

Low-emission zones and zero-emission construction equipment in China: An untapped policy opportunity

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Introduction

China's market for construction equipment has shown strong growth over the past two decades. China has led the world in sales as shown in Figure 1, accounting for about one-third of the global market in recent years. Construction equipment includes asphalt finishers, backhoe loaders, dozers, excavators, motor graders, and other equipment. Their total sales reached more than 1.6 million in 2021, propelled by a growth rate of about 25% annually over the past five years.

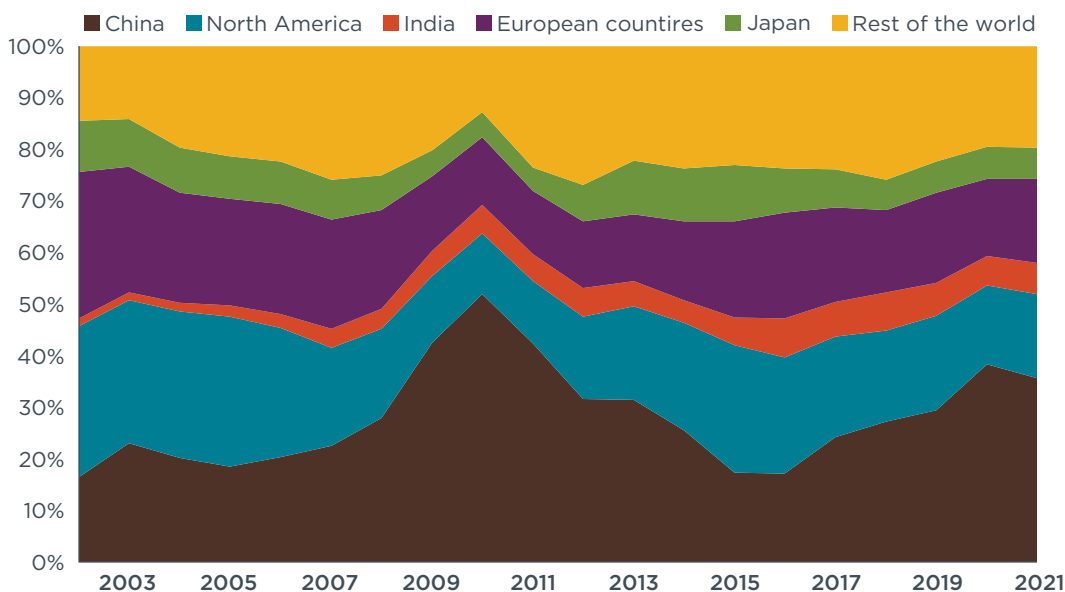


Figure 1. Global construction equipment sales by key market. (Data: Off-highway research, 2019)

European countries include Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and United Kingdom.

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The rapid increase in the market for construction equipment has resulted in the growth of pollutant emissions. The total PM emissions were about 77,000 tons in 2020, which was higher than that of motor vehicles (~68,000 tons) as presented in Figure 2. The NO_x emissions reached almost 1.5 million tons. Excavators and loaders are the top two equipment polluters, generating about 80% of the PM and NO_x emissions contributed by all construction equipment despite having a sales share of only 30% (Figure 3). Although forklifts claim two-thirds of the market, they contribute only about 10% of emissions. This is mainly due to their smaller engine size and high electrification rates (about 60% of 2021 sales). Construction equipment emissions have become a growing concern for China's urban air quality and carbon emissions.

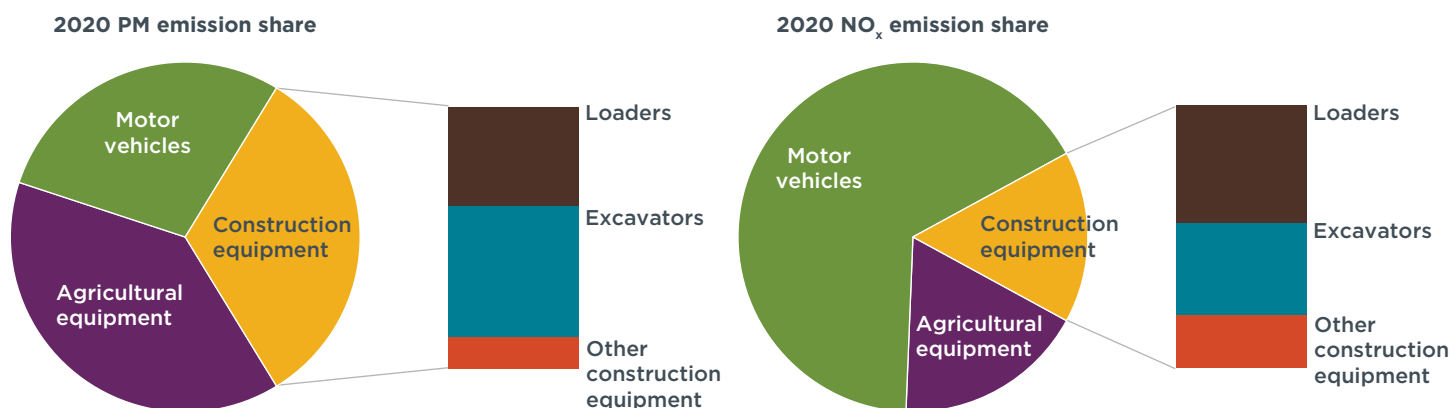


Figure 2. PM and NO_x emission shares, by construction equipment, 2020. Data source: Ministry of Ecology and Environment, 2021.

