BRIEFING - December 2024

Reducing emissions from non-road mobile machinery

How new CO_2 rules, public procurement and infrastructure provisions can bring clean, affordable off-road machines to market and establish Europe's industry as a zero-emission leader

Summary

Without legislative action on non-road mobile machinery (NRMM), Europe risks repeating the same mistake it made on cars and trucks by failing to respond swiftly and effectively to the increasing challenge posed by foreign competitors. To avoid losing out to foreign competition, EU policy-makers should introduce CO_2 rules for off-road equipment and bring the sector within the scope of the upcoming revision of the EU's public procurement framework and the alternative fuels infrastructure law (AFIR).

Non-road mobile machinery, also known as off-road equipment, encompasses a diverse range of machines that are vital to the functioning of our economy. This sector includes equipment such as excavators, wheel loaders, forklifts, agricultural tractors, household and garden tools, as well as inland waterway vessels and diesel trains.

However, the vast majority of these machines still rely on combustion engines that burn fossil fuels, making them substantial air, noise and climate polluters. Off-road equipment is responsible for 108 Mt CO_2 equivalent (CO_2e) per year, which represents 3.1% of the EU's climate emissions. This is the equivalent of almost 55 million cars driving in Europe, or more than half of what heavy-duty vehicles (HDVs) emit every year.

Around two-thirds of those emissions are caused by two sectors: industry and construction as well as agriculture and forestry. To maintain economic competitiveness while achieving climate neutrality by 2050, it is crucial for Europe to transition its machinery fleet to cleaner, zero-emission technologies, such as battery-electric and hydrogen-powered equipment.

Although NRMM falls under the Effort Sharing Regulation (ESR), which means that these machines fall under national climate targets, it lacks the necessary policy instruments which could help reduce the sector's GHG emissions. NRMM makes up 5% of total EU ESR emissions today and for certain EU countries this share is much higher, such as for Finland (13.5%), Sweden (12.7%), Denmark (11.5%), Latvia (11.5%), Croatia (8%) and Spain (8%).

The good news: The shift to zero-emission off-road powertrains is becoming increasingly viable for a growing share of use cases. Achieving total cost of ownership (TCO) parity for off-road machinery is increasingly feasible as production scales up and technology costs

decline. For example, Volvo Construction Equipment, one of the biggest equipment manufacturers, aims for 35% of its construction equipment sales to be electric by 2030, driven by expectations that upfront price parity with internal combustion engine (ICE) machines will be reached still within the 2020s.

However, the absence of supply- and demand-side regulations for mobile machinery is creating significant barriers to the widespread adoption of zero-emission equipment. Without legislative requirements mandating clean supply and demand, manufacturers as well as customers struggle to compete against traditional diesel equipment, which today remains the default option for most machinery makers and buyers.

Meanwhile global players, particularly from China, are scaling up their capabilities in clean technology, with significant advantages from their vertical integration in electric value chains. Without proactive policy measures to shape the future European machinery market, the EU risks losing ground, as seen in other sectors like cars and trucks, where mixed political signals are putting the competitiveness of the EU's automotive industry at risk.

The EU can shape the zero-emission machinery market with a targeted and effective policy approach. A coordinated policy framework during the Commission's new mandate can help ensure Europe's machinery industry is well-positioned to compete globally while supporting the transition to zero-emission technology. We therefore recommend to:

- **Introduce supply-side CO_2 rules** for machinery to create a level playing field, unlock clean supply and deliver technology cost reductions. A **CO_2 regulation** should prioritise regulating at the engine level and focus on zero emissions as the potential for further internal combustion engine (ICE) fuel efficiency improvements is limited.
- **Spur clean demand** by defining mobile machinery as a strategic industrial sector through the upcoming revision of the EU **public procurement framework**, which the Commission has committed to revise, and to put in place preferential procurement rules in the form of a 'buy green and European' clause for zero-emission equipment.
- **Incorporate the charging and refuelling needs** of the NRMM sector into the upcoming revision of the **Alternative Fuels Infrastructure Regulation** (AFIR). While most worksites with modest energy needs can rely on a few mobile power units for days, larger projects without grid access will require a continuous energy supply from mobile power units or hydrogen tanker trucks. We therefore recommend integrating the anticipated future energy demand of the NRMM sector, which will depend on public heavy-duty vehicle (HDV) infrastructure, into the AFIR.

1. Mobile machinery explained

1.1. Overview of NRMM segments

Non-road mobile machinery (NRMM), also known as off-road equipment, encompasses a diverse range of machines that are vital to the functioning of our economy. This equipment drives our industrial, construction, commercial, agricultural, and logistical activities, making them essential to our modern way of life. NRMM is categorised into eight segments, each serving different industries and applications (as further illustrated in the annex).

Overview of NRMM segments

Segment	Description	Engine	Power range	Example
Industry and construction	Machinery, such as loaders, excavators or mobile cranes, also used for mining and (air)port operations	Diesel, Gasoline, LPG	5 - 1,000+ kW	
Commercial	Equipment like forklifts, air compressors or street sweepers	Diesel, Gasoline, LPG	50 - 500 kW	
Agriculture and forestry	Equipment like agricultural tractors, combine harvesters or forest skidders	Diesel	20 - 500 kW	
Fishing	Boats for fishing operations	Diesel	100 - 1,000+ kW	
Residential	Household and gardening equipment, such as leaf blowers, lawn mowers or all-terrain vehicles like quads	Diesel, Gasoline	<1 - 100 kW	
Inland waterways	Barges for transporting goods along rivers and canals and passenger ferries	Diesel	200 - 4,000 kW	
Rail	Rail cars and locomotives for goods, passengers and for shunting operations	Diesel	1,500 - 4,500 kW	
Military and other	Vehicles like military trucks or recreational equipment such as jet skis	Diesel, Gasoline	45 - 500+ kW	

