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Smart charging of battery-electric construction machinery at construction sites; A case study in the municipality of The Hague.

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Executive Summary

This paper investigates smart charging strategies for battery-electric construction machinery (non-road mobile machinery, NRMM) through a case study of a large-scale housing project in The Hague, Netherlands. The study develops a methodology to estimate energy demands and simulate charging profiles during various construction phases. Using a combination of smart charging and temporary battery storage, the paper demonstrates that peak grid loads can be significantly reduced—by up to 46%—compared to conventional charging strategies. Simulations reveal that grid limitations, especially during early construction phases, can be overcome with optimized load management and supplemental battery systems. The findings highlight the importance of smart charging infrastructure and energy planning in enabling the transition to zero-emission construction practices. This research contributes to the practical implementation of electric NRMM in urban construction projects, addressing one of the key bottlenecks in decarbonizing the construction sector.

Keywords: Off-road & Industrial electric vehicles, Modelling & Simulation, Energy management, Energy storage systems, Electric vehicles

1 Introduction

Non-road mobile machinery (NRMM) contributes approximately 9% to CO2 emissions in the Netherlands (1). Emission control and regulation of construction equipment are already in place in many countries and urban areas (2). The Netherlands has set ambitious goals for significant emission reductions in the construction sector, supported by both incentivizing and regulatory measures (3)(4). Zero emissions are mandated for 13% of building projects within the residential and commercial sector (5). In contrast to the development of electric vehicles, the electrification of construction machinery is still in its infancy (6). However, the transition to electric power for these machines is inevitable, given the increasing demands for drastic reductions in greenhouse gas emissions.

Despite the rise of zero-emission NRMM, several barriers to full scale adoption have been identified. The most significant challenge for the electrification of mobile machinery is the availability of charging infrastructure and sufficient grid capacity at construction sites (7)(8)(9). These machines require high power capacities to operate effectively while often at construction sites only a limited power supply is available. The problem with the charging profiles of electric construction equipment is also mentioned by other research conducted about the electrification of NRMM (10).

This paper explores the potential for smart charging in combination with temporary energy system solutions at construction sites, which could manage energy demands more efficiently without compromising the operational availability of mobile machinery. This paper develops and tests a methodology to estimate the charging profiles during different phases of the construction depending on the type of construction work.

Using this charging profile net impact mitigation strategies such as smart charging or the use of static and mobile batteries is assessed.

To analyse the suitability of the different strategies for charging electric construction equipment, a general methodology is developed and applied to a case study. The case study is a construction project, named "Maestro", where 388 housing units are built in The Hague. The project began in 2023 and is scheduled for completion at the end of 2025. Although the construction project was not executed using zero-emission methods, this study assumes that all work is carried out with zero-emission equipment. This assumption was made in order to simulate and evaluate charging strategies for a fully electrified construction site, as is expected to become standard practice in the future.

2 Related works/state of the art

2.1 Development of electric non road mobile machineries

In this paper we will work with the following definition of NRMM: Any mobile machines, transportable equipment, or vehicles with or without bodywork or wheels, not intended for the transport of passengers or goods on roads, and includes machinery installed on the chassis of vehicles intended for the transport of passengers or goods on roads (11). The fleet of mobile machinery in the Netherlands comprised approximately 43,000 machines in 2021, with excavators and wheel loaders accounting for more than half of that number. (7). The electrification of these machines is still in its early stages, and reliable data on the number of electrified units is not administrated by the government. Due to the challenges in mapping the total fleet in the Netherlands, only data on mobile machinery in the Netherlands are provided, without reference to the share of electric mobile machinery in Europe or worldwide.

Mobile machinery can be retrofitted with an electric powertrain combined with a battery. Retrofitting is advantageous as it extends the lifespan of machines and reduces greenhouse gas emissions (12). The advantage of factory-produced mobile machinery is that it can be designed according to market demands. However, the full electrification of mobile machinery still faces technical limitations, such as power capacity and minimum operational runtime (10). In the short term, hybrid machines may therefore also be a suitable solution to meet operational requirements (13).

The transition to battery-electric NRMM presents both technical and economic challenges. To date, the economic viability of battery-electric NRMM remains uncertain, primarily due to the high cost of batteries, which limits the ability to power a machine for a full eight-hour workday, regardless of its size (14). Nevertheless, interest in full vehicle electrification is growing, and recent studies have begun to explore the cost structure of electric powertrains in heavy-duty vehicles more thoroughly. For NRMM, the availability and design of charging infrastructure play a critical role in both operational performance and total lifecycle costs (6).

