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SYSTEMATISATION OF THE TECHNOLOGICAL OFFER FOR ZERO-EMISSION NON-ROAD MOBILE MACHINERY

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Systematisation of the Technological Offer for Zero-Emission Non-Road Mobile Machinery

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Glossary

Non-road mobile machinery: Different criteria are used internationally to define which equipment is classified as non-road mobile machinery (NRMM). For this work, the European Union definition (EU Regulation No. 2016/1628) is adopted[1]: Non-road mobile machinery means any mobile machine, transportable equipment or vehicle with or without bodywork or wheels which is not intended for carrying passengers or goods on the road and includes machinery installed on the chassis of vehicles intended for the transport of passengers or goods on road.

Zero-emission machinery: The term “zero-emission” refers to machine that does not emit any air pollutants as a result of a combustion process. Only 100% electric and hydrogen technologies[2] comply with this characteristic. Note: For practical purposes, hybrid machinery has been included in this document as defined below.

Hybrid machinery: Hybrid technologies combine two energy sources. The most common are those that mix the use of electricity with the use of fossil fuels for their operation.

Some hybrid technologies have electric batteries and have an electric generator that allows the batteries to be charged when they are depleted during the operation of the machinery. In this case the external combustion engine is only intended to recharge the batteries.

Other hybrid technologies allow the machinery to operate at some intervals with an electricity source and when the electricity source is not available allow the machinery to operate on diesel.

Fossil fuels: They are a non-renewable source of energy and, due to their origin, contain large amounts of carbon. Their use as a source of energy is the main anthropogenic cause of air pollutant and greenhouse gas (GHG) emissions, which cause climate change. Fossil fuels used by NRMM include diesel, gasoline and natural gas.

Alternative, non-fossil fuels: There are other sources of energy, other than fossil fuels, that can also be used by NRMM. These energy sources are characterised by being renewable and having a lower impact on GHG emissions than fossil fuels. This group includes biogas and biodiesel, both produced from plant material such as bagasse, maize and oil palm.

[1] Regulation EU No. 2016/1628: REGULATION (EU) 2016/1628 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No 1024/2012 and (EU) No 167/2013, and amending and repealing Directive 97/68/EC.

[2] It is pertinent to consider that for machinery to be a greenhouse gas emission reduction solution beyond construction sites, green hydrogen would have to be used. The availability of this hydrogen will depend on the energy matrix of each country.

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1. Introduction

The study presented in this document was developed under the framework of the Climate and Clean Air in Latin American Cities (CALAC+) programme, implemented by Swisscontact and funded by the Swiss Agency for Development and Cooperation (SDC). Section 2 presents different international case studies on the use of zero-emission Non-Road Mobile Machinery (NRMM). The cases illustrate some of the main barriers to the use of these technologies, different alternatives that have been used to facilitate the projects and the advantages identified by the users of zero-emission NRMM.

Section 3 presents the result of identifying the zero-emission NRMM commercial offer. In this exercise, information was compiled by international parent companies, according to the lines of machinery available for the different sectors, and considering the offer in existing ultra-low emission and zero-emission technologies. The results of the technological offer are presented according to different characteristics such as end-use sectors of the machinery and size of the machinery available. Information on zero-emission machinery under development is also presented.

Section 4 provides an overview of different types of instruments that have been used at the international level to promote the use of zero-emission NRMM. The aim of this section is to present some of the alternatives that could be considered to accelerate the technological conversion of NRMM in the Latin American region.

Section 5 presents the final messages of the review conducted on the offer of zero-emission NRMM, use cases of the machinery and on the instruments identified globally to incentivize the use of zero-emission NRMM.

The results of this study include four annexes. Annex 1 presents a matrix with the technological offer of zero-emission NRMM, Annex 2 includes the image bank corresponding to the NRMM referenced in Annex 1, and Annex 3 is the compilation of the technical data sheets. Annex 4 shows a summary table of the case studies from the different countries organised by criteria of interest.

2. Case studies on the use of zero-emission NRMM

This section presents a review of international experiences in the implementation and development of zero-emission non-road mobile machinery (NRMM). This review seeks to identify barriers, advantages and opportunities in the implementation of NRMM in different contexts.

The case review was aimed at identifying the elements and different approaches that have been used globally to enable and promote the use of zero-emission NRMM. Seven pioneering case studies on the implementation of zero-emission NRMM at the global level are addressed, three of them in Latin America. These references in the use of zero-emission NRMM allow us to identify some of the favourable conditions for the introduction and widespread use of new technologies with lower air emission loads.

Table 1 summarises the technical criteria for machinery reported in the case studies.

Table 1. Summary of criteria selected for the case study review.

Case study country	Zero-emission NRMM end-use sector	Is information on the following aspects reported?				
		Charging infrastructure	Models	Power	Challenges	Advantages
Norway	Construction	✓	✓		✓	✓
California	Cross-cutting		✓	✓	✓	
Sweden	Mining	✓	✓	✓	✓	✓
Barcelona	Construction	✓	✓		✓	✓
Chile	Mining		✓	✓		
Peru	Mining	✓	✓	✓	✓	✓
India	Agriculture		✓	✓	✓	

Source: Own elaboration.

2.1. Oslo - Norway

Norway's greenhouse gas (GHG) emission reduction commitment is to achieve an emission level 55% below 1990 emissions by 2030. The goal for 2050 is for Norway to become a low-emission society, achieving a GHG reduction in the order of 90-95%, compared to 1990 (UNFCCC, 2020).

In the city of Oslo, different projects are being developed to reduce emissions from the building sector, which is responsible for 7% of the city's total GHG emissions. In 2017, the energy transition of the sector was initiated using sustainable biofuels. However, as this was not a solution to other impacts such as air and noise pollution, the city subsequently focused on the implementation of electric machinery as part of interventions to achieve zero-emission zones (Nasta, 2019a).

In 2019, different types of measures started to be implemented to support the entry of electric machinery. One of the main strategies was to boost market development through public procurement incentives. Other complementary actions have included support schemes such as incentives to invest in heavy duty vehicles and zero-emission machinery, commitment to building the necessary electric charging infrastructure to support electric machinery, cooperation through a closer relationship with industry, and funding for pilot projects (Nasta, 2019a).

Norway organised joint work between customers, builders, municipalities, research organisations, partners and stakeholder organisations to promote the development and manufacture of zero-emission construction machinery. In particular, work has been carried out with Norwegian construction machinery manufacturer Nasta, through public initiatives, funding and support programmes for the development of new zero-emission excavators (Nasta, 2019a).

In September 2019, the first construction site with zero-emission machinery started operating, using only electric machinery (see Figure 1). A prototype of the 9-tonne electric ZERON ZE85 with battery was used on Olav Vs Street and Klingenberg Street, together with a 17.5-tonne electric ZERON ZE160LC excavator with batteries and cable, the first to fully utilise the PeakShaver energy management system. PeakShaver is a system for managing peak demand and allows the machinery to be operated at maximum capacity with a conventional electricity power supply (Nasta, 2022c; The Explorer, 2022)..

It could be argued that as the type of NRMM needed for the site was identified, prototypes were electrified in order to be able to pilot where zero-emission machinery was not commercially available (CALAC+, 2022). Nasta was an important partner because of its experience in developing and converting internal combustion engine construction machinery to electric operation. The conversion procedure involved retrofitting the existing diesel vehicle with new powertrain components that used electric motors and drives to replace the combustion engine. This new powertrain included an energy storage system and a charging solution in place of the fuel tank (CALAC+, 2022).

Figure 1. Zero-emission construction site in downtown Oslo.

Source: (Construcción Latinoamericana, 2022).

The pilot construction project with electric machinery lasted one year. Significant improvements were evident in terms of noise generation and air emissions of gases and particulate matter. According to the operators, the electric machines worked in an equivalent way to diesel-fuelled machinery. Thanks to the use of electric construction machinery, 35,000 litres of diesel were saved in the pilot project and 92,500 kg of carbon dioxide (CO_2) were avoided, compared to what would have been generated by using conventional machinery. However, not all processes could be replaced by electric machinery, as in the case of the welding process, where conventional diesel technology continued to be used (Nasta, 2020).

Nasta modernised its construction machines by replacing diesel engines with ABB's electric powertrain. This brought significant advantages in terms of emission-free operation and noise reduction. ABB's electric powertrain solution ensures that the machinery withstands harsh environments, such as dust, humidity, strong vibrations and shocks. This development has been made possible by government support and the push for zero-emission construction sites, as customer demand for zero-emission machinery has increased as a result of this implementation. Nasta reports that it has undertaken dozens of electrification projects, and that the implementation of electric machinery has brought environmental benefits. A 24-tonne excavator typically consumes 18,000 litres of fuel per year, which produces an annual total of around 48 tonnes of carbon dioxide emissions. Following the upgrade, these CO_2 emissions are no longer produced, nor are sulphur oxides (SO_X). In addition, operators have reported that the electric machines are much more agile when it comes to digging (Nasta, 2022a).

Due to the success of the pilot project, one of the Municipality´s objective is that the works they carry out will be done with electric machinery and that in the next decade the zero-emission construction target will be met. To this end, a strategy combining best practices, public procurement incentives and modifications to construction permits has been proposed. This strategy relies on the purchasing power that the municipality has in public procurement construction projects (Bernard, 2022).

2.2. California - United States

The California Air Resources Board CARB, through Calstart[3] , aims to promote the use of clean technologies in the transportation market by providing services related to technology development, demonstrations, validations and evaluations that help fleet operators and governmental bodies to make decisions and implement new technologies and policies in on-road vehicles and NRMM.

CARB created the Beachhead model[4], which seeks to accelerate the market for zero-emission commercial vehicles, focusing initially on the sectors that are easiest to electrify in order to build a solid foundation in the supply chain that will enable further development in other sectors that demand higher volumes, availability and production of zero-emission equipment (Calstart, 2022b). The Beachhead model started with the electrification of light forklifts, gaining experience in terms of infrastructure, battery management and energy storage. Subsequently, at a second level, they moved into the tractor segment with application in air terminals and a third level has focused on medium-duty handling equipment. Currently, the programme is focusing its efforts on heavy lift and maritime handling equipment (Sokolsky, 2022). Figure 2 presents a schematic of the Beachhead model.

[3] Calstart is a US non-profit, non-governmental organisation that works with private companies and public entities, nationally and internationally, developing a network that connects nearly 300 members, including technology companies, transit operators, vehicle manufacturers, research institutions and government agencies, among other transportation stakeholders to overcome barriers to changes in the use of clean transportation technology, fuels and systems (Calstart, 2022a).

