

***EU-level Impact Assessment and Policy Options:
Transitioning to ZEMCON in European cities
(infrastructure and buildings)***



Title: EU-level Impact Assessment and Policy Options: Transitioning to ZEMCON in European cities (infrastructure and buildings)

Prepared by: Hafslund Rådgivning and Bellona

Prepared for: Climate KIC, NetZeroCities and City of Oslo

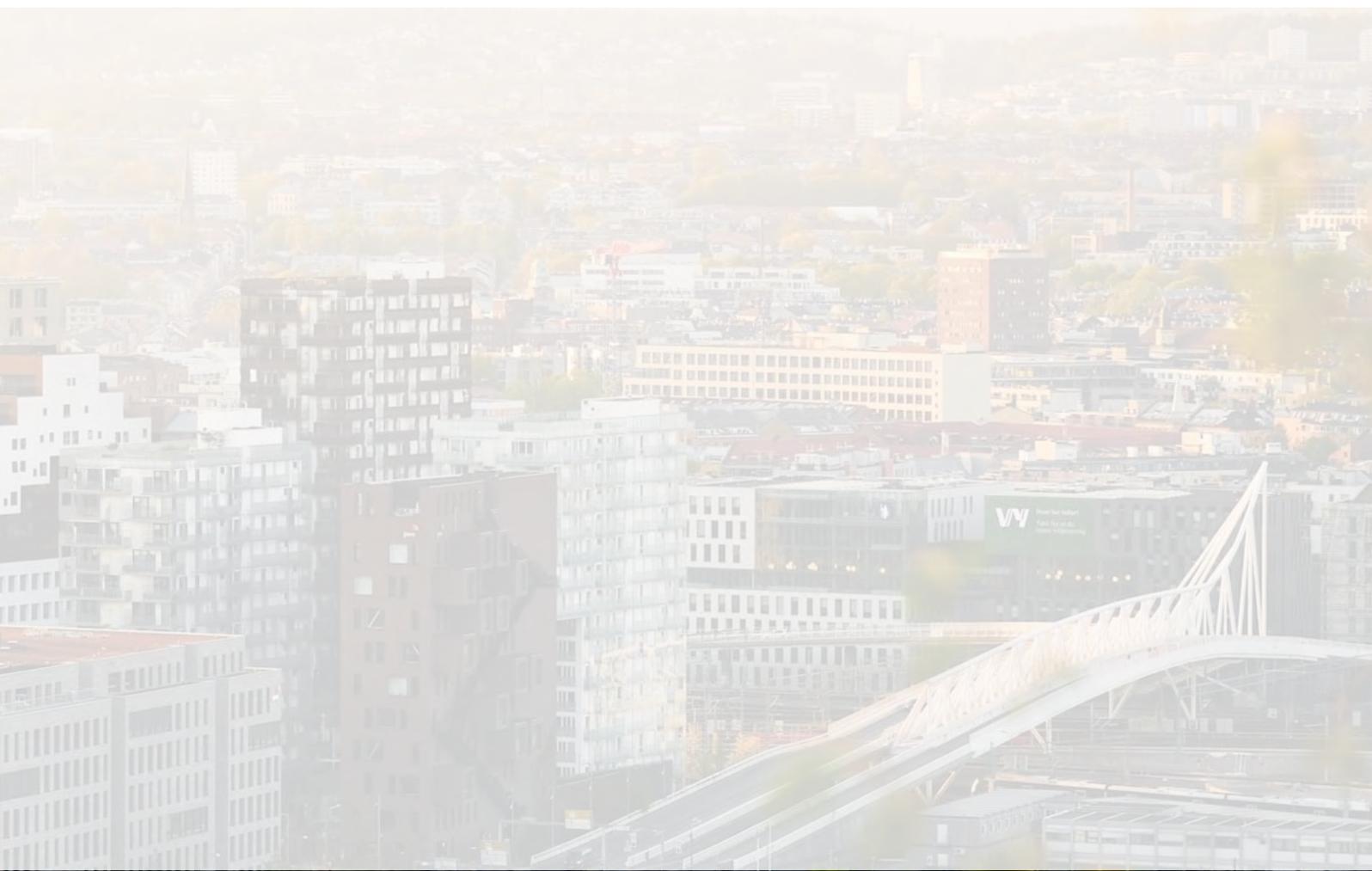
Published: February 2026

Version: 2026-01

Contact Hafslund Rådgivning: Ingrid Aamnes, ingrid.aamnes@hafslund.no

Contact Bellona: Irene Domínguez Pérez, irene@bellona.org

Photo: City of Oslo



Disclaimer

The content of this document reflects only the author's view. The European Commission is not responsible for any use that may be made of the information it contains.

Acknowledgement

The authors would like to thank all external experts who have contributed to improving the quality of the report by providing constructive feedback and sharing their experiences and data, in particular: Anna Huttunen (Climate KIC), Philip Mortensen (City of Oslo), Ella Havnevik Giske (City of Oslo), Christine Kihl (City of Oslo), Marianne Rose Kjendseth Wiik (SINTEF), Cristian Benito Manrique (Ajuntament de Barcelona), Vieve Smulders (City of Eindhoven), Paolo Mannesi (Volvo Construction Equipment Germany), Per Erik Österlund (City of Stockholm), Frida Nordström (City of Stockholm), Beatrice Seger Säll (City of Stockholm).

These experts do not necessarily endorse the findings of this report, nor does their organisation. The authors are solely responsible for the content of this report.

Authors:

Ingrid Aamnes, Hafslund Rådgivning

Kristine Hjorth-Gulbrandsen, Hafslund Rådgivning

Kim Engene Allgot, Hafslund Rådgivning

Irene Domínguez Pérez, Bellona

Linda Zarai, Bellona

Oliver Heim Hollingsæter, Bellona

Accelerating Zero-Emission Construction in European Cities

Key findings and policy priorities from an EU-level impact assessment



Why this matters

Construction activities are a significant source of greenhouse gas emissions, air pollution and noise in European cities. At the same time, the sector is essential for housing delivery, infrastructure development and urban growth. Reducing the environmental impacts of construction without constraining activity levels is therefore a central challenge for European cities. Transitioning to zero-emission construction sites is an important lever for achieving climate-neutrality, improving public health and supporting Europe's industrial competitiveness.



Key findings

1. Zero-emission construction is feasible and scalable today

Electrification of construction machinery and on-site processes is already technically viable for a large share of urban construction activities. While some niche applications still require further technological development, zero-emission alternatives are now market-ready for the majority of equipment categories.

2. Significant health and environmental benefits

Transitioning to zero-emission construction has the potential to deliver substantial environmental and health benefits by reducing local air pollution, noise exposure and greenhouse gas emissions from construction activity. While evidence at scale remains limited, this assessment indicates that electrification of construction machinery can materially improve urban air quality, reduce noise and eliminate almost all direct on-site carbon dioxide emissions.

3. Cost premiums are moderate and declining

Zero-emission construction typically involves higher upfront costs today, mainly related to machinery and temporary energy supply. Evidence from early adopter markets such as Norway and the Netherlands indicates that these cost premiums are temporary and decline rapidly as technologies mature, learning effects materialise and battery performance improves. Early markets have absorbed much of the initial transition cost, reducing barriers for later adopters. Over time, cost differences are expected to narrow significantly, particularly when accounting for avoided fuel costs, reduced maintenance, and broader societal benefits.

4. Limited impact on urban energy and power demand

Electrification of construction activity is one of several parallel drivers of increasing electricity demand as European energy systems transition away from fossil fuels, alongside electrification of transport, heating and parts of industry. While electrification of construction increases electricity use, its impact on total electricity demand at city and national level remains limited, although local peak loads can be significant. These challenges can be addressed through early coordination with grid operators, temporary grid reinforcements, smart charging strategies and on-site flexibility solutions such as mobile batteries. When

appropriately planned and integrated, electrification of construction activity does not represent a systemic barrier to the wider energy transition.

