PERSPECTIVES ON

Zero Emission Construction

Climate Agency, City of Oslo

Report No.: 2019-0535, Rev. 1
Document No.: 10155847-1
Date: 2019-05-08

Project name:	Perspectives on	DNV GL Energy
Report title:	Zero Emission Construction	Energy Markets & Technology
Customer:	Climate Agency, City of Oslo, [Address]	P.O. Box 300
Customer contact:	Philip Mortensen	1322 Høvik
Date of issue:	2019-05-09	Norway
Project No.:	10155847	Tel: +47 67 57 99 00
Organisation unit:	Energy Markets & Technology	
Report No.:	2019-0535, Rev. 1	
Document No.:	10155847-1	

Applicable contract(s) governing the provision of this Report:

Objective:

Paper to facilitate C40 workshop on the perspectives of zero emission construction.

Prepared by:	Verified by:	Approved by:
Ingrid Løken Konsulent	Guro Fasting Seniorkonsulent	Tore Eliassen Avdelingsleder
Beate Norheim Konsulent		

DNV GL Distribution:

☒ OPEN. Unrestricted distribution, internal and external.

☐ INTERNAL use only. Internal DNV GL document.

☐ CONFIDENTIAL. Distribution within DNV GL according to applicable contract.*

☐ SECRET. Authorized access only.

*Specify distribution:

Keywords:
Zero emission, fossil free, construction sites, greenhouse gases, local pollution, electrification, hydrogen, transport

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
1	2019-05-08	First issue	IL, BN	GF	TE

Table of contents

1 EXECUTIVE SUMMARY

An IPCC (The Intergovernmental Panel on Climate Change) special report on the impacts of global warming shows that a 2°C temperature rise, compared to 1,5°C, will have severe consequences for eco-systems, humans and society (IPCC, 2018). According to IPCC, global greenhouse gas emission must be reduced by about 45 % from 2010 level by 2030 to avoid global warming above 1.5°C. In 2018 the member cities of the C40 network emitted 2.4 Gt of CO2e (C40 Cities, 2018). In the decades ahead, the global population living in urban areas is expected to grow by approximately 1.5 million people every week. A rapid low-carbon transformation of the industry that produce urban infrastructure is thus among the critical steps necessary to fulfil the Paris ambitions.

This paper focuses on emissions *at the construction site.* Emissions at construction sites is mainly related energy use from construction machinery. Today, machinery used at construction sites are mainly diesel-based. There is a great potential for reducing greenhouse gas emissions, local air pollution and noise from construction sites by switching to zero emission alternatives such as electricity or hydrogen. Based on an assumption that emissions from construction sites represent between 5-10 % of total emissions in cities as well as greenhouse gas emissions from the C40 cities, the total annual greenhouse gas emissions from construction sites in the C40 cities is estimated to be in the range of 120 to 240 Mt of CO_2e. The demand for such alternatives today is however small and the alternatives therefore few.

The main reason for the low demand is additional costs related to zero emission alternatives. While electric construction machinery usually provides lower operating costs, as electric engines are more efficient than conventional diesel engines, immature markets and high battery prices lead to high investment costs. The costs of electric machinery can be reduced by connecting the machine to the grid during some of its operations and hence reduce the battery size.

The profitability of switching to electric machines varies between countries, depending on local diesel and electricity prices. In some countries, electric machinery can be profitable already today. With expected reduction in battery price and more mature markets for zero emission construction machinery, it is likely that electric machinery will become more economically attractive in the years ahead.

While electric construction machinery is a zero-emission solution *at the construction site,* the effect on total CO_2 emissions depends on the country's energy mix. Electric and other zero emission alternatives will however remove local air pollution and noise. Local air pollution contributes to severe health problems in many large cities. As cities with the highest construction activity often have the largest challenges with local air pollution, zero emission construction machinery can be an effective measure to increase the welfare of its citizens.

To meet the Paris targets and to realise the benefits zero emission alternatives provide, cities need to find ways to limit the use of fossil fuels, and fossil-free and zero emission solutions must be available and economically feasible. The demand for zero emission construction machinery is today small and the alternatives are therefore few. An increased demand for zero emission construction machinery will contribute to the development of such alternatives. In force of being important proprietors, the C40 cities can promote low-carbon alternatives and thereby contribute to development of a competitive market for zero emission construction machinery.

2 WHY CLEAN CONSTRUCTION

2.1 Sustainable urban infrastructure is key to meet Paris-targets

An IPCC (The Intergovernmental Panel on Climate Change) special report on the impacts of global warming shows that a 2°C temperature rise, compared to 1,5°C, will have severe consequences for eco-systems, humans and society (IPCC, 2018). According to IPCC, global greenhouse gas emission must be reduced by about 45 % from 2010 level by 2030 to avoid global warming above 1.5°C. In 2018 the member cities of the C40 network emitted 2.4 Gt of CO_2e (C40 Cities, 2018). In the decades ahead, the global population living in urban areas is expected to grow by approximately 1.5 million people every week. A rapid low-carbon transformation of the industry that produce urban infrastructure is thus among the critical steps necessary to fulfil the Paris ambitions.

This paper focuses on emissions *at the construction site.* Emissions at construction sites is mainly related energy use from construction machinery. In colder climate the use of energy for heating is also a relevant. Other activities that effect emissions from construction sites are production of material, transport to and from the construction site, demolition and waste handling and treatment.

