

Incentivizing zero-emission off-road machinery

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INTRODUCTION

As the global market for off-road mobile equipment—including agricultural machinery and equipment for construction, mining and quarrying, port handling, airport ground support, and materials handling—has grown rapidly in the past two decades, so, too, have the emissions from this equipment. Because the kind of regulations that have reduced emissions from on-road vehicles have lagged in the off-road sector, this equipment is becoming a major contributor to emissions in many regions. In recent years, California identified off-road diesel engines as being responsible for 29% of diesel particulate matter (PM) emissions in the state and 11% of nitrogen oxides (NO_x) emissions.¹ In China, off-road diesel equipment contributed over half of the PM emissions from mobile sources and consumed more than one-third of the diesel fuel.²

There is increasing interest in moving toward zero-emission off-road equipment. Regulatory agencies in key regions have set timelines to require sales of zero-emission equipment, and there are also pilot projects underway. Many zero-emission models are readily available on the market and major manufacturers continue to release new prototypes. However, information among stakeholders is not being widely shared globally, and there is generally a limited understanding of the policy progress in promoting zero-emission off-road equipment. To help, this briefing identifies key measures that promote the transition to zero-emission off-road equipment and

1 California Air Resources Board, “Off-Road Mobile Source Research,” n.d., <https://ww2.arb.ca.gov/resources/documents/off-road-equipment-research>

2 Zhenying Shao, “The Updated China IV Non-road Emission Standards,” (Washington, DC: International Council on Clean Transportation, 2021), <https://theicct.org/publication/the-updated-china-iv-non-road-emission-standards/>; Vehicle Emission Control Center, China Research Academy of Environmental Sciences, 非道路移动机械控制管理政策体系研究报告 [Research Report on Non-road Mobile Machinery Control and Management Policy System] 2018, <https://www.efchina.org/Attachments/Report/report-ctp-20190512-3/%E9%9D%9E%E9%81%93%E8%B7%AF%E7%A7%BB%E5%8A%A8%E6%9C%BA%E6%A2%B0%E7%AE%A1%E7%90%86%E6%94%BF%E7%AD%96%E5%88%86%E6%9E%90%E6%8A%A5%E5%91%8A.pdf>.

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highlights some successful cases. This builds on work done for the ICCT by Knibb, Gormezano and Partners that included a review of literature and discussions with stakeholders such as equipment manufacturers and end users.

TYPES OF MEASURES THAT PROMOTE ZERO-EMISSION OFF-ROAD EQUIPMENT

As shown in Figure 1, a combination of regulatory requirements and financial incentives have been adopted in leading markets to speed the transition to zero-emission equipment. In other markets, there are only pilots thus far. This section focuses on four categories of measures that we found are being used to incentivize the uptake of zero-emission off-road equipment: policies and regulations, fiscal instruments, market mechanisms, and industry strategies.