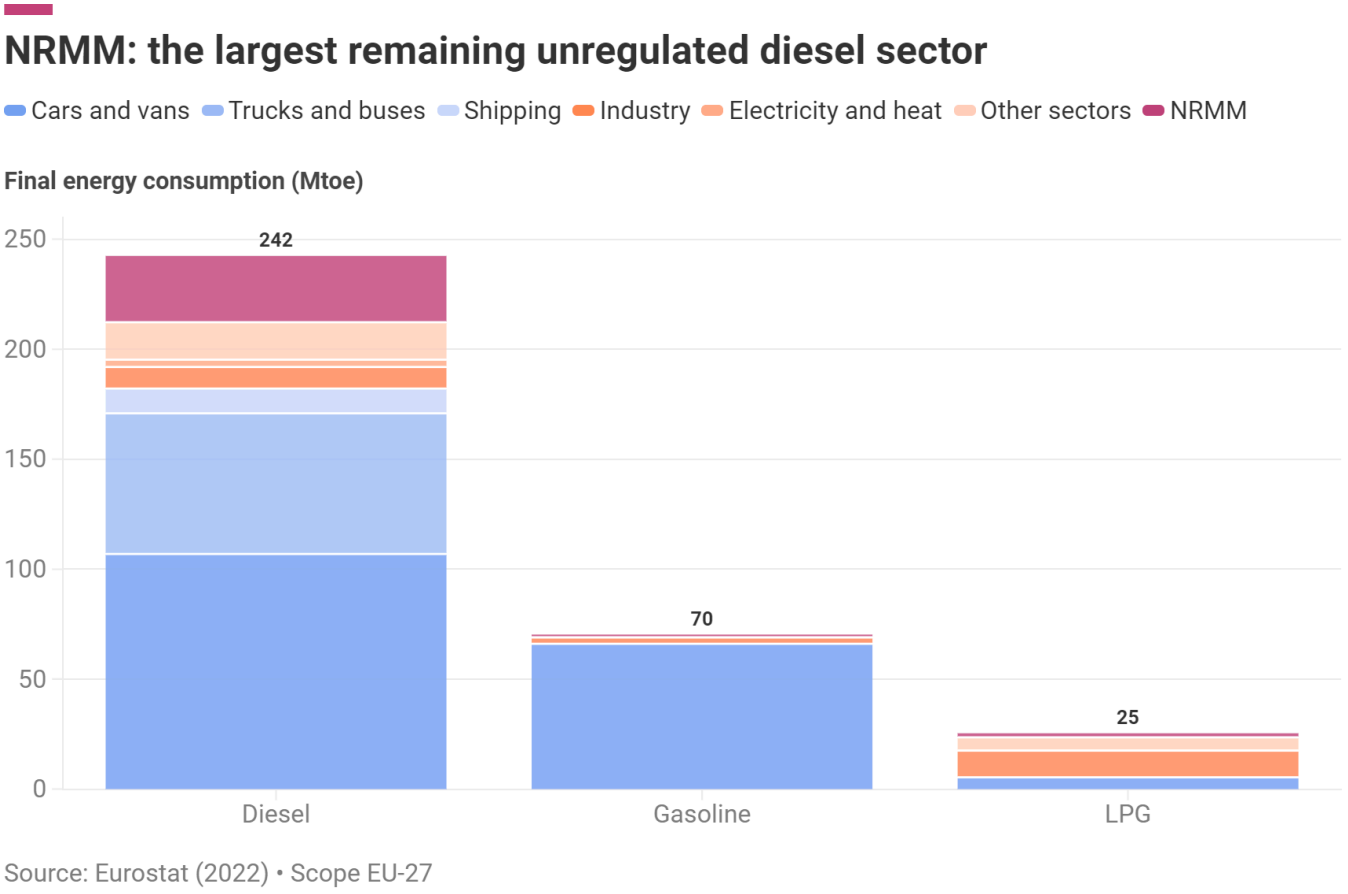
Source: EEA (2023). EMEP/EEA guidebook • Non-exhaustive list of examples.

However, the vast majority of these machines still rely on combustion engines that burn fossil fuels, making them substantial air, noise and climate polluters. To maintain economic

competitiveness while achieving climate neutrality by 2050, it is crucial for Europe to transition its machinery fleet to cleaner, zero-emission technologies, such as battery-electric and hydrogen-powered equipment.

1.2. Diesel: the (still) dominant technology

Off-road equipment today predominantly relies on diesel engines, with minimal use of gasoline and liquefied petroleum gas (LPG) technologies. In 2022, NRMM consumed 30 million tonnes of oil equivalent (Mtoe) of diesel, compared to 1.2 Mtoe of gasoline and 1.9 Mtoe of LPG.[1] Given that the EU has implemented emissions regulations for cars and vans, trucks and buses, as well as the aviation, shipping, industrial, and power sectors, mobile machinery now stands as the largest oil-consuming sector in Europe that remains largely unregulated.



Source: Eurostat (2022) • Scope EU-27

Electric and hydrogen machines show great potential to match the performance of their diesel counterparts and can significantly reduce fossil fuel consumption and emissions (see section 3 below). However, despite gradually gaining some traction in the market, they still represent a small fraction of new sales.

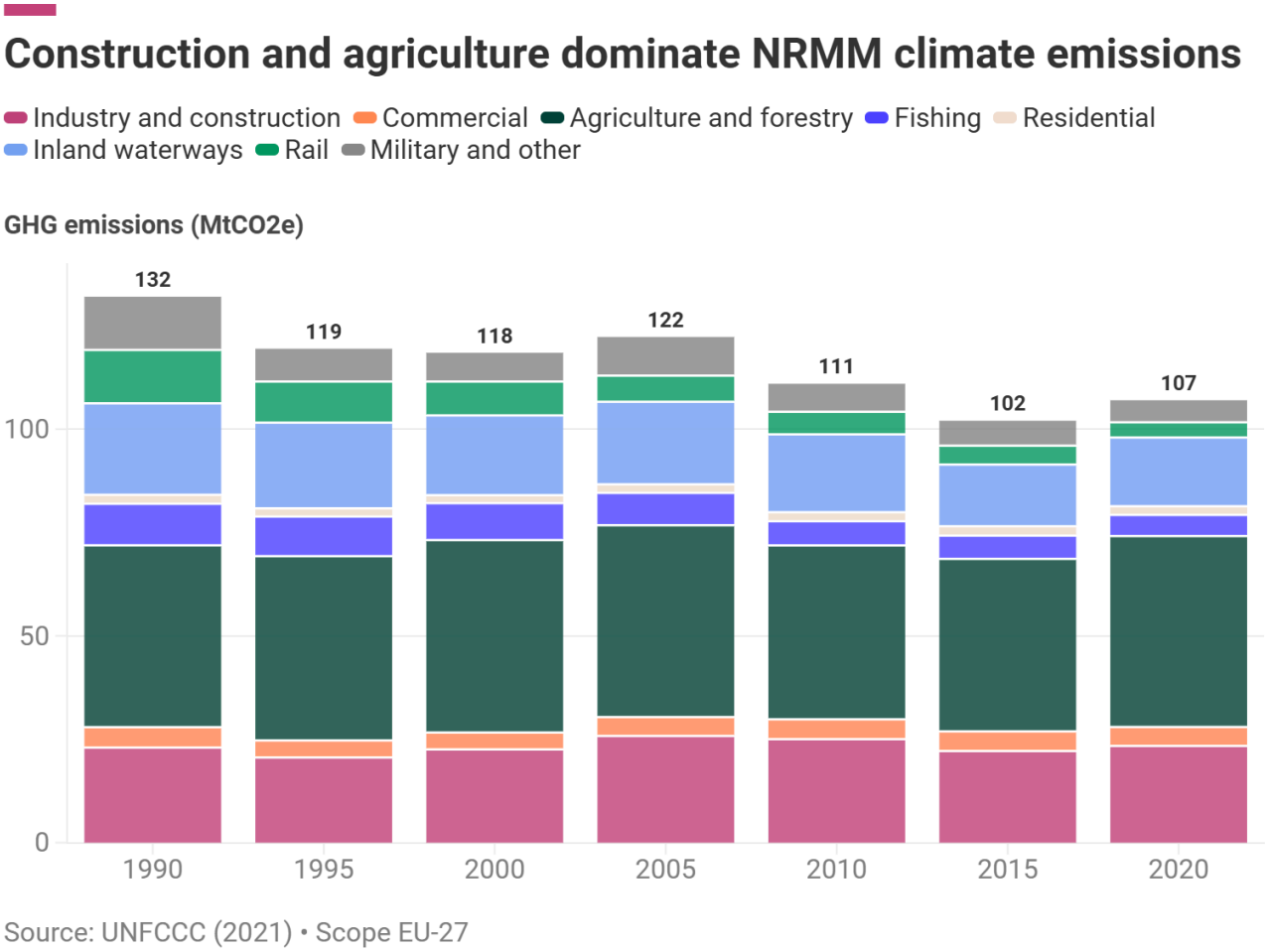
[1] Eurostat (2022). Complete energy balances. Link.