In addition to financial constraints, the current market availability of heavy-duty electric machinery is very limited. In contrast, small- and medium-sized electric machines are more widely available (7). This study focuses exclusively on fully electric mobile machinery, as these are expected to play a central role on construction sites in the future.

On a global scale, the demand for electric mobile machinery remains limited, making the production of electric equipment less attractive for manufacturers. In the Netherlands, this has led to delays in evaluated pilot projects involving the deployment of zero-emission equipment (15). However, major manufacturers (Volvo, Caterpillar and Liu Gong) of mobile machinery have already introduced their first machines with electric powertrains to the market (16).

2.2 State of the art of charging solutions

The charging demand of electric mobile machinery at construction sites can be met through multiple charging solutions. Since charging electric mobile machinery is still relatively new, this section discusses the state-of-the-art charging solutions. Twynstra Gudde has listed the possible charging strategies available for charging electric mobile machinery at construction sites, this is in line with the report by TNO about options for charging at construction sites (17)(18). Ramberg & Levin also defined a similar schedule for charging heavy duty electric vehicles (19). In Figure 1, several charging strategies are categorized. Existing assets, grid connections, or mobile charging solutions can be used to supply power to electric NRMM. The use of existing infrastructure is preferred, as it maximizes the utilization of current capacity. Additionally, electric NRMM can be charged via the grid connection that will be developed for future housing units. Finally, batteries can also be deployed to provide supplementary charging capacity. Figure 1 presents examples for each type of charging solution, with the grid connection categorized into large and small connections. In the Netherlands, small grid connections typically have a capacity of up to 3x80A.

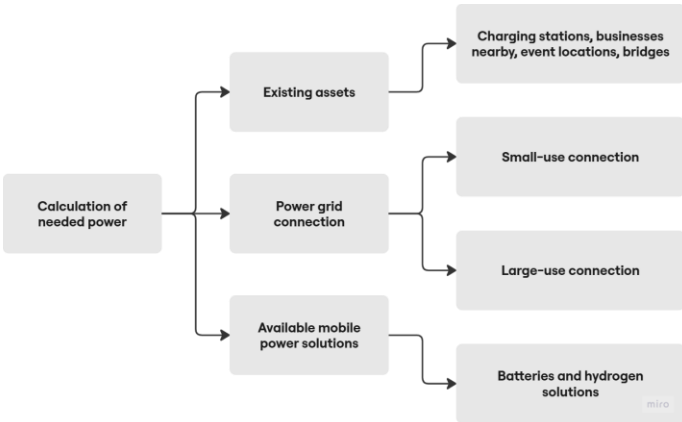

Figure 1 : Overview of charging strategies for charging NRMM

Several projects in the Netherlands involving electric mobile machinery have been monitored and evaluated. In one of these projects, charging plazas were used for recharging electric mobile machinery. These charging plazas were established at strategic locations, however, their usage proved challenging as the distance to the charging plazas required substantial energy consumption by the equipment (15).

Despite advancements in battery technology in recent years, heavier machinery cannot yet operate for an entire workday on a single charge during intensive tasks. In such cases, interchangeable batteries or fast-charging facilities are required to recharge equipment within a short period (e.g., during lunch breaks). In the De Groene Boog pilot project, 90 kW fast-charging facilities have been implemented via direct grid connections. However, a fixed high-power connection must align with local grid capacity constraints (15). Additionally, Lajunen conclude that fast-charging solutions are crucial to ensure the operational availability of NRMM Lajunen et al (6). Recently, fast and high-power charging solutions have been introduced, particularly for electric city buses (20).

According to Chergui, the future of charging non-road mobile machinery lies in transportable EV charging stations that can be temporarily installed on construction sites (21). Chergui also emphasizes that these stations must be customized to meet the specific requirements of the worksite, such as charging power capacity. A key prerequisite for this charging solution with transportable EV stations is the availability of a grid connection with sufficient power supply, which depends on the available local transmission capacity of the electricity grid.

3 Methodology

This chapter describes the method used to generate the research results. Figure 2 shows an overview of the research design, with each step explaining which method is applicable. In section 3.1 the content of the research design is discussed. The methodology is created as generic approach which contains generic conclusions which then can be applied to a case study to calculate the specific needs of a construction site and how different charging solutions could work at this site.

