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Executive Summary

The 3-year project "The Construction site of Tomorrow" is a collaboration of a consortium of 7 contractors, 2 knowledge institutes and the construction machinery supplier on the deployment of heavy-duty electric excavators. The practical experiences of the "Construction Site of Tomorrow" has resulted in technical improvements of the machines, new insights about energy consumption in different use cases, experience with the deployment of the machines and practicalities around charging the machines' batteries in different situations. In this paper we elaborate the findings of the project, including the usability of the machines, their energy consumption and total costs of ownership. This work has been coordinated by FIER Sustainable Mobility. The project was sponsored by the Netherlands Enterprise Agency.

Keywords: Off-road & industrial electric vehicles, charging business models, measuring methods & equipment, climate change, electric vehicles

1 Introduction

Electric non-road mobile machinery is a relatively new development, that allows construction without local pollutant emissions such as nitrogen oxides and particulate matter, for instance in the built environment. Additional benefit of electrification is a potential reduction of CO_2 emissions per unit of work, compared to traditional diesel engine powered machines. The practical implementation of electric machinery however requires machines to be available, reliable, preferably capable of replacing diesel machines in daily operation one-to-one, and affordable. Daily operation requires charging, if possible without hampering productivity.

Driven by the nitrogen deposition issues in the Netherlands and the limits these pose on writing tenders for construction works, the Dutch government is interested to know to which extent current heavy machinery is able to fulfil the abovementioned requirements. The project "The construction site of Tomorrow" is a demonstration project for heavy-duty electric excavators and was subsidised by the Netherlands Enterprise Agency RVO. It has been carried out by a consortium of 7 front running contractors, 2 knowledge institutes (TNO and FIER Sustainable Mobility) and a construction machinery supplier (Staad Group) which had just developed two types of electric excavators at the time of commissioning.

Within this project 7 battery-electric excavators have been monitored during full-time operation by the contractors.

The aim of the project was to gain new insights and knowledge from practical experience with these machines about their usability, energy consumption, emission savings, costs and logistical issues regarding, for example, the charging of the batteries of these machines.

This paper summarises the results of the project. The first part describes the findings in terms of usability, the electricity consumption and its dependence on the type of activities, and the avoided emissions compared to a diesel machine. The second part is an analysis of the Total Cost of Ownership (TCO) of the excavators in the project, and the sensitivity of it to several factors, such as electricity price.

2 Machines and use cases

Six 17-ton mobile excavators were monitored, and a single 35-ton tracked excavator, see Figure 1 and 2. All machines are converted diesel machines, and are fitted with a swappable battery box system. The 17-ton machines had two 114 kWh (usable) powerboxes at delivery, some were later upgraded to a single battery of 385 kWh usable. The tracked machine had 2 packs of 385 kWh from the start.

Figure 1: Left: 17-ton mobile excavator (type DX165W); right: 35-ton tracked excavator (type DX355LC)

More information about the machines can be found here: https://www.staad-group.com/electric/electric-machines

The data from the machines was categorised by type of operations, named “use cases”, as indicated per working day by the respective contractors. The use cases distinguished are:

- residential construction
- civil engineering
- forestry
- demolition works
- railway maintenance

3 Results: usability, energy consumption and emissions

3.1 Energy consumption

The activities during a total of 2,300 working days (>=1.5 hours) were monitored. Average hourly consumption of the 17-ton mobile excavator was 28 kWh, the 35-ton machine required 52 kWh per hour on average, which corresponds to 25% load; both numbers are exclusive of charging losses. Idle share was 30% and 29%, respectively.

The variation of the hourly energy demand for the different use cases is 33%, forestry being the most energy intensive and railroad maintenance the least. Table 1 shows the details per use case. On average, the machines were used for 7.9 hours per working day (a working day has at least 90 minutes of usage).

Table 1: Use cases and averages from monitoring; mobile excavators

DX165W	Unit	Civil	Residential	Forestry	Railway maintenance	Demolition works
Average motor power during use	kW	28.2	24.2	31.5	23.6	25.2
Operating hours per working day	Hours	8.1	8.0	6.6	8.3	6.6
kWh / working day	kWh	227	193	208	208	156
Number of working days monitored	-	1036	159	202	27	30

3.2 Usability

From a usability point of view, it is crucial to know whether the machines can operate until the end of the working day with the onboard battery, possibly factoring in a battery swap and/or opportunity charging. A histogram was made of the total energy consumption per working day. It is worth noting that in a few occasions, the machines performed working days of 20 hours or more; hence some very high numbers were seen. Figure 2 shows the cumulative histogram of the daily energy consumption (blue line) for the six 17-tons machines. The share of working days that can be attained with several configurations are depicted by the light orange boxes. The standard two battery boxes with a joined 228 kWh were sufficient for 56% of the working days. A 45-minute 40 kW[1] DC charge increased this to 73%. A battery swap, for instance during a lunch break, enables over 90% of the days. The upgraded battery hardly ever requires swapping or opportunity charging.