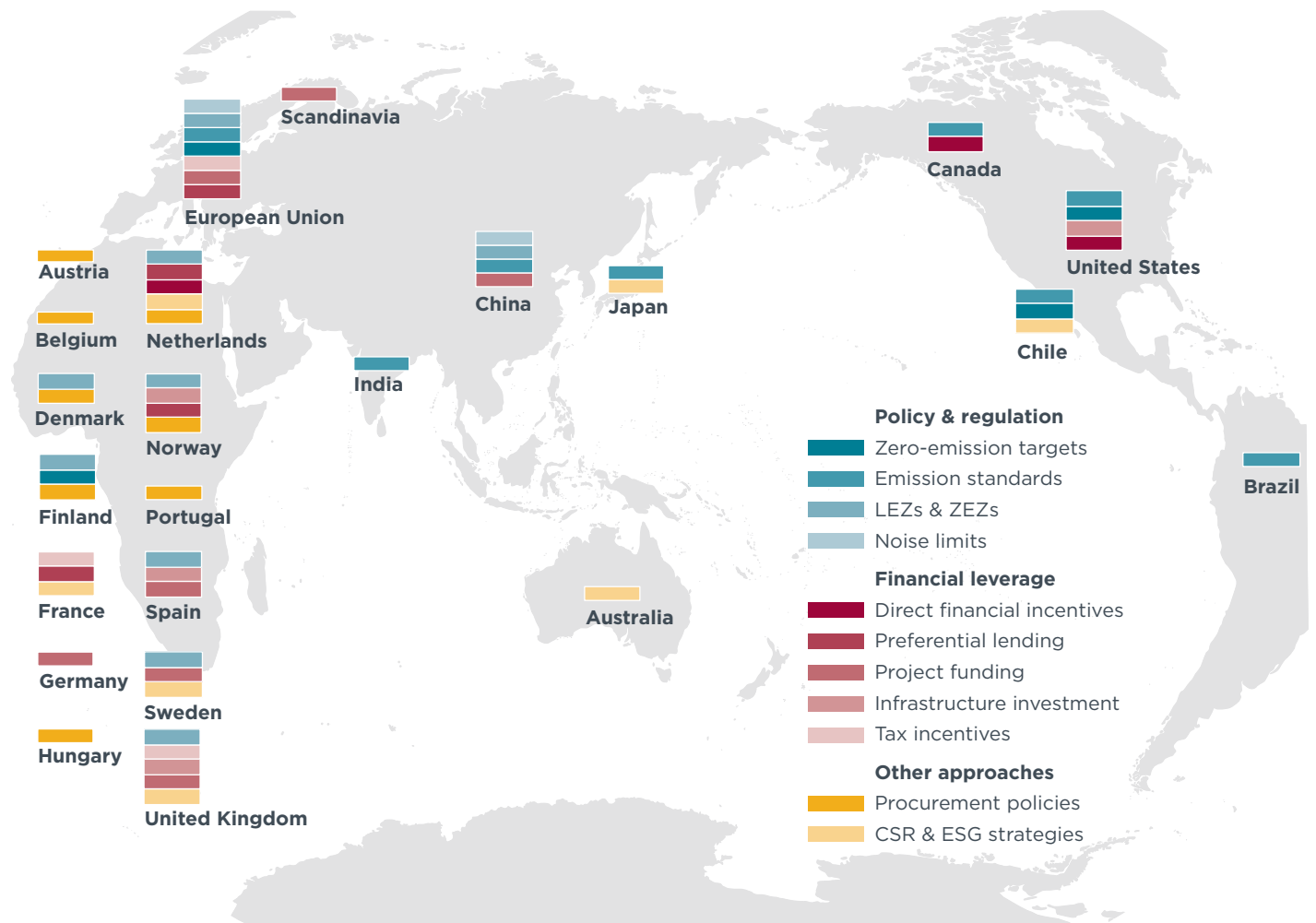


Figure 1. Countries and regions implementing measures to promote zero-emission off-road equipment

POLICIES AND REGULATIONS

Zero-emission targets

Zero-emission targets set requirements for the sale of new zero-emission off-road equipment. These can be binding or nonbinding and are often announced by the government. For example, **California** announced a goal to have a fully zero-emission off-road fleet “where feasible” by 2035. The state of **New York** adopted a 100% zero-emission sales goal for new off-road equipment for 2025, but it is not binding at present.³ **Chile** has a goal to achieve 100% zero-emission for sales of new equipment over 560 kW by 2035 and for new equipment between 19 kW and 560 kW by 2040.⁴ In Europe, **Finland** has set the goal of 100% “fossil-free” construction sites by 2025.⁵

Emission standards

Emission standards are widely adopted to reduce criteria pollutant emissions from off-road equipment. The Stage V emission standard, a regulation mandating particulate filters, is currently the most stringent in the world. The **European Union**, **India**, and **China** have adopted this standard. **North America**, meanwhile, is still at Tier 4f, a standard that can be met without filters. **California** is considering proposing Tier 5, which has more stringent limits, but this is also not a filter-forcing standard.