[4] According to Calstart (2022) the Beachhead model refers to a commercial strategy in which a secure initial position is gained and then used to achieve further progress (White Paper: The Beachhead Strategy: A Theory of Change for Medium- and Heavy-Duty Commercial Transportation). Likewise, the Corporate Finance Institute defines the Beachhead strategy as the strategy of pooling resources in a small area of the market (such as a product category or smaller market segment) to make it a stronghold before moving into the broader market or product categories. The Beachhead strategy allows a company to dominate small areas from which it can then move in and dominate the rest of the market. https://corporatefinanceinstitute.com/resources/management/beachhead-strategy/

Figure 2. Beachhead-CALSTAR model

Source: (Sokolsky, 2022).

For the Beachhead model, the total cost of ownership (including acquisition, operation and maintenance costs) of different types of vehicles and NRMMs was analysed. It was identified that for conventional diesel equipment, most of the total cost is related to the fuel used for its operation, while for electric equipment, the highest percentage is attributed to the initial acquisition cost, being the most important barrier for the sector to move towards zero-emission technologies (Sokolsky, 2022).

In response to what has been identified in this analysis and in order to accelerate the market and use of clean technologies, Calstart administers different programmes for the state of California. Among them is the Clean Off-Road Equipment Voucher Incentive Project (CORE). This project has seen an investment of over $1 billion in incentives for California NRMM users to purchase or lease zero-emission equipment currently available on the market (Sokolsky, 2022).

The CORE Program application process is done through a point-of-sale application. The State of California works with equipment dealers and distributors to provide fleet operators with a voucher to reduce the initial cost of the equipment. In this way, the CORE Programme offsets the higher cost of acquiring zero-emission technology and facilitates its delivery at the point of sale by minimising transaction costs for users.

In order to achieve its objectives, CORE is guided by the following principles (Sokolsky, 2022):

- Maintain the simplicity and straightforwardness of the process, enabling accelerated market transformation for clean technologies.
- Support CARB's long-term heavy-duty equipment investment strategy and drive fleet purchasing decisions and position zero-emission equipment on par with conventional equipment.
- Support the government's regulatory strategies and efforts.
- Avoid market disruptions caused by the unpredictable availability of funding.
- Support all state strategies that leverage financing for clean technologies.
- Promote full market uptake of clean technologies.
- Ensure equitable access to the programme for both small and large players.

Application to the programme is done through a few simple steps, which include selecting from the catalogue offered, the equipment that suits the user's needs and contacting an authorised dealer; and providing the dealer with the information required to make the application, and having the application sent to Calstart and CARB by the dealer. After this, the final stage is the approval of the application and the purchase of the NRMM using the voucher granted.

The following premises have been defined for the operation of the Programme:

- Any NRMM user in California is eligible to participate in the programme.
- The purchased machinery must be domiciled and operated in California for at least three years.
- Users of the machinery must submit activity reports for three years after purchase.
- The size of the fleet does not affect the eligibility for vouchers and users are not limited in the number of vouchers they can apply for.

Since its inception in 2019, the CORE Programme has made progress in the range of equipment categories available. The following options are currently available:

- Tractors for terminal use.
- Transport refrigeration units.
- Cargo-handling equipment.
- Airport ground support equipment: Cargo NRMM for airport use, wide-body tugs.
- Railway support equipment.
- Mobile and ground power units.
- Construction equipment: excavators, dozers, mini loaders, loaders, backhoes, mining equipment and other types of construction equipment.
- Agricultural equipment: harvesting equipment and agricultural tractors.
- Commercial harbour craft: fishing and excursion boats, ferries, tugboats, crew and supply vessels, barges, dredgers and other types of vessels.

It is important to mention that the initial acquisition vouchers are established according to the size of the equipment and the amount of emissions emitted by conventional counterpart machinery. Up to USD 500,000 is provided for the purchase of construction machinery and agricultural machinery, among other typologies (Sokolsky, 2022a) (see Figure 3).

Figure 3. CORE Programme: eligible equipment and amounts funded.

Source: (Sokolsky, 2022).

During the 2022-2023 period, the project has worked with 26 suppliers, 110 distributors and 127 types of machinery. In this period, 476 vouchers have been delivered, representing more than 125 million dollars, with 24.5% going to tractors, 24.5% to construction machinery and 10.5% to agricultural machinery (Sokolsky, 2022) (see Figure 4).

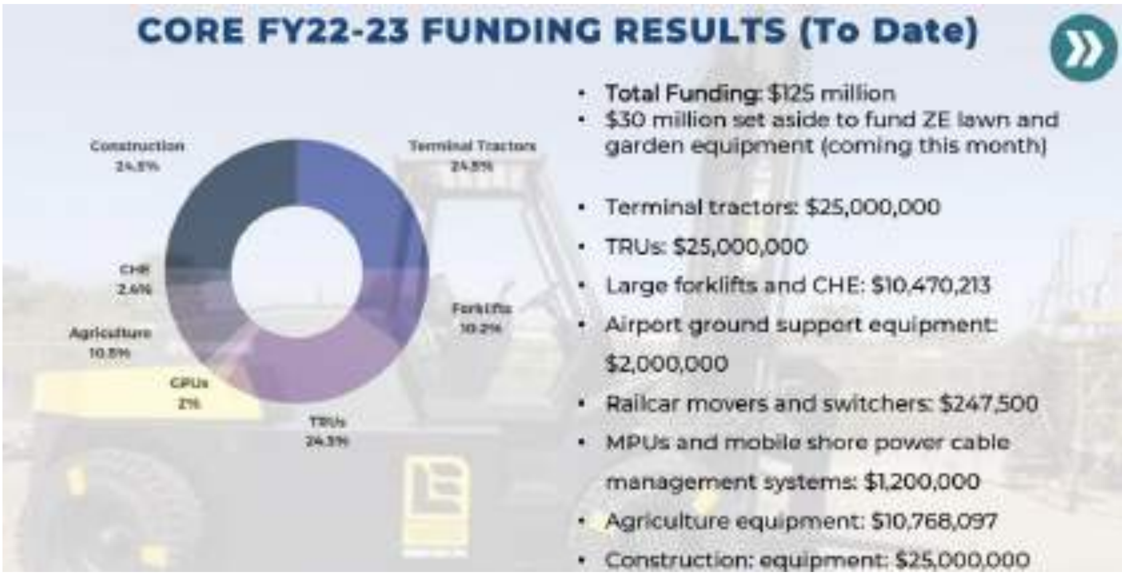


Figure 4. Results of CORE 2022-2023

Source: (Sokolsky, 2022).

2.3. Boliden - Sweden

Aitik, located in northern Sweden, is the largest open-pit copper mine in the country. Aitik works with some of the world's largest machines in continuous operation (Figure 5). A conventional truck consumes around one million litres of diesel fuel per year in the mine's loading operations. Boliden set out to pioneer high environmental standards in mining operations, and one of their strategies is truck electrification.

Figure 5. Loading operations at the Aitik mine.

Source: (Streamio, 2022).

During 2018 and 2019, a truck electrification project was carried out, in which a pilot was implemented with a trolley assist system for electrically driven mining trucks (Figure 6). The pilot project lasted two years. Four 795F AC trucks with an output of 3400 HP were electrified (Caterpillar, 2022a) and tested on a 700-metre trolley line. The trucks use electricity while connected to the trolley line and use diesel the rest of the time.

Figure 6. Cat trolley assist system for electrically powered mining trucks.

Source: (Streamio, 2022).

This implementation aimed to mitigate greenhouse gas emissions, reduce fuel costs and increase speed to achieve greater efficiency in mining operations. Due to the positive results of the pilot project, a decision was made in late 2019 to expand the project to a total of three kilometres of the trolley system, including the existing section, and to equip ten additional trucks with current collectors (Boliden, 2022).

The implementation of the trolley system significantly reduced emissions from diesel engines, as well as fuel consumption by substituting electricity during the most demanding part of the truck's duty cycle. The 700-metre line alone avoids the use of 800,000 litres of diesel per year per vehicle. Drivers perceive greater working comfort and a significant reduction in noise levels. Fuel costs have been reduced by 90%. This system of voltage trucks and trolleys manufactured by Caterpillar also provides advantages in terms of reduced capital costs for infrastructure and maintenance of power distribution (Boliden, 2022).

Productivity has also benefited from the operation of the vehicles. When operating with trolley assistance, speed on the grade increases by up to 100 percent compared to the diesel-only mode. Using a trolley, a loaded 795F can run at 28 km/h on a 10 percent physical grade with solid haul road conditions.

In the future, the expectation is to have 100% electric trucks with battery systems. With the current system there is a high cost of charging infrastructure that is only justified in parts of the mine where high production periods are expected. A technical challenge for battery-powered trucks is that they require more than 20 hours of heavy-duty operation per day, which is not yet feasible with existing batteries. Boliden's current trolley system has attracted the interest of many companies globally that hope to implement similar solutions in their fields of operation (Boliden, 2022).

2.4. Barcelona - Spain

Legislation in Catalonia provides for reducing GHG emissions to 55% by 2030, 65% by 2040, and finally 100% by 2050 compared to 1990 levels (European Parliament in Barcelona, 2022).

A reference case in GHG emissions mitigation has been the implementation of a pilot test, based on the public-private partnership between Barcelona City Council and *Aigües* de Barcelona together with Sorigué and Germans Homs, to use electric machinery in the renovation works of the water distribution network in Barcelona. In addition to mitigating GHG emissions, the pilot also aimed to reduce emissions of local pollutants and noise in the city's construction works. As part of the pilot, impacts on local and global emissions, energy consumption, costs, feasibility, impacts and efficiency of the machinery were analysed, comparing the conventional NRMM with the zero-emission NRMM (Valdéz, 2022).

The pilot was carried out in Balmes Street in July 2022 and later in Esplugues Avenue in August of the same year (see Figure 7). This lasted five weeks, during which an experiment was carried out to compare the performance of the same tasks using conventional diesel NRMM and electric NRMM (Valdéz, 2022) (see Figure 8).

Figure 7. Electrical machinery used in the pilot implementation of electrical machinery in Barcelona manufactured by WakerNeuson.

Source: (Wackerneuson, 2022).

Cuadro Sinóptico Maquinaria ZERO EMISSION

	Pisón (Rammer)	Bandeja Vibradora (Vibrating Shaft)	Cargadora ruedas (Wheel Loader)	Dumper	Excavator
Modelo	AP1840e	AS30e	WL20e (230)	DW15e	EZ17e
Tipo Batería	Ion-Litio	Ion-Litio	Plomo-Ácido	Plomo-Ácido	Ion-Litio
Tecnología baterías	BP1400-NCA	BP1400-NCA	AGM	3GEL	NCA
Capacidad Nominal (Ah)	28	28	230	300	500
Tiempo trabajo	60/45/35 min	80/80/60 min	2-3h	6-8h	5-7h
Tiempo de carga (100%)	390 (120)	390 (120)	6h	7h	4/7,5h
Enchufe Carga Standard					
Enchufe Carga Opcional			-	-	

Figure 8. Electrical machinery used in the Barcelona pilot.