The 2x385 kWh battery in the DX355 tracked excavator is sufficient for >99% of the working days (not shown in the graph).

[1] The machines are capable of 175 kW DC fast charging, but a 40 kW DC charger can be powered by a 3x63A connection on a construction site.

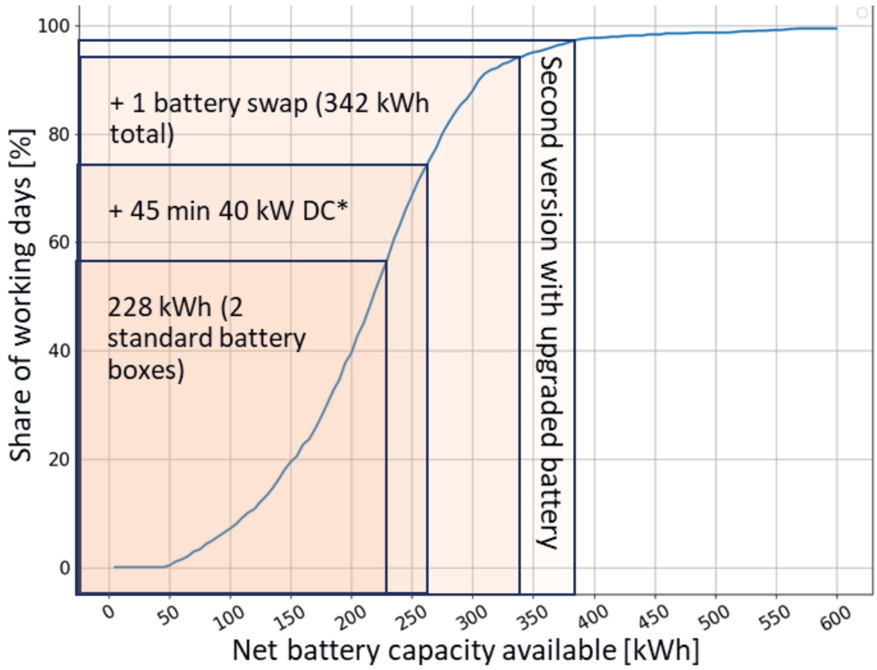

Figure 2: Relation between available energy in kWh and the share of working days during monitoring that could be fulfilled with this amount of energy

For machines running long hours, there is less time left to charge overnight. Figure 3 illustrates this. After an average working day, the DX165W needs approximately 12 hours to charge back to 100% state of charge, when connected to a 22 kW AC charger. After a 10-hour working day this is 15 hours, in other words impossible to sustain in a 24-hour day. On a side note, the machines can be charged using two 22 kW plugs simultaneously.

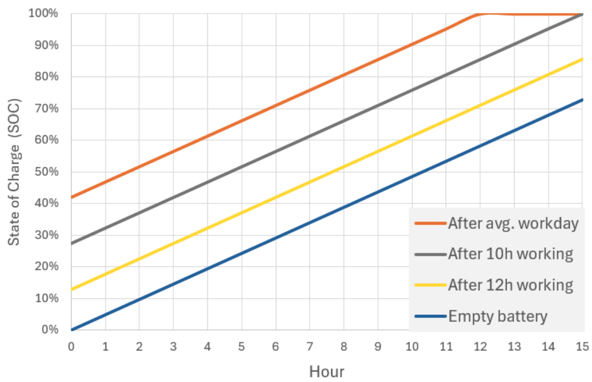

Figure 3: State of charge during charging overnight as a function of the depth of discharge at the start (22 kW AC)

More results can be found in the monitoring report [2] (in Dutch).