5. Cities already have a strong legal mandate to act

Existing European and national legislation on air quality, environmental noise and occupational health provides a solid legal basis for requiring zero-emission construction solutions, including in private construction projects. Policies requiring zero-emission construction are therefore not only permissible, but in many cases aligned with existing regulatory obligations and enforcement responsibilities.

6. Early movers create positive European spillover effects

Cities that adopt ambitious zero-emission construction policies stimulate demand for clean construction machinery, accelerate industrial learning and support European manufacturing competitiveness. Local action can therefore generate broader spillover effects across European markets, contributing to technology development, cost reductions and strengthened clean technology value chains.



Policy implications

For cities and public authorities

- Use public procurement and permitting processes to require zero-emission solutions in construction projects.
- Integrate construction electrification into urban energy and grid planning.
- Combine regulatory requirements with targeted and time-limited support measures during early market phases.
- Use air quality and noise objectives as a basis for local requirements and implementation plans.

For national governments

- Align construction, energy and transport policies to remove barriers to electrification.
- Support grid investments and flexibility solutions that enable temporary and mobile electricity loads.
- Ensure that national regulations, including rules for non-road mobile machinery, are consistent with zero-emission objectives.
- Use economic instruments, including support schemes and differentiated taxation, to accelerate the transition away from fossil construction machinery.

For the European Union

- Accelerate reform of the regulatory framework for non-road mobile machinery to enable and incentivise zero-emission technologies.
- Ensure coherence between electrification strategies, grid policy and industrial policy.
- Strengthen the role of air quality, noise and occupational health legislation as drivers for zero-emission construction.
- Use zero-emission construction as a lever for strengthening European clean technology value chains and industrial competitiveness.



Why act now

Zero-emission construction sits at the intersection of climate action, public health, energy security and industrial strategy. One of the challenges of the green transition is that the benefits take a long time to be felt by citizens and workers. However, the benefits of zero-emission construction are felt immediately, generating public trust and acceptance for broader climate policies that may take longer to show results. With technologies maturing and costs declining, delaying action risks locking in avoidable emissions, higher long-term costs and missed industrial opportunities. Cities, supported by national and European policy frameworks, can play a decisive role in accelerating the transition and delivering cleaner, quieter and more resilient urban environments across Europe.

Executive Summary

Construction activity is a major source of greenhouse gas emissions, local air pollution and noise in European cities, while at the same time being essential for delivering housing, infrastructure and urban development. The construction sector must therefore reduce emissions without constraining activity levels. The transition towards zero-emission construction (ZEMCON) is essential not only for achieving climate targets, but also for improving air quality and reducing the health impacts of environmental noise in cities. As such, the transition to zero-emission construction is increasingly a question of how and when it can be implemented at scale.

This study, initiated by NetZeroCities in collaboration with the City of Oslo, assesses what a large-scale transition to zero-emission construction could imply across different European city markets, with a specific focus on electrification of construction machinery and site operations. Electrification is selected as the analytical focus as it represents the most technologically mature and readily deployable zero-emission solution for construction sites today and is already being implemented in several European cities. The assessment examines the implications of electrification for environmental performance, energy systems, costs and broader strategic considerations. In addition, it provides evidence-based guidance to cities, national authorities and EU institutions on how regulatory frameworks and economic instruments can be designed to support and accelerate decarbonisation of the construction sector.

The construction sector represents an important part of the European economy

The construction sector plays a key role in the European economy, with a net turnover of €1.463 billion in 2024 across the EU and Norway (FIEC, 2025). It makes up 10.6% of the European Union's (EU) gross domestic product (GDP) and employs over 12 million people. The construction activity is highly concentrated in a few key markets. Germany leads the way with a substantial margin, at €335 billion in 2024, followed by Italy (€193 billion) and France (€188 billion).

European markets differ in their characteristics and underlying conditions for transitioning to zero-emission construction. By examining 12 national key markets across the continent, we identify a range of factors that shape their readiness and potential for change. These include differences in construction activity, energy system capacity, and environmental challenges. The overview below highlights some of the key features of each of the 12 countries.

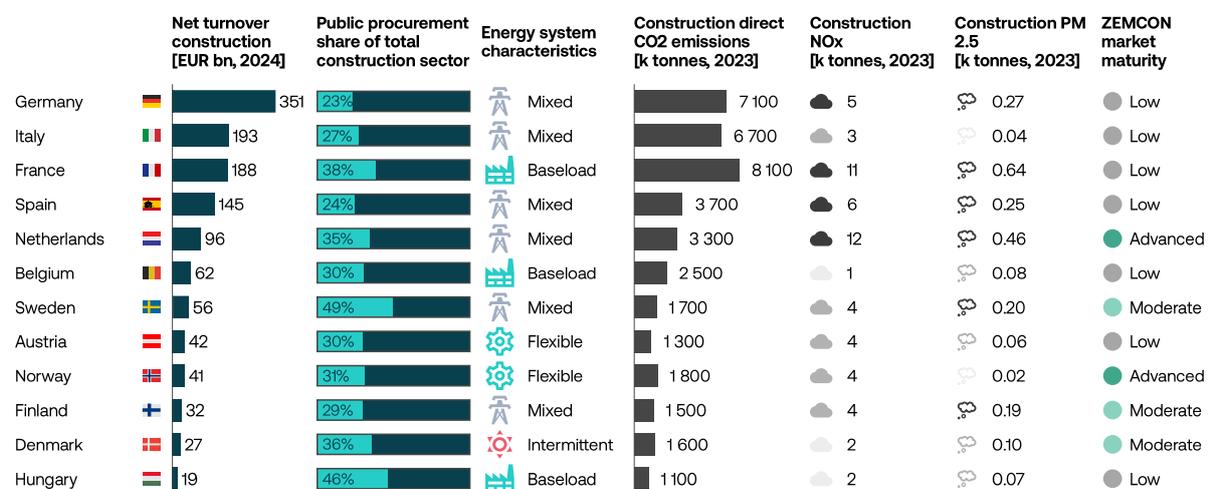


Figure 1: Summary of the characteristics for 12 analysed national markets in Europe. The presented figures are elaborated in Chapter 1.1.

A diverse selection of focus cities indicates current situation and transition impact

To assess the impact of a large-scale transition to zero-emission construction across Europe, a set of cities has been selected for the study as a representation of different types of European regions. The selected cities represent different types of European markets with varying ZEMCON maturity, geographical location, market size, industrial profile, and climate ambitions. The analysis therefore includes both large and medium-sized cities, northern and southern regions, and markets with differing levels of technological maturity. The cities studied in the project are Oslo, Stockholm, Eindhoven, Munich, Barcelona and Budapest, which have the diverse characteristics specified in the figure below.

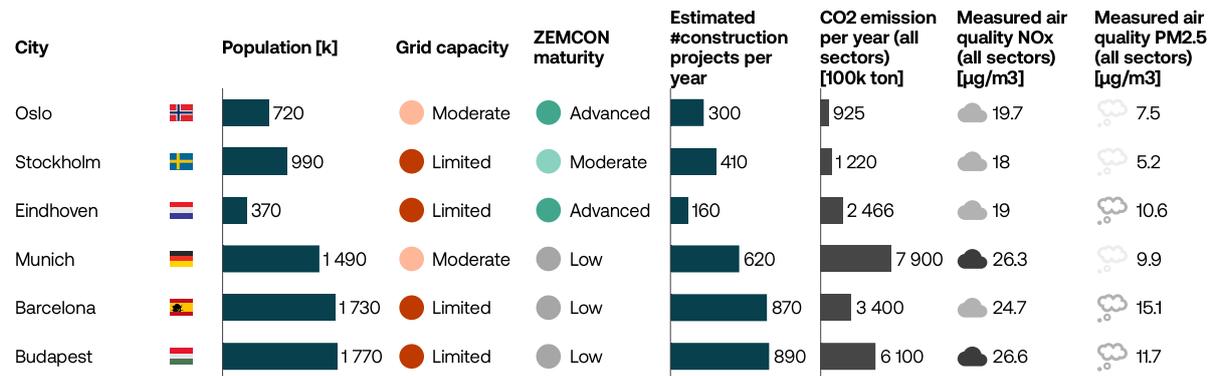


Figure 2: Market characteristics for selected European cities. The overview includes city population, evaluations of grid capacity (chapter 2.1.3 Energy system context and implications for electrification impacts) and ZEMCON maturity (chapter 2.1.4 Status for zero-emission construction), estimated number of ongoing construction projects per year (A.2 Methodology), annual CO2 emissions (Net Zero Cities , 2025) (Norwegian Environment Agency, 2024) (Ajuntament de Barcelona, 2020), measured air quality (EEA, 2022)