Source: (Valdéz, 2022).

During the pilot, the electric NRMM was charged at Endolla Barcelona's electric vehicle charging points. The point used for charging the pilot's machinery was a point available for motorbikes and for this reason, it had low power. As a solution to the power availability, a complementary battery was used, which was recharged at the same motorbike charging point (Valdéz, 2022).

The pilot developers identified the following as the main issues (Valdéz, 2022):

- Absence of a local market in Catalonia for electrical machinery, so that machinery is not immediately available.
- High purchase prices for electric NRMM, as a result of low supply. Developers perceive that market prices for this machinery are not competitive.
- Smaller electric machinery has charging autonomy due to the implementation of batteries. Larger-scale machinery relies on charging points close to the pilot project implementation area.
- The manufacturer supplying the electrical machinery for the pilot projects was the German company WackerNeuson, who provided this machinery to Germans Homs, a company dedicated to the rental of machinery in Barcelona (Figure 7). An additional barrier that was identified is that there is no regulation that establishes the need, feasibility and promotion of the use of zero-emission machinery. According to the developers, this situation is influenced by the high prices of commercially available electric machinery. Electric machinery is on average between 30% and 70% more expensive than its diesel counterpart (Valdéz, 2022).

As first conclusions of the pilot project, the operators reported that the performance of the electric machinery is practically equal to that of conventional diesel-powered machinery. They perceived significant advantages in noise reduction with electric machinery compared to conventional machinery. In addition, working conditions were improved by the reduction in heat generated by the machines when switching from conventional to electric machines. With the measurements monitored by sound level meters, no significant difference was found in the noise levels emitted by the construction site; however, the researchers report that this result is due to the fact that the noise emitted was natural to the activity of the construction site and not the emission of the machinery. The pilot project showed that electric machinery consumes 10 times less energy than conventional machinery. Finally, the indicators of CO_2 and particulate matter emissions improved notably with the implementation of electric machinery (Valdéz, 2022).

The main stakeholders in the implementation of the pilot project envisage delivering a Protocol of Electrical Machinery Connections for the different existing energy infrastructures in order to incentivise the market and deployment of these new technologies (Valdéz, 2022).

It is interesting to note that the selection of the pilot project and the construction sub-sector where the project was carried out was based on the commercial availability of the machinery. In other words, the type of construction site where the pilot project could be carried out was analysed according to the electrical machinery available in Barcelona (Valdéz, 2022).

2.5. Codelco - Chile

Chile is leading Latin America in the deployment of regulations and strategies to meet the climate agenda targets. The country has a National Electromobility Strategy that establishes strategic axes, policies and goals aligned with the reduction of GHG emissions in transport. The goal for 2035 is to achieve 100% of sales of most vehicle categories to be zero-emission. For NRMM, sales of mining, forestry, agricultural and construction machinery with a power greater than 560 kW is intended to be zero emissions by 2035, whereas sales of NRMM with a power greater than 19 kW will be zero emissions by 2040 (Government of Chile, 2021).

The public mining company Codelco, the world's leading copper producer, has a decarbonisation plan for its operations to 2050, with a goal of reducing 70% of its carbon footprint by 2030. Part of this strategy includes the electrification of the light-duty vehicle fleet and the electrification of the NRMM, for which Codelco has deployed several pilot projects for fleet use and zero-emission NRMM since 2018 (Codelco, 2022b).

At its *El Teniente* Division in April 2019, the mining industry's first hybrid truck was deployed globally as a pilot prior to its international roll-out. The Komatsu-built ore loading and unloading equipment operates on a hybrid basis, with electric and diesel drive system for motive power generation. It is credited with increasing machine productivity by 10% to 20% over conventional machines, benefits from a 30% reduction in operating costs, and a 25% reduction in fuel costs, emissions and noise. In addition, this equipment has between 10% and 20% greater reliability and availability, due to its longer useful life and the ease of component replacement (Codelco, 2019a).

El Teniente also began operating a 100% electric scissor lift for use inside the mine. The operating costs of this equipment were reduced by 70% compared to the diesel version, noise was reduced by 70% compared to the diesel version, fuel consumption and GHG emissions were avoided by 100%, and a reduction of 80% to 90% in heat generation was achieved (Codelco, 2019a).

In 2022, in this same division, Codelco and Epiroc started a pilot test of the first 100% electric underground loader (Figure 9), which was made possible by the joint efforts of the state and private sectors. With a capacity of 14 tonnes, the LHD equipment model Scooptram ST14 Battery, manufactured by the Swedish multinational company, was premiered at the Diablo Regimiento mine. With this equipment, 433 tonnes of GHGs were mitigated in one year of operation. A 60% reduction in maintenance costs and a 100%

reduction in direct greenhouse gas emissions was achieved, given the reduction of gases and heat emitted by the equipment. In addition, there was a significant reduction in vibrations and noise, generating a healthier working environment (Codelco, 2022a).

Figure 9. The electric loader in a mining operation demonstration.

Source: (Codelco, 2022a).

Regarding the fleet electrification strategy, electric buses have been implemented to transport workers at Codelco's different divisions. The pilot projects started in 2019 and 155 electric buses, the company's largest electric fleet, were expected to begin operating in 2022. The electric fleet accounts for 30% of the total number of buses transporting the mining company's personnel (see Figure 10). More than 100 buses will be locally manufactured by Reborn Electric Motors (REM) in the Rancagua region, reaffirming that Codelco's decarbonisation project has a strong component of innovation and local human capital development (Codelco, 2022b).

Figure 10. Electric bus fleet at Codelco.

Source: (Codelco, 2022b).

2.6. Anglo American - Peru

Quellaveco, the second largest copper deposit in Latin America and one of the 15 mines with the highest production globally, is located in the Moquegua region of southern Peru. This project is being developed by the mining company Anglo American in partnership with Mitsubishi Corporation (Anglo American, 2022c). Environmental management targets for 2030 include reducing net GHG emissions by 30% and improving energy efficiency by 30% (Anglo American, 2022d).

In 2022, the mine had five Caterpillar 794 AC hybrid (diesel + electric drive system) trucks (Figure 11), with a load capacity of 320 tonnes and a power of 3500 HP, and is expected to reach 27 units of this model in the coming years. This NRMM electrification project is being developed with the support of Ferreycorp, a Peruvian company representing the Caterpillar brand, which is also providing technical assistance to the project (Ferreycorp, 2022a).

Figure 11. Electric mining truck.

Source: (Ferreyros, 2022a)..

Tests carried out with the Caterpillar 794 AC fleet showed high productivity, availability of more than 92% and a speed of 16 km/h uphill with load (Ferreyros, 2022a).

The five Caterpillar 794 AC trucks are part of an autonomous fleet being expanded at the mine. With these, 100% autonomous haulage is achieved, which is attributed to improvements in safety, productivity and optimisation of truck usage. Caterpillar, through the MineStar Platform, can manage the autonomous operation of different types of machinery and trucks (MCoppa, 2021). Caterpillar's proposed autonomy system is comprised of Cat MineStar technology, machine-enabled hardware, mine optimisation processes and personnel management (Caterpillar, 2022; Florentini, 2020)..

At the Antamina, Toquepala, Cuajone and Cerro Verde mines, 20 Cat 798 AC trucks with a power of 4,150 HP were deployed (Ferreyros, 2022d). Quellaveco's 185 MW capacity power supply will be 100% green energy, provided by ENGIE from the future Punta Lomitas wind farm being built in Ocucaje (Ica) (Anglo American, 2022e).

The Quellaveco Project also implemented the first electric rope shovel model 7495 Cat (Figure 12). This is one of the largest pieces of mining equipment available in Peru, and its function is to load the 794 AC trucks during operations. This equipment has a bucket with a load capacity between 109 and 120 tonnes per pass, and average power between 945 and 13,322 kW. One of the challenges was the assembly of the shovel, which required 40,000 man-hours from a Peruvian team (Anglo American, 2022g).

Figure 12. Electric mining shovel.

Source: (Anglo American, 2022g).

An additional goal of Anglo American is to have hydrogen trucks on the road by 2030. These trucks offer multiple benefits, such as long hauls on a single refuelling. One of the advantages of these trucks is that one of the main materials is copper, which is produced in the mines on site (Anglo American, 2022a).

2.7. India

India faces one of the world's biggest challenges in terms of emissions reduction due to its high levels of air pollution and population growth. The country's air pollution levels pose a high health risk to the population. It is estimated that for 2017 approximately 78% of the population was exposed to air pollution levels exceeding the threshold recommended by the country's National Air Quality Standards (40 ug/m^3 of $PM_{2.5}$) (Balakrishnan et al., 2019).. The transport sector is attributed 9% of deaths associated with fine particulate matter ($PM_{2.5}$) and ozone (O_3) levels, and within these 19% are estimated to be attributable to NRMM mobile sources and trains (Anenberg et al., 2019).

The Indian government has regulations in place to govern emission levels of private vehicles, freight vehicles and NRMM. This regulation is issued by the Central Pollution Control Board of the Ministry of Environment, Forest and Climate Change and is called the *Bharat* emission standard. In 1999, the first stage of the *Bharat* emission standard was implemented for NRMM in the agriculture sector and in 2003, the first phase was implemented for NRMM in the construction sector (Shao, 2016). Both standards are currently in their fourth phase, and the fifth phase is planned to be operational by 2024 (Figure 13).

Engine Power	Date	CO	HC	NOx	PM	PN
kW		g/kWh				1/kWh
Trem Stage IV and CEV Stage IV						
37 ≤ P < 56	CEV: 2021.04 Trem: 2022.10	5.0	4.7*		0.025	-
56 ≤ P < 130		5.0	0.19	0.4	0.025	-
130 ≤ P < 560		3.5	0.19	0.4	0.025	-
Trem Stage V and CEV Stage V						
P < 8	2024.04	8.0	7.5*		0.4	-
8 ≤ P < 19		6.6	7.5*		0.4	-
19 ≤ P < 37		5.0	4.7*		0.015	1×10^{12}
37 ≤ P < 56		5.0	4.7*		0.015	1×10^{12}
56 ≤ P < 130		5.0	0.19	0.4	0.015	1×10^{12}
130 ≤ P < 560		3.5	0.19	0.4	0.015	1×10^{12}
P ≥ 560		3.5	0.19	3.5	0.045	-

* NOx + HC

Figure 13. NRMM emission standards used in agriculture (Trem) and construction (CEV).

Source: (DieselNet, 2022).

One of the major limitations of the agricultural NRMM standard is that to date (stage IV), vehicles below 37 kW are excluded from the regulation, although about 78% of NRMM sales are machinery between 19 and 37 kW (Bhatt & Shao, 2022). However, this limitation is expected to be overcome with the implementation of stage V, in which vehicles from 8 kW will be regulated (see Figure 13).