3.3 Avoided emissions

To determine the emission and energy savings by an electric machine, a comparative test was conducted of two sets of machines: diesel vs. electric, 17t and 35t. The test days were kindly hosted by the SOMA vocational school for infrastructure in Harderwijk. The electric machines were fitted with additional high frequency data loggers. Emission measurement equipment and data loggers were fitted to the diesel powered machines, see Figure 4. The two leftmost systems were developed in-house by TNO.

Figure 4: Measurement equipment; left: SEMS CAN/sensor data logger, middle: portable NO_x emission measurement system, right: portable particulate matter measurement system.

The machines were operated according to a test program, consisting of cold idle, loading a dumper, dig a ditch and close it (25 m), level a square of 25x25 m, drive in second gear (only mobile excavator), and warm idle.

For each liter of diesel consumed, both electric machines required approximately 4.1 kWh of electricity at the plug (AC charging losses are estimated at 15%). The NO_x emissions of the Stage IV machines tested were approximately 0.5 and 1.5 g/kWh for the 17-ton and 35-ton machine. Note that this is heavily influenced by the duration of the test, and not representative for an entire working day.

A model was made to predict Stage V tailpipe emissions, using the load profile from the monitoring data and the EMMA-MEPHISTO model [3]. The contractors have avoided the emission of approximately 115 kg of NO_x per machine per year, as well as 31 tons of CO_2 per machine per year (assuming Dutch average electricity mix 2023).

4 Results: Total Cost of Ownership (TCO)

4.1 Introduction

The purpose of this analysis is, on the one hand, to increase understanding for policymakers and potential clients about costs of deploying electric construction equipment. On the other hand, it provides insight for entrepreneurs considering the purchase of an electric excavator.

The costs analysis was updated for this paper, reflecting the 2024 situation in terms of purchase price and subsidies.

4.2 Common results

The analysis shows that currently the TCO of electric excavators is still significantly (34 - 42%) higher than that of a comparable diesel. See figure 5 for the TCO comparison for both machine types. These electric machines, including existing purchase subsidies and investment deduction schemes in the Netherlands, are still far from competitive. This means that the deployment of electric construction equipment requires additional financing from clients.

The reason for this large difference in TCO can largely be explained by the early stage that the market for electric construction equipment is currently in, especially internationally. It is expected that the scaling up of production capacity and further development of machines in the longer term will have a downward effect on the TCO of the electric machine, narrowing the gap with diesel.