Construction sites have a significant impact on local and global environment

The construction industry today poses significant environmental impacts when it comes to air pollution, noise and greenhouse gas emissions. Exposure to elevated levels of nitrogen dioxide (NO₂) and fine particulate matter (PM_{2.5}) has clearly documented adverse effects on human health. While air quality in Europe has improved notably in recent decades, many areas still experience pollutant levels that exceed current EU limits and the stricter guidelines set by the WHO at 10 $\mu\text{g}/\text{m}^3$ for NO_x and 5 $\mu\text{g}/\text{m}^3$ for PM_{2.5} (see Table 1 for full guidelines). In 2022, the number of deaths in EU-27 attributable to long-term exposure to key air pollutants were 239 000 deaths from PM_{2.5} and 48 000 deaths from NO₂ exposure. (European Environment Agency, 2024), as illustrated in Figure 3. This is linked to pollution both in countries with poor air quality, but also in countries with air quality levels well within the current and coming EU limits. For example, in Sweden, the associated costs of health effects of air pollution were estimated to be 168 billion SEK (15 billion EUR) per year (Gustafsson, Lindén, Forsberg, Åström, & Johansson, 2022), despite Sweden's relatively good air quality.

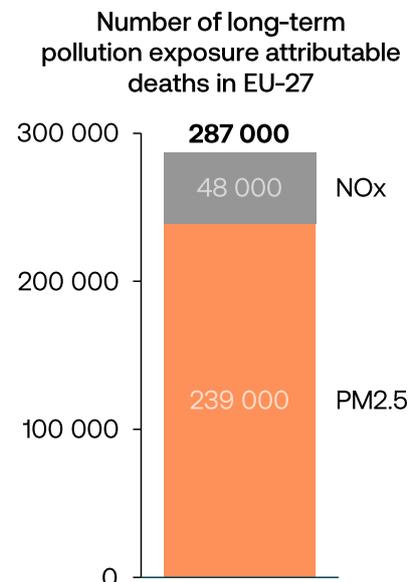


Figure 3: Number of deaths attributable to long-term PM_{2.5} and NO_x exposure

From an occupational perspective NO_x and PM emissions are a severe problem for the workers surrounded by heavy machinery using fossil fuels throughout the workday. Employees at

construction sites are systematically within close reach of diesel exhaust fumes, which the [International Agency for Research on Cancer classifies as a Group 1 human carcinogen](#), meaning there is sufficient evidence linking exposure to an increased risk of lung cancer (International Agency for Research on Cancer, 2012).

Among the focus cities, there is significant variation in measured concentrations of both NO_x and PM_{2.5}, reflecting both geographic conditions and differences in local policy, transport systems, and degree of electrification. However, all focus cities show air quality levels that are poorer than the recommended WHO guidelines, and several cities also breach the 2030 EU limits for pollution levels.

Transitioning to zero-emission construction machinery has the potential to significantly improve urban air quality by removing a key local source of nitrogen oxides and particulate matter. While construction activity is temporary, its emissions impact both workers and people living or working near active sites. Replacing diesel-powered equipment with electric alternatives eliminates tailpipe emissions and reduces exposure to harmful pollutants in the immediate surroundings. Figure 4 below illustrates the estimated reductions of NO_x emissions and PM_{2.5} emissions in Stockholm following electrification of construction sites, showing significant chutes, especially for NO_x.

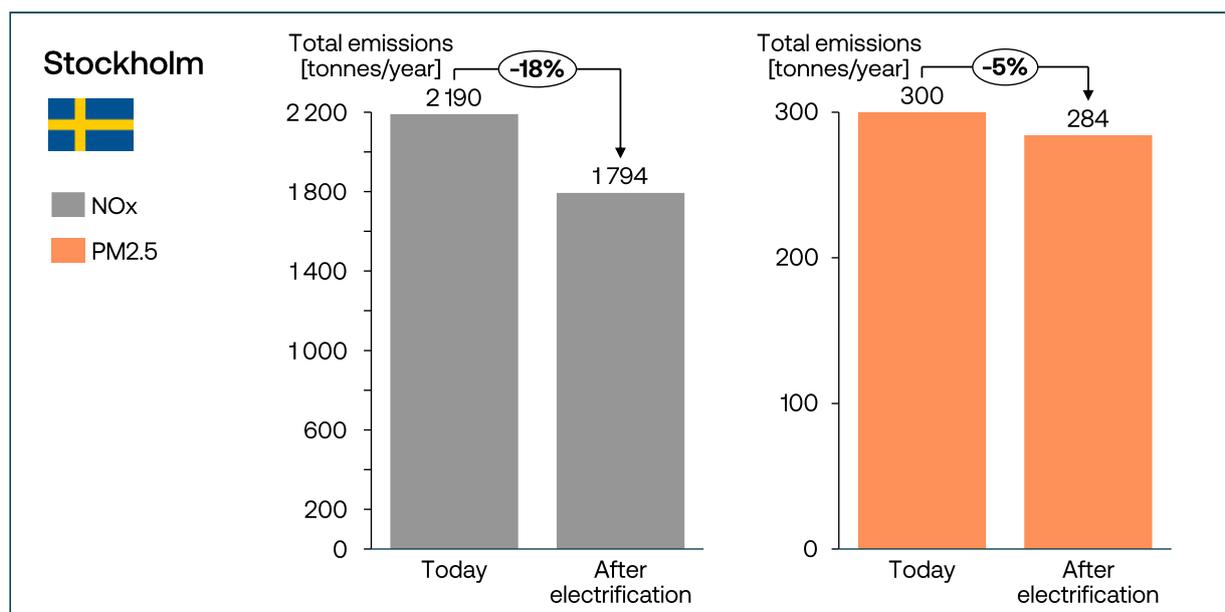


Figure 4: Estimated reduction in total NO_x emissions (left) and PM_{2.5} emissions (right) in Stockholm from electrification of all construction machinery.

While the scale of impact varies across cities, the potential for improvement through electrification is clear. Reducing NO_x and PM emissions at the source, particularly in densely populated areas, will not only help cities meet stricter EU air quality standards, but also deliver direct health and environmental benefits to those most exposed. This will again lead to fewer pollution related deaths and lower public health costs.

Noise pollution from construction sites affects many people

Noise from construction sites can be both bothersome and harmful to people living and working in adjacent areas. In the EU, more than 12 000 premature deaths are caused by long-

term exposure to environmental noise, and more than 22 million people suffer from chronic high noise annoyance (European Commission, 2024).