Today, machinery used at construction sites are mainly diesel-based. There is a great potential for reducing greenhouse gas emissions, local air pollution and noise from construction sites by switching to zero emission alternatives such as electricity or hydrogen.

In this context zero emission alternatives refer to machinery that do not lead to CO_2 emission or local air pollution (NOx and PM) *at the construction site*, i.e. from vehicle. Zero emission construction machinery include battery-electric machinery and electric machinery connected directly to the power grid (cable-electric). Zero emission heating alternatives include heating based on electricity, district heating and other energy carriers that do not lead to local emissions at the construction site. Fossil-free alternatives include sustainable biofuels. Figure 2-1 illustrates the differences between fossil, fossil-free and zero emission alternatives with respect to greenhouse gas emissions and local air pollution.

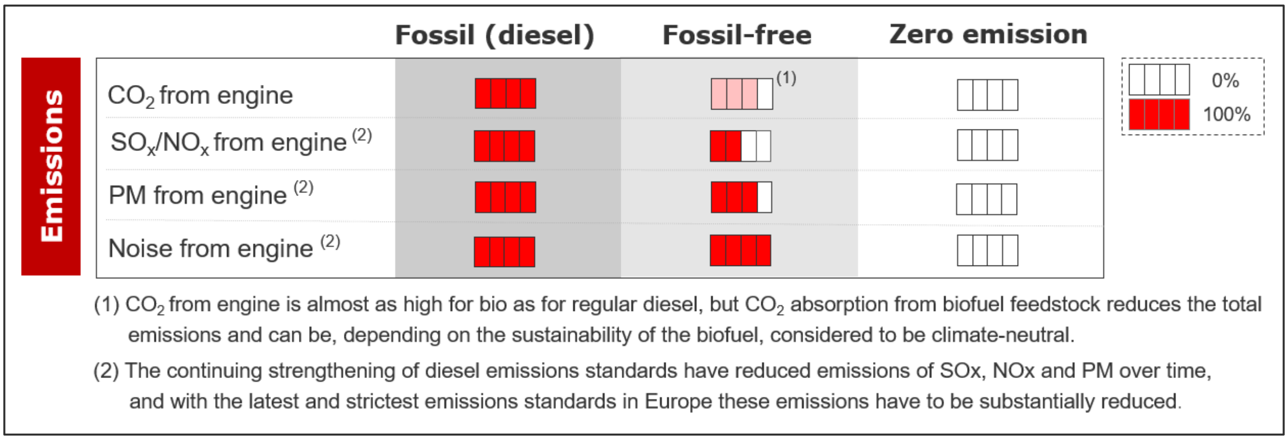

Figure 2-1. Illustration of greenhouse gas emissions and local air pollution from different fuel alternatives.

New EU requirements for non-road mobile machinery emissions are taking effect in 2019, which includes stricter restrictions on emissions of NOx and PM (European Comission, 2016).

2.2 The mitigation potential of zero-emission construction work

Today, diesel is the main energy source used as fuel for construction machinery. An analysis of CO_2e emissions from construction sites in Oslo estimates that approximately 7 % of the city's total CO_2e emissions is related to construction sites. Based on this result and greenhouse gas emissions from the C40 cities the total annual greenhouse gas emissions from construction sites in the C40 cities is estimated to be in the range of 120 to 240 Mt of CO_2e[1].

Table 1 shows annual energy use and CO_2e emissions for the C40 cities in a low and high scenario. In the low scenario it is assumed that emissions from construction sites accounts for 5 % of the C40 cities emissions, while the high scenario assumes that construction sites accounts for 10 % of the C40 cities emissions.

Table 1. Annual energy use and emissions from construction / building sites for C40 cities

Scenario	Energy use [GWh]	CO_2e [ton]
Low estimate (5 % of total CO_2e emissions)	208 130	120 000 000
High estimate (10 % of total CO_2e emissions)	416 250	240 000 000

Substituting fossil-based construction machinery with electric or other zero emission alternatives will have a large positive effect on the local environment. WHO consider air pollution to be one of the main reasons for unwanted health effects and premature death. Construction machinery also produces a vast amount of noise. According to European Environment Agency exposure to environmental noise and dangerous air quality contributes to respectively 10 000 and 500 000 premature deaths yearly in European countries (EEA, 2017), (EEA, 2014). A switch to zero emission alternatives will reduce local emissions and environmental noise and thereby contribute to better air quality and reduced negative health effects.

In London it is estimated that 12 % of the NOx emissions and 15 % of particle matter (PM_{10}) comes from construction and non-road mobile machinery (Mayor of London, 2014).

2.3 Heavy duty zero emission transport of waste and materials

Transportation of waste and materials to and from constructions sites is a significant source of emissions. One solution for reducing emissions from transport is better planning and optimization of transport routes. Furthermore, there are several available alternatives for heavy road vehicles. Diesel in heavy vehicles can be interchanged with renewable fuels like HVO, biogas or bioethanol and thereby reduce greenhouse gases from transport. Zero emission alternatives like hydrogen and electric trucks are also being developed. Transport vehicles in construction projects often travel relatively short distances and often recurring distances between the site, material and landfill stations, which make them more suitable for electrification or hydrogen alternatives.