2. The off-road climate problem

2.1. Machines pollute as much as 55 million cars

Off-road equipment is responsible for 108 Mt CO_2 equivalent (CO_2e) per year, which represents 3.1% of the EU's climate emissions.[2] This is the equivalent of almost 55 million cars driving in Europe, or more than half of what heavy-duty vehicles (HDVs) emit every year.[3] Without political intervention, mobile machinery is projected to pollute more than trucks and buses by the 2040s when considering the recent revision of the HDV CO_2 standards.[4]

Two-thirds of those emissions are caused by two sectors: industry and construction as well as agriculture and forestry. While the sector's emissions have somewhat decreased since 1990, this was solely due to reductions from rail (-71%), military (-54%), fishing (-49%) and inland waterways (-27%). The climate impact from industry and construction as well as agriculture and forestry, on the other hand, has grown over the past three decades, by 5% and 4% respectively.



[2] UNFCCC (2021). GHG data from UNFCCC. Link.
[3] T&E (2023). Why all new freight trucks and buses need to be zero-emission by 2035. Link.
[4] T&E (2024). MEPs sign off on climate targets for heavy-duty vehicles. Link.

2.2. Machines make it harder to reach the ESR targets

Although NRMM falls under the Effort Sharing Regulation (ESR), which means that these machines fall under national climate targets, it lacks the necessary EU and national instruments which could help reduce the sector's GHG emissions (see below). NRMM makes up 5% of total EU ESR emissions today (see table below).[5] For certain EU countries this share is much higher, such as for Finland (13.5%), Sweden (12.7%), Denmark (11.5%), Latvia (11.5%), Croatia (8%) and Spain (8%).

As climate emissions from other ESR sectors, such as road transport, buildings and small industry will decrease, the relative share of ESR emissions due to machinery will grow over time. This will increasingly become a problem for member states who are to meet their ESR targets but lack the policy instruments to reduce off-road emissions, as further explained in section 6 below.

NRMM makes it harder to reach the Effort Sharing Regulation (ESR)

NRMM share of total ESR emissions in EU countries

Country	NRMM share	Country	NRMM share	Country	NRMM share	Country	NRMM share
Austria	5.3%	Estonia	5.2%	Italy	6.0%	Portugal	3.2%
Belgium	2.7%	Finland	13.5%	Latvia	11.5%	Romania	3.4%
Bulgaria	2.4%	France	4.6%	Lithuania	2.8%	Slovakia	2.5%
Croatia	8.0%	Germany	2.9%	Luxembourg	3.7%	Slovenia	3.8%
Cyprus	2.3%	Greece	6.4%	Malta	7.3%	Spain	8.0%
Czechia	2.9%	Hungary	4.9%	Netherlands	5.2%	Sweden	12.7%
Denmark	11.5%	Ireland	2.8%	Poland	5.0%	EU-27	5.0%

Source: EEA (2021).

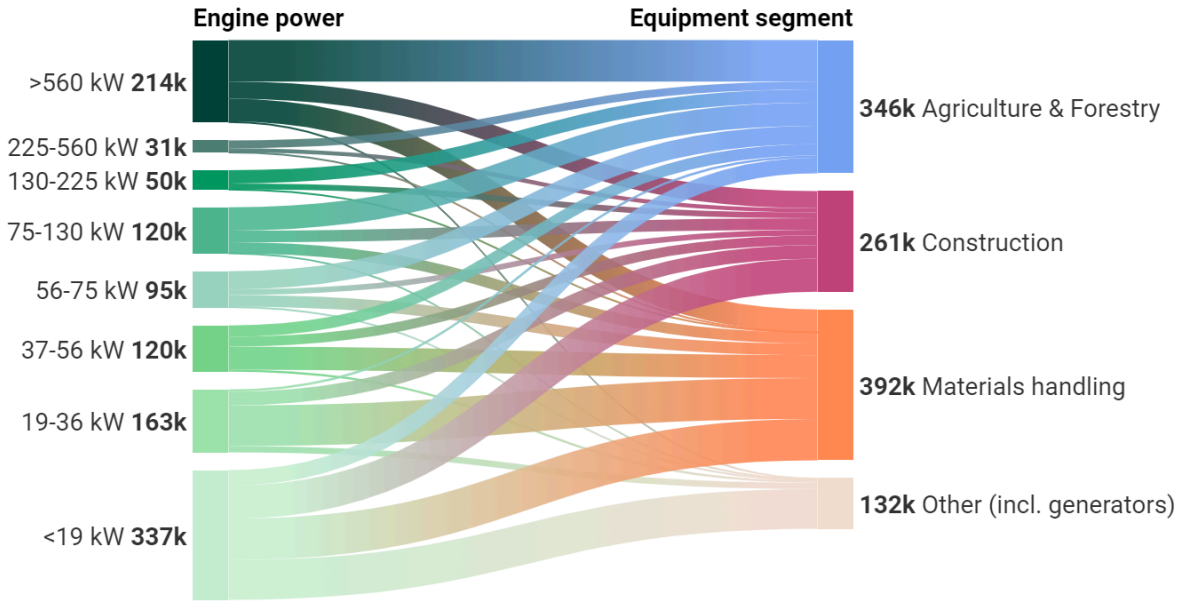
[5] EEA (2022). Greenhouse gas emissions under the Effort Sharing Legislation. Link.

3. Gearing up for zero-emission machines

3.1. Zero-emission equipment is operationally feasible

The shift to zero-emission off-road powertrains is becoming increasingly viable for a growing share of use cases. Engine power requirements provide an initial indication of the imminent electrification potential, with industry leaders like Deutz highlighting that machines in the 100–150 kW segment can be electrified without significant challenges.[6] This could already cover a larger share of the current applications in Europe. This particularly includes machinery such as generator sets, material handling equipment, and construction tools. Agricultural and forestry machines also show promise for transitioning to zero-emission technologies.

NRMM production by engine power and equipment segment



Source: KGP. (2024). Off-Road Machinery • Scope: EU-27, 2023. Electric equipment is included.

However, engine power alone does not fully determine the feasibility of electrification or hydrogen-powered alternatives. The specific design and operation of the machine plays a critical role, as it must accommodate electric drivetrains and batteries while addressing any other impacts, such as additional equipment weight or volume. The ability of current and emerging battery technologies to meet diverse operational requirements is equally important, particularly for applications with demanding uptime needs such as for example agricultural combine harvesters which are used around the clock depending on the season.

Charging and refuelling infrastructure will be a decisive factor in scaling up electrification across the NRMM sector. Permanent worksites with reliable grid connections could adopt

[6] Table.Today (2024). Wie lange brauchen wir den Verbrenner noch, Herr Schulte? Link.

cable-connected or dynamic charging systems[7], while battery-powered solutions will be suited to temporary or mobile operations. Stationary charging stations where feasible as well as mobile battery units[8] and possibly battery-swapping systems may also offer flexible options to address site-specific constraints and optimise uptime.