On the other hand, India is the leading manufacturer of NRMM used in agriculture, with production exceeding one million units in 2022 (Tractor and Mechanization Association (TMA), 2023). Some manufacturers are developing agricultural NRMM powered by alternative energy sources. For example, Sonalika introduced the first 11 kW electric-powered tractor, called Tiger Electric, in 2020 (see Figure 14), which is battery-powered (Sonalika, 2022). Similarly, Escort Limited is in the development stage of an electric tractor in the 15-22 kW range. Manufacturers Mahindra & Mahindra, and TAFE are working on the development of low-emission NRMM for agriculture (Bhatt & Shao, 2022).

Figure 14. Sonalika Tiger Electric Tractor.

Source: (Sonalika, 2022).

Although emission standards and environmental awareness can incentivise the technological transformation of NRMM for the agricultural and construction sectors towards low- or zero-emission technologies, the main obstacle faced by these units is their cost. Because of this situation, some experts have suggested that to facilitate the penetration of electric power-based technologies, additional measures such as subsidies for the purchase of low- or zero-emission NRMM by the central government or at the regional authority level, incentives and discounts on insurance rates, subsidies and reduced tariffs on electricity tariffs in the agriculture sector, investments in charging station infrastructure, and financial assistance in sector loans, are required (Shao & Anup, 2022).

3. Zero-emission NRMM offer

The review of the status of zero-emission NRMM offer with emphasis on mining, construction and agricultural machinery was approached through an analysis of global parent companies and new technology development centres, identifying machinery that is already commercially available, as well as processes under development and expected offering in the coming years.

Twenty-four global parent companies were identified that offer zero-emission NRMM solutions. These companies offer 19 classes of zero-emission NRMM for the agricultural, mining and construction sectors.

Most of the parent companies identified have electric machinery on offer (82%), with a much smaller proportion identifying hybrid (18%) and hydrogen (2%) options. According to the review, most of the offering is focused on zero-emission NRMM for the construction (58%) and mining (32%) sectors, with Europe being one of the main markets for this type of machinery. Of the machinery under development, the cases identified are mainly oriented towards the construction sector.

The autonomy of the machinery is one of the characteristics most highlighted by the parent companies, emphasising that the autonomy in most cases is sufficient to cover the operation patterns required by each sector. In the technical data sheets of the electric NRMM, characteristics regarding operation with cable or battery are also highlighted. In contrast, the information provided on end-of-life disposal practices is almost non-existent.

Annex *1* presents a matrix with the compilation and systematisation of information regarding the technological offer. For each case, technical aspects are documented, including: parent company, class, line, end-use sector according to the manufacturer's catalogue or technical data sheet, technology, battery power and capacity, charging capacity (when applicable), state of maturity of the technology, sales area and other technical characteristics of interest in each case. The machinery presented in the matrix is related to an identification code with an image bank (see Annex 2). This exercise has been complemented with a database of technical data sheets of the technological offer identified in the marketing stage (see Annex 3).

The aggregated information presented in Table 2, Table 3 and Table 4 is a summary of the sample of 50 machines characterised in Annex 1. Classification by sector, technology and machine size (e.g. engine size, load capacity) was done according to the information reported by the manufacturer in catalogues or data sheets.

Table 2. Share of technological offer by sector and technology.

Sector	Technology		
	Electrical NRMM	Hybrid NRMM	Hydrogen NRMM
Agricultural	100%		
Construction	84%	13%	3%
Mining	69%	31%	

Source: Own elaboration.

Table 3. Summary of technological offer by power, sector and load capacity.

Engine power (kW)	Sector			Load capacity (Kg)*
	Agricultural	Construction	Mining	
P<8	✓	✓		1,100
8 ≤ P <19	✓	✓		1,500-2,000
19 ≤ P < 37		✓		1,827-5,000
37 ≤ P < 56	✓	✓		4,500-9,000
56 ≤ P < 75			✓	3,600-6,000
75 ≤ P < 130	✓	✓		9,000-10,000
130 ≤ P < 225			✓	10,000-68,000
225 ≤ P < 450		✓	✓	20,000-42,000
P ≥ 560			✓	100,000-326,000

Source: Own elaboration.

*For this column of the table, machinery is excluded which, due to its characteristics, does not have a load-bearing capacity, such as drills, pavers, crushers and spreaders.

Table 4. Summary of technological offer by class and technology.

	Technology		
Class	Electrical NRMM	Hybrid NRMM	Hydrogen NRMM
Loader	✓		
Compact front-end loader	✓		
Medium front-end loader	✓		
Dumper	✓	✓	
Excavator	✓	✓	✓
Crawler crane		✓	
Telescopic handler	✓		
Mini truck	✓		
Mini excavator	✓		
Mini paver	✓		
Rope shovel	✓		
Paver	✓		
Drilling machine	✓		
Backhoe	✓		
Compacting roller	✓		
Drilling rig		✓	

	Technology		
Tractor	✓		
Shredder		✓	
Trolley Dump Trucks		✓	

Source: Own elaboration.

In reference to the state of maturity of the sample of the 50 machines characterised, it is found that 38 of them are in the marketing phase, of which 53% have an engine power of less than 75 kW, and are characterised by being relatively small machinery for agricultural and construction use. The distribution by power range of the machinery being marketed is shown in Figure 15.

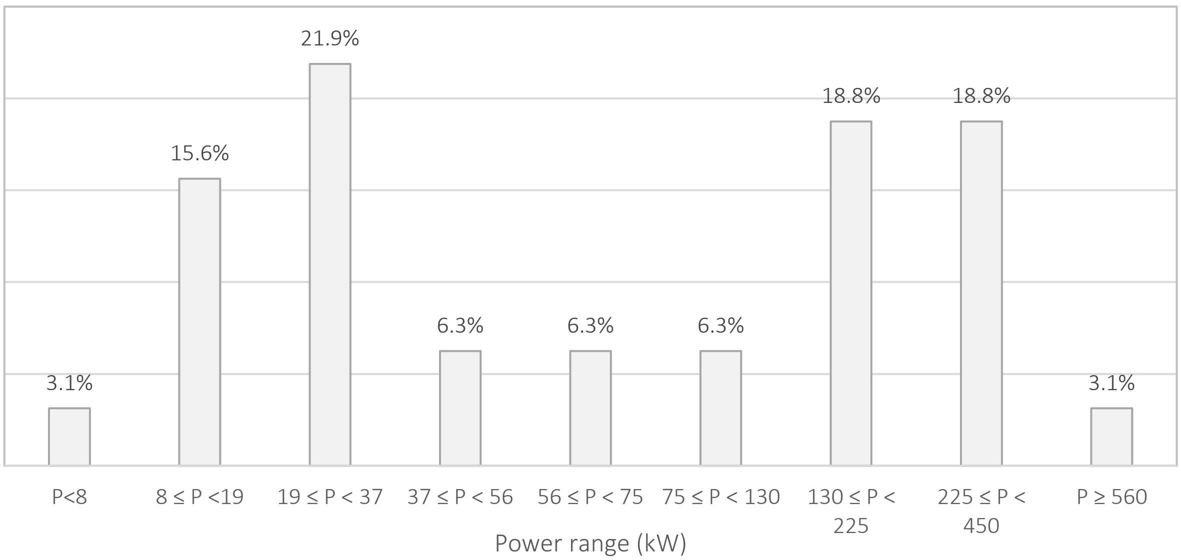


Figure 15. Machinery on the market by power range.

Source: Own elaboration.

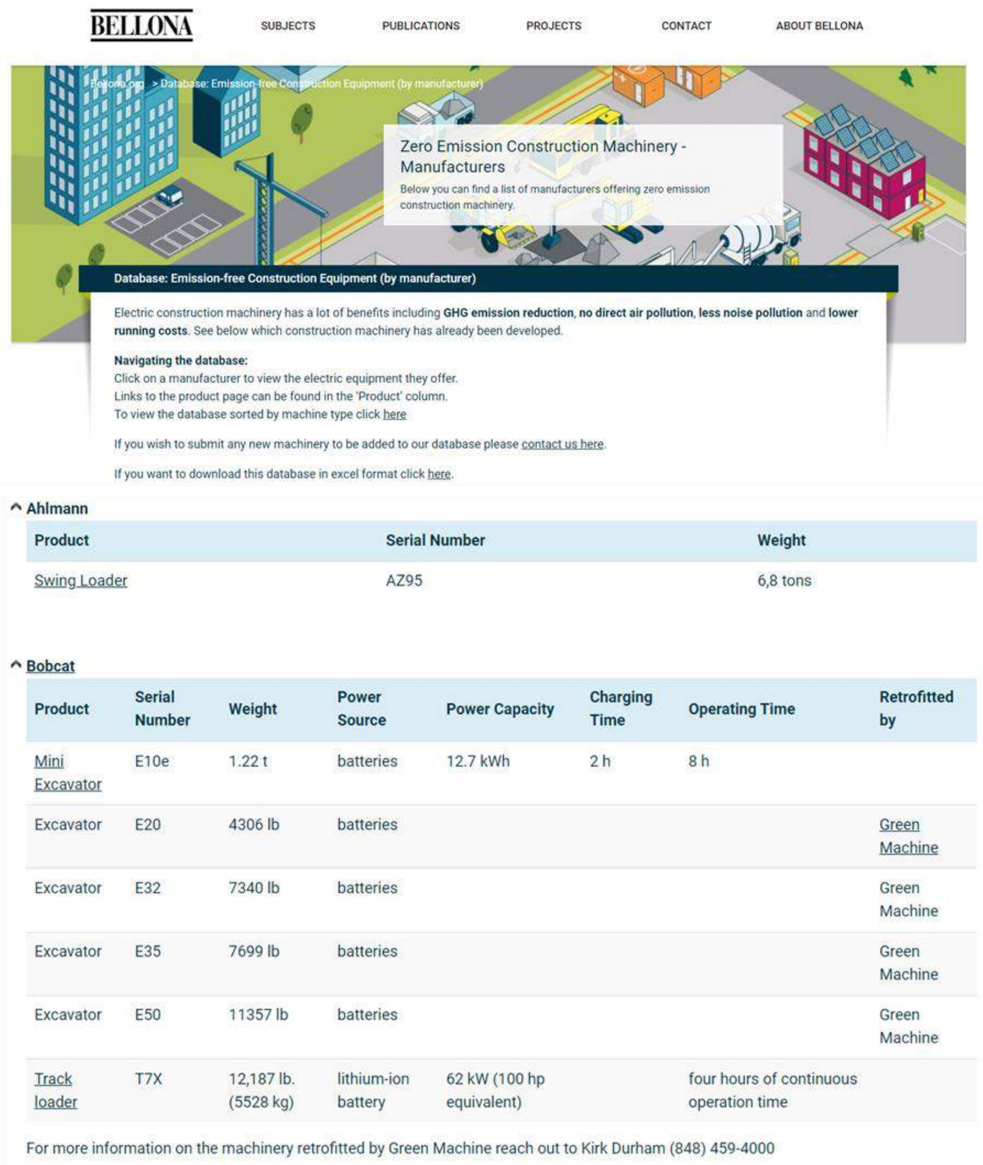
The following messages are highlighted from the identification of the technological offer:

- Zero-emission NRMMs are commercially available in all three sectors analysed.
- 50% of the identified cases mention that they have available supply of zero-emission NRMM in South America.
- The main manufacturers of zero-emission NRMM are present in the US, European and Asian markets.
- Peruvian NRMM manufacturer Resemin stands out as the third largest global manufacturer of underground mining drilling equipment, which is working on the development of a 100% electric mining drill and expects to commercialise 300 units by 2023 (Revista energiminas, 2019). Such developments by Latin American manufacturers may provide an opportunity to overcome the high acquisition cost barrier facing the zero-emission NRMM market.
- The commercial availability of battery-operated, cordless electric machinery is mostly limited to small NRMMs with engine power below 56 kW, which are mainly used in the agricultural and construction sectors.

