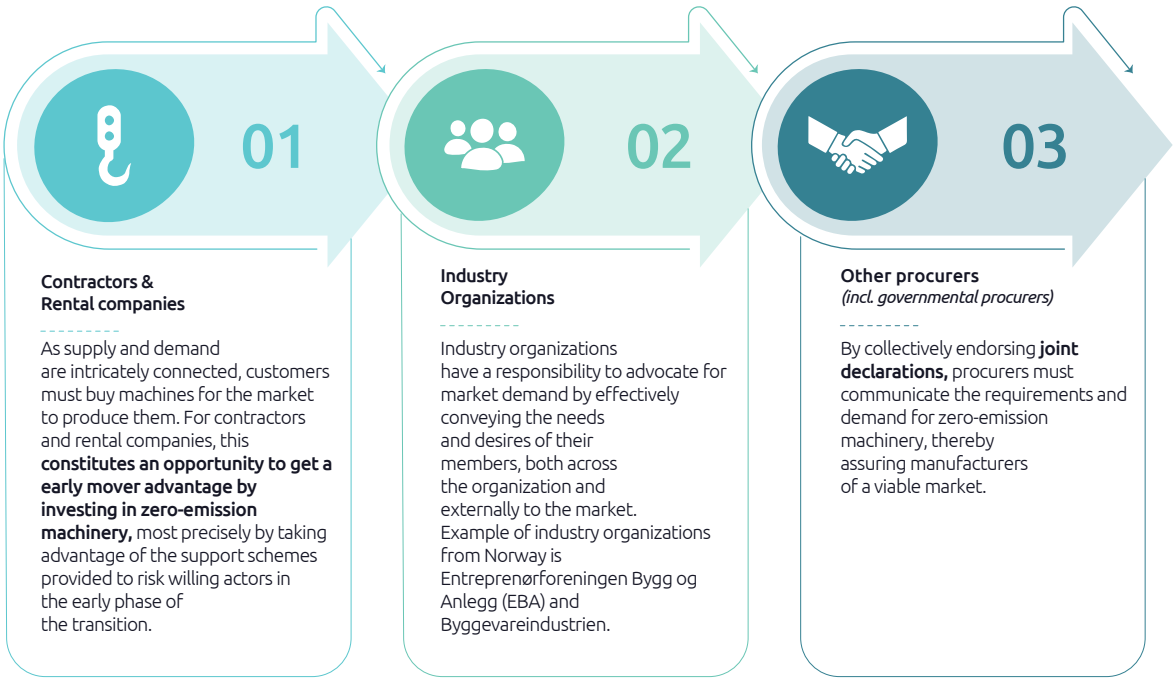
A successful business ecosystem can drive growth and value creation

- New ways of working unlock new types of business models such as ecosystem collaboration
- Ecosystem approach is used when multiple entities can benefit from the synergies and interactions between them, fostering collective growth
  - E.g. one could for instance consider an ecosystem approach to scale the technological development and production of electric construction machines

5

ENSURE SIZABLE DEMAND TO FACILITATE HIGH-SCALE PRODUCTION

Increasing market demand is an absolute essential to stimulate high-scale production of cost-effective and zero-emission construction machinery. In order to increase the supply of emission-free equipment in the European market, European market actors must stand together to substantiate a sizable demand. This includes both actors such as construction and rental companies, but also industry organizations and other procurers.



Cross-border commitment

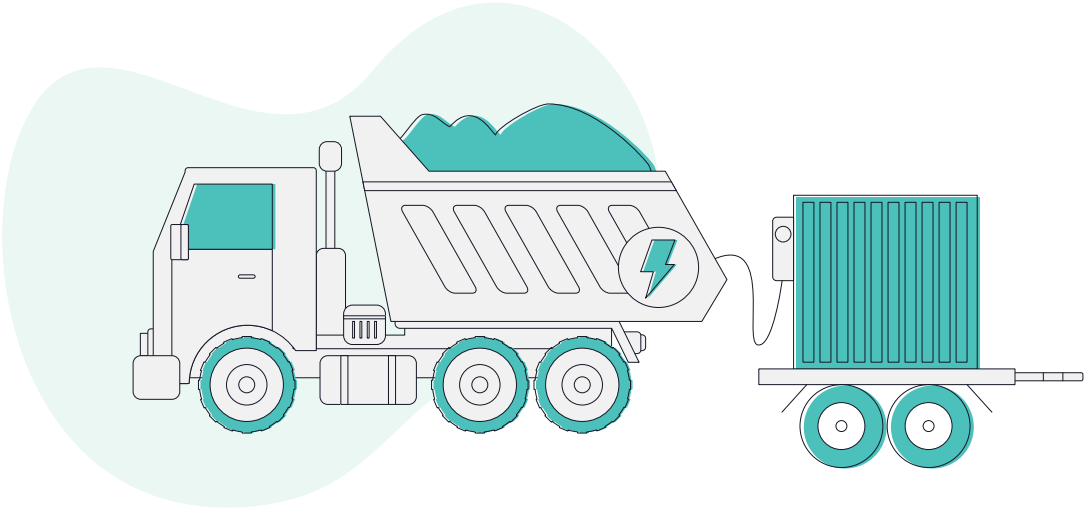
The Joint Statement of Demand composed by the Members of the Big Buyers Working Group (ICLEI) (51) is a clear indication of market demand for zero-emission machinery. Market actors and countries ready to commit to zero-emission construction should take part in joint initiatives to drive innovation and demand, such as the Big Buyers working group.