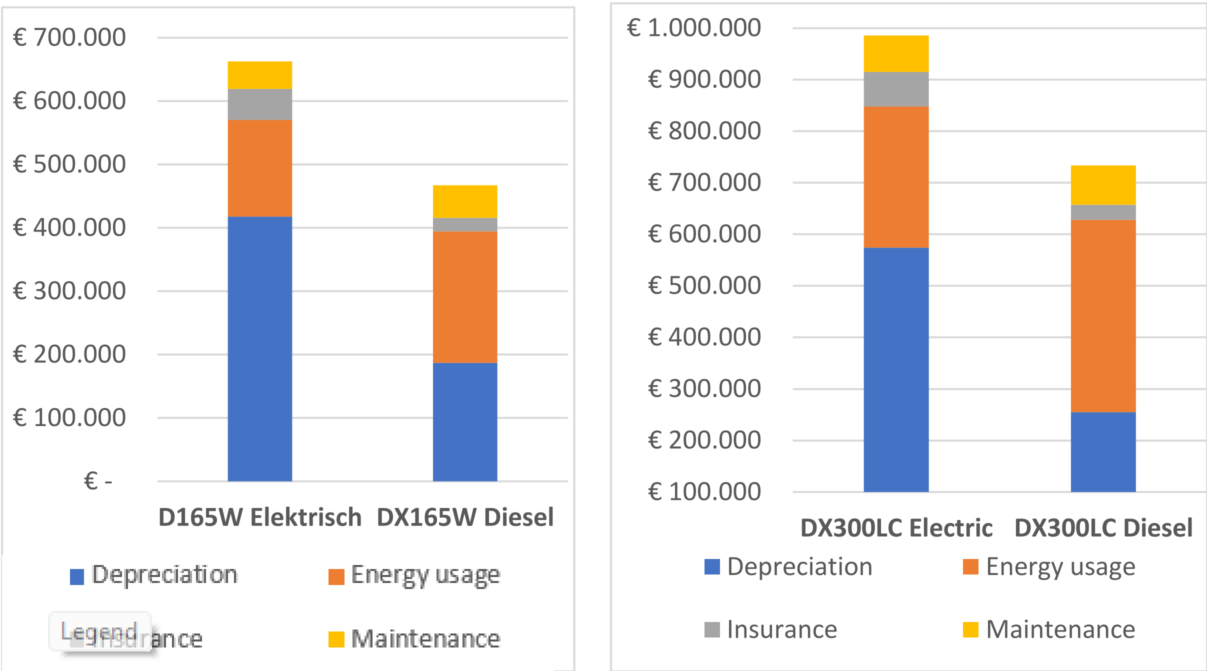

Figure 5: TCO comparison Diesel and Electric for two types of excavators

The utilisation of the machines affects the TCO of both electric and diesel. This is illustrated in Figure 6. The larger the deployment, the smaller the difference between the two becomes, but even when tripling the standard deployment, the TCO of the electric machine remains higher. Looking at Dutch incentives, the subsidy on the purchase of electric machines is significantly reduced compared to 2023. With purchase costs of the machine certainly not reduced, this means a significant deterioration in TCO compared to 2023. The analysis shows that the combined subsidy rate (MIA and SSEB purchase, available in the Netherlands) needs to increase by a factor of 2.5 for a competitive TCO for electric.

The TCO takes into account 0.35 €/kWh for the total cost of charging the machines. However, practice shows that the cost of charging varies quite a bit and it has a significant impact on the overall TCO of electric machinery.

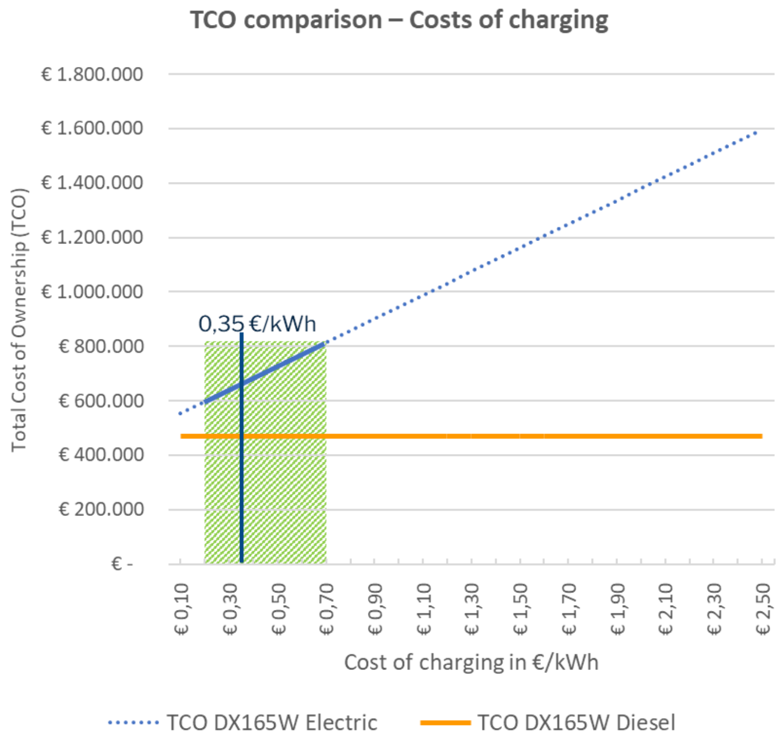

Figure 6: TCO comparison Diesel and Electric and influence of deployment

Figure 7 shows some practical examples of charging methods used in the project, and the paid rates. No conclusions can be drawn from these as to the most appropriate or average cost per charging method. This depends very much on the specific situation of the work and underlying factors. However, the examples do show that there is a large variation in charging costs between different methods. Here, proximity to a grid connection is an important factor in keeping costs down. In cases where no grid connection is available near the site, solutions such as swappable batteries or mobile energy storage containers should be used. The purchase costs of these assets and the logistics costs add to the overall cost. For larger, long-term projects this can be organized in a way that the additional cost of charging remains relatively low. For shorter-term projects, i.e. if swappable batteries or mobile energy storage containers are only used for a few weeks, the costs of charging will be significantly higher.