BYD has developed an electric dumper with a capacity of 10.6 cubic meter which is in operation in Shenzhen. Both Volvo and Tesla have announced that they will soon be delivering battery electric trucks to the market. While Toyota is testing hydrogen powered trucks in Los Angeles harbour and the Norwegian grocery wholesaler, ASKO, started in 2018 to use hydrogen driven trucks in their transport.

Transport of waste and materials are often conducted by external companies. Hence, it can be challenging to control the use of fuel. Infrastructure and availability of alternative fuels may also be a

[1] To estimate the total emissions from construction sites for the C40 cities, analyses done by DNV GL for The City of Oslo is used as a basis (DNV GL, 2018). Based on various types of building sites, the energy consumptions and the corresponding emissions have been estimated per square metre of construction site. The energy use and emissions are then summed up to annual numbers based on the size of typical construction site and construction activity in Oslo.

challenge in certain areas. A solution may be to have external tanks or containers with fuel at the construction site so that the trucks can be fuelled on-site.

3 SOLUTIONS

3.1 Available technologies and future development

The use of construction machinery varies widely from project to project. Projects with simple ground conditions usually only require a couple of excavators for a few months while more complicated projects also require machinery to move earth, piling, etc. A project's level of complexity considerably affects the energy use and emissions of construction machinery at construction sites.

Experience from fossil-free construction sites shows that almost all types of machinery are available for the use of biodiesel (HVO100). Technologically, a shift to fossil-free construction sites should therefore not be too complicated, which have been showed through several projects initiated by the municipality of Oslo. The availability of sustainable biofuels may however be a challenge and create competition between different users and segments. While there are several alternatives for reducing emissions at construction sites, biofuels may be the only available low-emission alternative for some transport segments, e.g. long-distance heavy transport, airborne traffic and maritime sector. Hence, the limited amount of biofuel available should be considered for the transport segments that need it the most. While sustainable biofuel is considered an emission neutral alternative, it does not provide all the same local benefits as electricity or other zero emission alternatives.

The development within zero emission construction machinery has been significant over the last years. Previously, only electric construction machinery connected to the grid through a cable, hand held equipment and smaller machines where available. Today, large battery electric mining loaders are on the market in the US and Pon Equipment has developed a 25-tonne battery electric excavator with a 300 kWh battery pack, which was unveiled in 2018 (Tek.no, 2019)

Electric construction machinery can be purely battery driven, dependent on a cable connection or a combination of the two. Construction machinery that is supplied with electricity via a cable will have limited movement, while the utilization period of battery electric machinery is limited by the battery's capacity. A combination of battery and cable is therefore seen as a good alternative. The battery can then ensure the mobility of the machinery and reduce the capacity needed from the grid, while the cable connections ensures that the machines utilization period is not limited.

In areas with limited grid capacity a way to increase the utilization period of mobile electric machinery may be to replace battery packs during operations or to include a hydrogen tank and fuel cell. An example of the latter is a Norwegian pilot project where a hydrogen-electric excavator is being developed (SINTEF, 2018).

A key to the increased availability of large electric construction machinery is batteries costs. The interest in battery technology and electricity storage has increased considerably over the past years. This is due, among other things, to the increased use of variable renewables, such as wind and solar power, as well as the interest for electric cars and a desire to stop using fossil alternatives in various markets, including construction sites. The increased demand for batteries is driving battery prices down. Figure 3-1 shows historic development in battery prices and Bloomberg New Energy Finance’s expected battery cost development towards 2030 (BNEF, 2019).