There is not a similar effort to mitigate climate-warming emissions from off-road equipment, even though almost all of it still runs on diesel fuel. There are no fuel consumption, carbon dioxide (CO₂), or greenhouse gas (GHG) emission standards for off-road equipment, but **California** and **China** are considering proposing such requirements. Experience in regulating cars, buses, and trucks shows that such standards can be effective in promoting the adoption of zero-emission technology if they are stringent and well structured.

CALIFORNIA'S ZERO-EMISSION FLEET TARGET

The California governor signed an executive order directing the California Air Resources Board to propose strategies to transition the entire in-use off-road fleet to zero-emission “where feasible” by 2035. As a result, the state is considering or has developed a variety of regulations and incentives to support the availability, adoption, and application of zero-emission technologies. For example, California:

- » Amended the In-Use Off-Road Diesel-Fueled Fleets Regulation in August 2023.^a Pursuant to this, equipment over 20 years old is required

to be phased out as early as 2028. (Some flexibility is offered for fleets using zero-emission equipment.)

- » Plans to require zero-emission forklift sales as early as 2026 and phase out those over 10 years old from the fleet starting in 2028.^b
- » Is considering GHG emission standards in the more stringent Tier 5 rulemaking process, which might include limits on CO₂, methane (CH₄), and nitrous oxide (N₂O).^c

3 California Air Resources Board, “Zero-Emission Off-road Strategies”; Governor’s Press Office, “In Advance of Climate Week 2021, Governor Hochul Announces New Actions to Make New York’s Transportation Sector Greener, Reduce Climate-Altering Emissions,” September 8, 2021, <https://www.governor.ny.gov/news/advance-climate-week-2021-governor-hochul-announces-new-actions-make-new-yorks-transportation>.

4 Oscar Delgado and Samantha Pettigrew, “New Legislation in Chile Shows Climate Leadership,” (Washington, DC: International Council on Clean Transportation, 2022), <https://theicct.org/chile-latam-lvs-leg-en-apr22/>.

5 “Finland Starts Targeting Emissions in the Construction Sectors,” *Bellona Europa*, May 5, 2020, <https://bellona.org/news/eu/2020-05-finland-starts-targeting-emissions-in-the-construction-sectors>.

- » Plans to set a Zero-Emission Targeted Manufacturer Rule to increase the availability and accelerate the production and sale of zero-emission equipment as early as 2031.^d
- » Adopted incentive programs such as the Clean Off-Road Equipment (CORE) Voucher Incentive

program, which provides direct financial incentives for a wide range of machines.^e CORE is the largest such program in investment terms globally; it allocated over \$508 million between 2017 and 2023; a subsidy of up to \$500,000 is offered for zero-emission equipment.

References:

- a. California Air Resources Board, “Zero-Emission Off-Road Strategies,” 2020, https://ww2.arb.ca.gov/sites/default/files/2020-11/ZEV_EO_Off-Road_Fact_Sheet_111820.pdf.
- b. California Air Resources Board, “Zero-Emission Forklift,” 2023 <https://ww2.arb.ca.gov/our-work/programs/zero-emission-forklifts>.
- c. California Air Resources Board, “Potential Tier 5 Rulemaking Greenhouse Gas (GHG) Reducing and Capping Standards,” 2022, https://ww2.arb.ca.gov/sites/default/files/2022-08/Capping%20Standards%20for%20Workgroup%20Meeting%2008082022%20V7%20Post%20Chris%20Revisions_ADA_07252022_%2802%29_SA_DL_JL.pdf.
- d. California Air Resources Board, “Listening Session for Off-Road Rulemaking and Incentives,” 2023, https://ww2.arb.ca.gov/sites/default/files/2023-05/Off-road%20Listening%20Session_final_1.pdf.
- e. California CORE, “Clean Off-Road Equipment Voucher Incentive Project,” 2023, <https://californiacore.org/>.