- There are reported cases of NRMM under development with engine power greater than 56 kW for cordless operation and battery autonomy greater than six hours.
- The supply of machinery with high load or heavy-duty capabilities in the mining sector is met by electric cable and hybrid machinery. The existence of hybrid alternatives (electric with cable and diesel) such as *Trolley Dump Trucks* that use electric power to climb peaks, by means of overhead cable power supply, stands out.
- In hydrogen-powered NRMM, only one case was identified under development for the construction sector, which corresponds to the JCB excavator 220X.
- The existence of adaptations of agricultural machinery for hydrogen operation is highlighted. In a pilot run by the New York-based company Amogy at Stony Brook University's Advanced Energy Center in the United States, a John Deer tractor has been successfully retrofitted with ammonia fuel, replacing the diesel engine with a system that converts ammonia to hydrogen. For Amogy, this development provides solutions to the hydrogen storage challenge facing the industry. (Amogys, 2022). In terms of power, it is mentioned that the tractor provides the same capabilities as the diesel model; however, the operation of the tractor is only a few hours with a 60-gallon ammonia tank (Farres, 2022).
- On the other hand, it is important to highlight the interest of manufacturers in providing solutions that facilitate the process of charging batteries for machinery by means of mobile energy storage systems based on batteries that make it possible to operate or charge electrified machines and equipment locally, by means of systems known as power packs (Liebherr, 2022).
- NRMM manufacturers are focusing their developments on achieving zero-emission targets, reducing noise emissions and achieving the autonomy to allow full working days. A longer-term challenge is electrification at a higher level, shifting from hydraulic to electric trains (CALAC+, 2022).

As a complement to the work presented in this report and its annexes on the identification of the zero-emission NRMM offer, the database for the construction sector developed by Belladona, a foundation headquartered in Oslo, dedicated to finding solutions to environmental challenges, should be consulted (see Figure 16).

This link provides access to the machine search system by manufacturer and type of NRMM. Characteristics such as line, weight, power supply, battery capacity, charging time, running time and a link to the manufacturer's website are recorded in the database. Additionally, the database can be downloaded in Excel format.



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Zero Emission Construction Machinery - Manufacturers

Below you can find a list of manufacturers offering zero emission construction machinery.

Database: Emission-free Construction Equipment (by manufacturer)

Electric construction machinery has a lot of benefits including **GHG emission reduction**, **no direct air pollution**, **less noise pollution** and **lower running costs**. See below which construction machinery has already been developed.

Navigating the database:
Click on a manufacturer to view the electric equipment they offer.
Links to the product page can be found in the 'Product' column.
To view the database sorted by machine type click here

If you wish to submit any new machinery to be added to our database please contact us here.

If you want to download this database in excel format click here.

Ahlmann

Product	Serial Number	Weight
Swing Loader	AZ95	6,8 tons

Bobcat

Product	Serial Number	Weight	Power Source	Power Capacity	Charging Time	Operating Time	Retrofitted by
Mini Excavator	E10e	1.22 t	batteries	12.7 kWh	2 h	8 h	
Excavator	E20	4306 lb	batteries				Green Machine
Excavator	E32	7340 lb	batteries				Green Machine
Excavator	E35	7699 lb	batteries				Green Machine
Excavator	E50	11357 lb	batteries				Green Machine
Track loader	T7X	12,187 lb. (5528 kg)	lithium-ion battery	62 kW (100 hp equivalent)		four hours of continuous operation time	

For more information on the machinery retrofitted by Green Machine reach out to Kirk Durham (848) 459-4000

Figure 16. Screenshot of the Belladona´s website, with database of zero-emission machinery for the construction sector.

4. Instruments to promote the use of zero-emission NRMM

The previous sections of the report have mentioned instruments used at the international level to incentivise the use of zero-emission NRMM. Very different strategies can be observed among the previously analysed cases. These include actions driven by the private sector, as in the cases of Boliden and Anglo American where the incorporation of zero-emission NRMM has been a response to international decarbonisation targets adopted by multinational companies. Public initiatives have been identified, such as in Oslo, where the contracting power of the municipality is used to promote the use of electric machinery in the construction processes contracted by municipalities through changes in contractor selection schemes.

Within the strategies adopted by the public sector to promote the use of zero-emission NRMM, the cases of California, Oslo and Barcelona show different possibilities. California, through its environmental authority CARB, bases its model on eliminating the main barrier of the high cost of acquiring the machinery, through the granting of vouchers. They designed a model that seeks to cover the entire electric NRMM market, but which starts with the sectors that are easiest to electrify in order to gradually overcome the barriers and thus move towards sectors where more challenges are identified. This model also highlights the instrument's emphasis on making it as easy as possible for end-users to access zero-emission NRMM purchase and lease vouchers. California's strategy is very broad in scope, as evidenced by the financial resources allocated annually to the programme and the rate of use of these resources.

In Oslo, the main focus of the strategy is the planning of the policy through the establishment of a roadmap. Subsequently, in the development of the pilot project, a relevant component of cooperation between the public and private sectors is identified, which also makes a very large commitment to local innovation. As the demand for different types of NRMM for the pilot project increased, the required equipment was electrified, which probably influenced the high cost of meeting the objective of having a zero-emission construction site. In Barcelona, the key objective of the pilot project was to demonstrate the feasibility of the initiative as a starting point for further development of the enabling conditions. The selection of the Barcelona pilot project was made by considering the type of construction site for which there was the greatest availability of the necessary electrical machinery according to the local market. Once the available machinery had been identified, the project promoters built the necessary elements to develop the pilot project.

Some additional instruments are identified at the international level that also seek to promote the use of zero-emission NRMM. Table 5 presents a compilation of policies, regulations and initiatives identified at the global level.

Some are indicative instruments that provide guidelines for the adoption of public policies in line with zero-emission NRMM, although they have not yet defined the specific mechanisms for their incorporation. Others refer to policy instruments and incentives aimed at ultra-low and zero-emission NRMM.

This review highlights the gradualness of the instruments adopted in different cities in China, where the requirements for low-emission zones become increasingly stringent, until it is no longer possible to operate non-zero emission NRMM. Some of the schemes adopted in China's urban areas vary their requirements for NRMM emissions depending on the level of air pollution, and this is reflected in schemes that vary with the time of year affected by different emission and weather conditions. Gradualness is also reflected in some cities in the prioritisation of sectors for which the technology transition begins.

In the case of China, it is worth mentioning that in order to ensure that NRMM operating in low-emission zones comply with the established requirements, there are monitoring platforms that allow real-time tracking through electronic detection systems of entry and exit of the zones and NRMM registration systems, among other mechanisms. For the overall NRMM emissions reduction strategy to work, it requires the participation and coordination of multiple public and private stakeholders (Shao, 2022).

Based on the review of the China case, Shao (2022) proposes four steps to accelerate low-emission zones with ultra-low or zero-emission NRMM. These four steps summarise very well the type of globally applicable instruments available, implementation mechanisms and prioritisation criteria that can be applied to accelerate NRMM technology change in different contexts.

1) **Establish the legal basis for zero-emission zones**. This allows local governments to implement the measures that support zero-emission zones and to have regulations on monitoring, control and penalties for non-compliance.

2) **Establish a multi-agency collaboration platform and data exchange system.** The operation of a low-emission zone requires authorities from different sectors and representatives from the private sector. The ability to share project data between entities works synergistically, and data is essential for each entity to fulfil its roles within the project.

3) **Increase the requirement for zero-emission zones, in parallel with incentive schemes.** Given that there is not a 100% supply of electric machinery, it is possible to start with ultra-low emission zones, where alternatives such as hybrid or alternative fuel NRMM can be used, when the electric version of the required equipment does not exist. Instruments such as incentives (fiscal and non-fiscal), contracting schemes, among others, support low-emission zones and the actions to achieve them. Flexible schemes are required, which allow them to be reviewed and adjusted periodically, seeking a wider scope and better project results in terms of costs and benefits.

4) **Prioritise regions, equipment types and applications for early-stage programmes.** Cities where pilots and low-emission zone projects are already in place, or where monitoring schemes for NRMM are already in place, may have conditions that facilitate the adoption of ultra-low and zero-emission NRMM. Another prioritisation criterion could be to start with sectors that already have a zero-emission NRMM technological offer. Projects to minimise personal exposure to pollution, such as in enclosed spaces like mines and tunnels, could also be prioritised.

Finally, the implementation of urban low-emission zones is one of the most widely used mechanisms to promote the use of ultra-low and zero-emission NRMM. Although in most cases these have emerged as a response to local pollution problems, the implementation of zero-emission NRMM is a solution both for local pollution and noise problems, as well as for global problems such as climate change. In the context of Latin America, reducing air pollution levels in urban centres is one of the priority environmental objectives for the coming years, and accelerating the electrification of NRMM for use in urban areas would provide a solution to several pressing problems.

Table 5. Instruments to promote the use of zero-emission NRMM.