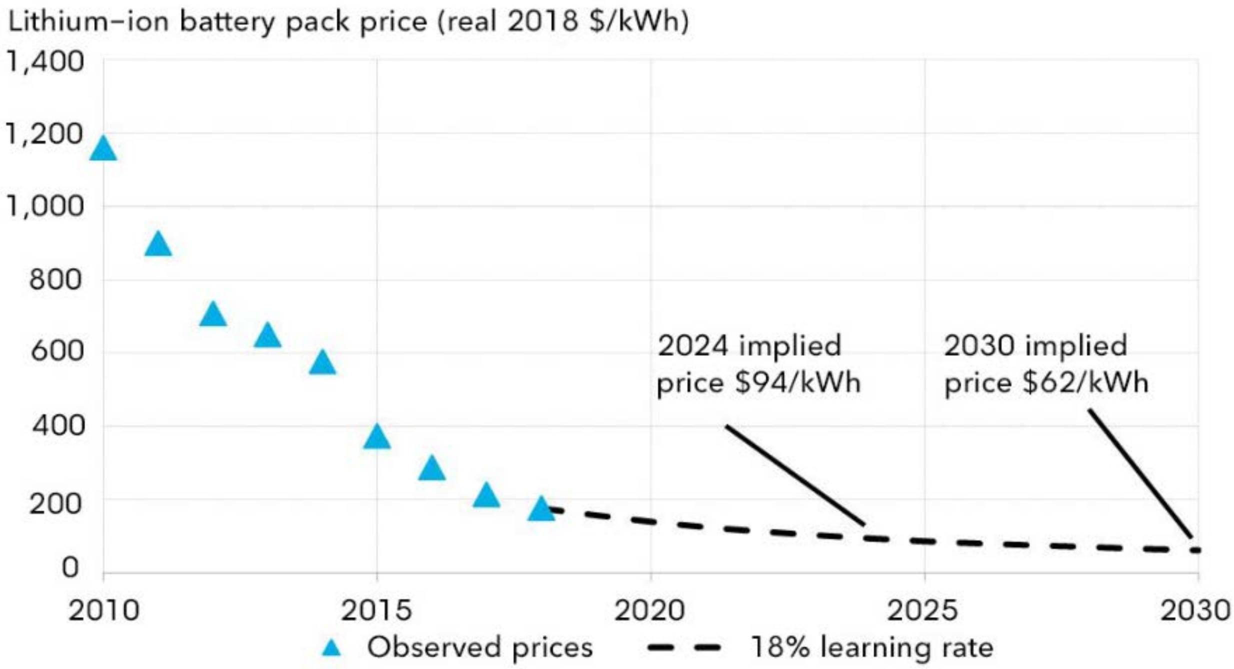

Figure 3-1: Battery cost development (BNEF, 2019)

Based on expected developments in battery technology it should be possible to electrify all types of construction machinery by 2030. The Norwegian construction industry says that they expect that zero emission machines will be widely available in 2030 - either electric or hydrogen-based - and that they are ready to start using these as soon as they are available.

3.2 Reinforced and flexible renewable Energy supply to construction site

In order to use zero emission solutions based on electricity at the construction site, there must be a connection to the local power grid. Depending on the power demand it may also be necessary to upgrade existing infrastructure elsewhere in the grid, which may be time consuming. It is therefore important to obtain an overview of the necessary measures as early on as possible. The necessary infrastructure, such as charging points and the logistics around them, must be well thought through.

In Norway, a substantial part of the road sector and ferries have switched to zero emissions alternatives, from diesel to electricity. One of the main findings from this transition is that available grid capacity is highly dependent on location. One way of reducing the need for upgrading the grid, and thereby the connection cost, is to reduce the total power demand (i.e. MW). The use of batteries packs to reduce the power demand in location or periods with limited grid capacity are an alternative. Another alternative is the use of hydrogen instead or in combination with electricity. A battery and/or hydrogen solution can thus offer a more reliable and flexible solution than connection directly to the grid.

4 THE BUSINESS CASE

4.1 The economy of zero emission construction

Investment costs for electric construction machinery range today from 20 % to three times the price of conventional alternatives, dependent on the type of machinery. Immature markets and is battery costs are the main reasons for this. Battery prices has however fallen rapidly the last years and are expected to continue to fall, cf. chapter 3.1. Development of machinery with a battery-cable combination is also expected to reduce the investment cost of electric alternatives as they will require small battery packs than pure battery-electric machinery. Falling battery prices and a more mature market for electric machinery is expected to reduce the additional costs of electric machinery in the future.

At the same time, the operating costs for electric machinery is in general lower than fossil-based machinery, mainly because electric engines are much more efficient than internal combustion engines (ICE). Lower maintenance costs due to fewer moving parts are also reducing the operating costs of electric vehicles. National variations in diesel and power prices are however large and fuel prices are decisive for the potential operational cost savings with electric machinery.

A cost estimate of a battery-electric and a diesel-based excavator over the machine's lifetime is presented in Figure 4-1. The operational costs are highly dependent on the diesel and power price in the area, which varies significantly for the C40 cities. In cities like Oslo, where fuel prices are high and electricity prices are relatively low, investing in an electric excavator is likely to be economically favorable over the machines' lifetime despite the high investment cost. To reflect the large variation in fuel prices four cases have been analyzed:

- Case El=Diesel+50%: Diesel price equals the brent crude oil price[2] and electricity price is 50 % higher than brent crude oil per kWh[3]
- Case Diesel=El: Both diesel price and electricity price equal the brent crude oil price per kWh
- Case Diesel=El+50%: Electricity price equals the brent crude oil price and diesel price is 50 % higher than brent crude oil per kWh
- Case Norway: Norwegian electricity price for industry and untaxed diesel prices[4]

Energy consumption for a diesel excavator and an electric excavator over a lifetime of 15 000 hours is presented in Table 2. It shows that the efficiency of the electric motor saves in total 2.0 GWh of energy or 284 000 liters of diesel.

Table 2. Lifetime costs for a 25 tonne diesel excavator and a 25 tonne electric excavator

	Unit	Diesel excavator	Electric excavator
Diesel consumption per hour	liter/hour	18.95	-
Energy consumption per hour	kWh/hour	(191.2)	57.4
Total diesel consumption	liter	283 950	-
Total energy consumption	kWh	(2 867 895)	860 369

[2] Brent crude oil price 29.04.2019 was 71.2 EUR/barrel, i.e. 0.6 EUR/litre (Macrotrends, 2019).

[3] Based on energy content in diesel, which is assumed to be 10.1 kWh/litre

[4] Electricity including relevant taxes for construction sites is set to 0.7 NOK/kWh, while untaxed diesel is priced at 10 NOK/liter (Cirkle K, 2019)

[5] Hourly consumption based on CAT 323 Hydraulic excavator (CAT, 2019)

Figure 4-1 shows the operational cost savings for an electric excavator over the machine's lifetime, compared to a diesel excavator. Reduced maintenance costs are not included.