Low- and zero-emission zones

Low-emission zones (LEZs) and zero-emission zones (ZEVs) started with on-road vehicles and now have been extended to construction sites in urban areas. LEZs and ZEVs vary from city to city. Typically, LEZs specify the minimum stage of emission standard required for vehicles and equipment to operate in the zone. ZEVs only allow vehicles and equipment with zero tailpipe emissions. In the **United Kingdom**, London introduced the first off-road LEZ in the world; the city is expected to shift to a ZEV by 2040.⁶ The city of Oslo, **Norway**, conducted the world’s first zero-emission construction site pilot.⁷ Copenhagen, **Denmark**, kicked off its first zero-emission construction site in August 2020. Other cities in Europe—including Helsinki (**Finland**), Vantaa (**Finland**), Rotterdam (**Netherlands**), Amsterdam (**Netherlands**), and Vienna (**Austria**)—have planned to spur zero-emission construction sites with demonstration projects.⁸ Barcelona, **Spain**, also started a small pilot project using electric machines for a construction project.⁹ Over 300 cities in **China** had introduced construction LEZs in urban areas by the end of 2021, as allowed under the Clean Air Law, and many of these cities are considering upgrading to ZEVs for construction equipment to further reduce emissions.¹⁰

Diesel restrictions

The emissions from diesel equipment are harmful to human health; concern is especially high with applications where ventilation may be limited. Although most markets do not ban the use of diesel machines, some health and safety regulations or guidelines restrict their use and/or impose certain requirements. In these cases, zero-

6 Mayor of London and London Commission, “Non-Road Mobile Machinery (NRMM),” *Greater London Authority*, n.d., <https://www.london.gov.uk/programmes-and-strategies/environment-and-climate-change/pollution-and-air-quality/nrmm>.

7 “Quiet, Clean and Green: Discover Oslo’s Zero-emissions Construction Site,” *Eurocities*, November 25, 2020, <https://eurocities.eu/stories/quiet-clean-and-green-discover-oslos-zero-emissions-construction-site/>.

8 European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, “Big Buyers Working Together,” n.d., https://bigbuyers.eu/fileadmin/user_upload/Materials/BBCE_ZEMCONS_Kick-off_12.04.21.pdf.

9 European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, “Webinar on How to Procure a ‘Zero Emission Construction Site,’” February 28, 2023, <https://public-buyers-community.ec.europa.eu/resources/webinar-how-procure-zero-emission-construction-site>.

10 Zhenying Shao, “Low-emission Zones and Zero-emission Construction Equipment in China: An Untapped Policy Opportunity” (Washington, DC: International Council on Clean Transportation, 2022), <https://theicct.org/publication/china-hvs-lez-construction-equipment-nov22/>.

emission machines may be cost-effective today. Many jurisdictions—including countries in **Europe, California, Canada, Japan, and China**—ban certain diesel road vehicles, but similar bans are not seen yet in the off-road sector.

Noise limits

Noise limits restrict operating hours for construction machinery, but electrical machinery typically generates less noise and can be used for longer in many applications. In the **European Union**, the Outdoor Machinery Directive is reducing machinery noise.¹¹ In **China**, guidance from the central government encourages regional and city governments to implement policies that support the adoption of low-noise equipment, and many of the recommended models are electric.¹²

OSLO ZERO-EMISSION CONSTRUCTION ZONE

Oslo's first ZEZ was a pilot, started in September 2019, that used zero-emission construction equipment to transform an area into a pedestrian-only street. The Olav Vs gate project was billed as the first “nearly ‘zero-emissions’” construction site in Oslo and unprecedented in the world. The tender documents for the construction work specified that all machinery and equipment had to run on alternatives to fossil fuels. The Olav Vs gate site used three electric excavators and some other electric machines. The machinery was supplied by Nasta (Hitachi's Scandinavian dealer) and Pon Cat, (Caterpillar's Norwegian dealer). Both manufacturers have been converting existing machines to electric. Oslo's ZEZ pilot also included an investment in charging infrastructure.