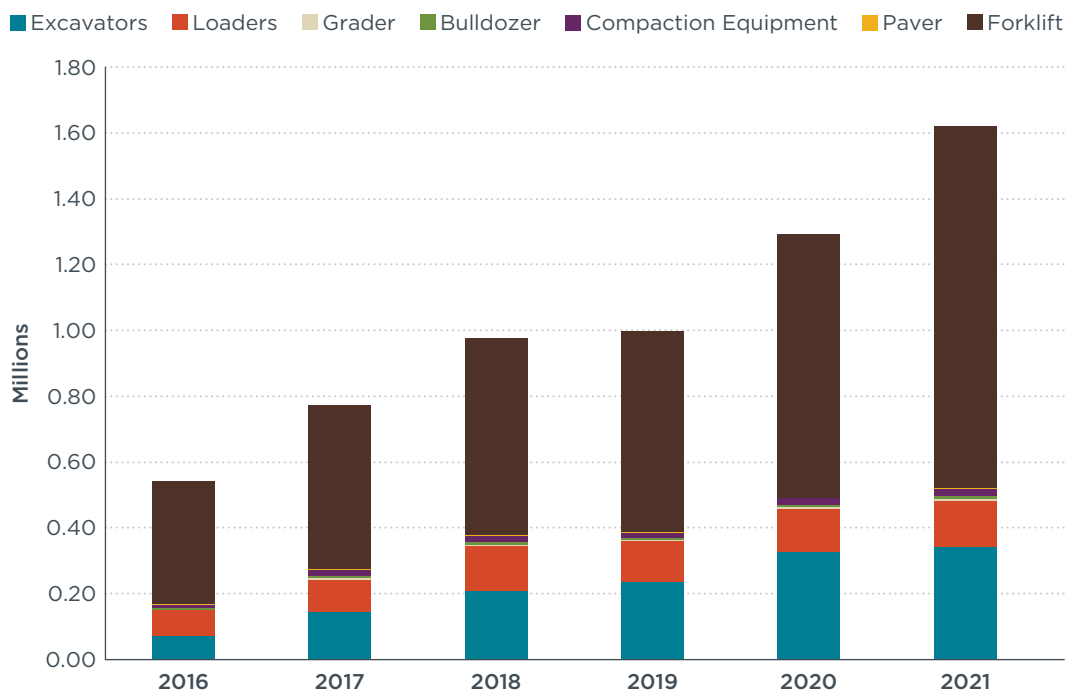


Figure 3. Sales of construction equipment in China, by major category

Cities in China have been under pressure to improve local air quality since China released its ambient air quality standard in 2012 (Ministry of Ecology and Environment, 2012). Emissions from construction sites, which are often located in urban areas, contribute a substantial share of local air pollution. Enabled by the Clean Air Law, cities have set off-road low-emission zones to restrict the use of high-emitting construction equipment

(China's National People's Congress, 2015).¹ Some cities (such as Shenzhen [Guangdong province], and Chengdu [Sichuan province]) have shown increasing interest in deploying zero-emission technologies and policies to dramatically reduce emissions from construction equipment since the success of ultra-low and zero-emission zones in pilot projects in European cities.²

However, major barriers remain in China. There is a lack of open-source data about model and technology availability and feasibility of zero-emission equipment even though manufacturers have presented zero-emission models for various types of construction equipment. Policy instruments and incentives to promote the development and adoption of zero-emission construction equipment are also lacking.

To address these barriers, this project will review the legislation and strategies for establishing construction low-emission zones in China and provide an overview of the current market for zero-emission construction equipment. For those interested in improving local air quality, we propose a set of recommendations regarding investing in construction zero-emission zones and promoting zero-emission construction equipment. We will identify regions where early adoption can be feasible based a review of their local policy measures in promoting clean, new energy, off-road equipment.

Policy efforts in promoting new energy off-road equipment

Given its high emission levels and rapidly expanding market, China has implemented a series of regulations and policies to reduce emissions from construction equipment and, more importantly, to promote the adoption of clean, new energy equipment. Figure 4 summarizes the key regulatory authorities and measures adopted in recent years. The regulations and policies in general target reducing emissions from diesel engines by tightening emission limits, removing/restricting high emitters, and promoting new energy equipment. The following section will review these existing policy efforts. Most of the efforts have broad sectoral targets, which include agriculture, mining, and material handling equipment, but this analysis will focus mainly on construction equipment.

1 The low-emission zones here refer to the areas where certain old, high-emitters (e.g., pre-China I equipment) are not allowed to perform, although clean, the usage of new-energy equipment is encouraged in some low-emission zones (e.g., Shenzhen [Guangdong province]).

2 Zero-emission zones refer as the ones where only zero-emission equipment are granted to perform; Ultra-low emission zones extend the usage of plug-in hybrid equipment, which can produce zero tailpipe emissions when operating in the zones.



* Other supporting department includes housing and urban and rural construction, agriculture and rural areas, forestry, gardening, water conservancy, market supervision, public security and traffic police, transportation, comprehensive administrative law enforcement, development reform, emergency management, natural resources, urban management, comprehensive law enforcement, water affairs, industrial information, animal husbandry, and veterinary and fishery bureaus.

Figure 4. Key authorities and policies for reducing emissions and promoting new, clean energy equipment

China didn't include the off-road sector in vehicle legislation until the revision of the *Clean Air Law* (refer as the Law) in 2015. The Law clarifies the roles of management and supervision systems for the off-road sector, which includes the departments of Ecology and Environment, Housing and Urban-Rural Construction, Agricultural Administration, Water Administration, and others. Specifically, the Law enables setting off-road low-emission zones at the local level with the goal of retiring high-emitters, promoting clean, new energy equipment, and reducing reliance on fossil fuel. Since 2016, regulations and guidance have been released by various levels to address emissions from off-road equipment.

The State Council announced the *Three-year National Plan of Blue-Sky Defense* in 2018 and the *Action Plan of Battle against Diesel Truck Pollution* in 2018, requiring all regions to set up low-emission zones for off-road equipment by mid-2020 along with the promotion of clean, new energy equipment (China State Council, 2018; MEE, 2019a). The plans also covered a compliance program that includes conducting random testing, inducing penalties, and removing the equipment with violations identified.

At the ministry level, the Ministry of Ecology and Environment (MEE) has led the regulations that target reducing emissions from off-road equipment. Given that the China IV off-road tailpipe emission standards were initially adopted in 2014 without a detailed implementation timeline, the MEE updated the standards in 2020 with the requirements of on-board diagnostics (OBD), particle number (PN), and real-world portable emission measurement system (PEMS) testing in the revision to ensure stringency and announced the implementation date as the end of 2022 in *Emission Control Technical Requirements of Non-road Diesel Mobile Machinery* (MEE, 2020). Those requirements are consistent with the ones in the world's most stringent standards—European Stage V non-road emission standard—which are designed to force manufacturers to include diesel

particulate filters in their equipment and improve compliance. In addition to the world-class standards for new equipment, the MEE released *Guidance on Strengthening the Response to Heavily Polluted Weather and Consolidating Emergency Emission Reduction Measures* for 39 key industries (MEE, 2019b). Companies in those key industries are not allowed to operate off-road equipment on heavy pollution days with requirements of up to all equipment complies with China III standards or above (including clean, new energy, and zero-emission equipment).

Following the Clean Air Law, local governments developed and adopted a wide range of policies and incentives to promote zero-emission off-road equipment. Table 1 summarizes the regions where the promotion of clean, new energy equipment is highlighted in their off-road emission control regulations. About half of the regions have poor air quality, as they did not meet the national Level II PM concentration ($35\mu\text{g}/\text{m}^3$), indicated by the red numerals. In general, four types of strategies are widely adopted:

- » *Promotion of new energy off-road equipment.* For example, leading cities like Beijing and Tianjin encourage the adoption of zero-emission off-road equipment in their existing low-emission zones.
- » *Investment in infrastructure.* Beijing adopts fiscal measures such as finance, taxation, and government procurement to promote the construction of zero-emission supporting and refueling infrastructures.
- » *Incentives to accelerate adoption of new energy equipment.* This is the most widely adopted approach, as financial measures are provided for purchasing zero-emission equipment. In addition, Foshan (Guangdong province) and Sichuan province also promote the adoption of non-fossil, clean energy.
- » *Designation of specific areas for new energy equipment use.* Jinan (Shandong province) prioritizes the needs of upgrading to new energy equipment in railway yards and airports.