3.1 Research design

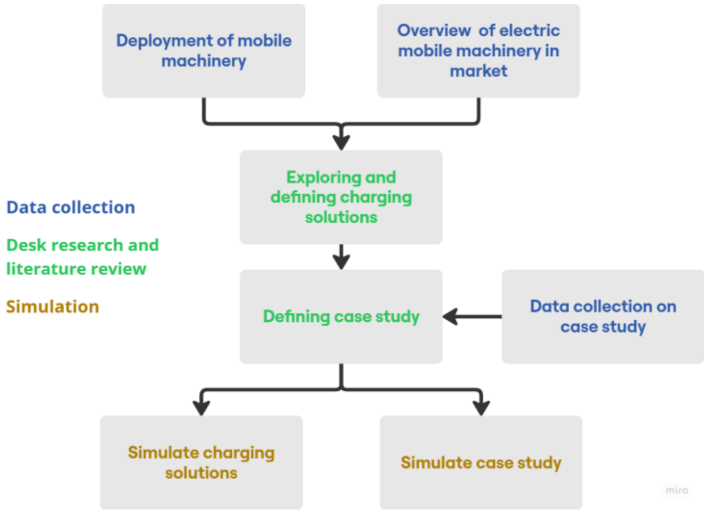

Figure 2 : Research design

Figure 2 provides an overview of the methodology followed in this research. The first part of the research focuses on a generic level data on the deployment of fossil fuel driven mobile machinery at construction sites. This data is gathered alongside data on available electric mobile machinery at the time of writing in the market. This allows for a comparison of the energy demand at a construction site and how capable currently available electric NNRM is to fulfil this energy demand.

The second part of the research focuses on supplying this energy demand. This is done by calculating the energy need and power profile at a case study site. Through simulation of different charging strategies at the case study conclusions are drawn at a more general level on the opportunities that these charging strategies may provide.

3.1.1 Data collection on energy demand

The energy supply on a construction site relates to the charging infrastructure (availability of grid connections) and alternative energy sources, such as battery containers. Energy demand is related to the deployment of mobile machinery during construction projects and the extent to which these machines consume energy for their operations.

For the collection of data on the use of NRMM the following data are a minimum requirement for the estimation of charging profiles at a construction site: the type of machinery deployed, engine power required per machinery, and the deployment of NRMM in which phase of the build and the expected number of hours to be deployed on the construction project. These variables allow for an estimation of energy use per vehicle per working day. Furthermore, in the Netherlands, obtaining a construction permit requires the submission of an AERIUS calculation, which assesses the nitrogen emissions of the respective construction project. An AERIUS calculation includes data on the estimated use of mobile machinery, specifying engine power and operating hours within the project. The information from these calculations is collected and used as input for the development of the simulation model and the categorization of different types of construction projects.

To allow for a calculation based upon deployment of electric NRMM a database of available electric machinery has been set up. Through an online search, an overview has been compiled of electric mobile machinery currently available on the market as of April 2025. Relevant specifications of these machines, such as operational power, battery capacity, and charging capabilities, have been included. This database allows for a per project calculation of the necessary required charging demand. This dataset can be found at https://doi.org/10.5281/zenodo.15337088.

The overview of electric NRMM with technical details is also collected by online research,. Details were found at the websites of the original equipment manufacturer or from technical brochures about the NRMM.

Table 1 : Variables of collected data about deployment of NRMM in construction projects

Variable	Unit	Description
Construction project name	-	Name of the project
Housing units build	-	Housing units includes ground based houses and apartments.
Building phase	-	The phase of the construction projects where the NRMM is deployed.
Type of NRMM	-	The category name of the NRMM.
Engine power	kW	Maximum engine power of the NRMM
Working hours	hours	Amount of hours deployed in the project

Table 2 : Variables of data about specifications of electric NRMM

Variable	Unit	Description
Name of NRMM	-	
Type of NRMM	-	The category name of the NRMM
Weight	Kg (tons)	Weight of the NRMM
Engine power	kW	Maximum power of the engine
Capacity of battery	kWh	Electric battery capacity in kWh
Charging power (regular)	kW	Specification of the charging power of the battery in kW
Charging power (fast)	kW	
Operation time	Hours	Possibility to operate with 1 full battery before need to recharge

3.1.2 Data collection and approach for energy supply at the construction site

The methodology for a charging profile requires two steps. First the required energy per day is calculated on the basis of the maximum power of each vehicle. Currently, little data is available on the actual energy use of electric NRMM. Only a single case study showed that ~25% of maximum power of the vehicle was used on average during a 8-hour workday (22). To obtain further insight, data on the building projects in the Netherlands was used. In 6 projects emission calculations also included fossil fuel use in Liters and working hours.