To assess the effect of noise from construction sites in each focus city, we estimated the probable number of people exposed to harmful and bothersome noise levels over time. Based on the assumptions described in *A.2 Methodology: Environmental implications*, we look at a simplified scenario where a 100-metre radius around construction sites to represent areas with bothersome noise levels (>55 dB on average over 24h), and a 50-metre radius for harmful levels (>60 dB on average over 24h). This radius was used to estimate the impacted area and, by extension, the likely number of people affected in each city. Figure 5 shows the estimated number of affected people:

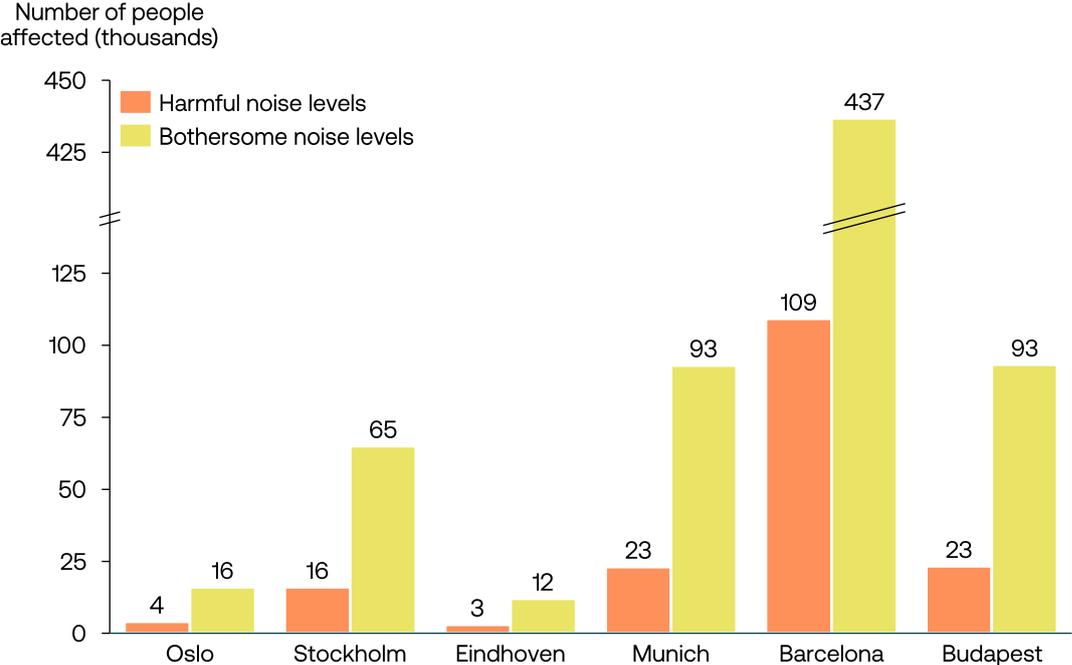


Figure 5: Estimated number of people experiencing bothersome and harmful noise levels in each focus city.

A transition to zero-emission construction machinery would reduce the numbers for people affected by both harmful and bothersome noise levels significantly. Electrification lowers the overall noise from machinery, especially by eliminating continuous engine noise. Overall, people living and working near construction sites will experience a tangible improvement in quality of life as the sector transitions to zero-emission machinery. This is especially important in dense urban areas, where construction is often carried out close to homes, schools, and offices, and where background levels of noise and pollution may already be high. Electrification of construction machinery will also significantly improve the working environment for the construction workers by reducing constant engine noise on site. For workers, this will provide better overall working conditions, lower stress levels, and reduced risk of long-term hearing damage.

Construction activity emits CO₂ equivalent to 14 million passenger cars across Europe

Construction activity generates substantial greenhouse gas emissions across all focus cities. Many European cities today have emission levels that must be significantly reduced to meet climate targets and improve the urban environment. Direct CO₂ emissions from construction machinery are estimated to amount to nearly 450 thousand tonnes across the six focus cities, based on assumptions regarding the number and composition of construction projects.

Electrifying construction activity provides a substantial reduction in greenhouse gas emissions. Net emission reductions reflect the difference between emissions from conventional diesel-powered machinery and the emissions associated with electricity generation. Based on today’s national power generation mixes, we estimate that the transition to zero-emission construction would reduce indirect emissions (Scope 2) by more than 330 thousand tonnes of CO₂ per year across the six focus cities, equivalent to approximately 165 thousand passenger cars. In addition, the transition would eliminate almost all direct on-site emissions (Scope 1) from diesel-powered construction machinery, corresponding to approximately 445 thousand tonnes of CO₂ per year. The estimated emission reductions by city, and the corresponding passenger car equivalents, are illustrated in Figure 6.

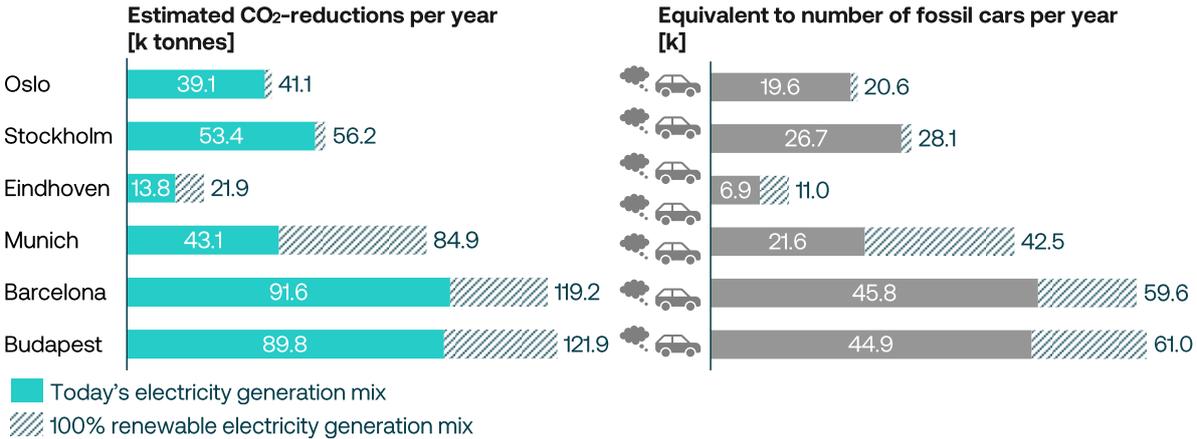


Figure 6: Estimated annual indirect CO₂ emission reduction from construction machinery per city and estimated equivalent from passenger cars in the EU based on 12 000 km/year and 170g/km

The estimated emission reductions vary across cities and countries, primarily depending on the carbon intensity of electricity generation and the overall scale of construction activity. Cities with highly decarbonised power systems achieve the largest net reductions per unit of construction activity, while cities with higher electricity-related emissions experience smaller relative reductions despite large absolute cuts, as shown in Figure 6.

At the European level, construction activity accounts for approximately 27 million tonnes of CO₂ emissions per year, equivalent to nearly 14 million passenger cars. As electricity production continues to decarbonise across Europe, the emissions associated with zero-emission construction activity will decline further. In the long term, near-zero emissions from construction activity are therefore achievable as part of a broader transition toward a fully decarbonised energy system.

Transitioning to zero-emission construction has a limited impact on urban energy and power demand

The electrification of construction activity increases demand for electricity from the grid, which can be challenging in urban areas where grid capacity is already constrained. However, construction activity is only one of several drivers of rising electricity demand in the years ahead. Europe is entering a broad energy transition, with electricity demand expected to grow rapidly across multiple sectors. This growth is driven primarily by the electrification of transport, alongside the expansion of heat pumps in buildings, increased electricity use in industry, and more limited growth in other sectors.

Among the focus cities, there is substantial variation in the share of electricity in total energy consumption. These differences are reflected in the relative peak-load contribution from

construction activity: cities with a high existing share of electricity tend to experience smaller relative increases in peak power demand. The increase in peak demand from construction activity, together with the expected growth in demand from other sectors towards 2040, is illustrated in Figure 7.