Among these regions, Chengdu (Sichuan province) is the first one (in 2017) to adopt a regulation promoting new energy equipment using fiscal incentives. Beijing, Tianjin, Hebei province, and Xuchang (Henan province) have all four strategies in place, according to their regulations.

Table 1. Elements of support for clean, new energy equipment, by region

Region	Implementation time	Average PM _{2.5} concentrate in 2021 (µg/m ³)*	Support clean, new energy equipment by			
			Promoting sales	Investing in infrastructure and facilities	Providing incentives	Designating key areas
Beijing	2020	33	✓	✓	✓	✓
Tianjin	2020	39	✓	✓	✓	✓
Hebei	2020	45	✓	✓	✓	✓
Lvliang, Shaanxi	2018	29			✓	
Jinan, Shandong	2020	40		✓	✓	✓
Foshan, Guangdong	2019	23			✓ (clean energy)	
Daqing, Heilongjiang	2020	27		✓	✓	
Huainan, Anhui	2020	42			✓	
Xuchang, Henan	2020	44	✓	✓	✓	✓
Sichuan	2021	32			✓ (clean energy)	
Shandong	2019	39			✓	
Chengdu, Sichuan	2017	40			✓	
Mianyang, Sichuan	2018	35			✓	
Xining, Qinghai	2020	35			✓	
Guangxi	2019	28			✓	
Guizhou	2018	n/a			✓	
Jiangsu	2018	33		✓	✓	
Shenzhen, Guangdong	2017	18	✓		✓	✓

*The red font indicates that the average PM_{2.5} concentrate exceeds China's Level II requirements, which is 35 µg/m³.

Best practices for implementing low-emission zones

Empowered by China's Clean Air Law, local governments started designing and implementing their low-emission zones to restrict the use of old, high-emitting equipment in 2016. The State Council issued a deadline for setting up low-emission zones in the *Action Plan of Battle against Diesel Truck Pollution*, which was the end of 2019 for key regions and mid-2020 for the rest of the areas. As a result, over 92% of the prefecture-level cities (313 out of 337 cities) had introduced low-emission zones in urban areas. In general, low-emission zones are set within urban areas and/or key locations (such as ports, railway yards, municipal construction sites, and transloading areas), where old, and/or heavily polluting off-road equipment is not permitted. The rules and approaches to defining old and heavily polluting equipment vary across regions. Figure 5 highlights the regions with multiple outstanding rules in regulating and implementing the low-emission zones, as introduced below.

	Improving stringency over time	Prioritizing specific equipment types	GPS tracking and emission monitoring system	Approaches in certifying equipment tailpipe emission standard	Approaches in certifying equipment level III limits in smoke check	Approaches in certifying equipment third-party authority to run the test	Approaches in certifying equipment Smoke check	Supervision and monitoring on implementation	Enforcement with civil penalty
Anyang	●		●	●	●		●	●	
Hebi	●		●	●	●			●	
Beijing	●	●			●			●	
Nanyang	●		●			●		●	
Chengdu	●					●	●	●	
Jinan	●		●					●	
Zhengzhou	●		●					●	
Xuchang	●		●					●	
Luoyang	●		●					●	
Jiaozuo	●		●					●	
Sanmenxia	●		●					●	
Xinyang	●		●					●	
Zhoukou	●		●					●	
Zhumadian	●		●					●	
Shanghai	●			●	●				
Jinhua	●						●	●	
Nanning	●	●						●	
Huanggang			●	●				●	
Shijiazhuang	●				●			●	
Baoding	●						●	●	
Shenzhen	●						●	●	
Tai'an				●	●				
Hangzhou	●						●		
Tianjin	●						●		
Jincheng	●						●		
Jinzhong	●						●		
Yuncheng	●						●		
Changzhi	●						●		
Zigong	●						●		
Taiyuan	●						●		
Lüliang	●						●		
Mianyang	●						●		
Hengshui	●							●	
Tangshan	●							●	
Xingtai	●							●	
Foshan	●							●	
Dongguan	●							●	
Guangzhou	●							●	
Huizhou	●							●	
Wuhan	●							●	
Yichang	●							●	

Figure 5. Cities with multiple rules for regulating and implementing low-emission zones

Improving stringency over the time (brown)

Some regions increase the stringency of their off-road low-emission zones as local air quality targets tighten. Most of the regions highlighted in Figure 5 have tightened the requirements of low-emission zones more than once to ensure that cleaner equipment is performing in the designated area. In addition to one consistent timeline for phasing in low-emission zones, some regions propose a dynamic timeline based on local air quality. Regions such as Xining (Qinghai province) require China III standards or better on equipment operating in low-emission zones during the winter season (November

to February when air pollution is most severe), and China II standards or better for the rest of the year. Some other regions introduce several timelines with more stringent requirements phasing in over time. For example, Ezhou (Hubei province) set a deadline of October 2020 for implementation of its low-emission zone, with the requirement that all equipment meet China II standards or better, and October 2021 as a deadline for complying with China III standards or better.

Prioritizing specific equipment types (blue)

Equipment targeted for regulation in low-emission zones varies. Some regions, such as Beijing, identified excavators, loaders, backhoe loaders, and forklifts as equipment to prioritize due to the high market share, long duty hours, and/or significant emissions contribution. Some, such as Yichang (Hubei province) and Nanning (Guangxi province), prioritize the specific equipment used in key locations such as ports, road and bridge construction sites, landscaping, municipal construction sites, etc. Most of the other regions do not distinguish equipment types for low-emission zones.

GPS tracking and emission monitoring system (red)

Some regions also introduce GPS tracking and emission reporting systems to track the usage and emissions of off-road equipment. These systems are required for off-road equipment certified under the upcoming China IV rules. Regions including Nanchang (Jiangxi province), Henan and Shandong province require or encourage existing off-road equipment to install the systems for reporting the real-time location and emission with local Ecology and Environmental Department. This machinery, if meeting the relevant requirements, can be exempted from smoke testing when operating in low-emission zones.

Approaches in certifying equipment (purple, green, orange, and yellow)

The methods of identifying and certifying qualified equipment are different across regions. Some regions, such as Beijing and Shijiazhuang (Hebei province), use level III limits (the most stringent one) defined in *Limits and Measurement Methods for Exhaust Smoke from Non-road Mobile Machinery Equipped with Diesel Engine (GB-36886-2018)* as the threshold and some others as Xinzhou (Shanxi province) rely on the tailpipe standards the equipment certified.³ Regions such as Huanggang (Hubei province) and Tai'an (Shandong province) combine those two approaches. Others, including Wuzhong (Ningxia province), and Xiangtan (Hunan province) require certifications from third parties to ensure that the equipment complies with emission standards and smoke tests.