To calculate the energy use per day it was assumed that diesel NRMM have an efficiency of 30% (23). Diesel has an equivalent energy content of 9,8 kWh/Liter. An efficiency of 95% for electric NRMM was assumed.

$$E_{day} = \frac{\frac{Diesel\ used}{working\ hours} * E_{Diesel} * 9{,}8 * 8}{E_{Electric}} \quad (1)$$

The energy use per day was compared to the maximum power of the vehicle. An analysis of the deployment of 49 vehicles showed an average energy use of 30% of the maximum engine power of the vehicle. To calculate the required battery capacity of electric NRMM a 8-hour workday is assumed without stops. The required battery capacity is compared to the actual battery capacity in currently available vehicles.
Charging is done outside working hours within the base case maximum charging power from the moment the vehicle is plugged into the charging station.

The calculation of different charging strategies and required grid loads is done using mixed-integer optimisation which is applied through the Gekko optimisation suite. A non-dynamic steady state optimisation is applied for the power demand of a single day. Optimisation functions include minimum required time (to simulate basic charging profiles) and the minimum peak power required (to minimise the necessary grid connection which is the main constraint). In scenarios that include a battery the battery size varies between 0 and 1200 kWh and the power of the battery with a C-rate of three.

4 Results

4.1 Descriptive statistics

A total of 94 construction projects from the Netherlands were analysed, involving the deployment of 744 units of NRMM. The projects were classified as small, medium, or large based on the number of housing units constructed. This classification follows the same categorization as used by Topsector Logistiek (24). Small projects involve the construction of fewer than 30 housing units, medium-sized projects include between 30 and 100 units, and large projects consist of more than 100 housing units. The NRMM themselves were categorized according to engine power, using the classification system adopted by the SEB program in the Netherlands (3). See Table 3 for the classification of the NRMM. Figure 3 illustrates the distribution of NRMM deployment across the different project categories. It reflects the number of recorded observations, rather than the technical specifications of the equipment.

Table 3 : Categories of NRMM based on engine power

Category	Engine power
Mini	< 19 kW
Small	19 – 56 kW
Medium	56 – 130 kW
Large	130 – 560 kW
Extra Large	> 560 kW

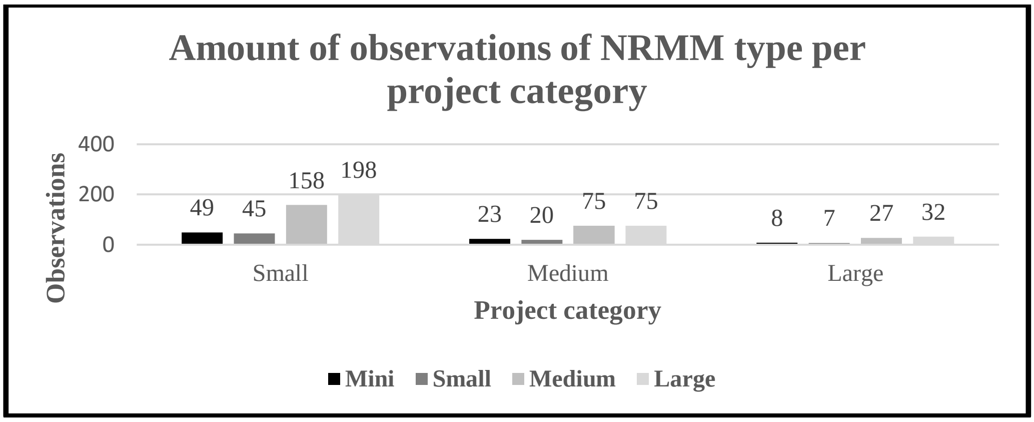

Figure 3 : Overview of observations from the collected data

4.1.1 Conversion factors: Diesel to electric

A total of 71 electric types of construction equipment were collected, with the majority consisting of excavators and wheel loaders. In the overview of available electric NRMM, the most relevant technical variables were charging power and battery capacity. However, many technical brochures lacked complete information regarding these variables. In particular, data on charging power was often missing.

To estimate the battery specifications of conventional machinery in the case study, battery capacity was inferred based on known engine power values. The calculated conversion factors are shown in Table 4, these factors are derived from the available collected data.