OPPORTUNITIES BEYOND COMPLIANCE

Industry players must think transition and restructuring, extending beyond mere electrification, and capitalize on the opportunities arising from digitalization, data, and connectivity, among others. Securing a strong position within zero-emission practices not only confers a competitive edge but, in tandem with prioritizing data at the core of the business, can significantly support the acceleration of zero-emission construction sites.

> ***"It is a bit cool to be part of this transition. Especially since the industry has been at a standstill for years"*** *(Svein Nilsplass, Area Manager Oslo, NCC Infrastructure)*

> ***"The EV operation planning needs to consider mileage, speed, topography, temperature (++). More data sharing and analytics are necessary for real-time optimization, planning operations (i.e., collection routes) and maintenance. Similarly, charging routines must be taken into consideration when planning operations."(31)***



6

REAP THE BENEFITS OF BEING A FIRST MOVER OR EARLY ADOPTER

The transition to zero-emission practices, alongside other measures related to more sustainable construction, break up traditional market structures allowing new actors to emerge and capture market share, among others.

Some specific opportunities arising from being a first mover are:

- Changing the traditional ways of working often results in new demands, e.g., for new technology, which can lead to new markets and business propositions. The adoption of mobile charging solutions is one example of this. There is minimal need for mobile charging solutions in traditional construction, but when changing to electric construction machinery, these technologies are by many seen as a part of the solution to ensure feasibility. As a result, a number of market players have recently entered the field of construction batteries.
- As seen multiple times through history, even well-established actors with significant footprint can be thrown out of their market leading position if they do not keep up with technology and market trends. This allows for smaller actors or new entrants to potentially gain market share through first mover advantages.
- Younger generations are showing growing interest in sustainability and digitalization. Organizations that focus and advance with in these fields will therefore often be viewed as more appealing by these employees, and followingly attract new talents with applicable skill- and mindset.

7

DIGITALIZATION

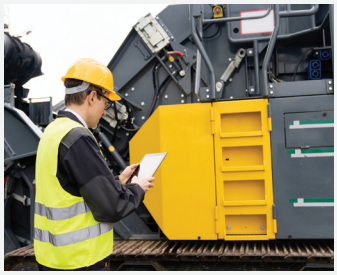
Utilize digitalization to implement new value adding technology to cope with and take advantage of the potential of future construction sites. Digitalization not only fosters connectivity within the company and industry but also plays a significant role in improving operational efficiency and cost management.

For instance, zero-emission machinery are often more connected than its traditional counterparts, meaning that it can produce and process data. If one combines this with communication technology such as IoT and 5G, this opens a wide range of value adding opportunities, such as intelligent automation, insights driven operations, and automated construction forecasts.

Optimization

The transition to zero-emission construction introduces new types of operating costs, with charging solutions and fluctuating electricity prices being examples. To cope with this, the need for increased cost control becomes more important, of which real-time optimization of operations will become an essential element to allow savings and increase margins.

- Optimization of driving patterns and charging routines to maximize effective working time, by considering both charging time and minimizing electricity demand.
- Establish performance benchmarking for zero-emission machinery to allow industry actors to compare the project's productivity against its peers. This includes establishment of common methodology for calculating performance and success.



86% of survey participants anticipate a rise in investments in digitalization over the next 24-36 months.

8

DATA MONETIZATION

Increased access to and improved quality of operational data (e.g. construction machinery, energy consumption) unlocks opportunities for new and additional revenue streams from data monetization. Industry actors can monetize on data by converting accessible data to insights, products, or services that can be sold, shared, or exchanged for revenue.