Supervision and monitoring of implementation (black)

To ensure that all equipment that performs in low-emission zones complies with requirements, cities have established supervision and monitoring platform that allows key stakeholders from various agencies to collect and track the data. The platform method includes registration of non-road mobile machinery, entry and exit registration, a real-time monitoring and reporting system (for emissions and location) and electronic fence etc.

» *Registration and license.* Registration of non-road mobile machinery has become the most common regulatory approach considering that all equipment is required to be licensed as stated in MEE's *Notice on Accelerating the Registration of Non-Road Mobile Machinery and the Investigation* in 2019. Elements such as equipment type, model, production day, emission standards certified are recorded and used for license. Cities like Huainan (Anhui province) require equipment used in the

³ The smoke tests are designed to assess the particle emissions of in-use equipment while tailpipe standards are mainly for manufacturers to certify their new equipment/models.

low-emission zones to hold a license after registration to ensure compliance, as key information can be read directly from the license (e.g., emission standards certified) to determine whether the equipment qualifies for the low-emission zones.

- » *Entry and exit registration.* Some cities require registration for all equipment that enters low-emission zones. The information collected includes the time of entry and exit, equipment license, and responsible party/person. Cities such as Chengdu (Sichuan province) and Anyang (Henan province) develops Monitoring Applications to record the information, which allows various stakeholders, including the department of Ecology and Environment, to track remotely.
- » *Real-time monitor and reporting system.* Real-time online monitoring and emission reporting systems are mandatory for all new China IV construction equipment, which will enhance compliance with low-emission zones. But regions including Nanchang (Jiangxi province), Henan province, and Shandong province require and/or encourage in-use equipment to install real-time online monitoring and emission reporting systems for the department of Ecology and Environment and other stakeholders to collect and track real-time information.
- » *Electronic fence.* “Electronic fences” are adopted in cities such as Beijing, Hangzhou (Zhejiang province), and Ya’an (Sichuan province) along with the requirement of installing a GPS location system. Key stakeholders, including the department of Ecology and Environment, can thus track the operational location of the off-road equipment to ensure compliance with low-emission zones.

Enforcing with civil penalty (cream)

Several regions have laid out the detailed rules for penalties. Regions, including Zhejiang, Guangxi, Hubei, and Guangdong province, have specified the penalty in the regional rules. Zhejiang province assigns the Ecological and Environmental Department to collect the penalty and defines the penalty as between RMB 5,000 and RMB 50,000 (-USD 740 to 7,400) for violations. Other regions mostly copy the high-level regulatory language from the Clean Air Law as the department of Ecology and Environment will administer the penalty but without a detailed penalty range provided.

The implementation of the low-emission zone requires the collaboration of multiple departments and stakeholders. In addition to the Ecology and Environment Department, many other departments as highlighted in Figure 4 need to be involved in supervision and management of the implementation, with access to the data sharing platform and enforcing the compliance. For example, Yunfu (Guangdong province) requires the Department of Construction Approval and Supervision to enforce the eviction of the violators from the low-emission zones and the Department of Ecology and Environment to collect the penalty. Handan (Hebei province) and Zhanjiang (Guangdong province) require the departments of transportation, construction, and other relevant construction approval supervision departments to work together to ensure compliance. Some regions also require that companies that use and/or rent the equipment ensure that only certified equipment is used in the zones.

Pilot projects for zero-emission equipment

With the upcoming China IV standards and increasingly stringent low-emission zones, manufacturers have already released China IV-compliant products, even though the standards will not be implemented until December 2022. Manufacturers started releasing the China IV certified models as early as February 2021 (Ministry of Ecology and Environment, n.d.). By May 2022, more than 1,600 China IV-certified models had been released, although most are forklifts as shown in Figure 6, followed by loaders and excavators.

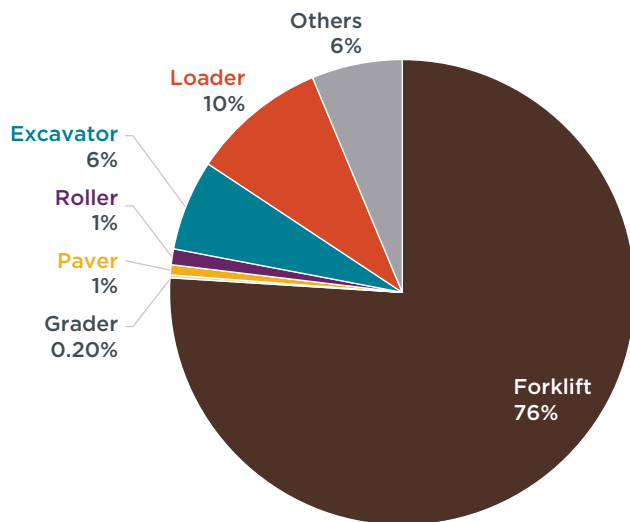


Figure 6. China IV-certified construction equipment share (as of the end of March 2022)

In fact, manufacturers have gone beyond early compliance with China IV standards by releasing zero-emission construction equipment using clean, new energy equipment. In addition to the forklifts, loaders and excavators are the other two equipment types that lead the electrification pathway in the construction equipment, as presented in Figure 7. The electric models of excavators and loaders reached almost 30, and the others added up to about 10. The cumulative sales of electric loaders reached 499 units the first half of 2022, most of which fall in the category of five tons (Yang, 2022). The sales of excavators are lower, most of which are still in the trial stage.