Table 4 : Conversion factors for NRMM specifications

Conversion factor	NRMM	
Engine power -> Charging power	Mini/small	0.28
	Medium	0.23
	Large	0.12
Engine power -> Battery capacity	Mini/small	0.72
	Medium	0.71
	Large	0.65

4.1.2 Charging power of electric NRMM

The charging power of electric NRMM is often not clearly specified in the available technical brochures. However, the most frequently listed charging power levels in the collected data are around 3.7, 7.4, 11, and 22 kW. These values correspond to standard charging capacities for electric vehicles using alternating current (AC) chargers, such as the Mennekes Type 2 connector. In addition, some NRMM models offer the option of fast charging via direct current (DC) chargers, specifically using the CCS2 standard. The information available on charging power serves as a useful input for converting conventional NRMM into electric variants for the purposes of this case study.

4.2 Case study

4.2.1 Characteristics of the case study

The case study used in this research to illustrate a future construction site where NRMM is electrically charged is the "Maestro" project. This construction project, located in The Hague, involves the development of 388 new housing units. The site previously hosted an elderly care facility, which has been demolished to make room for the new development. Within the case study it is assumed that all conventional NRMM with combustion engines are replaced by electric variants, in line with the ongoing electrification trend in the construction sector.

4.2.2 NRMM deployed in case study

The specific deployment of NRMM for the "Maestro" project is presented in Table 5 which includes all relevant variables. The data has been obtained from the AERIUS calculation for the project (25). The energy consumption in kWh per hour is calculated using formula 1, with the maximum engine power as the input parameter. Maximum charging power and battery capacity are derived using the conversion factors listed in Table 4. The final column indicates the required battery capacity to support an 8-hour workday, based on the estimated energy consumption. Static equipment such as generators, construction lighting, and site cabins for construction personnel are excluded from this table.

Table 5 : Deployment of NRMM in the case study project "Maestro"

Building phase	Type of NRMM	Max engine power (kW)	Energy use (kWh/h)	Charging power max (kW)	Battery capacity current models (kWh)	Battery capacity 8h workday (kWh)	Max overnight charging 15h (kWh)
Building preparation	Crawler excavator	230	67.2	27.6	149.5	537	414
	Excavator	200	58.8	24.0	130.0	470	360
	Wheel loader	100	30.9	23.0	71.0	247	345
	Crawler excavator	230	67.2	27.6	149.5	537	414
	Vibratory plate	10	5.7	2.8	7.2	46	42
Construction	Geothermal drilling	250	72.7	30.0	162.5	582	450
	Mobile crane	270	78.3	32.4	175.5	627	486
	Excavator	150	44.8	18.0	97.5	359	270
	Piling rig	240	69.9	28.8	156.0	560	432
	Tower crane 1*	-	-	-	-	-	-
	Tower crane 2*	-	-	-	-	-	-
	Crane Spiering*	-	-	-	-	-	-
	Aerial work platform	20	8.5	5.6	14.4	68	84
	Wellpoint pump*	20	-	-	-	-	-
	Concrete pump truck	20	8.5	5.6	14.4	68	84
Site finishing	Vibratory plate	10	5.7	2.8	7.2	46	43
	Wheel loader	100	30.9	22.9	71.0	247	344

The construction phase is important because it affects how many NRMMs need to be charged simultaneously. Charging all machines at the same time can create problems on the construction site. The available grid connection is often not strong enough to charge all NRMMs to the desired state of charge (SOC), which may lead to reduced uptime of the machines. Since maximum uptime (100%) is crucial for construction companies, it is assumed that all NRMMs are fully charged (100% SOC) before 7:00 a.m. This time is chosen because, in the Netherlands, construction work typically starts at 7:00 in the morning.

The equipment deployed at the construction site includes both dynamic and static machinery that draw from the available power supply. Not all equipment listed in Table 5 is dynamic in nature. Unlike dynamic equipment, which requires charging only when battery levels are low, static equipment consumes power continuously. Examples of static equipment include lighting systems, on-site worker accommodations, and tower cranes. For the purpose of simulation, the total load from static equipment is treated as a constant charging demand, while the charging of dynamic equipment is assumed to be flexible and distributed between the end of the working day and the start of the following workday.

4.2.3 Static machines/materials deployed in case study

In the "Maestro" project, there is also a demand for static power from various users on the construction site. The static equipment is indicated with an asterisk (*) in Table 5. During the construction phase, two electrically powered tower cranes are employed. These are connected to the grid via power cables. It is assumed that during working hours, the peak power demand of the tower cranes is reserved to ensure uninterrupted crane operations. The average peak power of a tower crane is estimated at 70 kW (26), this value is adopted as the required capacity for the tower cranes in this case study. The mobile crane used is manufactured by Spierings; however, the specific model is not indicated in the NRMM deployment overview. Therefore, the K487-AT3 eDrive & eLift model is used as a representative example. This crane operates fully electrically and is connected to the grid with a continuous power demand of 22 kW during operation (27). Consequently, the three cranes employed during the construction phase collectively draw 162 kW from the grid during working hours.