The success of electrifying off-road worksites will depend on foresight, planning, and flexibility as equipment, infrastructure, storage and power access will need to be synchronised with today's work processes. Volvo Construction Equipment (Volvo CE) recently demonstrated such efforts by trialing a so-called 'electric worksite'.[9] The project mapped the infrastructure needs for electric equipment through real-world testing in Sweden and aimed to bring together different groups in the supply chain to understand how to use electric equipment in cities. It focused on testing electric machines, energy storage, and charging infrastructure at various urban sites. This helped identify the different technical and organisational needs for using electric equipment effectively in real-world environments.

The introduction of electric machines by key industry players highlights the fast pace of technological advancements. Caterpillar[10] is developing dynamically charged heavy mining equipment, while Liebherr[11] has partnered with Fortescue to supply nearly 500 battery-electric dump trucks, excavators, and bulldozers. Rio Tinto[12] is piloting battery-swapping systems for 90-tonne dump trucks, and Komatsu[13] is testing a 800-tonne surface mining excavator connected to an on-site grid via power cable. The agricultural sector is also making strides toward electrification, with trials of 100 kW battery-electric tractors highlighting the potential for zero-emission farming solutions.[14]

Hydrogen drivetrains are increasingly being tested across the off-road sector. Volvo CE is testing the world's first articulated hauler powered by hydrogen fuel cells.[15] JCB[16] has developed a hydrogen engine for construction, agricultural equipment, and generator sets, while MAN Engines[17] has introduced a hydrogen solution for agricultural machinery. Liebherr[18], in

[7] CharIN (2024). White Paper Dynamic Charging Interface (DCI) of CharIN Mining Taskforce. Link.
[8] Volvo CE (2023). Volvo Construction Equipment boosts charging flexibility with mobile Power Unit. Link.
[9] Volvo CE (2024). Study proves viability of urban electric construction – with big benefits for society. Link.
[10] Caterpillar (2024). Caterpillar introduces groundbreaking dynamic energy transfer solution for battery and diesel-electric mining equipment. Link.
[11] Liebherr (2024). Largest order in the company's history: 475 Liebherr machines to be delivered to Fortescue. Link.
[12] Rio Tinto (2024). Rio Tinto and China's State Power Investment Corporation partner to trial battery swap truck technology. Link.
[13] BBC (2024). Planes, trains and monster diggers: The vehicles pushing the limits of electric power. Link.
[14] TADUS (no date). The TADUS tractor. Link.
[15] Volvo CE (2022). Volvo CE starts testing of the world's first prototype hydrogen articulated hauler. Link.
[16] JCB (2023). JCB hydrogen world first makes international debut. Link.
[17] MAN Engines (2023). MAN Engines presents groundbreaking hydrogen combustion engine for off-road applications. Link.
[18] Liebherr (2024). Pioneering work in the quarry: Liebherr and STRABAG test hydrogen wheel loader. Link.

partnership with STRABAG, is trialing its first hydrogen-powered wheel loader, and Mahle[19] is leading an international consortium to advance hydrogen powertrains in off-road applications.

Europe's rail network is already 60% electrified, supplying 80% of passenger and freight traffic, with further electrification planned.[20] For non-electrified routes, battery electric trains are optimal for most cases, while hydrogen may play a role for very long distances.[21] A recent study, taking Germany as an example, suggests that battery-electric trains are optimal for 80% of cases, with hydrogen better for the remaining 20%.[22] Countries like the UK[23] and Canada[24] aim to phase out diesel locomotives by 2040 and 2050, respectively, and California's Air Resources Board (CARB)[25] has introduced zero-emission locomotive requirements starting this decade.

Zero-emission transport for inland waterways and rail is becoming increasingly viable with advancements in battery and hydrogen technologies. Passenger ferries and freight barges are adopting direct electrification or hydrogen power, offering cost-effective solutions for longer routes. As highlighted by two EU projects on zero-emission inland shipping, advancements in battery technology and hydrogen fuel cells are making these options increasingly cost-effective.[26]

3.2. Zero-emission equipment is economically viable

Achieving total cost of ownership (TCO) parity for off-road machinery is increasingly feasible as production scales up and technology costs decline. This shift is already visible in the construction segment, where companies like Volvo CE project significant growth in electric machine sales. By 2030, Volvo CE aims for 35% of its construction equipment sales to be electric, driven by expectations that upfront price parity with internal combustion engine (ICE) machines will be reached still within the 2020s.[27]

Upfront cost challenges, stemming from the capital-intensive nature of electric machinery, can be addressed through targeted policies and innovative business models. Supply-side measures like CO_2 or zero-emission standards are needed to create a level playing field for manufacturers to scale production, reducing unit costs. New ownership models — such as rentals, leasing, 'machine as a service,' and 'cost-per-hour' options — can ease financing barriers, particularly for small and medium-sized enterprises (SMEs), enabling broader access to zero-emission equipment.

[19] Mahle (2024). Consortium led by MAHLE develops hydrogen engines for off-road applications. Link.
[20] EAFO (2021). Electrification of rail infrastructure. Link.
[21] VDE (2020). Bewertung klimaneutraler Alternativen zu Dieseltriebzügen. Link.
[22] Fraunhofer ISI (2022). Alternative Antriebe im Schienenverkehr. Link.
[23] Financial Times (2018). Diesel-only trains in UK to be phased out by 2040. Link.
[24] Government of Canada (2023). Transport Canada and Railway Association of Canada join forces to further reduce emissions in Canada's rail transportation sector. Link.
[25] CARB (no date). Locomotive Fact Sheets. Link.
[26] Horizon (2022). Ramping up renewables to power the clean future of inland shipping. Link.
[27] Volvo CE (2021). Infographic: Electromobility Milestones. Link.

There are also several operational benefits and productivity improvements associated with transitioning to zero-emission equipment. Electric machines eliminate the engine-related service costs that are currently incurred with diesel-powered equipment, such as the need for engine oil and filter changes. The lifespan of electric components is expected to match or even surpass that of traditional combustion machinery. These advantages can significantly increase operational uptime on-site and reduce downtime in the workshop. That also means that maintenance and repair costs are lower: Research is showing that electric machines can have a 50% longer lifetime than their diesel counterparts due to less moving parts which are less prone to wear and tear.[28]

Cost reductions will also come from technological spillovers between on-road and non-road sectors. A shared industrial base as well as research and development investments across these interconnected markets will accelerate advancements in electrification and battery technologies when adapting them for use in off-road applications. These synergies with cars, vans, trucks and buses are crucial for lowering costs and broadening the adoption of zero-emission machinery.

However, challenges remain. Transitioning entire construction worksites, where multiple machines must operate in tandem with synchronised operations, requires careful ecosystem planning. Differences in ownership models — for example where equipment operators often rent or contract machinery — can complicate life cycle business cases.[29]

Nonetheless, as highlighted further in this briefing, robust CO_2 standards and public procurement rules are critical to driving demand and scaling up clean supply. Without coordinated policies to align market conditions and foster electrification, reaching widespread TCO parity for zero-emission off-road machines may face significant delays or even be put off entirely.