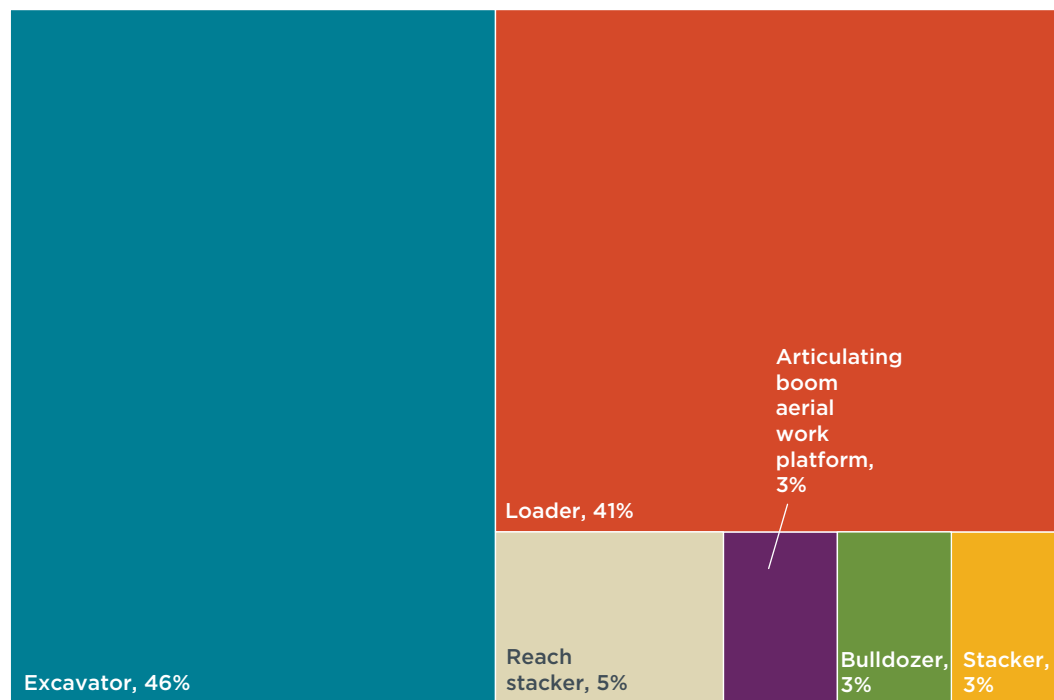


Figure 7. Share of electric models by equipment types. (The chart does not include electric models of forklifts, given their high electrification rates.)

As a highly concentrated industry, the leading manufacturers in the market often successfully embrace cutting-edge technology. Using excavators as an example, XCMG, SANY, and Liugong dominate the sales of excavators as shown in Figure 8 (right side), and they also advance the technology by certifying China IV models early and

releasing electric models. The top five manufacturers that led the early certification of China IV released most of the electric excavators, accounting for over 85% of the available models.

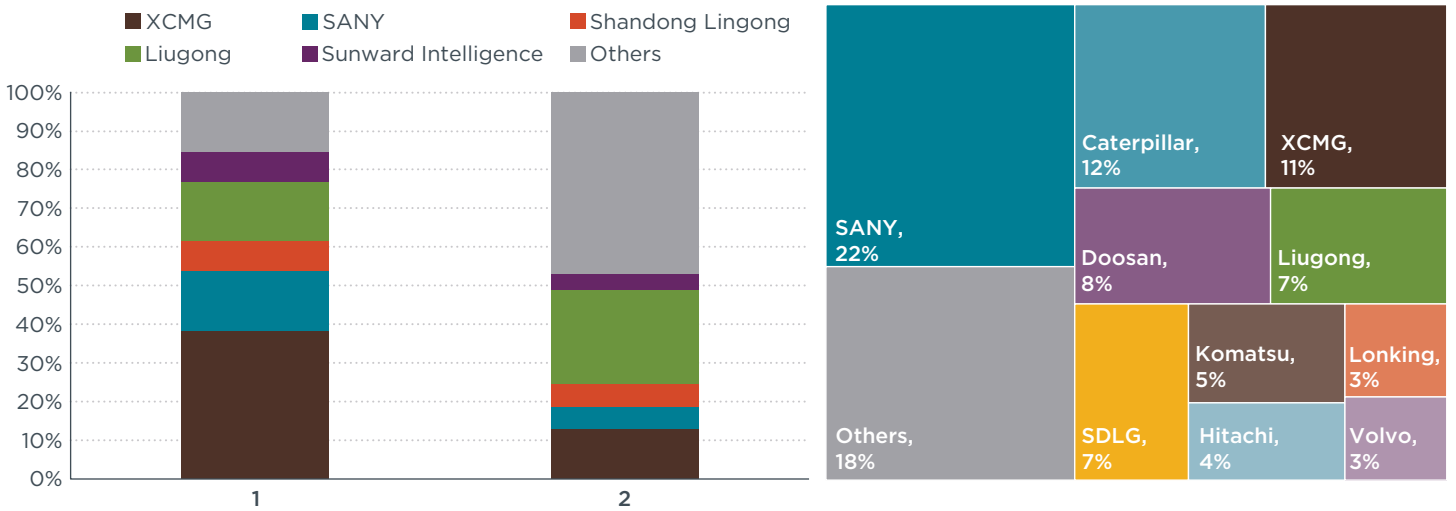


Figure 8. Leading manufacturers of excavators, electric models and China IV models

Zero-emission equipment has begun to emerge in major equipment weight categories. Figure 9 maps the specifications of electric excavators available in China's market. Most of the products available are designed to weigh less than 30 tons. Excavators under 10 tons and those between 15 and 30 tons are the most popular categories. Of the 14 models collected, 12 are battery-powered electric versions, indicating a very concentrated technology pathway. Based on the preliminary survey, there are 14 models available, produced by six leading manufacturers. Most of the equipment is still in the trial stage, but models such as SY16E of SANY and XC968-EV and XE215E of XCMG are in mass production.⁴