Category	Name	City - Country	Description	Sector/Type of machinery	Source
Public policy guidelines	Climate and Energy Strategy	Oslo, Norway	This policy tool was created for the city to implement actions aligned with emission reduction targets. Zero-emission technologies and fuels for NRMM are mentioned among the strategies to achieve GHG emission reductions.	NRMM for construction	(KlimaOslo, 2021b)
	Adaptation Strategy	Oslo, Norway			(KlimaOslo, 2020)
	Net-Zero Carbon Buildings Roadmap	Colombia	Roadmap for implementation of public and private sector actions to decarbonise buildings in Colombia. It includes targets for mitigation of GHG emissions in embodied carbon aligned with Colombia's Long Term Climate Strategy (E2050). Within the mitigation actions, measures to reduce GHG emissions in the construction phase of buildings are recommended.	NRMM for construction	(CCCS & MADS, 2022)
	National Mining Policy 2050	Chile	Policy by which a model for the mining industry is proposed, boosting mining in the short, medium and long term in the operation of zero-emission fleets.	NRMM used in mines	(Government of Chile, 2020)
	National Electromobility Strategy		The objective of this strategy is to establish the strategic axes, policies and goals that will enable the accelerated and sustainable development of electric transport. One of the targets proposed is that 100% of sales of machinery (mining, forestry, construction and agricultural) of more than 560 kW of power should be zero emissions from 2035, and of more than 19 kW as of 2040.	NRMM for construction	(Government of Chile, 2021)
Agreements	Clean Construction Declaration	Five C40 cities: Budapest, Los Angeles, Oslo, Mexico City, San Francisco, London, Milan.	Cities that sign this declaration commit to reducing embodied carbon emissions from buildings. Specifically, they have three commitments: - Reduce embodied carbon emissions by at least 50% in all new buildings and major refurbishments by 2030, striving for at least 30% by 2025. - Reduce embodied carbon emissions by at least 50% in all infrastructure works by 2030, striving for at least 30% by 2025.	NRMM for construction	(C40, 2021)

Category	Name	City - Country	Description	Sector/Type of machinery	Source
			- Require zero-emission NRMM for construction of municipal projects from 2025 and zero-emission construction sites citywide by 2030.		
Air quality regulation	London's 'Low Emission Zone' for Non-Road Mobile Machinery	London, England	Through this policy, low-emission zones were implemented for construction, thus encouraging the use of low-emission NRMM in the city.	NRMM implemented in the construction sector.	(London City Hall, 2022)
	Clean Air Action Plan	Amsterdam, The Netherlands	This plan includes the "Green New Deal", which was signed by different sectors to work over the next four years to reduce emissions of CO_2, NO_x and particulate matter by encouraging fuel savings.	NRMM for construction and agriculture	(Gemeente Amsterdam, 2021)
	Clean Air Urban Areas	Bogota, Colombia	A decree is currently under development to regulate Clean Air Urban Areas, similar to the low-emission areas that exist in many cities around the world. Clean building areas could meet the objectives of the measure in different parts of the city.	NRMM for the construction sector	(SDM, 2022)
	Clean Air Act	China	The Clean Air Act enabled Chinese cities to establish low NRMM emission areas for the construction sector. By 2022, 92% of urban areas had defined low emission zones. High-emission NRMM cannot operate in these areas; however, there are differences in definitions between regions as to what "high-emission NRMM" means. Different types of interventions have been implemented including: promotion of low-emission NRMM in Beijing and Tianjin; Beijing has used fiscal instruments to build electric fleet charging stations; incentives to accelerate the purchase of electric NRMM; prioritisation of sectors for technological upgrading (NRMM for airports and railway sector in Jinan); Chengdu implemented regulation to give fiscal incentives for the purchase of low-emission NRMM.	NRMM for construction, airports and railway sector	(Shao, 2022)

Category	Name	City - Country	Description	Sector/Type of machinery	Source
			The schemes adopted in China have been gradual in some areas and in others vary according to air pollution levels.		
Climate change regulation	Climate budget 2021	Oslo, Norway	In Oslo, zero-emission building sites have been established to achieve the emission reduction target. The city is aiming for all building sites to be zero-emission by 2030.	NRMM implemented under construction.	(KlimaOslo, 2021a)
Incentives for the manufacture and use of zero-emission NRMM	Supreme Decree No. 4539	Bolivia	- Tax incentives for the manufacture, assembly and import of electric and hybrid motor vehicles and electric and hybrid agricultural machinery. - Financial incentives for the manufacture, assembly and purchase of electric and hybrid motor vehicles and electric and hybrid agricultural machinery.	Electric and hybrid agricultural machinery.	(Supreme Decree N° 4539 from 2016, n.d.)
	Incentive programme for the use of clean technology NRMM	California, United States	The CORE programme offsets the cost of zero-emission technology (acquisition cost) with a discount that becomes effective for users at the point of sale. For this, vouchers are given for the purchase or rental of zero-emission NRMM.	Cross-cutting	(CALAC+, 2022)

Source: Own elaboration.

5. Final messages

Technological offers and access to information: The review of the zero-emission NRMM technological offer shows important developments for the mining, industrial and agricultural sectors. For all three sectors there is already a commercial offer of zero-emission NRMM, with the main focus on electric construction and mining machinery. While most of the zero-emission NRMM available is of small- (>75 kW[5]) and medium- (>450 kW) size, larger (<560 kW) models are also becoming available and there is rapid progress made by different parent companies to cover all segments and sizes of machinery. The machinery identified includes electric powertrain technologies, hybrid solutions (diesel-electric), portable electric charging solutions, wired solutions, hybrid methods of operation (battery-cable) and other charging methods such as trolley wires for mining machinery.

In order to facilitate technology change in NRMM, access to user information from manufacturers is particularly important. Key parameters and variables are related to machine charging possibilities, autonomy, driving cycles and energy recovery rates, among others. Aspects such as machine lifetime and portability possibilities that are relevant for project developers are not commonly available among the features reported by manufacturers. Information on end-of-life waste management practices for batteries and machinery is also not publicly available for consultation.

Regarding the return on investment of electric machinery, as observed in the case studies listed in section 2, it is possible to see significant reductions in costs associated with fuel consumption over time; however, it is necessary to highlight that this market is not yet widespread and what is presented here relates to specific cases. Generic payback calculations will require more time and scale-up of these technologies to be compiled. Final costs will also depend on fuel and energy costs in each country (DNV GL 2019).

There are different approaches to promote the use of zero-emission NRMM: For Latin America to move forward in the implementation of NRMM, there are examples of different approaches already piloted by other countries in the world.

The case studies show different ways of encouraging the use of NRMM. The public sector has led some of the initiatives; however, the leading role of the private sector in developing these types of projects is also clear. In all cases, the need for articulation between financiers and implementers of the programmes, manufacturers and representatives who can provide local technical support, representatives of the different national and local public sectors, end users of the machinery and the community benefiting from improved environmental conditions is highlighted.

The case studies also show a great diversity in the strategies applied to promote the use of ultra-low and zero- emission NRMM. The strategies vary in the support instruments they use, with some relying on contracting schemes, and others using, independently or in addition, financial and non-financial incentives, regulation for local pollution reduction and regulation for GHG emissions mitigation. Strategies to boost the use of zero-emission NRMM also differ in the approaches with which they select the starting points for NRMM substitution; some are defined according to technology availability in the local market, others

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[5] The kW values given here do not correspond to fixed ranges but are indicative to give the reader an idea of the sizes of the machines. In general, when talking about diesel engines for all applications (including locomotives, ships, generators, etc.) the words small, medium and large use larger power ranges such as: small (> 188 kW) medium (188 - 750 kW) and large above 750 kW (https://swiftequipment.com/types-of-diesel-engines-and-its-applications/). However, emission regulations for diesel engines have focused preferentially on sizes below 560 kW as they are more common in urban environments where emissions are exposed to a larger number of people.

according to priority projects for urban areas, some define them according to existing supporting framework regulations, while for some cities the local innovation stakes are the most important criterion and therefore the availability of technologies is not the main barrier. In other cities, the strategies are defined gradually in the requirements of the emission levels allowed for the NRMM, and also with temporal graduality in the scope of the programmes.

Learning potential of pilot projects: Pilot projects play an important role in the transition towards zero-emission NRMM. Through these experiences, needs are identified for the different stages of zero-emission NRMM projects; and multi-stakeholder solutions are proposed that make the projects feasible. In this way, pilot projects become a way to overcome barriers; and lessons learned from the pilots can be used in the consolidation and replication stages of zero-emission NRMM programmes.

Pilot projects are also very relevant to measure the benefits of using NRMM in relation to the environment (reduction of local pollutants and GHGs), reduction of fossil fuel costs, increase in productivity and improvement of the working environment by reducing noise, emissions (resulting from incomplete combustion) and the heat generated by conventional machinery. Documentation of the pilot projects is valuable both for the implementers and for sharing the experience with other sectors and cities that may be interested in developing similar projects.

Dissemination of information to overcome knowledge barriers: Dissemination of information about the difficulties, solutions and advantages of zero-emission NRMM can help to reduce current barriers in knowledge about new technologies. The results of the cases analysed show very positive data on various aspects such as environmental, financial and productivity. In this sense, the role of the CALAC+ collaboration platform is highlighted, through which the exchange of experiences can continue to be promoted at a global level and between Latin American countries, as well as the C40 Clean Construction initiative, which has a similar purpose of sharing information between cities, and the CCAC Transport Initiative, which seeks to address the issue of reducing black carbon emissions in machinery and thus support its government partners at a global level.

Annexes

Annex 1. Zero-Emission NRMM offer matrix.

Table A 1. Zero-emission NRMM offer matrix.

ID	Head office	Class	Line	Sector	Technology	Engine power (kW)	Battery capacity	Other technical features	Material loading capacity	State of Maturity	Sales Area	Source
1	Suncar	Excavator	ZE85	Construction	Electric	40	Capacity: 100 kWh Full charge in two hours, CEE 400v Possibility to charge up to 150 kW with CCS2, reduces charging time to 35-45 min.	Battery and cable operation.	8,000-9,000 kg	Marketing	Europe	Link here
2	Amman	Compacting roller	EARX 26-2	Construction	Electric	25	Capacity: 31.5 kWh	Designed to optimise energy use. Ideal for small to medium sized construction sites.	N/A	Marketing	NE	Link here
3	Ausa	Dumper	D151AEG	Construction	Electric	17,3	Capacity: 12.4 kWh Full charge in two hours, 230V External fast charge one hour and twenty-four minutes, 415V	Integrated charger allowing direct connection to an AC power supply. Power regeneration on deceleration.	1,500 Kg	Marketing	Spain	Link here
4	Bobcat	Mini excavator	E19e	Construction /Agriculture	Electric	10	Capacity: 17.28 kWh Full charge in two hours with external supercharging	Autonomy for a full working day in a normal work routine.	1,800 Kg	Marketing	Europe, Asia, Africa and America	Link here
5	Bobcat	Mini excavator	E10e	Construction /Agriculture	Electric	7,5	Capacity: 11.52 kWh Full charge in two hours with external supercharging	Autonomy for a full working day in a normal work routine.	1,100 Kg	Marketing	Europe, Asia, Africa and America	Link here
6	Case	Backhoe	580 EV	Construction	Electric	n.d	Capacity: 90 kWh Charging at 220V	Zeus project, winner of the 2020 Good Design Award from the Chicago Athenaeum Museum of Architecture and Design and Metropolitan Arts Press. Autonomy of 8 continuous hours.	N/A	Development	NA	Link here
7	Caterpillar	Mini excavator	301,9	Construction	Electric	n.d	Capacity: 32 kWh	Autonomy of 8 hours.	N/A	Development	NA	Caterpillar announces four electric machine prototypes - Construcción LatinoAmericana (construccionlatinoamericana.com) Link here