3.3. Zero-emission equipment is better for the climate

Zero-emission machines offer a much cleaner alternative to their diesel counterparts, and their environmental benefits will only increase as Europe's electricity grid and battery production becomes increasingly green. For instance, a life cycle analysis (LCA) conducted by Volvo CE demonstrates that electric machinery is capable of significantly reducing emissions already today.[30]

Electric excavators, wheel loaders, and haulers powered by the EU average grid are approximately 50% cleaner per operating hour over their lifetime compared to their diesel

[28] City of Oslo (2022). A survey of the requirements for emission-free building and construction sites. Link.
[29] Volvo CE (2018). Why electric construction equipment won't solve the Total Cost of Ownership dilemma. Link.
[30] Volvo CE (2024). Volvo CE reveals industry's most extensive Product Carbon Footprint reports. Link.

equivalent.[31] Currently, 45% of Europe's electricity comes from renewable sources.[32] This share is expected to rise to 62% by 2030, 83% by 2040, and 90% by 2050, based on the plans of EU member states, already factoring in the growing electricity demand from other economic sectors.[33]

4. Lack of clean supply and demand causes market failure

The absence of supply- and demand-side regulations for mobile machinery is creating significant barriers to the widespread adoption of zero-emission equipment. Without legislative requirements mandating clean supply and demand, manufacturers as well as customers struggle to compete against traditional diesel equipment, which today remains the default option for most machinery makers and buyers.

The currently still existing price premium for zero-emission machinery discourages widespread adoption, especially among budget-conscious operators in industries such as construction and agriculture. As a result, cities and builders eager to transition to sustainable operations often find themselves unable to access the clean equipment they need.

The key challenge is the still higher cost of clean alternatives, driven by low production volumes and the niche status of the current market. Small-volume equipment manufacturers and aftermarket retrofit providers are unable to achieve the economies of scale necessary to reduce technology prices. Progressive manufacturers willing to invest in zero-emission technology face hurdles due to the uneven playing field in the market.

5. Europe's industry (again) at risk from foreign competition

In light of their climate goals, more and more buyers and contractors in the machinery market are looking for zero-emission supply. Meanwhile, global players, particularly from China, are scaling up their capabilities in clean technology, with significant advantages from their vertical integration in electric value chains.[34]

Without proactive policy measures to shape the future European machinery market, the EU risks losing ground, as seen in other sectors like cars and trucks, where mixed political signals are putting the competitiveness of Europe's automotive industry at risk.

To remain attractive and competitive, Europe's machinery sector must be prepared for the shift to zero-emission technologies. Currently, over 20% of engines used in European-manufactured

[31] Volvo CE (2024). Product environmental documentation. Link.
[32] Eurostat (2024). Renewables take the lead in power generation in 2023. Link.
[33] Ember (2022). European Clean Power Pathways Explorer. Link.
[34] Ministry of Ecology and Environment of the People's Republic of China (2023). China Mobile Source Environmental Management Annual Report. Link.

machinery are already imported, primarily from Asia, even as most final assembly remains within Europe.[35] As demand for zero-emission equipment grows, foreign manufacturers are likely to expand their presence in the European market, with or without EU policies. Ensuring a balanced competitive environment and level playing field will be key to maintaining a strong domestic machinery industry.

The EU can shape the zero-emission machinery market with a targeted and effective policy approach. A coordinated policy framework during the Commission's new mandate can help ensure Europe's machinery industry is well-positioned to compete globally while supporting the transition to zero-emission technology.

As further outlined below, introducing CO_2 or zero-emission standards can drive innovation and provide market certainty for manufacturers and operators alike. Public procurement policies, such as 'buy clean and European' provisions, can level the playing field for domestically producing zero-emission machinery. Finally, integrating the NRMM sector into the alternative fuels infrastructure regulation (AFIR) as part of its upcoming review can support the development of the necessary charging and refueling systems.

6. Machines are (largely) unregulated in Europe

Europe lacks the policy instruments which would be needed to effectively reduce emissions from off-road equipment. Despite their significant climate pollution, mobile machinery has been suffering from a lack of political attention and regulatory action.

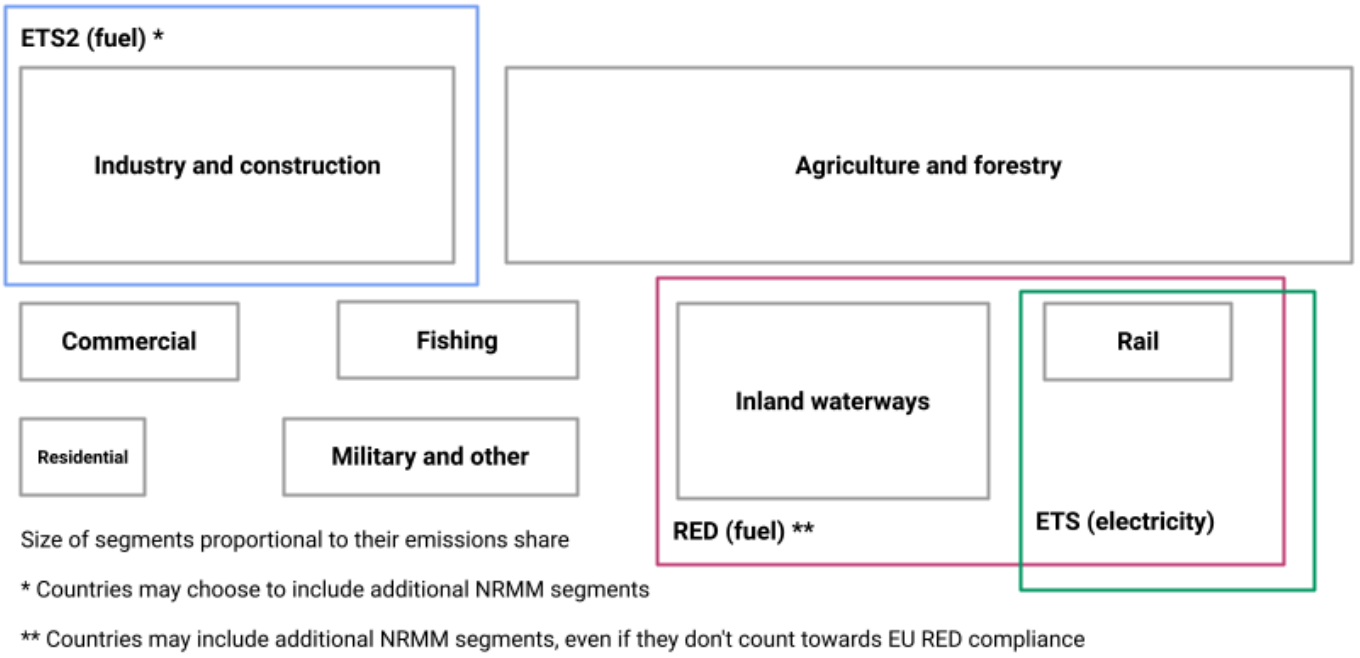
6.1. EU legislation turns a blind eye

The most polluting NRMM segments benefit from big fuel duty rebates in many member states. The Energy Taxation Directive (ETD) allows countries to tax the use of diesel below the minimum rates (in the case of plants and machinery used for construction and industrial purposes), or even exempt it (in the case of agriculture and forestry).[36]

For example, 23 member states grant significant rebates or exemptions to agricultural machines, while Germany, Greece and Sweden grant reduced rates to fuels used by mobile machinery used in the manufacturing industry.[37]

[35] KGP (2024). Non-road mobile machinery service. Link.
[36] European Union (2024). Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity. Link.
[37] European Commission (2021). Impact Assessment Report Accompanying the document Proposal for a Council Directive restructuring the Union framework for the taxation of energy products and electricity. Link.

Apart from being subject to the emissions reduction targets under the ESR, as it is the case for all non-ETS sectors, climate pollution from machines is still mostly unregulated, whether at EU or national level (see Figure below).