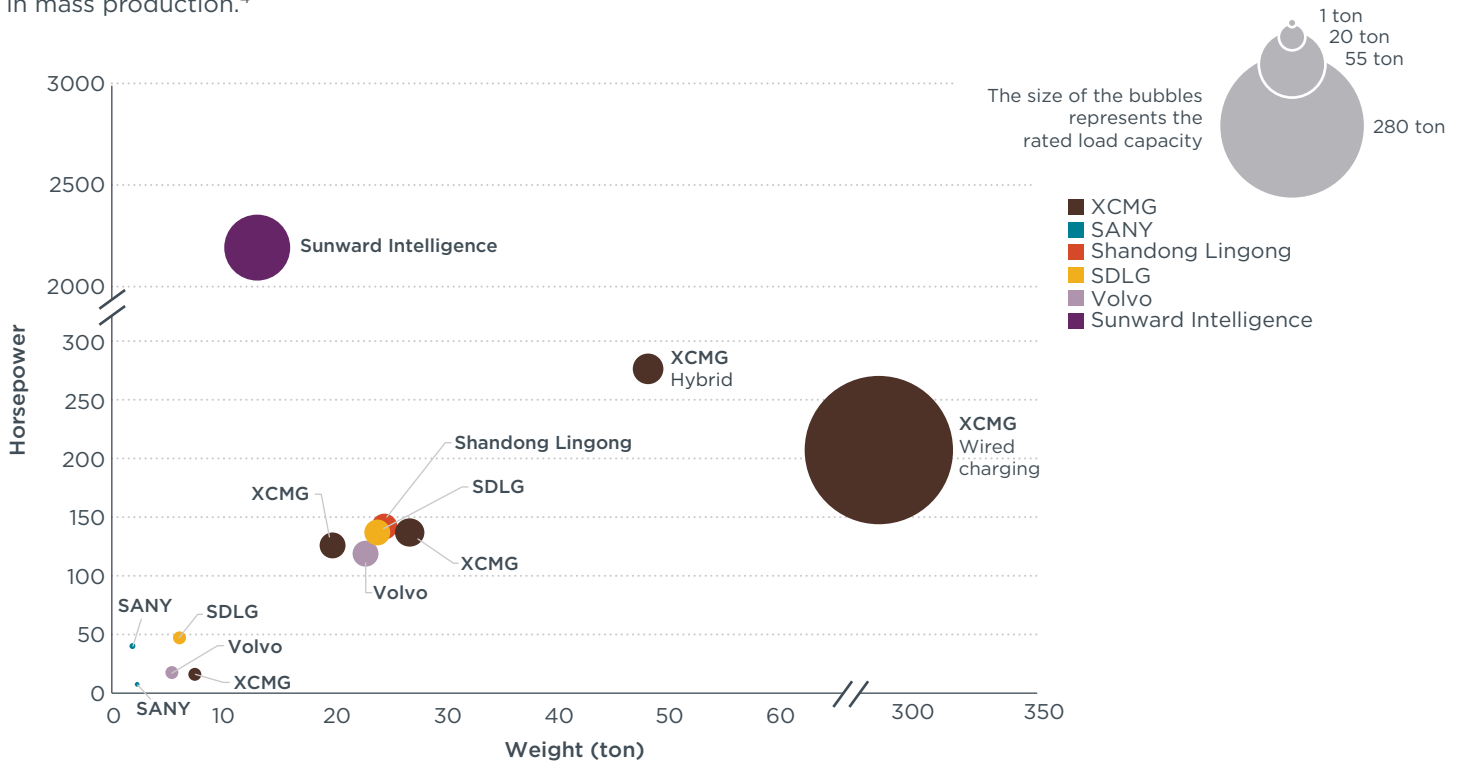


Figure 9. Map of electric excavators' power, by manufacturer

⁴ See Appendix I for detailed specifications of key electric construction equipment available on the market from leading manufacturers.

Some local governments have provided incentives to promote zero-emission construction equipment. However, the impacts vary. Shenzhen (Guangdong province) has subsidized electric forklifts as stated in the 2018 “Shenzhen Blue” Sustainable Action Plan, with incentives being provided based on battery size, which is about RMB 800 (-USD 118) per kilowatt-hour offered (up to RMB 40,000 [-USD 5,915] per forklift). About 31 companies claimed over 1.6 million RMB (-USD 0.24 million) purchase incentives in 2019, and the numbers increased to 55 companies with almost 5 million RMB (-USD 0.74 million) incentives.⁵ Meanwhile, Tianjin adopted the *Interim Measures for Promoting Green Development in Tianjin Economic and Technological Development Zone* in 2020 and encourages the replacement of diesel machinery with electric versions, with about 30% of purchase incentives (up to RMB 20,000 [-USD 2,957]) provided. Even with about RMB 100 million (-USD 15 million) budgeted for each calendar year, only a couple of forklifts were replaced by the end of 2021—mainly because those companies are reluctant to retire the diesel equipment completely, even with the electric version purchased.

In addition to battery-powered equipment, hydrogen also shows great potential for zero-emission construction equipment. Tianjin offers subsidies for purchasing and renting hydrogen forklifts in its Port Free Trade Zone between 2020 and 2024 with the implementation of *Tianjin Hydrogen Energy Industry Development Action Plan (2020-2022)*. The incentives are about RMB 7,000 (-USD 1,035) per kilowatt for purchases, and/or 60% of rental costs, with a monthly cap of RMB 3,500 (-USD 518). Taking advantage of the incentives, Yanshan Petrochemical purchased 37 hydrogen forklifts in October 2021, representing China’s first commercial application of hydrogen fuel cell forklifts. Beijing announced the plan for promoting fuel cell equipment with incentives of about 10% of the purchase costs (up to RMB 50,000 [-USD 7,394]) provided.⁶ Other key regions, including Jing-Jin-Ji, Shanghai, and Guangdong province, have announced plans for promoting fuel cell vehicles with hydrogen refueling stations and facilities built. This could potentially be used for supporting fuel cell off-road equipment as well.

A pathway toward zero-emission zones

Cities in China still face the challenges of improving local air quality, while emissions from construction equipment can be a growing concern. They might need to further tighten the requirements of low-emission zones for construction equipment. Opportunities arise as zero-emission construction equipment become available for commercial application. Introducing off-road ultra-low and zero-emission zones kills two birds with one stone. Thus, policy measures will be essential to encourage continuous investment in zero-emission construction equipment and upgrades to zero-emission zones. Experience learned from implementing low-emission zones can potentially apply to introducing ultra-low and zero-emission zones for interested regions. Thus, we recommend the following steps to help accelerate the creation of zero-emission zones and to support zero-emission progress for construction equipment.

Establish the legal foundation for zero-emission zones

Enabled by the Clean Air Law, local governments can release detailed rules and regulations for low-emission zones that best meet the local needs. However, this privilege is not granted to zero-emission zones yet. Designated legislation is needed from the National People’s Congress to enable the promotion and implementation of zero-emission zones. This will allow the State Council, Central Ministries and Administrations, and local government to set in place various supportive policy measures targeting zero-emission zones. In addition, a clear civil penalty plan including leading authorities is needed for violations.

5 <https://baijiahao.baidu.com/s?id=1670188333429948763&wfr=spider&for=pc>, <http://www.hcwgx.com/4986.html>, <https://www.chndaqi.com/news/299859.html>

6 <https://news.dlcm.com/20220105134518.shtml>

Establish a multi-agency collaboration platform and data sharing system

One of the best practices learned from implementing low-emission zones is to rely on teamwork from various stakeholders, including multiple government agencies. To enhance the collaboration among stakeholders, a system that tracks the equipment is essential for key stakeholders. The existing technology used in low-emission zones allows remote access of the location, real-time emission level and operation status of the monitored equipment, which can be adopted to support the implementation of zero-emission zones. The Department of Ecology and Environment can lead in supervision, and other agencies including the departments of transport and construction, along with others, should support enforcement and management.

Increase the stringency of zones towards zero-emission, in step with incentives

Many cities have tightened the requirements for low-emission zones along with the adoption of more stringent standards. Considering that only a limited number of zero-emission models are available in the market, the promotion of zero-emission zones can phase in starting from piloting zero-emission construction sites to ensure that zero-emission equipment is available for the work needed. Ultra-low emission zones can serve as an intermediate approach that allows plug-in hybrid equipment to be used when zero-emission options are not available. Supporting policies, including fiscal and non-fiscal incentives, financing, evaluations, and municipal bidding, are essential for promoting clean, new energy equipment, which needs to be adjusted periodically to encourage participation and increase cost benefits. Such adjustments can also be made to address local emissions and air quality concerns.