ID	Head office	Class	Line	Sector	Technology	Engine power (kW)	Battery capacity	Other technical features	Material loading capacity	State of Maturity	Sales Area	Source
8	Caterpillar	Compact wheel loader	Cat 906	Construction	Electric	n.a	Capacity: 64 kWh	Autonomy of 6 hours. Presented at Bauma Munich 2022.	6,200 Kg	Development	NA	Caterpillar announces four electric machine prototypes - Construcción LatinoAmericana (construccionlatinoamericana.com) Access here
9	Caterpillar	Medium wheel loader	Cat 950 GC	Construction	Electric	n.a	Capacity: 256 kWh	Autonomy of 6 hours. Presented at Bauma Munich 2022.	N/A	Development	NA	Caterpillar announces four electric machine prototypes - Construcción LatinoAmericana (construccionlatinoamericana.com) Access here
10	Caterpillar	Excavator	Cat 320	Construction	Electric	120	Capacity: 320 kWh Integrated 22 kW charger Full battery charge in 6 hours	Autonomy of 8 hours. Presented at Bauma Munich 2022.	N/A	Marketing	NA	Z Line Cat 320 | Pon Team (pon-cat.com)
11	Caterpillar	Rope shovel	*7495 with front end boom *7495 with Hydracrowd *7495 HF with balancing rope *7495 HF with Hydracrowd *7495 HD *7395 *7295	Mining	Electric	n.a	N/A	Operation with Hydracrowd. Power requirements- Maximum power: 2,152 kW-3,778 kW.	Working weight, with dipper and standard links: 793,259 Kg-1,442,274 Kg	Marketing	Europe, Asia, Africa, America and Oceania	Link here
12	Dynapac	Paver	eCity SD1800W	Construction	Electric	55	Full charge in over three hours. It takes about 3 hours to go from 5% to 80% @ 400V 22kW (AC) and 40 min to go from 5% to 80% @ 80kW (DC). Charging is done via a wall box or charging station. Charging is done with a CE	Autonomy of 4 hours. Paving width of 4.1 metres.	Maximum paving capacity 350 t/h	Marketing	Europe, Asia, Africa and America	Link here

ID	Head office	Class	Line	Sector	Technology	Engine power (kW)	Battery capacity	Other technical features	Material loading capacity	State of Maturity	Sales Area	Source
							compliant Type 2 plug for 400V, 6-32A, 1.4-22.0kW AC.					
13	Epiroc	Underground loader	Scooptram ST7	Mining	Electric	149	Capacity: 165 kWh Load at 575 VAC	Autonomy of 4 hours. Quick battery exchange (two batteries).	6,800 Kg	Marketing	Europe, Asia, Africa and America	Battery Shovel ST7: Underground Shovels: Epiroc
14	Epiroc	Loader	Shovel EST1030	Mining	Electric	132	N/A	Wired operation. Fastest loader in its class with a maximum speed of 15 km/h.	10,000 Kg	Marketing	Europe, Asia, Africa and America	Scooptram EST1030: Underground Shovel: Epiroc
15	Epiroc	Loader	Shovel EST2D	Mining	Electric	56	N/A	Wired operation.	3,629 Kg	Marketing	Europe, Asia, Africa and America	Link here
16	Epiroc	Loader	Shovel EST3.5	Mining	Electric	74,6	N/A	Wired operation.	6,000 Kg	Marketing	Europe, Asia, Africa and America	Link here
17	Epiroc	Loader	ST14 Battery loader	Mining	Electric	200	Capacity: 300 kWh Full charge in two hours External charger	CCS 2.0 connector type 1 or 2. Allows battery replacement.	14,000 Kg	Marketing	Europe, Asia, Africa and America	ST14 Battery loade r: Underground Shovel: Epiroc
18	Epiroc	Mini truck	MT2010 Battery	Mining	Electric	301	Capacity: 165 kWh Artisan, 165 kWh, LiFeP04, 630 VDC	Battery charger: 575 VAC input.	20,000 Kg	Marketing	Europe, Asia, Africa and America	Minetruck MT2010 Battery | Epiroc
19	Epiroc	Mini truck	MT42 Battery	Mining	Electric	2x200	Capacity: 375 kWh External charger Full charge in 3.5 hours	CCS 2.0 connector type 1 or 2. Allows battery replacement.	42,000 Kg	Marketing	Europe, Asia, Africa and America	Link here
20	Faresin	Telescopic handler	*17.45 Full Electric *14.42 Full Electric *17 .40 Full Electric	Agricultural	Electric	51	n.a	51 kW engine for transmission. 23 kW engine for machine services.	4,000 Kg - 4,500 Kg	Development	N/A	Faresin presents the Big Range full electric at Bauma (noticiasmaquinaria.com)
21	Hitachi	Excavator	ZX55U-6	Construction	Electric	33	Capacity: 39 kWh	Battery-powered or wired operation.	5,000 Kg	Marketing		5-tonne class battery-powered mini excavator to start accepting orders in European market - Hitachi Construction Machinery (hitachicm.com)
22	Hitachi	Excavator	*Prototype 2 tonnes	Construction	Electric	10 to 85	Capacity: 18 kWh - 198 kWh	Presented at Bauma Munich 2022.	2,000 Kg - 13,000 Kg	Development	N/A	Battery-powered

ID	Head office	Class	Line	Sector	Technology	Engine power (kW)	Battery capacity	Other technical features	Material loading capacity	State of Maturity	Sales Area	Source
			*Prototype 13 tonnes									mini and compact excavators to be showcased at bauma 2022 - Hitachi Construction Machinery (hitachicm.com)
23	Hitachi	Trolley Dump Trucks	Trolley Dump Trucks	Mining	Hybrid	1490	N/A	DC 2400-2600 V. They use electric power while climbing hills, which is supplied by overhead wires. On downhill or unwired sites they use diesel.	180,000 kg - 326,000 kg	Development	N/A	Link here
24	JCB	Mini excavator	19C-1E	Construction	Electric	20	Capacity: 19.8 kWh Full charge in 10.5 hours at 110V or 5 hours at 240V Fast charge in 2.5 hours at 415V supply	Autonomy for a full day. Pack of 4 batteries.	1,827 Kg	Marketing	Europe, Asia, Africa and America	19C-1E : Mini Excavators : JCB.com
25	JCB	Dumper	E-TECH ITE	Construction	Electric	20	Capacity: 10 kWh Full charge in 2 hours, 35 minutes at 230V Fast Charge in 1 hour, 40 minutes at 415V	Autonomy for a full day.	1,000 Kg	Marketing	Europe, Asia, Africa and America	Link here
26	JCB	Excavator	220X	Construction	Hydrogen	N/A	N/A	100 million investment for hydrogen-powered engine development. Powered by a hydrogen fuel cell, it has been undergoing rigorous testing at JCB's quarry proving ground for more than 12 months.	20,000 Kg	Development	N/A	JCB launches industry's first hydrogen-powered excavator - JCB
27	Jhon Deere	Backhoe	E-power	Construction	Electric	75		Works with an interconnected electricity grid.	N/A	Development	N/A	John Deere's prototype electric backhoe loader put to the test on real construction sites - News - Híbridos y Eléctricos | Coches eléctricos, híbridos enchufables (hibridosyelectricos.com)
28	Jhon Deere	Tractor	SESAM	Agricultural	Electric	100	Capacity: 130 kWh	Wired operation. Autonomy of 50 kilometres	N/A	Development	N/A	https://www.hibridosyelectricos.com/ar

ID	Head office	Class	Line	Sector	Technology	Engine power (kW)	Battery capacity	Other technical features	Material loading capacity	State of Maturity	Sales Area	Source
								on the road and four hours of work in the field.				ticulo/actualidad/john-deere-presenta-tractor-electrico-autonomo-necesita-baterias/2018121318594 0023921.html
29	Keestrack	Shredder	B7e	Mining	Hybrid	160	N/A	Wired operation. Electrically operated.	600 tonnes/hour	Marketing	Europe, Asia and America	Link here
30	Kleeman	Shredder	MR 130(i) pro	Mining	Hybrid	n.a	N/A	Wired operation. Electrically operated.	375 tonnes/hour	Marketing	Europe, Asia, Africa and America	MR 130i EVO2 | Mobile Impact Mills | Kleemann (wirtgen-group.com)
31	Komatsu	Excavator	PC210E	Construction	Electric	123	n.a	Autonomy of 8 hours. To be launched in Europe in 2023.	21,000 Kg	Development	N/A	Link here
32	Manitou	Telescopic handler	*MRT 2260e *MRT 2660e	Construction /Agriculture	Electric	n.a	Capacity: 65 kWh	vision + range. Launch at Bauma 2022.	6,000 Kg	Marketing	Europe, Asia, Africa and America	Link here
33	Vögele	Mini road paver	*500e *502e	Construction	Electric	n.a	n.a	Launch at Bauma 2022.	Widths 0.25 to 1.80 metres	Marketing	Europe	Bauma 2022 : New mini road pavers from VÖGELE (wirtgen-group.com)
34	Volvo	Excavator	ECR25	Construction	Electric	30	Capacity: 20 kWh Full on-board charging in 5 hours at 230V Full off-board charging in 50 minutes at 400V	Autonomy of 4 hours.	2,780 Kg	Marketing	Distributors in North America	ECR25 Electric | Electric Machines | Overview | Volvo Construction Equipment (volvoce.com)
35	Volvo	Excavator	ECR18	Construction	Electric	18	Capacity: 16 kWh Fully charged in 10 hours at 110V Fully charged in 5 hours at 240V	Autonomy of 3 to 5 hours.	1,765 Kg	Marketing	Distributors in North America	Link here
36	Volvo	Charger	L25	Construction	Electric	22	Capacity: 40 kWh Total on-board charging in 6 hours at 400V Total off-board charging in 2 hours at 400V	Autonomy of 8 hours.	4,900 Kg	Marketing	Distributors in North America	L25 Electric | Electric Machines | Overview | Volvo Construction Equipment