Olav Vs gate is helping to meet the goal of reducing climate emissions across the city by 95% by 2030.

Construction equipment and vehicles are believed to account for approximately 30% of the city's traffic emissions.^a All municipal construction sites are expected to be fossil-fuel-free by 2025, and all other sites by 2030.^b Oslo's climate budget is integrated into the city budget. Climate requirements are included and tracked in the financial budgeting process to meet the goal of cutting 95% of the direct GHG emissions from the 2009 level by 2030.^c As a result, only spending plans that are consistent with climate goals can be approved.

The Olav Vs gate project saved an estimated 35,000 liters of diesel and the equivalent of nearly 93 tons of CO₂.^d The project cost \$7.2 million, more than the estimated \$6.6 million for a more traditional project; this was largely because electric machines are currently scarce and cost more to purchase.^d

References:

- a. “Oslo European Green Capital 2019,” *Sustain Europe, 2019*, <https://www.sustaineurope.com/oslo-european-green-capital-2019-20191023.html>.
- b. C40 Cities Climate Leadership Group, City of Oslo, & C40 Knowledge Hub, “How Oslo is Driving a Transition to Clean Construction,” *C40 Knowledge Hub*, January 2020, https://www.c40knowledgehub.org/s/article/How-Oslo-is-driving-a-transition-to-clean-construction?language=en_US.
- c. Raymond Johansen, “Oslo's Climate Budget Process is Working. This is How,” *C40 Knowledge Hub*, October 2022, https://www.c40knowledgehub.org/s/article/Oslo-s-climate-budget-process-is-working-This-is-how?language=en_US.
- d. Thomas Reuters, “Zero-emissions” Building Sites Ditch Diesel Machinery in Oslo, Norway,” *CBC/Radio-Canada, December 16, 2020*, <https://www.cbc.ca/news/science/zero-emissions-building-site-1.5843304>.

11 European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs “Noise Emission by Outdoor Equipment,” n.d., https://single-market-economy.ec.europa.eu/sectors/mechanical-engineering/noise-emission-outdoor-equipment_en#:~:text=The%20Outdoor%20Noise%20Directive%202000,or%20in%20parks%20and%20gardens.

12 Ministry of Ecology and Environment of the People's Republic of China, 《低噪声施工设备指导名录（第一批）》（四部门公告2023年 第12号）[*Guidance List of Low-Noise Construction Equipment (First Batch)*] May 23, 2023, https://www.mee.gov.cn/xgk/2018/xgk/xgk10/202305/t20230523_1030831.html

FISCAL INSTRUMENTS

Direct financial incentives

Direct financial incentives for zero-emission equipment, which are focused mostly on the construction sector, lower capital expenses and are mostly seen in Europe and North America. In addition to **California's** CORE subsidy program, the **Netherlands** has a national incentive program called the Clean and Emission-Free Construction Material Subsidy Scheme (SSEB); it will provide €270 million in funding by the end of 2030 and offer up to 50% of the purchase price of each piece of equipment.¹³ The Netherlands is the only country in Europe with such a program.

Preferential lending

Financing for zero-emission machines will be needed, especially to help small fleets and operators. Finance companies, however, are uncertain about the residual value and operating costs of the new machines and can therefore be reluctant to finance them. At present we believe only Oslo has low-cost financing for zero-emission machinery; this is limited in scope and availability, and the program is more focused on public procurement. At the **EU** level, the European Investment Bank has invested in the fleet of **French** rental company Loxam, supported by the EU's new InvestEU program. The funding will be used to replace fossil fuel equipment with electric equipment. Loxam is targeting a 30% reduction in indirect emissions by 2030 and a 50% reduction in direct emissions. Out of a total budget of €400 million, €70 million was invested in 2021.¹⁴ Collé Rental & Sales, an equipment rental company based in the **Netherlands**, also received a loan of €50 million from the European Investment Bank to purchase electric machines for its fleet. The investment is guaranteed by the European Fund for Strategic Investments, part of the Investment Plan for Europe.¹⁵

Project funding, including pilot projects

Project funding for pilot projects has been adopted at both the national and local government levels, and many manufacturers have also run their own pilots to test the zero-emission equipment.