For the construction sector, this includes taking advantage of the synergies and opportunities arising from enhanced digitalization, increased connectivity, and data capabilities. In other words, the transition to zero-emission construction accounts as an opportunity to not only deliver zero-emission to be compliant, but also to establish new types of business models and revenue streams.

General Electric goes digital

General Electric is an example of an industrial giant succeeding in monetization of data, more precisely IoT, to build a digital line of revenue (55).

The company changed how they make money and moved away from merely selling products (traditional product sales model) to monetizing data (subscription-based model) by leveraging IoT. General Electric integrated sensors and data collection capabilities into their industrial machinery and equipment. This shift allowed them to gather large amount of operational data in real-time which in turn were processed, analyzed, and lastly, sold through digital platforms. With time, this strategic fit proved to be fruitful and resulted in new and important revenue streams.

> "We believe our hardware will be differentiated by our software that will maximize results for our customers"
> - Steve Martin, acting CEO for GE Digital 2019 (55)

The example of General Electric does not only demonstrate the power of data monetization in modern businesses, but also how data can supplement existing solutions and increase competitiveness.

UNADDRESSED QUESTIONS

Realizing zero-emission construction is seen as an important step to ensure reduction of greenhouse gas emissions. In this report, the focus has centered around electrification of construction sites, taking into account challenges and how to assess these. However, there are several considerations that must be further investigated to fully understand the environmental impact of transitioning to zero-emission construction, especially related to the primary use of electric construction machinery.

Is there still a rationale for electrification if fossil fuels continue to play a significant role in the power grid?
99% of the Norwegian electricity is generated from renewables and power used in zero-emission construction machinery is consequently grounded in renewable energy sources. This is not given across Europe, as many countries are currently reliant on and will continue to depend on fossil energy sources for a considerable time ahead. Does it still make sense to electrify the construction sector? Will the local environmental benefits, such as air and noise pollution, exceed the climate impact caused by electricity generated from fossil fuels?

How sustainable is it to replace well-functioning conventional construction machinery with new zero-emission machines just to be compliant?
High ambitions and targeted climate goals require new and large procurements of zero-emission construction machinery. New machines will be essential to deliver on tender requirements and not at least to reach emission targets. But what happens to the conventional construction machine that recently took part in the machine fleet? Is it more sustainable to maximize the utilization throughout the lifespan of the machine, retrofit the machine and replace the engine with a battery, or leave it in storage? What do we do with all the existing conventional machines?

Have we sufficiently considered the environmental impact of producing the batteries needed to realize zero-emission construction?
Batteries are a crucial part of a more sustainable energy supply. However, their actual level of sustainability is a subject of concern as many batteries rely on materials such as lithium, cobalt, and nickel, which are limited in supply and often mined under conditions that raise ethical and environmental questions. As the transition to zero-emission construction will increase the demand for batteries significantly, questions regarding their sustainability becomes prominent. Will we by eliminating emissions from construction, just move the problem to another part of part of the value chain? Does the transition rely on new battery technology to be sustainable?

Is Norway an applicable case study as their acceleration is much owed to government incentives, which are unrealistic for many countries?
Providing predictable and stabile incentives are one of the main recommendations of this report, but what does one do if the national economy does not allow for this? Are incentives a disservice, making the industry reliant on financial support instead of forcing them to find independent long-lasting solutions? And followingly, should Norway look to other countries with lower governmental support for learnings?

SUMMARY AND CONCLUSION

The construction industry accounts for approximately 23% of global CO2 emissions, underscoring the pressing need to decarbonize the sector. For that reason, this study was initiated to identify key challenges and related opportunities that need to be addressed to expedite the adoption of zero-emission construction sites. Norway has emerged as a front-runner in this transition, and other countries can thus gain valuable insights from harnessing Norwegian experiences to facilitate their deployment of zero-emission construction sites. Thus, to sum up, we aspire, through this report, to make a meaningful contribution towards mitigating sector related CO2 emissions, by sharing insights and offering recommendations drawn from Norwegian experiences.