The remaining static power demand on-site is not explicitly specified in the case study. Construction lighting and personnel offices are assumed to have a separate grid connection of 3×35A and are therefore excluded from the definition of static equipment. Only the groundwater dewatering pump, with a power demand of 20 kW, is included in the simulation of the total charging power profile of the construction site (25). The dewatering system is assumed to operate continuously.

4.2.4 Overview of grid connections at constructions sites in the Netherlands

A common characteristic of construction projects in residential and commercial construction is that they are frequently carried out in locations where connection to the power grid is not yet available. However, in renovation projects an electrical connection is usually already in place. In the Netherlands, construction companies and private individuals can request a temporary construction power connection, which will later be converted into a permanent power connection upon completion of construction activities. In the context of constructing a residential apartment complex, an estimation is made of the electrical power required to supply the future apartments. In the case study, a total of 388 apartments are being developed. Based on the Velander formula, the total load of the apartments can be calculated, which corresponds to the total capacity of the future grid connection (28). It is assumed that the full grid connection capacity can be utilized for charging equipment at the construction site. The maximum equivalent power demand per apartment is calculated using the following formula:

$$P_{max,eq} = \alpha * V_1 + \beta * \sqrt{\frac{V_1}{n}} \tag{2}$$

Where: $\alpha = 0.23 \times 10^{-3}$, $\beta = 0.016$, V_1 = Annual electricity consumption of a single apartment and n = Total number of apartments

In this study, V_1 is assumed to be 2,140 kWh/year, based on national household electricity consumption data in the Netherlands (29). This results in a total grid connection capacity of **206 kW**.

For large grid connections (>3x80A), long waiting times apply due to grid congestion in the Netherlands. Grid operator Liander in the Netherlands announce average waiting time of 1,5 year for new large grid connections (30).

4.3 Simulations

This chapter presents the results of the simulations. Four different scenarios were simulated to evaluate the feasibility of charging electric NRMM using the available grid connection on the construction site. Table 6 provides an overview of the simulation parameters that were kept constant across all scenarios.

Table 6 : Base line for all scenarios

Parameter	Description
Workday	8h
Battery capacity	The batteries of all the NRMM are able to operate a full workday
Deployment of NRMM	Deployment is the same in every scenario
Grid capacity	206 kW
Charging capacity	50 kW

The data on available electric NRMM shows that much of the equipment is equipped with an AC charging capacity of 22 kW. However, to recharge the large battery packs required to power NRMM throughout a full working day, higher charging power is needed. Therefore, it is assumed that all NRMM are capable of charging at 50 kW DC.

4.3.1 Regular charging

In the first scenario, the electric NRMM is charged using a regular charging strategy, meaning that equipment is plugged in immediately after working hours. The results for regular charging at the "Maestro" project with fully electric NRMM are shown in Figure 4. Without any form of load management, as is the case with regular charging, the resulting peak power demand exceeds the available grid capacity. This occurs during both the first and second phases of the project. In contrast, the site finishing phase involves significantly less equipment use and therefore does not experience any charging issues.