While the EU's Emissions Trading System (ETS) caps GHGs from electricity consumed by the NRMM sector, this is currently relevant only to the rail segment due to its high rate of electrification.[38] The upcoming Emission Trading System 2 (ETS2) will introduce a carbon price to non-road fuels used by industry and construction as well as the commercial segment, but other important segments such as agricultural vehicles will remain exempt.[39]

Given the low price elasticity of non-road diesel due to the lack of affordable alternatives, it is highly questionable whether carbon prices on their own will transition the sector. CO_2 prices are unlikely to reach sufficient levels quickly enough to reduce fuel demand. This is even less likely as many NRMM segments still benefit from fuel duty rebates as mentioned above.

While the ETS2 will contribute to decreasing the TCO gap between fossil-powered and clean equipment, a carbon price on non-road fuels will do nothing about reducing the capital cost gap between clean technologies and combustion machines.

The transport target under the Renewable Energy Directive (RED) only requires EU countries to reduce the emissions intensity of fuels used by inland waterway and rail transport, but exempts

[38] European Union (2023). Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a system for greenhouse gas emission allowance trading within the Union. Link.
[39] Except in a limited number of member states which decide to opt in additional segments on a voluntary basis. For example, Austria, the Netherlands and Sweden decided to apply ETS2 to additional NRMM segments. Germany is expected to do so as part of transposing its current national emissions trading system into the ETS2.

the larger NRMM segments.[40] It should be noted that a limited number of member states include additional NRMM segments in their national systems even if they are not taking into account for compliance with the EU targets.

6.2. National policies are experimental at best

In regard to national policies, few European countries have adopted regulatory requirements or financial incentive schemes to incentivise the uptake of cleaner machinery.[41] Overall, the number of requirements and incentives is limited and often focuses solely on the demand-side.

For example, Finland announced a voluntary target to reach '100% fossil-free' construction sites from 2026, and aims for 50% of construction machines in 2030 to be powered by electricity, hydrogen or biomethane. And while electrification is seen as the key technology by stakeholders to reach that target, the government's mid-term evaluation highlights the availability and development of the electric machines as the main challenge to meet those targets.[42] A number of European cities, such as in the UK[43], Norway[44], Denmark[45], Finland[46], the Netherlands[47], and Austria[48] are experimenting with zero- and low-emission construction zones.

A few entities offer funding programmes, such as the Netherlands that provides subsidies to cover up to 50% of the purchase price of clean equipment.[49] In terms of financing support, the European Investment Bank (EIB) has experimented with preferential loans for a French equipment leasing company under the InvestEU programme to electrify their machinery fleet.[50]

However, even if these rules and programmes may help somewhat on the demand-side, they are not able to solve the fundamental issue of the sector: the difficulty to source clean equipment due to a lack of supply from manufacturers. What is urgently needed is legislative action at EU level to bring zero-emission machines to market at scale and to create the necessary demand to bring them into operation.

---

[40] European Union (2023). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Link.
[41] ICCT (2023). Incentivizing zero-emission off-road machinery. Link.
[42] Finnish Government (2024). Green Deal agreement on emission-free work sites has boosted efforts to phase out fossil fuels. Link.
[43] Mayor of London (no date). The Mayor's Ultra Low Emission Zone (ULEZ) for London. Non-Road Mobile Machinery (NRMM). Link.
[44] Oslo Municipality (2022). Accelerating the transition to an emission-free construction process. Link.
[45] City of Copenhagen (no date). The CPH 2025 Climate Plan. Zero-emission construction sites. Link.
[46] City of Helsinki (2022). European cities accelerate the implementation of zero-emission construction sites. Link.
[47] CE Delft (2023). Zero-emission construction site. Development and additional costs. Link.
[48] BMK (2024). Erste Praxistests für emissionsfreie Baustellen in Wien und Oberösterreich. Link.
[49] Netherlands Enterprise Agency (2024). Subsidy for Clean and Zero Emission Construction Equipment (SSEB). Link.
[50] EIB (202). France: InvestEU - Loxam receives €130 million loan from the EIB to support its energy transition. Link.

7. Introduce CO_2 rules for machines to unlock clean supply

As outlined in this briefing, the limited effects of carbon pricing through the introduction of ETS2 and some sporadic demand-side incentives at national level are not enough to transition Europe's off-road equipment sector to cleaner technology. What is required is an effective mix of policy instruments which can create supply at scale, leverage public demand and provide the necessary enabling conditions like infrastructure in order to send a strong signal to the industry.

Introducing supply-side CO_2 rules for machinery can create a level playing field, unlock clean supply and deliver technology cost reductions. Such CO_2 standards or zero-emission targets can drive a faster transition to cleaner machinery technologies, aligning the sector with the EU's climate goals and secure a competitive future for Europe's equipment manufacturing industry.

Focussing on cleaning up fossil-powered machines could also alleviate some pressure on the housing and agriculture sectors by cutting both nitrogen pollution and climate emissions. Electric machines offer opportunities to lower costs for businesses in the medium and long term, reducing expenses for construction and farming operations while boosting productivity. For construction companies, this means cheaper projects, while farmers benefit from enhanced efficiency and sustainability.

7.1. How to design a CO_2 regulation

7.1.1. Regulate at engine level to reduce complexity and costs

A future CO_2 regulation for the NRMM sector should prioritise regulating at the engine level rather than encompassing entire machines. This approach would significantly reduce complexity and administrative burdens for both industry and stakeholders. Regulating complete machines would necessitate the creation of a detailed certification and simulation framework for all components, alongside a comprehensive mapping of diverse operational use cases — a time-intensive and resource-heavy process.

Such a system was developed for heavy-duty vehicles (HDVs) with the "Vehicle Energy Consumption Calculation Tool" (VECTO).[51] While effective and sensible for trucks and buses, it has taken the European Commission over a decade to develop and expand for various vehicle and powertrain types, and the process is still ongoing. Applying a similar approach to NRMM would be impractical, as the benefits would not justify the extensive time and resources required.

Focusing legislation at the engine level offers a more efficient and practical solution. This approach would avoid unnecessary simulations, streamline compliance to a smaller number of

[51] European Commission (no date). Vehicle Energy Consumption calculation TOol - VECTO. Link.

entities - that is engine manufacturers - and align with the sector's existing practices such as for the type-approval legislation on air pollutant emission limits.

Limiting the regulation to the engine would also make things easier by avoiding complications from the multi-stage manufacturing process which is also common for machinery production. Additionally, since engines are often replaced at least once during a machine's lifespan, an engine-focused regulation would accelerate the turnover of older, more polluting engines, supporting retrofitting initiatives and achieving a cleaner machinery fleet more rapidly.

7.1.2. Focus on zero emissions as efficiency gains are limited

A future CO_2 regulation for NRMM could take the form of CO_2 standards or zero-emission targets, each offering distinct benefits. CO_2 standards would act as an efficiency benchmark that encourages better fuel economy for combustion-powered engines while supporting the adoption of cleaner, zero-emission powertrains. Zero-emission targets, on the other hand, would establish a binary system by requiring an increasing share of electric and hydrogen-powered machines over time.

Although CO_2 standards can technically leverage both the efficiency and zero-emission potential of machines, they would require a more complex regulatory process that may increase costs and burden for regulators and industry. The potential for further fuel efficiency improvements in combustion-powered engines also appears limited. At the very least, to reduce complexity, CO_2 standards should focus at the engine and tailpipe level, targeting key emissions sources directly as outlined above.