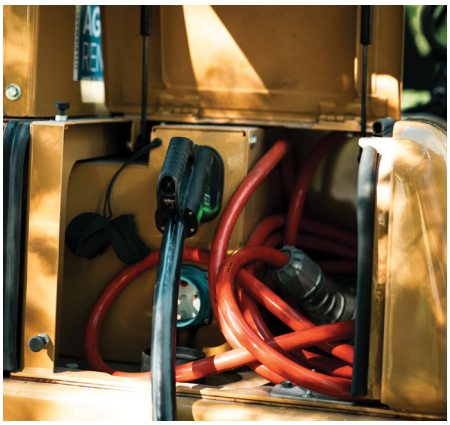


Photo: Aneo Build

The study identified five challenges as the most prominent: additional costs and limited willingness to pay; absents of stable and predictable incentives; lack of standardized requirements and regulations; limited accessibility of zero-emission machines; infrastructure challenges, incl. charging and electricity availability. Moreover, it became apparent that these challenges are closely interlinked and connected to current mega trends as well as sector characteristics.

It is key to mitigate these challenges as they imped the realization of zero-emission construction. A vital part of this study was therefore to identify recommended actions for all relevant industry stakeholders. These include that authorities must ensure predictability, both in regulations and incentives, to lower the financial risk of investing in zero-emission solutions. Contractors and other market players must increasingly collaborate and share knowledge, to ensure effort is optimized and that the industry as a whole moves in the right direction. Lastly, one should not limit oneself to seeing the transition to zero-emission as a task or a hurdle. Such an upheaval, as electrification represents, is also an opportunity for value creation through e.g., reaping first mover advantages or deploying new products and services to meet upcoming market needs.

To conclude, it has become evident that this transition requires effort from actors across the whole value chain. Furthermore, additional research is needed to gain further insight into the topic discussed in this report, and to investigate the questions we left unaddressed. Nevertheless, this study suggests that while there are several challenges that slows down the transition, achieving zero-emissions is not only feasible, but also provides opportunities for value creation.

ACKNOWLEDGEMENTS

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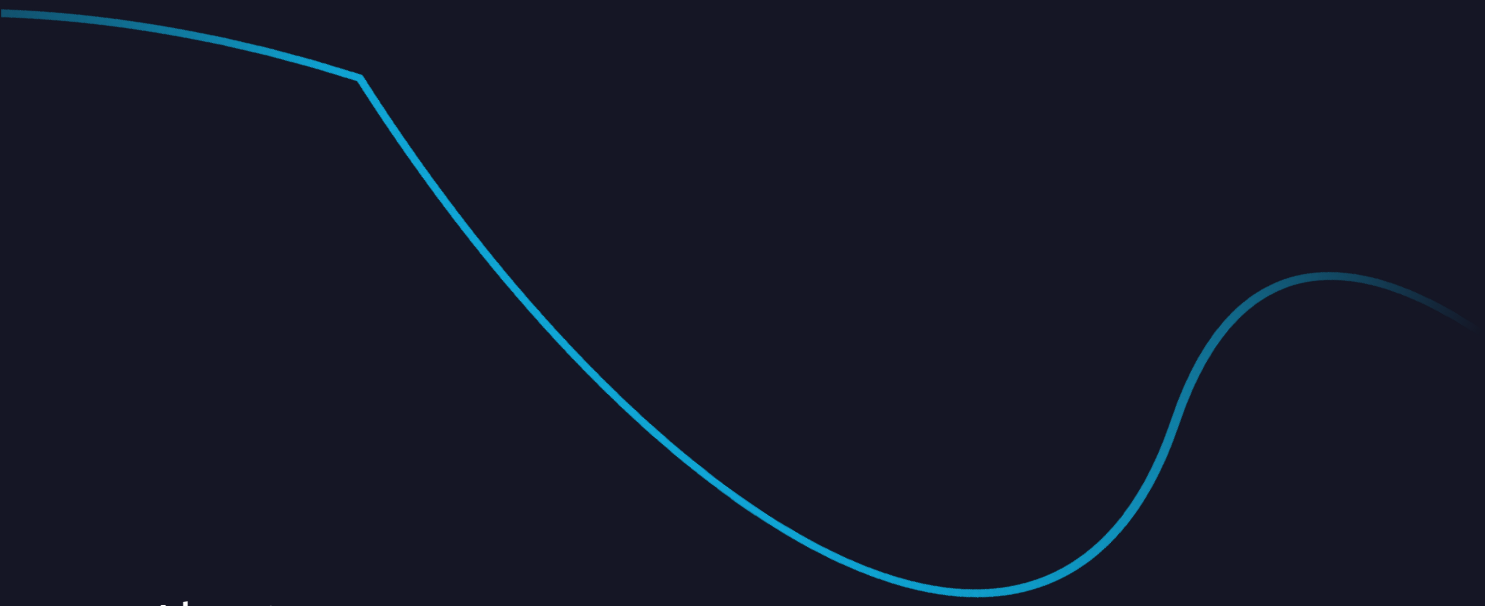

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