Prioritize key regions, equipment types, and application for early implementation

The review of China's off-road low-emission zones highlights that progress can vary significantly across regions. Key regions with poor air quality, advanced piloting experience, comprehensive supervision capacities, and/or developed economies usually are the ones that prioritize the phase-in of stringent requirements and advanced technologies. This can shed some light on the regions where piloting zero-emission zones could be introduced first. As detailed in Appendix II, cities including Beijing, Tianjin, Jinan (Shandong province), Zhengzhou (Henan province), Xuchang (Henan province), Anyang (Henan province), Chengdu (Sichuan province), Shenzhen (Guangdong province), and Suzhou (Jiangsu province) are potential candidates for early adoption of zero-emission zones based on the ambitious efforts identified in low-emission zones. In addition, for early adoption, great potential and interest are seen in provinces including Shanghai, Guangdong, Hebei, Henan, Shandong, Shanxi, Zhejiang, and Jiangsu. Regions with hydrogen stations can also be prioritized for piloting fuel cell equipment.

Another prioritization can focus on the type and application of construction equipment based on the rule of low-emission zones. In addition to forklifts, for which electrification progress is already advanced, excavators and loaders show technology readiness. These two types also lead the construction equipment market and contribute the most to tailpipe emissions. In addition, locations such as tunnel construction, railway freight yards, ports, and mining enterprises can be prioritized for piloting zero-emission zones because the use of the equipment often is limited to fixed locations. For application at high altitudes, deploying zero-emission construction equipment can avoid the power drop of diesel engines. Zero-emission equipment can also reduce air pollution in closed environments such as tunnel construction and coal mines.

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Appendix I. Zero-emission construction equipment manufacturers

The construction equipment industry is highly concentrated, with the top ten manufacturers dominating almost 90% of the sales market, as presented in Figure 10. Based on 2018 data, XCMG and SANY shared about 15% of total sales, followed by Liugong, SDLG, and Lonking, each of whose share was around 10%.

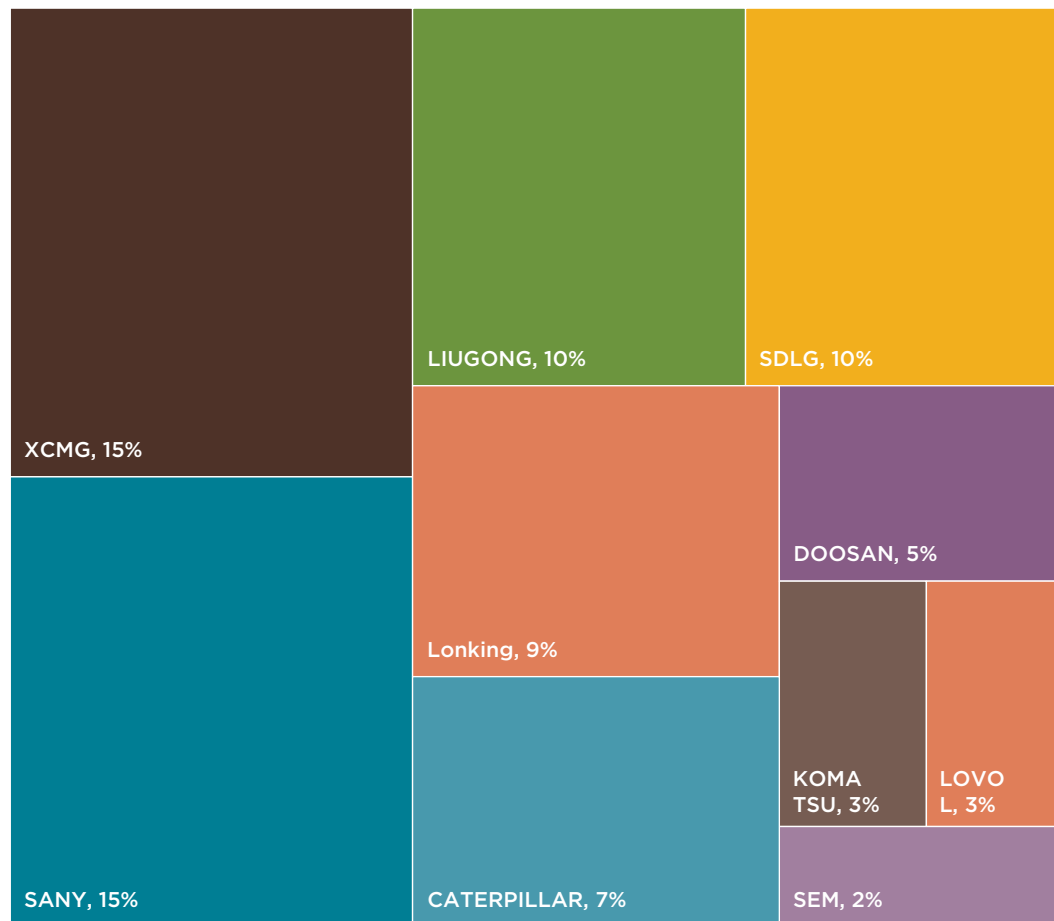








Figure 10. Top ten manufacturers and their market share (excluding forklifts).
Data source: Off-highway research, 2019



Using key manufacturers' websites and general news updates, the following section provides an overview of available zero-emission construction equipment by manufacturer. The data presented below provides only a general idea regarding existing zero-emission models. It does not serve as a comprehensive database that tracks all zero-emission equipment in China's market.




BRETON Società per Azioni (S.p.A.) (Public Limited Companies by Shares)	
Business type	An Italian privately held company
Segment	 Loaders
Electric model number	4
Available model(s)	BRT958E BRT956EV BRT936EV BRT966EV
Rated power (kW)	100-270
Rated weight (ton)	3-6.5
Power type	Battery electric
Application	Coal industry, etc.


Guangxi LIUGONG Machinery Co., Ltd.		
Business type	A Chinese multinational construction machinery manufacturing company	
Segment	 Excavators	 Loaders
Electric model number	3	2
Available model(s)	CLG922F-E CLG006F-E CLG924FTN-E	CLG856H-EV CLG856E-MAX
Rated power (kW)	50-165	180-300
Rated weight (ton)	6-25	5
Power type	Battery electric	Battery electric
Application	Tunnels, etc.	n/a


Lonking Holdings, Ltd.	
Business type	A private manufacturer of construction machinery in China
Segment	 Loaders
Electric model number	1
Available model(s)	LG855N-E
Rated power (kW)	n/a
Rated weight (ton)	5-6
Power type	Battery electric
Application	n/a




Shandong Lingong Construction Machinery Co., Ltd.		
Business type	Subsidiary of Volvo	
Segment	 Excavators	 Loaders
Electric model number	2	1
Available model(s)	E6500FHB E6225H EV	L956H-EV
Rated power (kW)	145-245	n/a
Rated weight (ton)	22-50	5
Power type	Battery electric, hybrid electric	n/a
Application	Mines, etc.	n/a


Shantui Construction Machinery Co., Ltd.		
Business type	A subsidiary of Shandong Heavy Industry	
Segment	 bulldozer	 Loaders
Electric model number	1	2
Available model(s)	DE17-X	LE56-X2 LE59-X2
Rated power (kW)	145	150
Rated weight (ton)	19	5-5.5
Power type	Battery electric	Battery electric
Application	Power plants	Ports, coal yard, grain depot, etc.