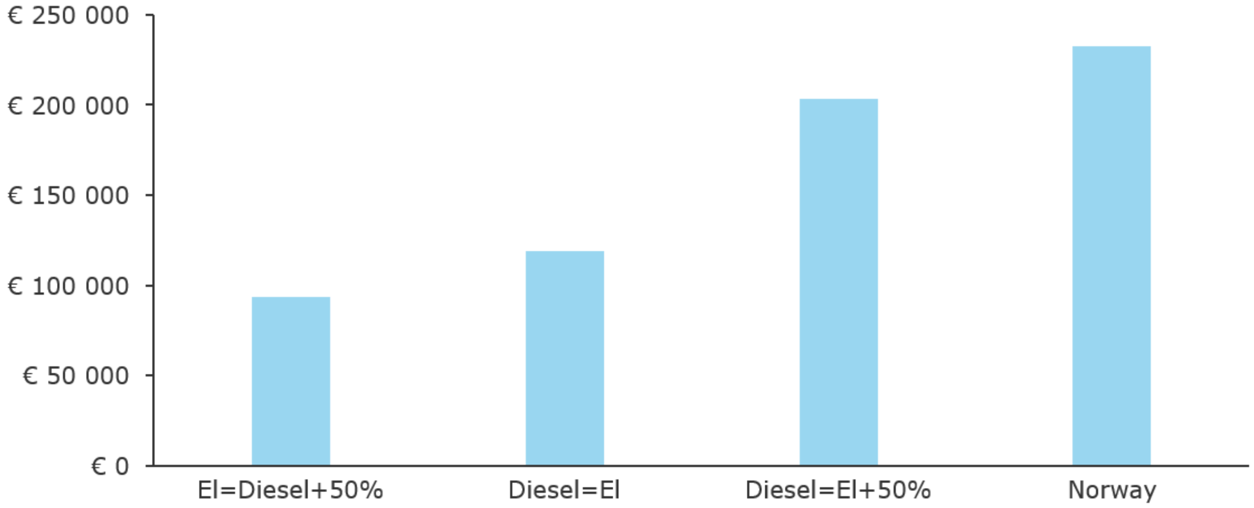

Figure 4-1. Energy cost savings for replacing a diesel excavator with an electric excavator over a lifetime of 15 000 hours

Looking at the operational cost, an electric excavator is profitable compared to a diesel excavator. However, the business case for fossil free machinery also depends on the investment cost.

To illustrate how the investment cost affect the business case for an electric excavator two scenarios for the four different fuel price cases are presented[6]. In scenario 1 the investment cost for an electric excavator is assumed to be 200 % higher than a conventional excavator, while in scenario 2 the electric excavator is assumed to be 50 % higher. Electric machinery is expected to have 50 % longer lifetime than the diesel machinery. To account for this and obtain comparable results, emissions for manufacturing and end of life handling of fossil-based machinery are multiplied with a factor of 1.5.

Figure 4-2 shows that even though the operational cost for an electric excavator is lower than for a diesel-based, the overall lifetime cost is higher in scenario 1 due to the large additional purchasing cost. However, if the additional purchasing cost is reduced to 50 % the electric excavator is less expensive than the diesel-based in all the four fuel price cases. For the Norway case, where the diesel price is significantly higher than the electricity price, the business case for an electric excavator in scenario 2 is very strong.

[6] In the business case the following assumptions are applied: The investment cost for a conventional excavator is assumed to be EUR 200 000. The lifetime of an electric excavator is expected to be 15 000 hours for an electric excavator and 10 000 hours for a diesel-based excavator (SINTEF, 2018).