In **Sweden**, a pilot program funded by Skanska and Volvo tested zero- and low-emission machinery in a quarry. Leading smaller equipment supplier Wacker Neuson piloted its machines at test sites in **Stuttgart** and **Barcelona**.¹⁶ An EU program called LIFE CLEANAIRMM piloted energy storage by replacing generators on 12 construction sites in Europe.¹⁷

13 Netherlands Enterprise Agency, "Subsidy for Clean and Zero Emission Construction Equipment (SSEB)," 2023, <https://business.gov.nl/subsidy/clean-and-zero-emission-construction-equipment-sseb/>.

14 European Investment Bank, "France: InvestEU-Loxam Receives €130 million Loan from the EIB to Support Its Energy Transition," September 26, 2022, <https://www.eib.org/en/press/all/2022-376-investeu-in-france-loxam-receives-eur130-million-loan-from-the-eib-to-support-its-energy-transition>.

15 Megha Paul, "Collé Rental Gets Charged with €50 Million from EIB to Speed Up Electrification of Rental Machinery," *Tech.eu*, August 22, 2022, <https://tech.eu/2022/08/22/dutch-company-colle-rental-sales-receives-eur50-million-from-eib-for-further-electrification-of-rental-machinery/>.

16 "Electric Construction Machines Impress in Practical Test in Stuttgart Inner City," Wacker Neuson Magazine, March 30, 2022, <https://magazine.wackerneuson.com/en/electric-construction-machines-impress-in-practical-test-in-stuttgart-inner-city/>; "Electric Excavation and Compaction - with Self-Sufficient Construction Site Power Supply" Wacker Neuson Magazine, January 26, 2023, <https://magazine.wackerneuson.com/en/electric-excavation-and-compaction-with-self-sufficient-construction-site-power-supply/>.

17 European Climate, Infrastructure and Environment Executive Agency, "Zero-emission Battery Power Supply for Cleaner Air," April 20, 2022, https://cinea.ec.europa.eu/news-events/news/zero-emission-battery-power-supply-cleaner-air-2022-04-20_en.

VOLVO ZERO-EMISSION PILOTS

Volvo and partner Skanska created the first “fossil-free” quarry in the world as a research project in 2018.^a Volvo teamed with Skanska Sweden, the Swedish Energy Agency, and two Swedish universities—Linköping University and Mälardalen University—in October 2015 to collaborate on the SEK 203 million project (US\$22.34 million), which was referred to as Electric Site. Volvo took responsibility for developing the zero-emission machines and systems while Skanska took responsibility for providing logistical solutions, application-related and on-site knowledge. The Swedish Energy Agency helped fund the project and universities carried out research.

The viability of the Electric Site research project was tested over 10 weeks at Vikan Kross quarry, Skanska’s second largest quarry. It aimed to electrify each transport stage in the quarry, from excavation to primary crushing, and from transport to secondary crushing. Three main types of concept machines operated at the site:

Carriers: Eight small prototype HX02 autonomous, battery-electric load carriers transported the material from the primary mobile crusher up to the

secondary static crusher. The prototypes have a lithium-ion battery to power two electric motors that drive the machine. The hydraulics are driven by an additional electric motor.

Crusher: The primary crusher on the site was loaded by the 70-ton, dual-powered, cable-connected EX1 excavator prototype. The EX1 automatically starts in electric mode when its cable is connected to electricity. If the cable is not connected, the machine starts in diesel mode.

Loaders: The project also used Volvo Construction Equipment’s LX1 prototype electric hybrid wheel loader, which delivered a 50% improvement in fuel efficiency at the quarry and significant reductions in emissions and noise pollution compared to conventional counterparts.