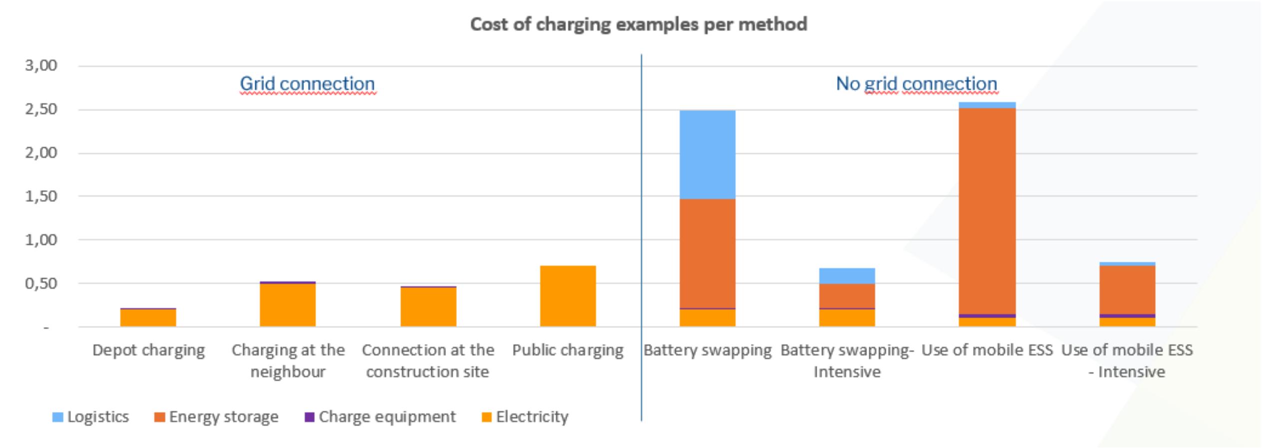

Figure 7: This comparison of costs by charging methods is based on examples. The final cost per charging method is highly dependent on the specific circumstances and thus may vary

Another important aspect to highlight is that the higher power demand and the relative immobility of tracked excavators requires different charging solutions than those employed for wheeled excavators.

The report contains more elaborate results, including findings specifically relevant to clients in the construction industry.

5 Conclusions

The following conclusions can be drawn:

- The electric excavators have been successfully used in the project “Construction Site of Tomorrow”.
- The energy consumption per hour is reasonably comparable among the different use cases.
- The number of operating hours per day varies widely. It has been proven to be possible to run double shifts, even with the limited battery capacity of the first generation batteries when making use of the battery swap system (and good planning). Using the upgraded batteries of 380 kWh makes this even easier.
- The grid connection on the construction site has to have sufficient capacity to be able to charge the machines overnight, and if necessary separate swapped out batteries during the daytime. In the case of long working hours it can become critical even with 2x22 kW (3-phase 64A per machine).
- The comparative emission measurements point at expected emissions reductions of around 21 tons of CO_2 and 114 kg of NO_x per year for the mobile excavator, and 34 tons of CO_2 and 202 kg of NO_x per year for the larger tracked machine.
- When replacing a diesel machine by an electric one, it can be expected that 4 kWh from the grid is needed for every liter of diesel consumed.
- The TCO of electric excavators is considerably higher (34-42%) than that of comparable diesel excavators, given the Dutch situation and the assumptions made.
- Upscaling and technological developments will have a positive impact on the TCO of electric machines in the long term.
- The costs of charging is very much dependent on the local situation. A grid connection is the most cost effective. If not available, energy storage and/or logistics give rise to higher costs.
- Charging requires organisation and planning ahead. It is attractive in case of long-running projects and the use of multiple machines.

Acknowledgments

List acknowledgments here if appropriate.

For bibliography, please use the attached bst file or format as follows:

References

[1] W.Christiaens et. al: Economische Analyse Boutplaats van Morgen; https://www.fier.net/projects

[2] Zult, M., Gijlswijk, R. van, and Mark, P. van der, October 2024: De Bouwplaats van Morgen: Resultaten monitoring elektrische graafmachines, TNO report 2024 P11947; https://publications.tno.nl/publication/34643295/humX67IH/TNO-2024-P11947.pdf

[3] Dellaert, S.N.C. et al., 2023: EMMA – MEPHISTO model – calculating emissions for Dutch NRMM fleet, TNO report 2023 R12643

Presenter Biography

René van Gijlswijk is researcher sustainable mobility, specialised in acquiring insight in the environmental effects of zero emission vehicles and machinery by means of monitoring and data analysis. Furthermore he has a background in life-cycle assessment. Besides conducting policy advice studies, he is active in Green NCAP, aiming to provide independent information on the real world environmental performance of vehicles to citizens and to promote the development of clean and efficient vehicles.