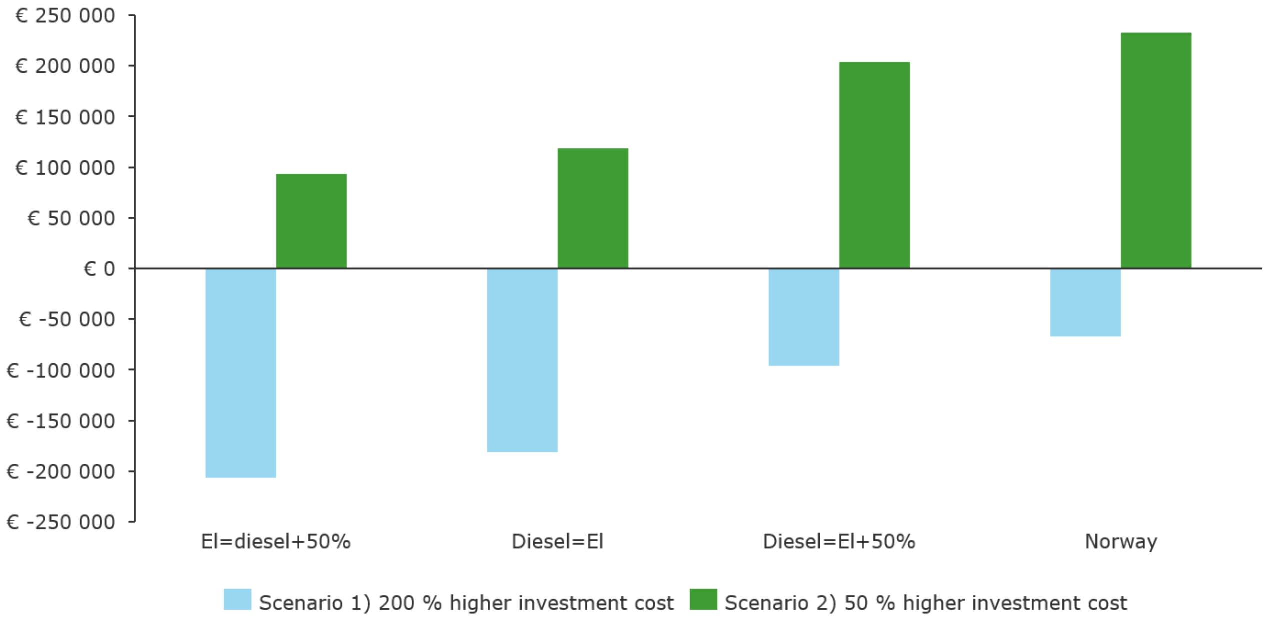

Figure 4-2. Business case for an electric excavator compared to a conventional diesel-based excavator

The business case is based on a relatively fuel-efficient machine and an expected reduction in maintenance cost for the electric excavator is not included. Compared to less efficient diesel machines the business case for electric excavator will be even stronger.

4.2 LCA for zero emission construction machinery

Total greenhouse gas emissions are highly dependent on fuel consumption of the construction machinery and the electricity mix used for both producing and powering the battery. If the construction machinery use electricity produced from renewable sources, the lifecycle emissions of GHG can be reduced up to 90 %.

The objective of this analysis is to compare the greenhouse gas emissions produced by electric construction machinery and internal combustion construction machinery over their lifetime. A life cycle analysis (LCA) is therefore performed. The analysis includes emissions from both the manufacturing, use phase and end of life processes. Two different type of construction machinery are analysed; light duty (2 tonne) and heavy duty (25 tonne). Main assumption regarding the two types are presented in Table 3.

Table 3. Construction machinery assumptions

Construction machinery	Fuel	Weight [kg]	Energy use [kWh/year, L/year]	Lifetime [y]	Battery size [kWh]
Light duty	Battery	2 200	9 843	15	35
	Diesel	2 000	3 281	10	-
Heavy duty	Battery	25 000	57 358	15	300
	Diesel	25 000	18 930	10	-

Electric vehicles (EV) produce less environmental burden than internal combustion vehicles (ICE) during the use phase. However, various studies dispute the environmental benefits of electric vehicles. The largest part of the energy use in the production of lithium-ion batteries comes from electricity use. Because of this the electricity mix both in the production and the use phase is a critical factor for the greenhouse gas emissions from electric vehicles. If the electricity mix is based mainly on coal fired power plants, there are several studies pointing in the direction that electric vehicles are less environmentally friendly than fossil-based ones (Romejko, 2017).

There are no previous studies, to DNV GLs knowledge, that has performed a LCA for emission of construction machinery. Total greenhouse gas emission is therefore based on various LCA studies for passenger vehicles (Swedish Environmental Research Institute, 2017), (Philipport et al., 2019) and (Romejko, 2017)[7]. The emission values are scaled, based on weight, battery size and fuel consumption, for light and heavy duty machinery. Electric machinery is expected to have 50 % longer lifetime than the diesel machinery. To account for this and obtain comparable results, emissions for manufacturing and end of life handling of fossil-based machinery are multiplied with a factor of 1.5.

Furthermore, the LCA's are performed based on three different electricity mixes; One low emission mix, which consists mainly of renewable energy sources, one based on the combined electricity mix of the OECD countries (OECD, 2015), and one for a future EU scenario[8], which is calculated based on Eurostat and EU's Roadmap2050 (Standard Norge, 2018).

Table 4. CO_2 emissions from electricity generation

Electricity mix	CO_2 emissions
Renewable-based	18.5 g/kWh
OECD	432 g/kWh
EU 2050 scenario	136 g/kWh

Figure 4-3 shows the historic development of the CO_2 emissions from electricity generation in the OECD countries. With the global focus of decreasing emissions from electricity production further the effect of electrification will continuously be enhanced in the years to come.

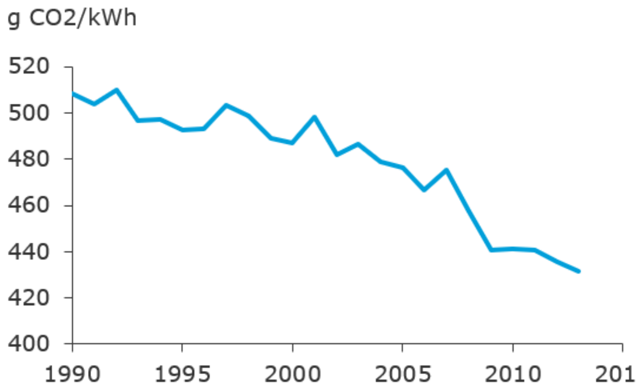

Figure 4-3. Development of CO2 emissions from electricity generation in OECD countries (OECD, 2015)

Figure 4-4 shows the result of the analysis for the two types of machinery for the different electricity mixes. The total CO_2 emissions are reduced for electric machinery compared to diesel machinery for all three electricity mixes. The figure illustrates how the electricity mix affects the CO_2 emissions of electric machinery, and that electricity based on renewable energy sources reduces the lifetime CO_2 emissions by 90%.