ID	Head office	Class	Line	Sector	Technology	Engine power (kW)	Battery capacity	Other technical features	Material loading capacity	State of Maturity	Sales Area	Source
												(volvoce.com)
37	Volvo	Charger	L20	Construction	Electric	22	Capacity: 33 kWh Full on-board charging in 5 hours at 400V Full off-board charging in 2 hours at 400V	Autonomy of 6 hours.	4,550 Kg	Marketing	Distributors in North America	L20 Electric | Electric Machines | Overview | Volvo Construction Equipment (volvoce.com)
38	Kiesel	Excavator	ZE19-T	Construction	Electric	n.a	Fully charged in three hours with fast charge Fully charged in 12 hours with on-board charger	4 hours of autonomy. Quick charge in 45 minutes.	N/A	Marketing	n.a.	Link here
39	Suncar	Excavator	TB216E	Construction	Electric	18,5	Full charge in 3 hours	Autonomy of four hours. Wired and battery-powered. Standard 400V/CEE 32 A connection.	2,000 Kg	Marketing	n.a.	Takeuchi TB260E kaufen & mieten | Huppenkothe n GmbH
40	Liebherr	Drilling rig	LB 16 unplugged	Mining	Hybrid	265	Fully charged in less than 7 hours	Autonomy of ten hours. Wireless.	N/A	Marketing	Europe, Asia, Africa and America	LB 16 unplugged Liebherr drilling rig
41	Liebherr	Crawler crane	LR 1250.1	Construction	Hybrid	255	Capacity: 196 kWh Full charge in 4.5 hours	Autonomy of 4 hours. Wired and battery operated.	N/A	Marketing	Europe, Asia, Africa and America	Link here
42	Liebherr	Dumper	T 236	Mining	Hybrid	895	n.a	Electric drive. Trolley assistance system.	100,000 Kg	Marketing	Europe, Asia, Africa and America	T 236 | Liebherr
43	Liebherr	Excavator	*LH 26 M *LH 26 C	Construction	Electric	125	n.a	Wired operation.	Operating weight: 26,200 Kg - 27,900 Kg	Marketing	Europe, Asia, Africa and America	LH 26 M Industry Litronic | Liebherr
44	Liebherr	Excavator	LH 110 C	Construction	Hybrid	300	n.a	Stage V Stage IIIA (compliant) Versions: *Industry Litronic *High Rise Industry Litronic *Gantry Industry Litronic *Port Litronic *High Rise Port Litronic *Gantry Port Litronic	Operating weight: 105,000 Kg-140,000 Kg	Marketing	Europe, Asia, Africa and America	Access the link here
45	Liebherr	Excavator	LH 150	Construction	Hybrid	400	n.a	Emission standard: Stage IV Stage IIIA Versions: Industry Litronic *High Rise Industry Litronic *High Rise Industry Litronic	Operating weight: 130,000 Kg-140,000 Kg	Marketing	Europe, Asia, Africa and America	Access the link here
46	Sandvick	Drilling rig	DD422iE	Mining	Electric	205	Capacity: 100 kWh	Battery charging during drilling. Battery charging using the braking system.	N/A	Marketing	Europe, Asia, Africa and America	Sandvik DD422iE Electrical Drilling and Jumbo Mining Rig -

ID	Head office	Class	Line	Sector	Technology	Engine power (kW)	Battery capacity	Other technical features	Material loading capacity	State of Maturity	Sales Area	Source
												Sandvik Mining and Rock Technology
47	Sandvick	Drilling rig	DL422iE	Mining	Electric	205	Capacity: 100 kWh	Continuous and unmanned operation with automation and teleremote for drilling during shift changes and breaks.	N/A	Marketing	Europe, Asia, Africa and America	DL422iE Long-hole drilling rig - Sandvik Mining and Rock Technology
48	Focor	Loader	*FKWJ-0.6E *FKWJ-0.75E *FKWJ-1E *FKWJ-2E *FKWJ-3E *FKWJ-6E	Mining	Electric	30 - 180	n.a	Wired operation according to photographic references.	1,200 Kg - 12,000 Kg	Marketing	America, Pakistan, Russia, Africa, Eastern Europe.	China Electric Scooptram Suppliers - Good Price Electric Scooptram for Sale - Focor (focormach.com)
49	Kobelco	Excavator	17SR	Construction	Electric	n.a	n.a	n.a	1,700 Kg	Development	NA	Access the link here
50	Sumitomo	Excavator	SH200HB-7	Construction	Hybrid	119	n.a	Hybrid operation, energy storage via capacitor.	Operating weight: 21,900 Kg	Marketing	n.d	Hybrid SH200HB-7: Sumitomo Construction Machinery Corporation (sumitomokenki.co.jp)

N/A: not applicable; n.a.: not available.

Annex 2. Zero-emission NRMM image bank.

Table A 2. Zero-emission NRMM image bank.

ID	Image	Fuente
1		https://suncar-website.fra1.digitaloceanspaces.com/media/filer_public/49/bb/49bb214f-b4bd-45af-ac46-e82912debd22/brochuere-ze85-kteg.pdf
2		https://www.directindustry.es/prod/ammann/product-41134-2052883.html
3		Rigid and articulated dumpers - Learn about our range of products | AUSA Official Website

ID	Image	Fuente
4		Bobcat E19e miniexcavator
5		Bobcat E10e mini excavator
6		CASE 580 EV - The Industry's First Fully Electric Backhoe Loader | CASE Construction Equipment (casece.com)

ID	Image	Fuente
10		Caterpillar announces four electric machine prototypes - Construcción LatinoAmericana (construccionlatinoamericana.com)
11		C10162830 (scene7.com)
12		Load and change the way you look at pavers • Dynapac - Fayat Group

ID	Image	Fuente
13		Scooptram ST7 Battery | Underground loader | Epiroc
14		Scooptram EST1030 | Underground loader | Epiroc
15		Scooptram EST2D | Underground loader | Epiroc

ID	Image	Fuente
16		Scooptram EST3.5 | Underground loader | Epiroc
17		Scooptram ST14 Battery | Underground loader | Epiroc
18		Minetruck MT2010 Battery | Epiroc

ID	Image	Fuente
19		Underground truck | Minetruck MT42 Battery | Epiroc
20		Faresin introduces the Big Range full electric at Bauma (noticiasmaquinaria.com)
21		The 5-ton battery-powered mini-excavator will begin taking orders in the European market. - Hitachi Construction Machinery (hitachicm.com)

ID	Image	Fuente
22		Battery-powered compact and mini excavators to be showcased at bauma 2022 - Hitachi Construction Machinery (hitachicm.com)
23		Electric Construction Machinery - Hitachi Construction Machinery (hitachicm.com)
24		19C-1E | Miniexcavators | JCB.com

ID	Image	Fuente
25		https://www.jcb.com/es-es/productos/d%C3%BAmperes/1te
26		JCB Introduces Industry's First Hydrogen-Powered Excavator to Market - JCB
27		John Deere's prototype electric backhoe loader put to the test on real construction sites - News - Híbridos y Eléctricos | Coches eléctricos, híbridos enchufables (hibridosyelectricos.com)

ID	Image	Fuente
28		John Deere introduces an autonomous electric tractor that does not need batteries - News - Híbridos y Eléctricos | Coches eléctricos, híbridos enchufables (hibridosyelectricos.com)
29		Keestrack B7e frantoio a mascelle | Keestrack
30		MR 130i EVO2 | Mobile Impact Crushers | Kleemann (wirtgen-group.com)

ID	Image	Fuente
31		Komatsu's PC210E excavator with engine Proterra - Carreteras Pan-Americana (carreteras-pa.com)
32		Manitou MRT 2260 360 e, télescopiques rotatifs - Manitou
33		Bauma 2022 | New mini road pavers from VÖGELE (wirtgen-group.com)

ID	Image	Fuente
34		ECR25 Electric | Electric Machines | Overview | Volvo Construction Equipment (volvoce.com)
35		ECR18 Electric | Electric Machines | Overview | Volvo Construction Equipment (volvoce.com)
36		L25 Electric | Electric Machines | Overview | Volvo Construction Equipment (volvoce.com)

ID	Image	Fuente
37		L20 Electric | Electric Machines | Overview | Volvo Construction Equipment (volvoce.com)
38		ZE19-T | Kenki Technology Group (kteg-company.com)
39		Takeuchi TB260E kaufen & mieten | Huppenkothen GmbH

ID	Image	Fuente
40		LB 16 unplugged drilling rig | Liebherr
41		https://www.liebherr.com/es/col/productos/gr%C3%BAas-automotrices-y-sobre-orugas/gr%C3%BAas-sobre-orugas/gr%C3%BAas-sobre-orugas-lr/details/lr12501unplugged.html
42		T 236 | Liebherr

ID	Image	Fuente
43		LH 26 M Industry Litronic | Liebherr
44		https://www.liebherr.com/es/col/productos/manipulaci%C3%B3n/m%C3%A1quinas-para-la-manipulaci%C3%B3n-de-materiales-de-accionamiento-el%C3%A9ctrico/details/89386.html https://www.liebherr.com/es/col/productos/manipulaci%C3%B3n/m%C3%A1quinas-para-la-manipulaci%C3%B3n-de-materiales-de-accionamiento-el%C3%A9ctrico/details/89390.html https://www.liebherr.com/es/col/productos/manipulaci%C3%B3n/m%C3%A1quinas-para-la-manipulaci%C3%B3n-de-materiales-de-accionamiento-el%C3%A9ctrico/details/89388.html https://www.liebherr.com/es/col/productos/manipulaci%C3%B3n/m%C3%A1quinas-para-la-manipulaci%C3%B3n-de-materiales-de-accionamiento-el%C3%A9ctrico/details/68702.html https://www.liebherr.com/es/col/productos/manipulaci%C3%B3n/m%C3%A1quinas-para-la-manipulaci%C3%B3n-de-materiales-de-accionamiento-el%C3%A9ctrico/details/68706.html https://www.liebherr.com/es/col/productos/manipulaci%C3%B3n/m%C3%A1quinas-para-la-manipulaci%C3%B3n-de-materiales-de-accionamiento-el%C3%A9ctrico/details/68710.html
45		https://www.liebherr.com/es/col/productos/manipulaci%C3%B3n/m%C3%A1quinas-para-la-manipulaci%C3%B3n-de-materiales-de-accionamiento-el%C3%A9ctrico/details/68521.html https://www.liebherr.com/es/col/productos/manipulaci%C3%B3n/m%C3%A1quinas-para-la-manipulaci%C3%B3n-de-materiales-de-accionamiento-el%C3%A9ctrico/details/68529.html

ID	Image	Fuente
46		Sandvik DD422iE Electric drill rig and mining jumbo equipment — Sandvik Mining and Rock Technology
47		DL422i Longhole drill rig — Sandvik Mining and Rock Technology
48		China Electric Underground Loader Suppliers - Focor (focormach.com)

ID	Image	Fuente
49		KOBELCO launches its first mini electric excavator (noticiasmaquinaria.com)
50		https://www.sumitomokenki.co.jp/excavator/sh200hb-7/

Annex 3. Zero-emission NRMM data sheets.

(see attached folder)

Annex 4. Review of NRMM use cases and tools.

(see attached file)

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