Zero-emission targets offer a more straightforward binary approach by scaling up electric and hydrogen technologies through quotas for zero-emission equipment sales. Tailoring these quotas to specific segments and applications would drive adoption while a flexible compliance system based on characteristic duty cycles and the varying emissions intensity of different use profiles.

Focusing on the diminishing returns of internal combustion engine (ICE) efficiency would not provide the long-term certainty needed to make long-term investment decisions. With road transport already moving rapidly towards zero emissions, mobile machinery has similar potential. Establishing the right regulatory framework through CO_2 standards or zero-emission targets will be critical for unlocking this transition and providing clarity for manufacturers, operators and the entire value chain.

7.1.3. Introduce an EU-wide registration system for new equipment sales

Unlike road transport vehicles, there is currently no EU-wide central registration system for new NRMM entering the market. Existing mechanisms primarily involve surveillance provisions and

obligations to ensure that equipment meets type-approval standards.[52] Some European countries, however, have begun implementing or considering national registration systems. For instance, Norway has introduced a voluntary registration system for new equipment sales, while Sweden is exploring a similar approach.

To support any future CO_2 or zero-emission machinery regulation, a robust and effective Union-wide monitoring and reporting system will be essential. Such a system would document new equipment registrations in order to check compliance and track progress toward regulatory targets.

The EU can build on existing legislative frameworks to develop this system. Recent EU legislation aimed at harmonising technical requirements for NRMM use on public roads provides a valuable reference.[53] These rules are designed to simplify registration processes across member states, replacing fragmented regulatory regimes with one unified single-market registration standard. The system also includes a definition for 'registrations,' covering machinery entering service on public roads and issuing registration numbers for these vehicles.[54]

7.2. Reduce red tape: tackle climate, air, and noise pollution at once

While reducing climate pollution from NRMM is a priority, the sector's air pollutant and noise emissions remain significant health hazards for Europe's citizens and will persist for decades without intervention. Addressing these emissions is also essential to improve working conditions and health standards for workers, farmers, and residents who are exposed to machinery operations in both urban and remote areas.

A holistic policy approach is needed to tackle the environmental and industrial challenges of the sector effectively. This strategy should aim to harmonise and streamline existing and new legislation to maximise their impact, minimise costs, and avoid redundancy. Specifically, the possible future introduction of a CO_2 regulation for machines could provide a pathway to decarbonise the sector while addressing related air and noise emissions at the same time.

This could eliminate the need for the planned revision of the current air pollutant emission limits under the existing NRMM type-approval legislation as well as the upcoming review of the outdoor noise directive, reducing complexity and regulatory overlap. By integrating climate, air quality, and noise considerations into a unified framework, policy- makers can ensure a

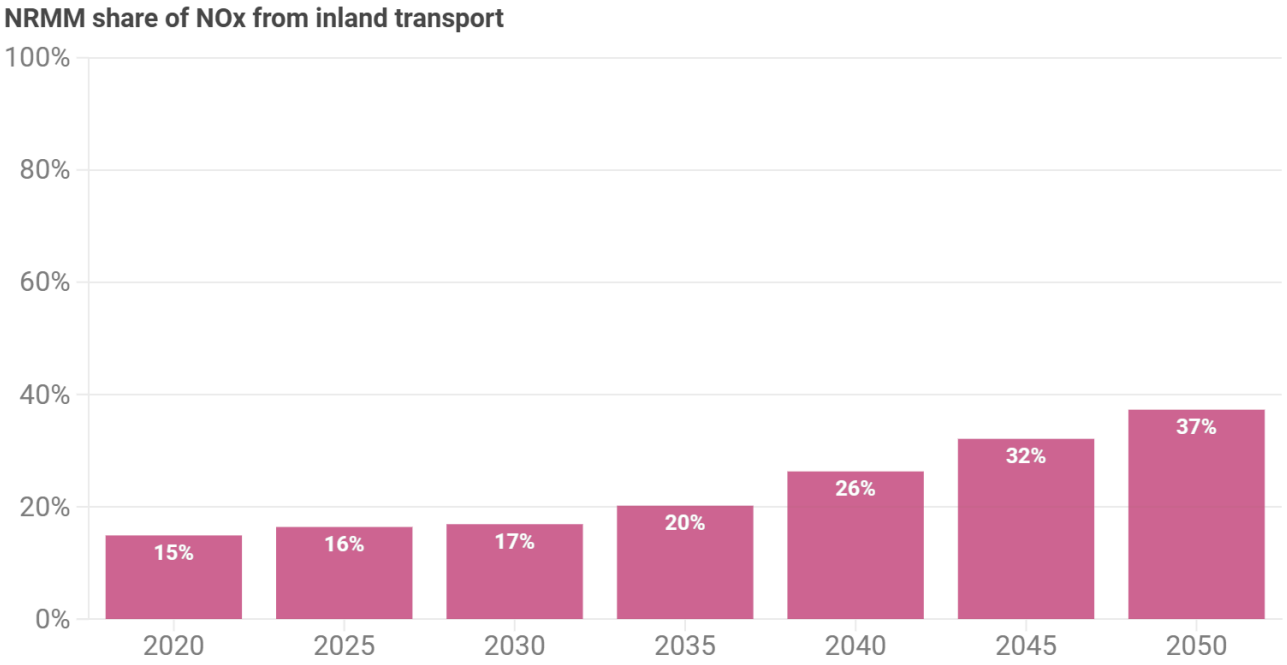
[52] Euromot (2021). Guide for identification of non-road mobile machinery and engines compliant with regulation 2016/1628. Link.
[53] European Commission (2024). New mobile machinery rules to ease safe circulation on public roads across the EU. Link.
[54] European Parliament (2024). Approval and market surveillance of non-road mobile machinery circulating on public roads. Adopted text. Link.

comprehensive and efficient response to the sector's environmental impacts, while safeguarding its competitiveness.

In 2016, the EU adopted the 'Stage V' air pollutant standards for non-road mobile machinery (NRMM) under its type-approval framework.[55] The NRMM type-approval framework also includes provisions for in-service monitoring (ISM) tests, which provide real-world emissions data.[56] Over the next two years, manufacturers will have to submit ISM results to the Commission which offers an opportunity to assess both pollutant and CO_2 emissions under real-world conditions.

While the new Stage V standard has successfully reduced harmful local emissions (see figure below), it falls short of addressing the persistent issue of criteria pollutants from construction equipment, agricultural machines, trains, and waterborne transport. These emissions contribute significantly to air pollution, which is linked to 327,000 premature deaths annually in the EU.[57]

NRMM to make up over a third of NOx emissions from inland transport before 2050



Source: IIASA (2021). GAINS Europe • Scope: EU-27. Modelling takes into account pollutant reductions from Stage V emissions standards. Data reflects the Baseline scenario until 2030 and the 1.5TECH scenario from 2035. Besides NRMM, inland transport includes cars, vans, trucks, buses and two-wheelers.

[55] ICCT (2016). European Stage V non-road emission standards. Link.
[56] European Union (2017). Commission Delegated Regulation (EU) 2017/655 with regard to monitoring of gaseous pollutant emissions from in-service internal combustion engines installed in non-road mobile machinery. Link.
[57] EEA (2023). Harm to human health from air pollution in Europe: burden of disease 2023. Link.