[7] In the analysis a factor of 50-300 kg CO2e per kWh have been used to estimate the greenhouse gas emissions from the battery manufacturing. For the use process an emission factor for diesel of 2.5 kg CO2e/L is applied. To account for differences in the electricity mix between cities, an emission factor of 0.02 kg CO2e/kWh is applied for a low emission electricity mix and 0.8 kg CO2e/kWh for a high emission electricity mix.

[8] The EU 2050 scenario is an average of the production mix in 2015 and the expected production mix in 2075.

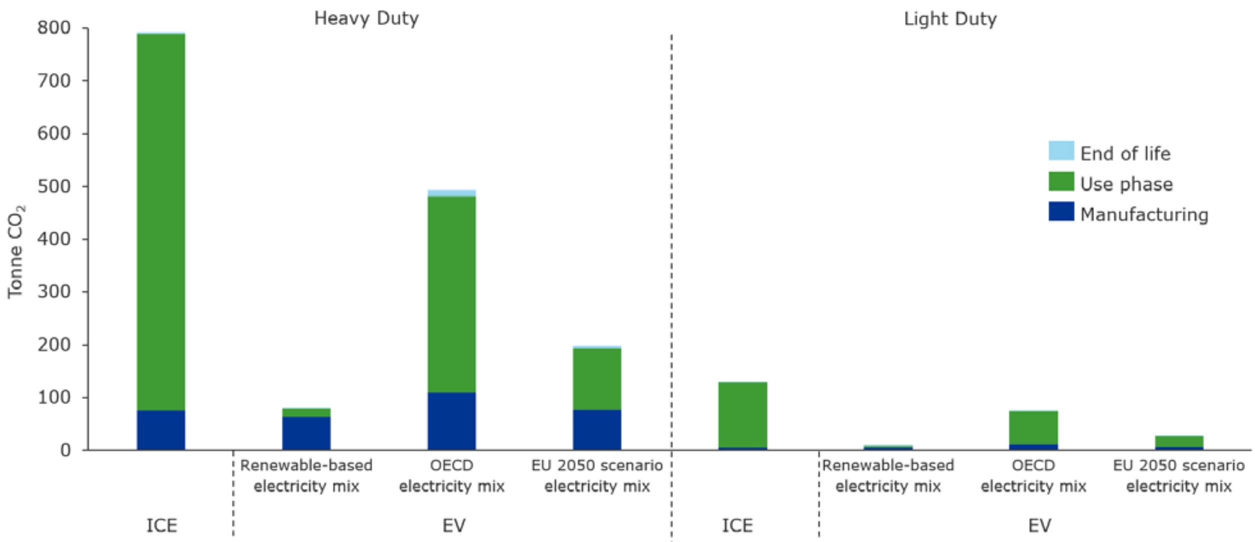

Figure 4-4. Total CO_2 emissions from light duty (2 tonne) and heavy duty (25 tonne) construction machinery.

5 THE WAY FORWARD – A ROADMAP TO ZERO EMISSION CONSTRUCTION

A transition to zero emission solutions at construction sites will have significant benefits both locally and globally. Global reductions of CO_2 emissions will depend on the different countries' energy mix, while local reduction of air and noise pollution will be significant. As the cities with the highest construction activity often have the largest challenges with local air pollution adopting zero emission alternatives at construction sites may be a very efficient measure.

The construction process may however need to be revised to ensure that the necessary steps are taken to facilitate the use of fossil-free and zero emission alternatives. The figure below indicates specified action points that it is important to take into consideration when working towards a fossil-free or zero emission construction site (DNV GL, 2018).

r - responsible
e - executes
c - to be consulted
i - to be informed
d - decides

Phase	Activity	Developer	Contractor	Subcontractor	DSO	District heating co.	Fuel supplier
ADAPTING THE CHOSEN CONCEPT	A1. Estimate the building's electric power and heat demand when in operation	r					
	A2 Find out what fossil-free and emission-free alternatives are available at the building site in question	r		c	c	c	c
	A3. Find out the existing alternatives for reducing the building site's energy demand	r			c		c
DETAILED PLANNING	D1. In the invitation to tender, stipulate realistic requirements for the use of fossil-free and emission-free alternatives at the building site	r	c	c			
	D2. Map the energy and power demands	i	r	c			
	D3. Plan the building of infrastructure up to the building site	i	r	c	c	c	i
	D4. Ensure that the logistics at the building site are adapted to the use of fossil-free and emission-free alternatives	i	r	i	c	c	c
PRODUCTION AND DELIVERIES	P1. Logistics and execution plan		r	e			
	P2. Measuring and reporting energy usage for continuous learning	r	e	i	c	c	c

Figure 5-1. Guide to facilitating the use of fossil- and zero emission solutions at construction sites

To meet the Paris targets and to realise these local benefits zero emission alternatives provide, cities need to find ways to limit the use of fossil fuels. As fossil-based alternatives today are more economically attractive putting a price on emissions or other regulations and incentives to promote low-carbon alternatives is considered necessary. An incentive that have shown very efficient in Norway is to use the public procurement process to promote fossil-free and zero emission alternatives. The municipality of Oslo has realised several fossil-free construction sites in this way and are now in the tendering process for two construction projects where award criteria require emission-free solutions. The procurement process has also been used extensively in Norway to promote zero emission alternatives in the maritime sector. This has shown to be very efficient in the operation of ferries where 70 out of 130 ferry routes have been or are in the process of becoming electrified (Tekna, 2019).