The test showed a 98% reduction in carbon emissions, a 70% reduction in energy costs, and a 40% reduction in operating costs. The test highlighted that zero-emission equipment is 10 times more efficient. There were zero accidents, zero unplanned stops, and zero direct emissions. These results support the potential for a 25% reduction in the total cost of operations.

Reference:

- a. “Testing Begins at World’s First ‘Emission-Free’ Quarry,” *Volvo Construction Equipment Global*, August 29, 2018, <https://www.volvoce.com/global/en/news-and-events/news-and-stories/2018/testing-begins-at-worlds-first-emission-free-quarry/>.

Infrastructure investment

There has been little investment to date in infrastructure for zero-emission machines because use of such equipment is not common. However, Oslo’s ZEZ pilot included investment in infrastructure, as building charging infrastructure is included in the city’s climate budget.¹⁸ In some port projects, including Valencia¹⁹ in **Spain** and the Port of Los Angeles and Long Beach in **California**, infrastructure investment is being provided for off-road machines, including terminal tractors, reach stackers, and container handlers.

Tax incentives

Carbon taxes increase the cost of operating diesel machines relative to electric ones. Carbon taxes are still generally quite low around the world, but they are being expanded across Europe. Emissions credits can be traded across the **European Union** and the system may be expanded to cover construction machinery emissions in future.

18 C40 Cities Climate Leadership Group, City of Oslo, and C40 Knowledge Hub, “How Oslo is Driving a Transition to Clean Construction,” *C40 Knowledge Hub*, January 2020, https://www.c40knowledgehub.org/s/article/How-Oslo-is-driving-a-transition-to-clean-construction?language=en_US.

19 “Port of Valencia – H2Ports / Fuel Cells and Hydrogen in Ports,” World Ports Sustainability Program, International Association of Ports and Harbors, 2019, <https://sustainableworldports.org/project/port-of-valencia-h2ports/>.

In some markets, fuel taxes for off-road applications are lower than for on-road vehicles. Increasing diesel taxes and/or eliminating diesel subsidies would make the operational and fueling costs associated with zero-emission equipment relatively lower. In the **United Kingdom**, a diesel with lower tax rates (known as red diesel) was used for construction equipment until April 2022. Red diesel now is only allowed to be used in agricultural applications. As a result, construction equipment that relies on diesel fuel faces higher fueling costs. **France** began gradually eliminating its reduced tax rate for off-road diesel in 2019.²⁰ Such changes directly impact not only end users but also rental companies, as they benefit from machines that are cheaper to operate.

Many markets have incentives for investment in capital equipment, but this is not restricted to zero-emission equipment at present. For example, **France's** corporate tax incentives cover electric, natural gas, hydrogen, and hybrid machines.

MARKET MECHANISMS AND INDUSTRY STRATEGIES

Procurement policies

The Big Buyers Initiative, a working group on zero-emission construction sites, brings together the cities of Amsterdam, Brussels, Budapest, Copenhagen, Helsinki, Lisbon, Oslo, Trondheim, and Vienna, and it was partly funded by the **European Union**.²¹

Corporate social responsibility (CSR) and environmental, social, and governance (ESG) strategies

Leading construction and mining companies are driving decarbonization by incorporating emissions reduction into their CSR and ESG policies. Examples include Royal BAM in the **Netherlands**, which has developed an electric Asphalt Finisher with a partner. Lendlease in **France** adopted electric excavators in its Manchester Town Hall renovation project; the company has a zero-carbon target by 2040.²² Sunbelt Rentals (Ashtead Group) procured a fleet of electric mini excavators in the **United Kingdom**. In **North America**, the rental company purchased two thirds of an initial run of electric loaders that are developed and produced by the company and Doosan Bobcat, an off-road equipment manufacturer.²³ There are many mining companies in **Australia** and **South America** and there are expected to be more programs like Zero Emissions in Western Australia Mining.²⁴ Manufacturers are also working on pilots in this segment: Komatsu founded the Komatsu GHG Alliance,²⁵ and a broader group is called the Charge on Innovation Alliance.²⁶

20 "2020 Finance Bill Contains Measures on Corporate Tax Rate Reduction," Deloitte, September 30, 2019, <https://www.taxandhand.com/article/12284/France/2019/2020-finance-bill-contains-measures-on-corporate-tax-rate-reduction>.