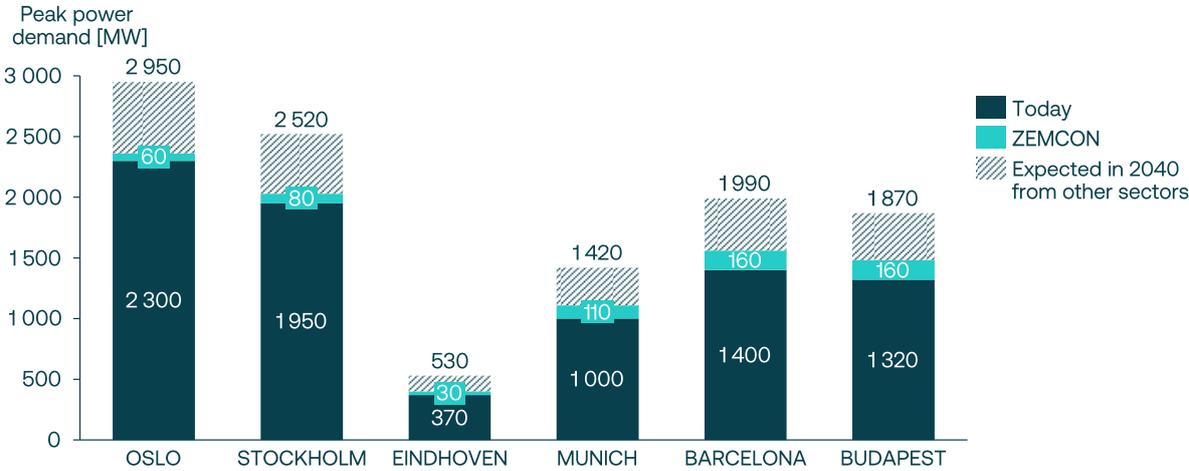


Figure 7: Peak power demand for electricity today (Blokhuys, Brouwers, van der Putten, & Schaefer, 2011) (Norwegian Water Resources and Energy Directorate, 2025) (Stadtwerke München, 2024) (Endesa, 2025) (ENTSO-e, 2025), estimated demand from 100% ZEMCON and expected demand from other sectors in 2040 for each focus city (ENTSO, 2025) (Norwegian Water Resource and Energy Directorate (NVE), 2025) (Swedish Energy Agency, 2025)

Electrification across construction activity, transport, heating and industry will require substantial reinforcement of the European electricity system, as well as increased use of flexible and mobile energy supply solutions. Electrification of construction activity is expected to occur gradually towards 2050 and largely in parallel with other sectors. Early projects typically involve partial electrification and relatively modest power demand, which reduces the need for high-capacity grid connections. Where grid access is limited, overnight charging and temporary solutions such as mobile batteries and charging units can support construction operations.

While electrification increases electricity consumption from construction activity, its contribution to overall energy demand remains modest compared with other sectors. The expected increase in annual electricity use from construction activity is around 1 percent in Oslo and approximately 3 percent in Budapest. These increases are small relative to the broader electrification of transport, heating and industry, which together account for the dominant share of future growth in electricity demand.

The additional cost for zero-emission construction will drop rapidly as the market matures
 Since the first pilot projects in Oslo 2019, the city has conducted more than 180 construction projects with heavy duty electric machinery, providing a strong empirical basis for assessing performance and cost. Zero-emission construction offers several environmental benefits. But electric construction machinery is still in an early stage of commercialisation, with a significant up-front cost premium. In addition, temporary energy supply and charging infrastructure involves significant extra cost. At the same time, significant savings can be expected from more efficient energy use, improved battery technology and reduced maintenance needs (Oslo Economics, Hafslund Rådgivning, 2025).

Importantly, early cost premiums are not inherent or persistent. Experience from Oslo shows a clear downward cost trajectory as technologies improves, supply chains develop and

operational experience increases. Gradual implementation strategies, targeted support schemes, and systematic knowledge sharing can significantly reduce both the magnitude of cost and duration of the commercialisation phase. As zero-emission construction is adopted across a growing number of markets, accumulated learning effects, technological maturation, and cross-border transfer of experiences are expected to shorten this phase and lower associated costs for new and less mature markets.

For leading markets such as Oslo, rapid technology and market development indicates that zero-emission construction can reach a development phase already by around 2030, where fully electric projects are commercially competitive compared to conventional fossil operation. The pace and scale of cost reductions will vary across markets, reflecting differences in technological maturity, grid conditions and local market characteristics.

Continued improvements in machinery technology and battery capacity enable a shift towards overnight charging and reduced reliance on high-power daytime charging. This both lowers energy costs and reduces operational disruptions during working hours. While this study assesses full electrification as a reference case, the transition in practice is expected to be gradual, with increasing shares of electric machinery. As a result, near-term cost impacts are likely to be lower than those implied by immediate full conversion, reinforcing the conclusion that current cost premiums are transitional rather than structural. Further details on the cost assessment, based on estimated cost levels and observed market development, are provided in the Oslo case study in 2.2 Impact assessment for electrifying construction sector.

Transitioning to zero-emission construction has significant strategic implications in Europe
The strategic implications of the transition towards zero-emission construction sites are significant. The [Draghi report on the future of European competitiveness](#) makes clear that decarbonisation is no longer a peripheral environmental objective but a central condition for Europe's long-term economic strength, security and political relevance.

Construction is a foundational sector, and failure to decarbonise its operations would lock in inefficiencies, expose projects to volatile fossil-fuel prices and undermine the credibility of Europe's broader net-zero strategy. Conversely, accelerating ZEMCON can contribute to lowering operational energy costs over time, stimulating demand for clean technologies and reinforcing Europe's position as a rule-setter in sustainable industrial practices.

A shift towards ZEMCON has significant upstream implications for European machinery and equipment manufacturers and can directly support the development of Europe's domestic battery industry. As highlighted in the Draghi report, clean technologies are among the fastest-growing global markets. By linking ZEMCON deployment with European battery production, the EU can strengthen industrial competitiveness and reduce strategic dependencies in a critical technology.

As large cities push forward with climate targets, air quality regulations, and public procurement requirements, they help create early markets for zero-emission construction machinery, energy supply solutions, and digital site management tools. These city-level transitions can generate positive ripple effects: scaling demand, driving learning curves, reducing costs through serial production and enabling European manufacturers to become global leaders in electric, hydrogen-based and digitally integrated construction equipment, as illustrated in Figure 8.

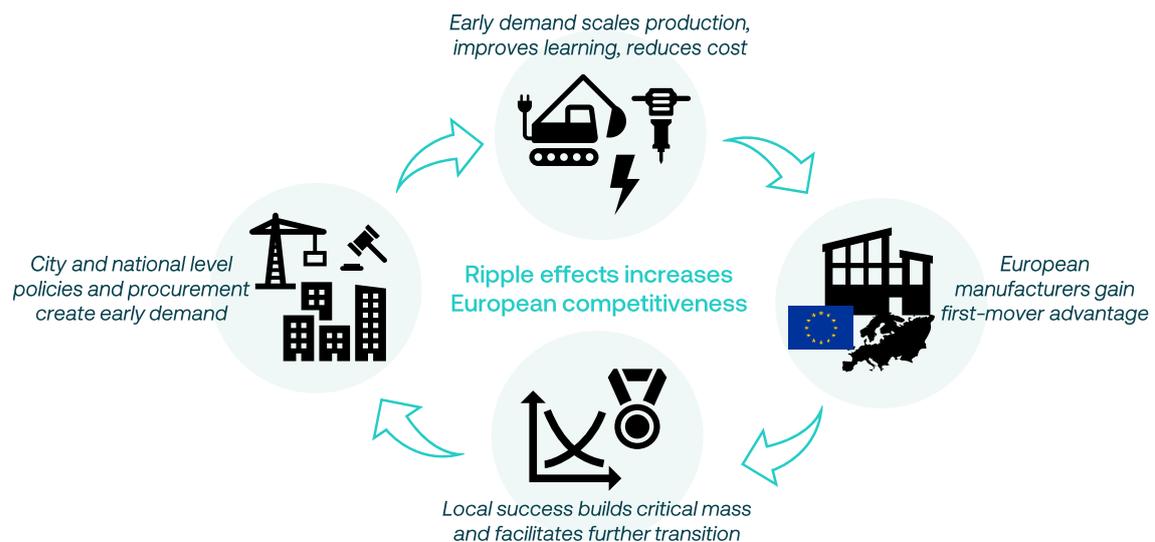


Figure 8: Illustration of zero-emission construction could lead to ripple effect and increase European competitiveness

ZEMCON also contributes to objectives concerning resilience, supply chain security and reduced dependencies by supporting greater reliance on locally produced and European energy sources, particularly electricity from renewables, rather than imported fossil fuels. Embedding ZEMCON within a European industrial and energy ecosystem can enhance robustness by shortening supply chains, improving monitoring of critical assets and reinforcing strategic autonomy in both energy and machinery production.