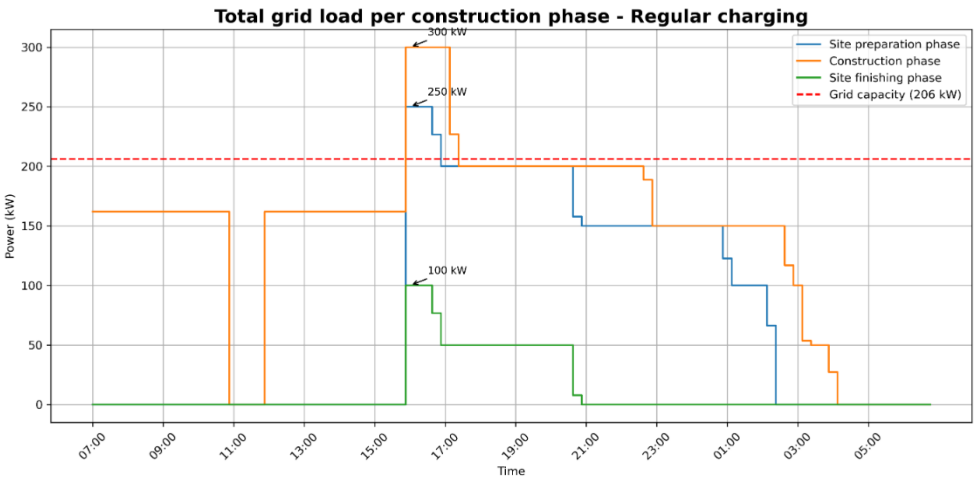

Figure 4 : Grid load for regular charging strategy

4.3.2 Smart charging

In the smart charging scenario optimised to minimise the grid connection, it is evident that the available grid connection on the construction site is sufficient to supply electricity to the electric NRMM. Smart charging is simulated by optimizing the peak load on the grid connection. During the construction phase, the required grid capacity is reduced by 46% compared to the regular charging scenario. For the site preparation phase, this reduction reaches 56%. The limiting factor in further reducing the net load is the power demand of static equipment, such as cranes. These static machines contribute up to 162 kW of peak demand during working hours, which is sufficient to fully charge the mobile NRMM during nighttime charging periods. Figure 5 presents the results of the simulation for the scenario involving smart charging of electric NRMM.

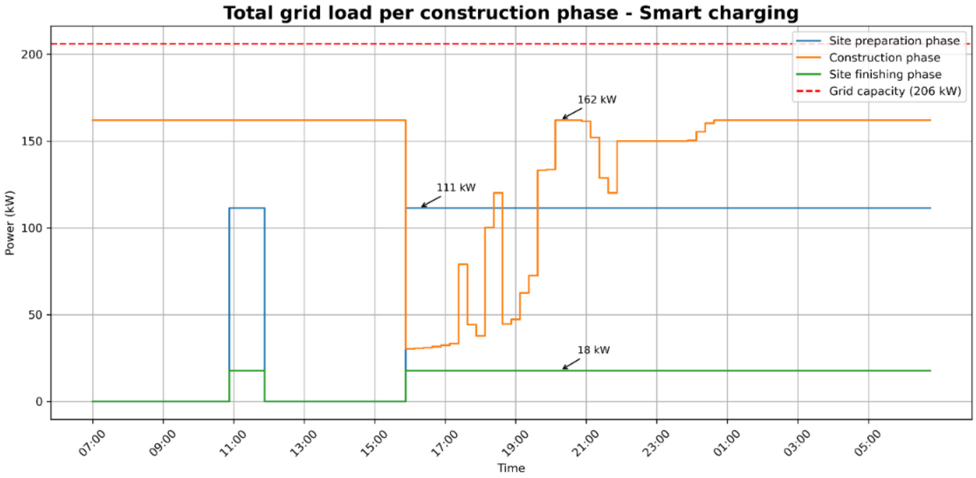

Figure 5 : Grid load for smart charging strategy

4.3.3 Regular charging with battery

To evaluate the effectiveness of battery integration, a simulation was conducted to determine the required battery size in relation to the available grid capacity. The simulation focused exclusively on the construction phase, as this period represents the highest power demand due to the operation of NRMM. In this scenario, it is assumed that NRMM is charged as quickly as possible following working hours, resulting in a substantial grid connection requirement of 300 kW. This demand is equivalent to the previously outlined scenario without battery support. In the scenarios battery size is differed and grid connections are minimized.
Figure 6 presents three strategies for charging the battery using the grid connection. The underlying principles for the 10%, 80%, and 100% scenarios are described in Table 7.

Table 7 : Description of charging strategies with battery at construction site

End of day percentage	Description of strategy
10%	Every day a full battery is delivered to the construction site.
80%	The battery is fully charged in the weekend to provide electricity throughout the week.
100%	Every day, the battery is charged up to 100% with the grid connection.