SANY Heavy Industry Co., Ltd.			
Business type	A Chinese multinational state-owned heavy machinery manufacturing company		
Segment	 Excavators	 Forklift truck	 Reach Stackers
Electric model number	2	1	1
Available model(s)	XE16E XE19E	SRSC45E	SDCE90K7
Rated power (kW)	43	210	n/a
Rated weight (ton)	1	45	9
Power type	Battery electric, wired charging	Battery electric	Battery electric
Application	n/a		

SINOMACH-HI International Equipment Co., Ltd.	
Business type	A subsidiary of China SINOMACH Heavy Industry Corporation (SINOMACH-HI), a major State-owned enterprise directly managed by the central government
Segment	 Excavators
Electric model number	3
Available model(s)	323Ev 950E 955Ev
Rated power (kW)	140-189
Rated weight (ton)	5-30
Power type	Battery electric
Application	Plateau highway, etc.

Sunward Intelligent Equipment Co., Ltd.	
Business type	
Segment	 Excavators
Electric model number	2
Available model(s)	SWE240FED SWE550FE
Rated power (kW)	n/a
Rated weight (ton)	24-55
Power type	Battery electric
Application	Mines, etc.

Xuzhou Construction Machinery Group Co., Ltd. (XCMG)			
Business type	A Chinese multinational state-owned heavy machinery manufacturing company		
Segment	 Excavators	 Loaders	 Reach Stackers
Electric model number	5	3	1
Available model(s)	XE270E XE215E XE35U-E XE2800E XE500HB	XC958-EV XC918-EV XC968-EV	XCS45-EV
Rated power (kW)	18.2-1,200	270	200
Rated weight (ton)	5.8-220	1.8-5.5	45
Power type	Battery-electric, hybrid, wired charging	Battery-electric	Battery-electric
Application	Tunnel, steel mills, docks, mine, plateau, etc.	Steel mills, power plants, mines, etc.	Ports

Volvo Construction Equipment	
Business type	A subsidiary and business area of the Volvo Group
Segment	 Excavators
Electric model number	2
Available model(s)	EC55 Electric EC230 Electric
Rated power (kW)	n/a
Rated weight (ton)	5-22
Power type	Battery electric
Application	n/a

Zoomlion Heavy Industry Science and Technology Co., Ltd.	
Business type	A Chinese construction machinery and agricultural machinery manufacturer
Segment	 Articulating boom aerial work platform
Electric model number	1
Available model(s)	ZE14JE
Rated power (kW)	n/a
Rated weight (ton)	n/a
Power type	n/a
Application	n/a

Appendix II. Evaluation of cities potentially ready for zero-emission zones

Province	City	Regulations					Promote zero-emission equipment					Set up and implement low-emission zone					Other elements				Readiness for zero-emission zones
		Release regional law	Encourage production of zero-emission equipment	Build zero-emission (charging) infrastructure	Provide fiscal incentives	Identify key areas	Control high-emitters	Include off-road in industry evaluation	Prioritize new energy	Provide incentives for new energy	Improve the stringency	GPS monitor	Level III smoke tests	Third party tests	Random smoke check	Supervision and management	Key regions	Poor air quality	Leading the promotion of zero-emission vehicles	Leading the promotion of hydrogen	
Beijing		✓	✓	✓	✓	✓		✓		✓				✓		✓		✓	✓	***	
Tianjin		✓	✓	✓	✓	✓	✓	✓		✓					✓	✓		✓	✓	***	
Hebei	Baoding	✓	✓	✓	✓	✓		✓		✓					✓			✓	✓	***	
	Hengshui	✓	✓	✓	✓	✓		✓		✓					✓			✓	✓	***	
	Shijiazhuang	✓	✓	✓	✓	✓		✓		✓		✓			✓			✓	✓	***	
	Tangshan	✓	✓	✓	✓	✓		✓		✓					✓	✓		✓	✓	***	
	Xingtai	✓	✓	✓	✓	✓		✓		✓					✓	✓		✓	✓	***	
Shanxi	Taiyuan	✓								✓					✓	✓				*	
	Lüliang	✓			✓					✓					✓	✓				***	
	Jincheng									✓					✓	✓	✓			***	
	Jinzhong									✓					✓	✓				*	
	Yuncheng									✓					✓	✓				*	
Changzhi									✓					✓	✓				*		
Liaoning	Huludao									✓										*	
	Jinzhou									✓										*	
	Shenyang									✓										*	
	Yingkou									✓										*	
Jilin	Changchun	✓								✓										*	
Shanghai		✓	✓					✓		✓						✓		✓	✓	***	
Jiangsu	Nanjing	✓		✓	✓			✓		✓						✓		✓		**	
	Changzhou	✓		✓	✓			✓		✓						✓		✓		***	
	Nantong	✓		✓	✓			✓		✓						✓				**	
	Suzhou	✓		✓	✓			✓		✓						✓		✓		**	
	Wuxi	✓		✓	✓			✓		✓						✓				**	
Zhejiang	Hangzhou									✓					✓	✓		✓		**	
	Jinhua									✓					✓	✓				**	
Anhui	Huainan	✓														✓				*	
	Bozhou													✓		✓				*	
Jiangxi	Nanchang							✓				✓								*	
Shandong	Jinan	✓			✓		✓	✓		✓				✓	✓	✓				***	
Henan	Xuchang	✓	✓	✓	✓	✓		✓		✓				✓	✓					***	
	Luoyang							✓		✓					✓	✓				**	
	Nanyang							✓	✓	✓			✓		✓	✓				**	
	Zhengzhou	✓						✓		✓					✓	✓				***	
	Anyang							✓		✓					✓	✓	✓			***	
	Hebi							✓		✓		✓			✓	✓	✓			**	
	Jiaozuo							✓		✓					✓	✓	✓			***	
	Sanmenxia							✓		✓					✓	✓				**	
	Xinyang							✓		✓					✓	✓				**	
Zhoukou							✓		✓					✓	✓				**		
Zhumadian							✓		✓					✓	✓				**		
Guangdong	Foshan	✓			✓					✓								✓	✓	*☆	
	Shenzhen									✓					✓			✓	✓	***	
	Dongguan									✓								✓	✓	*	
	Guangzhou									✓								✓	✓	*	
	Huizhou									✓									✓	*	
Guangxi	Nanning	✓			✓					✓										*	
Sichuan	Chengdu	✓			✓					✓					✓			✓		***	
	Mianyang	✓			✓					✓					✓					*	
	Zigong	✓								✓					✓					*	
Shaanxi	Xi'an	✓								✓					✓		✓		*		
Qinghai	Xining	✓			✓					✓									*		
Hubei	Wuhan	✓								✓								✓		*	