Public authorities already have a strong legal basis to require zero-emission construction machinery

The transition to zero-emission construction sites is not only compatible with existing European law but is, in many cases, already supported or required by it. Although current environmental, health and safety, and energy legislation were not designed specifically for zero-emission construction machinery, it provides a strong and underused legal basis for action by municipalities, regions and member states. Within the EU's multi-level governance system, local authorities play a critical role in implementing EU obligations on air quality, noise reduction and occupational health, and are legally empowered to set requirements for cleaner construction practices in both public and private projects.

Figure 9 summarizes different types of policies existing on an EU, national and local level supporting zero-emission construction. The figure also outlines an evaluation of the policy and legal framework impact to transition to ZEMCON, which is further elaborated in Chapter 3.

Type	Policy/Instrument	Level	Impact
Collaborative Governance	Voluntary Agreement	🇳🇵 National	Low
	Private-public market dialogue	🇳🇵 National	Medium
	Joint Statements/Declarations	🇳🇵 National	Medium
Economic	Financing schemes for municipal support	🇳🇵 National	High
	Subsidies for zero-emission machinery	🇪🇺 EU	High
	ETS2 & Energy Taxation Directive	🇪🇺 EU	Medium
	GBER	🇪🇺 EU	Medium
	Support schemes for machinery and infrastructure	🇳🇵 Local/National	High
Energy	Electrification Action Plan	🇪🇺 EU	Medium
	European Grids Package	🇪🇺 EU	Medium
Public Procurement	Public Procurement Directive	🇪🇺 EU	High
	Clean Vehicles Directive	🇳🇵 National	Medium
	Zero-emission requirements in public procurement	🇳🇵 Local/National	High
	Pilot projects	🇳🇵 Local	Medium
Regulatory	NRMM Regulation	🇪🇺 EU	High
	Ambient Air Quality Directive	🇪🇺 EU	High
	Plans, goals and roadmaps for ZEMCON transition	🇳🇵 Local/National	Medium
	Air quality plans and roadmaps	🇳🇵 Local/National	Low
	Environmental Noise Directive	🇪🇺 EU	Medium
	EPBD	🇪🇺 EU	Medium
	Directives on workers protection	🇪🇺 EU	Medium
	Taxation and fees on fossil machinery and fuels	🇳🇵 National	High
	Municipal targets	🇳🇵 Local	Medium

Figure 9: Policy and legal options on different levels and with an evaluation of their potential impact

At the core of this framework are binding EU directives such as the revised Ambient Air Quality Directive (AAQD) and the Environmental Noise Directive (END). The AAQD establishes enforceable air quality limits, mandatory planning obligations and legal accountability mechanisms that directly justify measures to reduce emissions from diesel-powered construction machinery, a major source of local air pollution. The END, while lacking binding limit values, still imposes clear duties on monitoring, mapping and action planning for noise, reinforcing the case for quieter, electric machinery in urban areas. These obligations are underpinned by constitutional and human rights protections, including the right to a healthy environment, and by EU occupational health and safety law, which prioritises eliminating risks at source where technically feasible. This further strengthens the legal rationale for zero-emission equipment.

Beyond the core legal drivers, the chapter identifies important policy gaps and emerging opportunities at EU level that could accelerate ZEMCON deployment. Forthcoming initiatives such as the Electrification Action Plan and the European Grids Package can reduce key barriers by improving grid access, enabling smart charging and flexibility, and lowering total cost of ownership for electric machinery. In contrast, the current Non-Road Mobile Machinery Regulation is increasingly misaligned with EU climate, zero-pollution and competitiveness objectives, as it lacks CO₂ standards and does not incentivise a shift to zero-emission technologies.

Overall, through legal analysis and real-world examples from national legislation, legal cases, roadmaps, and financial incentives, the chapter concludes that public procurers already have a legally sound basis to act, and that aligning upcoming EU policies with zero-emission construction can unlock faster, fairer and more competitive pathways towards clean, quiet and healthy construction sites across Europe.

Table of Contents

EXECUTIVE SUMMARY	7
TABLE OF CONTENTS	16
INTRODUCTION	17
Abbreviations and acronyms	19
1. BASELINE	20
1.1 The construction sector in European markets	21
1.2 Status for zero-emission construction in Europe	24
2. IMPACT ASSESSMENT	31
2.1 Current situation and the construction sector's impact today	31
2.2 Impact assessment for electrifying construction sector	46
3. POLICY AND LEGAL OPTIONS	69
3.1. Introduction to Legal Framework	71
3.2. Policy gaps and opportunity analysis	80
3.3. Economic implications & cost mitigation options	87
ANNEXES	94
A.1 ABOUT THE COLLABORATING CONSULTANCY TEAMS	95
A.2 METHODOLOGY	96
A.3 INTERACTION BETWEEN EU, NATIONAL AND LOCAL POLICY FRAMEWORKS	109
A.4 DISTRIBUTION OF COMPETENCES ON EU, NATIONAL AND LOCAL LEVELS	110
LIST OF FIGURES	113
LIST OF TABLES	115
REFERENCES	116

Introduction

The construction sector is a large source of greenhouse gas emissions and local environmental impacts in Europe (European Commission, u.d.). Construction activities contribute not only to CO₂ emissions, but also to local air pollution, noise and energy demand in urban areas. At the same time, construction is a fundamental enabler of economic activity, housing development and infrastructure provision. Emission reductions in this sector therefore cannot be achieved through reduced activity alone but require changes in how construction is carried out.

The transition to zero-emission construction (ZEMCON) represents a critical and timely frontier in the decarbonisation of European cities. The electrification of construction machinery and site operations offers a viable pathway to significantly reduce emissions and local environmental impacts while maintaining necessary construction activity. Electric solutions are currently the most technologically mature and scalable zero-emission option for construction sites, making electrification a central focus of current policy and market development. While local efforts such as those in Oslo demonstrate what is technically and politically possible, the broader European market still faces significant barriers to adoption, ranging from grid capacity and energy infrastructure to procurement practices and private-sector readiness.

Oslo provides an ambitious and instructive starting point. With all municipal construction sites required to be zero-emission from January 2025 and a national regulation (FOR-2025-04-03-594) empowering municipalities to mandate emission-free and biogas-powered construction, the city is establishing one of Europe's most progressive regulatory frameworks. This is backed by strong political will and strategic use of public procurement. However, the next regulatory step, extending the zero-emission requirement to all construction activity in Oslo, regardless of project ownership, will test the limits of local authority and market responsiveness.

Scaling such initiatives across Europe brings multiple systemic challenges. Many cities lack legal instruments or political capital to enforce similar requirements. Energy infrastructure is a key bottleneck, with limited grid capacity and flexibility restricting the rollout of electric machinery. Additionally, procurement structures in both public and private sectors often lack mechanisms or incentives to prioritise zero-emission solutions. In markets with fragmented construction value chains and low-margin business models, widespread adoption requires more than regulatory mandates: it also depends on credible business cases, cost-effective technologies and coherent policy frameworks.

This report is pivotal within the broader EU policy landscape. It directly supports the goals of the Net Zero Cities initiative and the EU Mission on 100 Climate-Neutral and Smart Cities. Its purpose is to assess the current situation in the European construction sector, analyse the potential impacts of a large-scale transition to zero-emission construction, and identify policy and legal frameworks that can support a more effective and cost-efficient transition. This way, the report may provide evidence-based guidance to cities, national authorities, and the European Commission on how to design enabling regulatory frameworks and align economic instruments to accelerate decarbonisation in the construction sector while supporting complementary objectives. The analysis focuses on electrification as the primary zero-emission pathway, while recognising that other technologies may also contribute to emission reductions in specific contexts.