21 European Commission, "Big Buyers Working Together."

22 "Using Electrified Plant to Cut Carbon Emissions at Manchester Town Hall," Lendlease Corp., May 18, 2021, https://www.lendlease.com/au/insights/using-electrified-plant-to-cut-carbon-emissions-at-manchester-town-hall/?utm_source=url-redirect&utm_medium=www-lendlease-com_better-places_using-electrified-plant-to-cut-carbon-emissions-at-manchester-town-hall.

23 "Responsible Business Report: Driving Real Cultural Change," Ashtead Group, 2022, https://www.ashtead-group.com/files/downloads/reports/2022/Ashtead_AR22_Responsible_Business.pdf.

24 Minerals Research Institute of Western Australia, "Net Zero Emission Mining," 2023, <https://www.mriwa.wa.gov.au/minerals-research-advancing-western-australia/focus-areas/net-zero-emission-mining/>.






























































25 "Komatsu Announces Collaborative Customer Alliance to Advance Zero-Emission Equipment Solutions—New Offerings to Leverage Electrification for Next Generation," Komatsu Ltd., August 2, 2021, <https://www.komatsu.jp/en/newsroom/2021/20210802>.

26 Charge On Innovation Challenge, "Electrifying Mining," 2023, <https://chargeoninnovation.com/>.

SUMMARY AND POLICY IMPLICATIONS

We identified 12 categories of measures to promote zero-emission off-road equipment (Table 1). The above review is high-level guidance regarding existing approaches and although most of the efforts are still at the preliminary stage, there is growing interest in zero-emission off-road equipment around the world.

Table 1. Measures for promoting zero-emission off-road equipment.

	Policies and regulations					Fiscal instruments					Others	
	Zero-emission targets	Emission standards	LEZs & ZEZs	Diesel restrictions	Noise limits	Direct financial incentives	Preferential lending	Project funding	Infrastructure investment	Tax incentives	Procurement policies	CSR & ESG
National level												
												
												
												
Regional/city level												
												
												
												
Corporate level												
												
												
												

 Construction equipment  Port equipment  Mining equipment  Agriculture equipment

Based on the review, we offer the following suggestions for policymakers seeking to reduce emissions from the off-road sector.

» **Build a database and inventory of the off-road sector in your jurisdiction.**

In most regions, there is a lack of clarity regarding the size of the market and inventory, application patterns, performance characteristics, and costs associated with off-road equipment. Such data are essential for setting feasible goals, developing effective policy measures, and evaluating the impacts of those measures.

» **Set long-term emissions reduction or decarbonization targets for the sector that align with climate mitigation goals.**

A clear emissions reduction or decarbonization goal that is mandatory could force robust policy efforts and the adoption of advanced technologies.

» **Develop standards and requirements for the medium term.**

A set of regulations and standards are likely needed to spur zero-emission technologies and accelerate the transition away from diesel. These should also cover compliance and enforcement of the standards.

» **Fiscal incentives can accelerate market development.**

Given the higher costs associated with advanced zero-emission technology, financial incentives are

common in pilots and demonstration projects and can be effective in promoting early adoption. Fiscal measures can take various forms, including short-term direct financial subsidies, preferential loans, and infrastructure investment.

- » **Build a multi-stakeholder platform to engage policymakers, industry, end users, and research entities to develop integrated solutions.** Even when the goals of carbon neutrality are shared, close collaboration and engagement among stakeholders are essential to driving faster progress towards zero-emission vehicles.