Despite progress, there remains significant untapped potential to reduce real-world pollutant emissions from NRMM. Research from industry[58] and government[59] indicates opportunities to improve emissions performance beyond the Stage V limits. However, introducing a new Stage VI pollutant standard may involve disproportionate administrative and bureaucratic burden. Many stakeholders, including affected industries, might question the value of pursuing another criteria pollutant standard, especially as cleaner technologies and alternative regulatory approaches gain traction.

Noise pollution remains another critical concern, with over 100 million Europeans exposed to harmful levels, as reported by the European Environment Agency (EEA).[60] These impacts disproportionately affect disadvantaged communities, as well as workers, farmers, and citizens living near NRMM operations in both urban and remote areas.[61] Under the EU's ambient noise directive,[62] the Commission is asked to continuously review the law's effectiveness and whether the limits and scope are still appropriate, as they have done the last time back in 2020.[63]

Anyone who has lived near a construction site can attest to the excessive noise generated by these machines and can imagine the noticeable improvement in quality of life that could come from introducing quieter zero-emission machinery to these worksites which would reduce the stress and discomfort of nearby residents.

A more integrated solution may lie in addressing air and noise pollution through a future CO_2 regulation. Leveraging the co-benefits of zero-emission machinery adoption can tackle both climate and local pollutant impacts while streamlining regulatory efforts. Skipping a Stage VI regulation and reducing noise emissions through new CO_2 rules instead of the ambient noise directive could minimise the administrative burden on manufacturers. After all, increasing the market share of electric and hydrogen-powered machinery offers a practical path to reducing air and noise pollutants while accelerating the sector's transition to zero-emission technologies.

8. Use public procurement to boost demand for clean machines

To address the challenge of creating sufficient demand for clean machinery, public procurement policies can play a central role. By mandating the use of clean machinery in public projects and procurement, governments and public authorities can stimulate demand and create a lead market for zero-emission equipment.

[58] AECC (2023). Real-world NOx emissions of Stage V NRMM. Link.
[59] Ministry of Infrastructure and Water Management (2024). Reducing emissions from non-road mobile machinery. Link.
[60] EEA (2020). Health risks caused by environmental noise in Europe. Link.
[61] EEA (2018). Unequal exposure and unequal impacts: social vulnerability to air pollution, noise and extreme temperatures in Europe. Link.
[62] European Union (2019). Directive 2000/14/EC on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors. Link.
[63] European Commission (2020). Report from the Commission to the European Parliament and the Council on the implementation and administration of Directive 2000/14/EC. Link.

Initiatives such as the 'Big Buyers Initiative' provide a framework for collaboration among cities and public authorities to pool demand and accelerate the transition.[64] These measures demonstrate the economic and operational viability of zero-emission machinery and encourage broader adoption across the private industry. For example, this can be implemented in the form of so-called 'zero-emission construction sites' such as the initiatives led by the City of Oslo.[65]

With the upcoming revision of the EU's public procurement framework as part of the Commission's new mandate, we recommend defining mobile machinery as one of the strategic industrial sectors within scope and to put in place preferential procurement rules in the form of a 'buy green and European' clause for zero-emission equipment.[66]

9. Include machines in the alternative fuels infrastructure law

As outlined earlier in this briefing, transitioning Europe's machinery fleet to electric and hydrogen will require a robust charging and refueling infrastructure. Permanent and temporary worksites with the possibility to connect to the grid will rely on cable-connected or dynamic charging, while battery-powered solutions and mobile charging options, including battery-swapping systems, provide flexibility for temporary or mobile operations which have no option to access the grid directly.

For temporary worksite locations, mobile battery units are expected to play a key role in providing on-site power, allowing equipment to be fast-charged during work breaks. Hydrogen could also serve as an alternative, with containerized mobile refueling systems offering additional flexibility. Both solutions would involve delivery to the site by truck, use until depleted, and subsequent transport to centralized facilities for recharging or refueling, before being returned to the worksite.

For most worksites, where the number of machines and energy demands are relatively modest, a small number of mobile power units could remain on-site for several days to meet energy requirements. For larger construction projects where grid connections are not feasible, mobile power units or hydrogen tanker trucks would need to provide a continuous energy supply to ensure uninterrupted operations.

These more extensive logistical operations will depend on an infrastructure backbone of accessible charging and hydrogen refueling stations where mobile power units and hydrogen tanker trucks can be replenished. The growing network of (semi-)public charging pools and hydrogen refueling stations for heavy-duty trucks and buses, which member states are mandated to deploy over the coming years, could therefore serve as a convenient solution for

[64] European Commission (no date). Public Buyers Community. Link.
[65] European Commission (no date). Zero Emission Construction Sites. Link.
[66] European Commission (2024). President von der Leyen's mission letter to Stéphane Séjourné. Link.

recharging and refueling the mobile power units and hydrogen tanker trucks which provide the power to the off-road machines operating on worksites in the same area.

However, this approach will also require accounting for the additional power and energy demand on the infrastructure network that supports the expanding truck and bus fleet. We therefore recommend incorporating the anticipated future energy needs of the NRMM sector that will rely on public heavy-duty infrastructure into the upcoming revision of the Alternative Fuels Infrastructure Regulation (AFIR). In addition, the revision should also be used as an opportunity to start a structured dialogue with the machinery industry about their future infrastructure needs and address the offroad sector's operational and logistical specificities, as well as possible requirements for standardisation and certification.

Further information

Fedor Unterlohner

Freight Manager

Transport & Environment

fedor.unterlohner@transportenvironment.org

Mobile: +32 (0)485 639492

Annex. Example list of mobile machinery

Equipment	Segment	Engine	Power range	Example
Agricultural tractors	Agriculture and forestry	Diesel	20 - 250 kW	
Combine harvester	Agriculture and forestry	Diesel	50 - 500 kW	
Forest skidders	Agriculture and forestry	Diesel	25 - 150 kW	
Fishing boats	Fishing	Diesel	100 - 1,000 kW	
Air compressors	Industry and construction, Commercial	Diesel	10 - 120 kW	
Crawler Excavators	Industry and construction	Diesel	10 - 1,000+ kW	
Forklifts	Industry and construction, Commercial	Diesel, Gasoline, LPG	20 - 100 kW	
Mobile cranes	Industry and construction, Commercial	Diesel	100 - 250+ kW	
Power generators	Industry and construction, Commercial	Diesel, Gasoline	5 - 1,000 kW	
Reachstackers	Industry and construction, Commercial	Diesel	200 - 500+ kW	
Wheeled loaders	Industry and construction, Commercial	Diesel	15 - 250 kW	
Wheel-steered mine dumpers	Industry and construction	Diesel	300 - 500 kW	
Street sweepers	Commercial	Diesel	50 - 130 kW	
All-terrain vehicles	Residential	Gasoline	3 - 67 kW	
Leaf blowers	Residential	Gasoline	<1 - 4 kW	
Lawn mowers	Residential	Diesel, Gasoline	<1 - 15 kW	
Barges	Inland waterways	Diesel	200 - 4,000 kW	
Locomotives	Rail	Diesel	1,500 - 4,500 kW	
Military trucks	Military and other	Diesel	75 - 500+ kW	
Jet skis	Military and other	Gasoline	45 - 230 kW	

Source: EEA (2023). EMEP/EEA guidebook • Non-exhaustive list of examples.