The report is structured in three main parts:

- **Part 1** provides a concise baseline assessment of construction activity in Europe and its associated environmental impacts. This part outlines current levels of construction activity, key emission and impact indicators, and presents an overview of the status of zero-emission construction across European markets.
- **Part 2** presents an impact assessment for a selection of European cities, analysing how zero-emission construction can contribute to reducing greenhouse gas emissions, improving local air quality and noise conditions, and strengthening European competitiveness. In addition, this part examines the cost implications for market actors and the potential impacts on energy systems. The analysis begins with a more detailed baseline assessment of the focus cities, followed by an in-depth assessment of the different impact dimensions across varying city characteristics.
- **Part 3** discusses policy and legal options at EU, national and local levels, outlining how regulatory frameworks and economic instruments can enable and accelerate the transition to zero-emission construction.

This report is intended for stakeholders in the field of zero-emission construction, particularly for contracting authorities at all levels of governance, city leaders considering to implement zero-emission construction sites, EU officials working on the topic, and manufacturers looking to expand their zero-emission portfolio. The report aims to provide a high-level perspective of the sector, assess the potential impacts of ZEMCON deployment in various areas, including cost, as well as the strategic implications and the legal options that exist to support the uptake of zero-emission construction sites across European cities and regions.

Abbreviations and acronyms

Acronym	Description
CAPEX	Capital Expenditures
EPBD	Energy Performance of Buildings Directive
GDP	Gross domestic product
GHG	Greenhouse gas
GWP	Global warming potential
MEAT	Most economically-advantageous tender
NOx	Nitrogen Oxides
NRMM	Non-Road Mobile Machinery
NZC	NetZeroCities
OPEX	Operational Expenditures
SMEs	Small & Medium Enterprises
TCO	Total cost of ownership
TSO	Transmission System Operator
PM	Particulate matter
WLC	Whole-life carbon
ZEMCON	Zero-emission construction

1

Baseline

This chapter maps out the baseline for Europe’s construction sector by looking at 12 different markets. It looks at the overall scale and distribution of activity across countries, the environmental impacts of construction work, and the sector’s current readiness for a transition toward zero-emission construction sites (ZEMCON). The aim is to provide a clear, evidence-based understanding of where the sector stands today, and what this implies for the adoption of new technologies.

The analysis begins with an overview of construction activity in European markets, highlighting differences in market size and procurement patterns. It then examines the overall environmental footprint of the sector, with attention to energy use, greenhouse gas emissions, air pollutants, and noise. Building on this, the chapter explores the degree of readiness for zero-emission solutions, reflecting on policy frameworks, market drivers, and industrial capacity.

Figure 10 summarizes the characteristics for some of the important European markets, and the different parameters are described on the following pages.

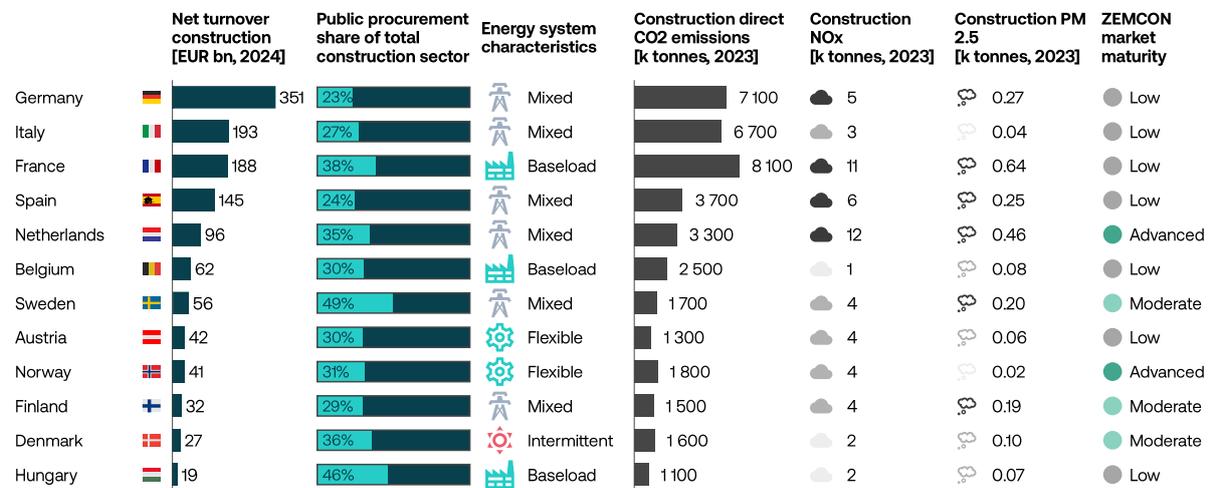


Figure 10: Summary of the characteristics for 12 analysed national markets in Europe. ZEMCON market maturity reflects the level of zero-emission construction activity in each market, based on the number and type of implemented projects. Low maturity indicates few or no pilot projects, moderate maturity reflects multiple pilot projects, while advanced maturity represents markets with several projects approaching or entering commercial deployment. The presented indicators are further elaborated in the following pages, and the methodology is described in A.2 Methodology.

1.1 The construction sector in European markets

1.1.1 Construction activity

Construction sector market sizes and public procurement shares

The construction sector plays a key role in the European economy, with a net turnover of €1.463 billion in 2024 across the EU and Norway (FIEC, 2025). It makes up 10.6% of the European Union's (EU) gross domestic product (GDP) and employs over 12 million people, representing 31.2% of regional industrial employment (FIEC, 2025).

In 2024, the total construction sector net turnover of the 12 analysed countries (Germany, Italy, France, Spain, Netherlands, Belgium, Sweden, Austria, Norway, Finland, Denmark, Hungary) reached €1200 billion (FIEC, 2025). The construction activity, however, appears to be highly concentrated in a few key markets. Germany leads the way with a substantial margin, at €335 billion in 2024, followed by Italy (€193 billion), France (€188 billion), Spain (€122 billion), and the Netherlands (€96 billion). Together, these five markets account for almost 64% of the European construction sector's net turnover (FIEC, 2025). At the European level, the largest potential markets for zero-emission construction naturally emerge in the three biggest construction economies: Germany, Italy, and France. Figure 11 below illustrates the net turnover for construction and what share of public works compared to the total of the construction.

Beyond these core markets, the Nordic countries represent smaller shares of total activity. However, these markets are among the most advanced in piloting zero-emission construction sites, driven by strong national climate targets and city-level initiatives.

The public procurement shares in the different countries highlight the significant role of government demand in shaping these markets. The highest public procurement shares in the construction sector are found in Hungary and Sweden, where public clients account for almost 50% of total construction output. Denmark and France follow at 40%. Germany has a relatively low public procurement share of just 20% but still has a high overall volume of public construction procurement in absolute terms because of the general market size. The implications of this dynamic are particularly relevant when seeking avenues to promote greening in the construction sector, especially in construction machinery fleets. In fact, as national or local authorities generally commission infrastructure projects, green public procurement (GPP) could play a vital role in driving the creation of lead markets for zero-emission construction machinery.