To meet the Paris targets and to realise the benefits zero emission alternatives provide, cities need to find ways to limit the use of fossil fuels, and fossil-free and zero emission solutions must be available and economically feasible. The demand for zero emission construction machinery is today small and the alternatives are therefore few. An increased demand for zero emission construction machinery will contribute to the development of such alternatives. In force of being important proprietors, the C40 cities can promote low-carbon alternatives and thereby contribute to development of a competitive market for zero emission construction machinery.

6 REFERENCES

Bellona, 2018. *Zero emission construction sites: The possibilities and barriers of electric construction machinery.* [Online]
Available at: https://network.bellona.org/content/uploads/sites/3/2018/06/ZEC-Report-1.pdf
BNEF, 2019. [Online]
Available at: https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/
C40 Cities, 2018. *C40 Cities Annual Report 2017.* [Online]
Available at: https://c40-production-images.s3.amazonaws.com/other_uploads/images/2056_C40_ANNUAL_REPORT_2017.original.pdf?1544802871
CAT, 2019. [Online]
Available at: https://s7d2.scene7.com/is/content/Caterpillar/CM20171025-07423-02014
Cirkle K, 2019. [Online]
Available at: https://m.circlek.no/no_NO/pg1334073738687/business/milesDrivstoffbedrift/Priser.html
DNV GL, 2018. *Emission-reduction potential of fossil- and emission-free building and construction sites,* s.l.: s.n.
DNV GL, 2018. *Guide to arranging fossil- and emission-free solutions on building sites,* s.l.: s.n.
EEA, 2014. *Noise in Europe 2014.* [Online]
Available at: https://www.eea.europa.eu/publications/noise-in-europe-2014
EEA, 2017. *Air quality in Europe - 2017 report.* [Online]
Available at: https://www.eea.europa.eu/publications/air-quality-in-europe-2017
European Comission, 2016. *Regulation (EU) 2016/1628.* [Online]
Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016R1628
Li, X. C. J. P. D., 2017. China's electrcity emission intensity in 2020 - an analysis at provincial level. *Energy Procedia,* Volume 142, p. 2779.2785.
Macrotrends, 2019. [Online]
Available at: https://www.macrotrends.net/2480/brent-crude-oil-prices-10-year-daily-chart
Markets Insider, 2019. [Online]
Available at: https://markets.businessinsider.com/commodities/oil-price/euro
Mayor of London, 2014. *The control of dust and emissions during construction and demolition.* [Online]
Available at:
https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/Dust%20and%20Emissions%20SPG%208%20July%202014.pdf
NVE, 2017. *Batterier i bugg kan få betydning for det norske kraftsystemet.* [Online]
Available at: http://publikasjoner.nve.no/rapport/2017/rapport2017_66.pdf
OECD, 2015. *Climate Change Mitigation Policies.* [Online]
Available at: http://www.compareyourcountry.org/climate-policies?cr=oecd&lg=en&page=2
OECD, 2015. *Climate Change Mitigation: Policies and Progress,* Paris: OECD Publishing.
Oslo Kommune, 2018. *Fokemengde og endringer.* [Online]
Available at: https://www.oslo.kommune.no/politikk-og-administrasjon/statistikk/befolkning/folkemengde-og-endringer/#gref
Philipport et al., 2019. Eco-Efficiency of a Lithium-Ion Battery for Electric Vehicles: Influence of Manufacturing Country and Commodity Prices on GHG Emissions and Costs. *MDPI*, February, pp. 1-23.
Romejko, K. a. M. N., 2017. Life cycle analysis of emissions from electric and gasoline vehicles in different regions. *International Journal of Automation Technology* , 04 11, pp. 572-582.
SINTEF, 2018. *30 tonns utslippsfri gravemaskin - Teknologistatus, kartlegging og erfaringer,* s.l.: s.n.
Standard Norge, 2018. *Metode for klimagassberegninger for bygninger,* s.l.: s.n.
Stortinget, 2015. *Stortinget.no.* [Online]
Available at: https://www.stortinget.no/no/Saker-og-publikasjoner/Publikasjoner/Innstillinger/Stortinget/2015-2016/inns-201516-078/?lvl=0
[Accessed 24 04 2019].
Swedish Environmental Research Institute, 2017. *The life cycle energy consumption and greenhouse gas emissions from lithium-ion batteries,* Stockholm: Swedish Environmental Research Institute.
Tek.no, 2019. [Online]
Available at: https://www.tek.no/artikler/sniktitt-catepillar-323f-z-line-zero-emission-verdens-forste-av-sitt-slag-og-den-er-bygget-i-norge/456478
Tekna, 2019. *Electric ferries - a success for the climate and for the Norwegian battery production.* [Online]
Available at: https://www.tekna.no/en/news/newsletter-february-2019/electric-ferries/
[Accessed 06 05 2019].

About DNV GL

DNV GL is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.