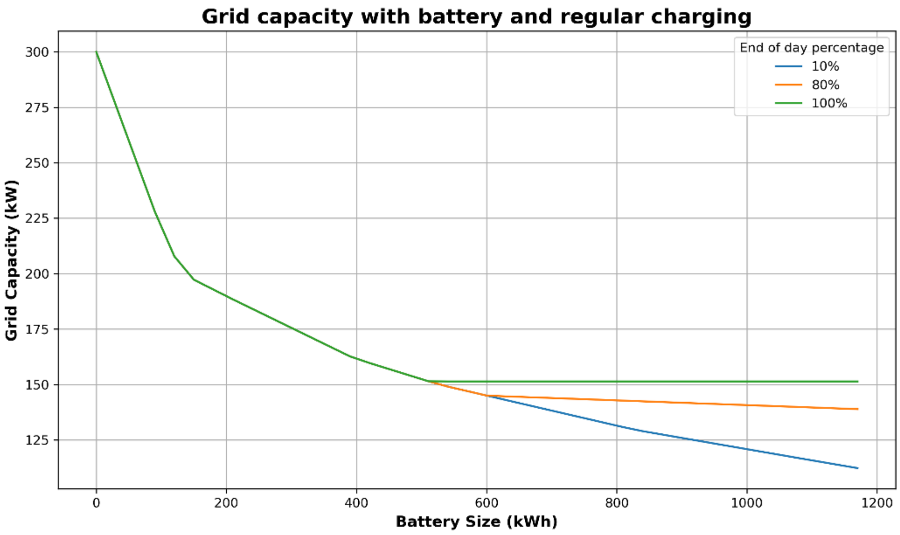

Figure 6 : Grid capacity vs battery size with regular charging in construction phase

The results in Figure 6 show that deploying a battery can sufficiently decrease the required grid connection. With smaller battery sizes the charging strategies do not differ as the battery mainly aides to support the fixed demand earlier in the day or during the peak charging. Further reduction of charging power at other times no longer reduced the peak power required. Only for larger battery packs the majority of energy required could be supplied by batteries that are swapped at the end of the day.

4.3.4 Smart charging with battery

In contrast to the deployment of the battery above, the charging of NRMM is also optimised in this simulation. This already reduces peak power by 46% at the start of charging. With larger batteries that are replaced by the end of the day smaller grid connections could be realised. Sufficiently large battery backs (>1500 kWh) could even lower demand to more readily available grid connection (3x80A = 55 kW) which could reduce waiting times for the grid connection.

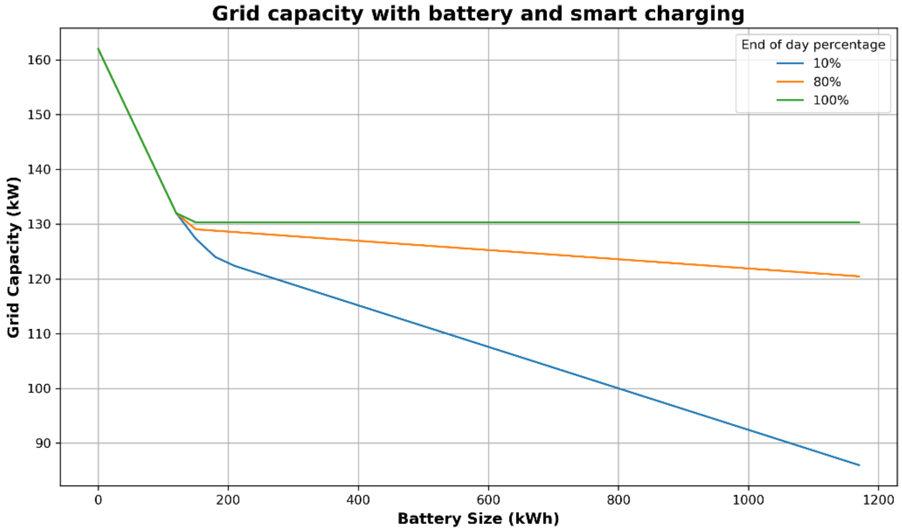

Figure 7 : Grid capacity vs battery size with smart charging in construction phase

5 Conclusion

Charging electric mobile construction equipment in the future will require the implementation of intelligent strategies. In the case study conducted in The Hague, the grid connection intended for the future residential units is insufficient to support the charging of electric NRMM that must operate for a full working day. However, the same grid connection proves to be sufficient when smart charging is applied. In fact, the required grid capacity can be reduced by up to 46% during the construction phase compared to regular charging. Application of a (swappable) battery storage unit could reduce the required grid capacity even further,

The case study represents a large-scale project according to the Dutch roadmap toward zero-emission construction sites, which also implies the availability of a relatively large grid connection during construction. Smaller projects may face grid capacity constraints more quickly, posing greater challenges for charging NRMM due to limited infrastructure. Grid limitations are frequently cited as a key barrier to the electrification of construction machinery.

At present, many electric mobile machines are unable to operate for an entire day without recharging, as current battery capacities are insufficient. Interim charging solutions are therefore necessary. Battery swapping is one such solution, and the market is expected to move in that direction, alongside the trend of increasing battery sizes. AC charging at 22 kW is inadequate to recharge the battery packs needed for full-day operation. Moreover, due to the substantial efficiency losses associated with 44 kW AC charging, it is advisable to equip machinery with DC charging capabilities of at least 50 kW as standard.

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