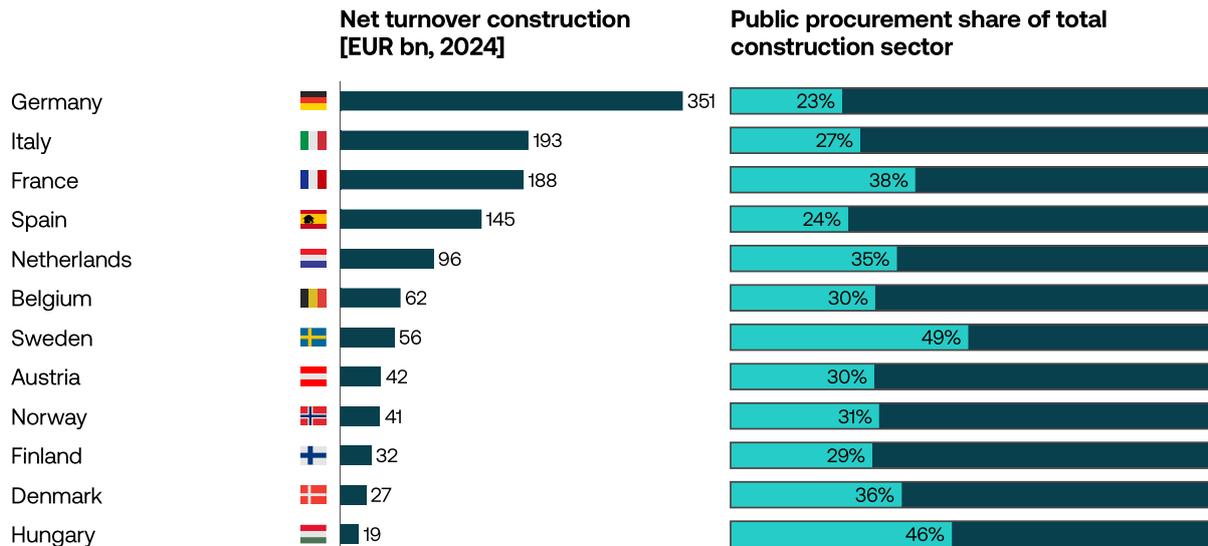


Figure 11: Net turnover, public procurement shares and size of lead markets for zero-emission machinery in European construction markets (FIEC, 2025) (Statistics Norway, 2023) (Brussels school of governance, 2024)

Construction machinery

In Europe, the construction equipment market went through a downturn in 2024, with sales dropping across all regions and segments. The projections for 2025 have been more positive, with modest growth expected by mid-year (CECE, 2025). Nevertheless, most of this market assessment referred to sales of machines with internal combustion engines (ICE). Replacement demand, especially from rental companies, is beginning to support activity, while major infrastructure programs and the ongoing energy transition are creating new opportunities.

According to a recent [report from Global Market Insights](#), the size of construction equipment sales in Europe accounted for approximately 40 EUR bn in 2024. The global electric construction equipment market reached USD 10.5bn in 2023 and is expected to grow more than six times to USD 70.1bn by 2032 (Vantage Market Research). Europe is leading this shift, accounting for 37.8% of global revenues, making it the largest regional market, which would indeed result in almost USD 4bn, aligned with the above estimation. This leadership reflects the EU's strict climate policies, city-level low-emission zones, and strong demand for greener infrastructure projects. With its regulatory drive and early customer demand, Europe is emerging as the leading market for sustainable construction equipment, establishing standards that other regions are likely to follow, and providing the industry with a pathway toward sustainable growth despite ongoing economic and geopolitical uncertainties.

1.1.2 Environmental impact of construction activity in Europe

Construction sites have a distinct environmental footprint. Unlike buildings in operation, which consume electricity or gas and produce emissions mostly off-site at power plants, construction sites burn fuel on-site (primarily diesel) for machinery and generators. This directly impacts local air quality and contributes to global carbon emissions. In this section, we establish a baseline of these impacts across twelve European countries, focusing on energy use, greenhouse gas (GHG) emissions, and air pollutant emissions associated with construction machinery.

Air quality

Diesel machinery not only emit CO₂, but also harmful air pollutants, including nitrogen oxides (NO_x) and particulate matter (PM_{2.5}). From Eurostat’s CLRTAP-based inventory (NFR 1A2gvii, 2023), the twelve countries emitted in 2023 a combined 56,860 tonnes of NO_x and 2,380 tonnes of PM_{2.5} from non-road mobile machinery in construction and manufacturing.

The largest NO_x emitters are the Netherlands (11,700 t) and France (10,590 t), followed by Spain (5,890 t) and Germany (5,150 t). For PM_{2.5}, France (640 t) and Netherlands (460 t) again stand out, with other countries ranging from 20–270 tonnes in 2023.

These emissions, while smaller in mass than CO₂, are still important because they are released at ground level in densely populated areas. In cities with strong clean air policies for traffic, construction machinery can account for a disproportionately large share of remaining local NO_x and PM_{2.5} emissions. It should be noted that the pollutant data (NFR 1A2gvii) combine manufacturing and construction machinery. Moreover, precise attribution varies by country. For this reason, the pollutant totals presented here are best understood as an upper bound for construction. Future work should refine this split.

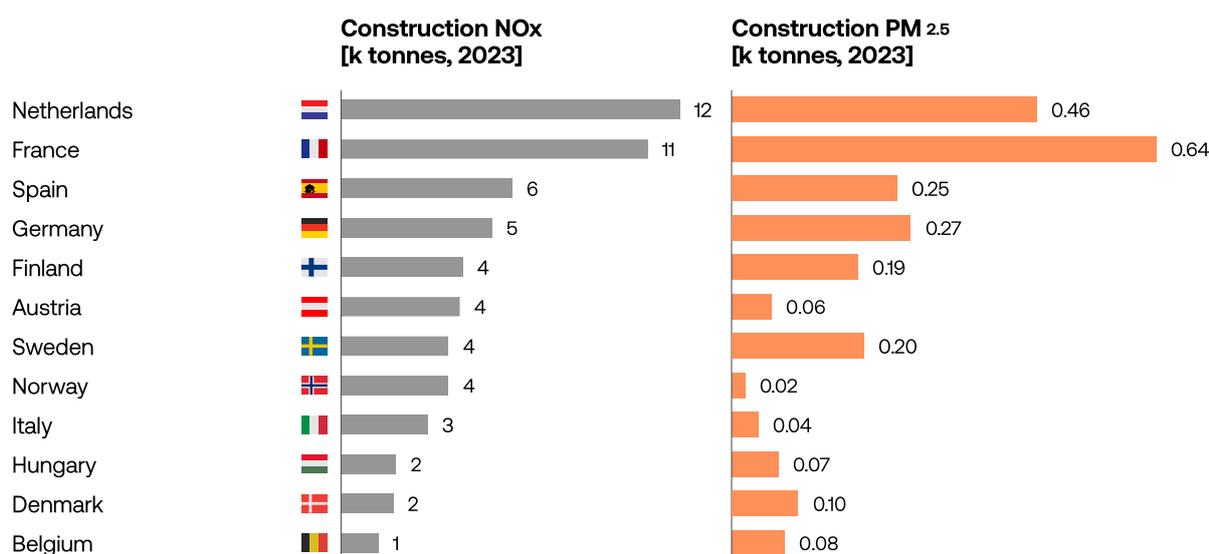


Figure 12: NO_x and PM_{2.5} emissions in thousand tonnes for Mobile combustion in manufacturing industries and construction (Eurostat, 2025).

Energy use and GHG emissions

The construction sector’s machinery emits large amounts of CO₂ and are a significant energy consumer. Based on Eurostat’s 2023 air emissions accounts, direct CO₂ emissions from construction (NACE F) amount to 40.3 million tonnes across the 12 countries studied. Using the IPCC default diesel emission factor (74,100 kg CO₂/TJ), this corresponds to an energy demand of 543,000 terajoules (TJ), which equals approximately 151 TWh. At country level, the largest emitters are France (8.1 Mt CO₂; 109,000 TJ), Germany (7.1 Mt; 96,000 TJ), and Italy (6.7 Mt; 90,000 TJ), aligning with the largest construction markets.

Virtually all these emissions stem from fossil fuels used in non-road mobile machinery and auxiliary site equipment (e.g. generators, heaters). A transition to zero-emission machinery would therefore eliminate almost all direct CO₂ emissions.

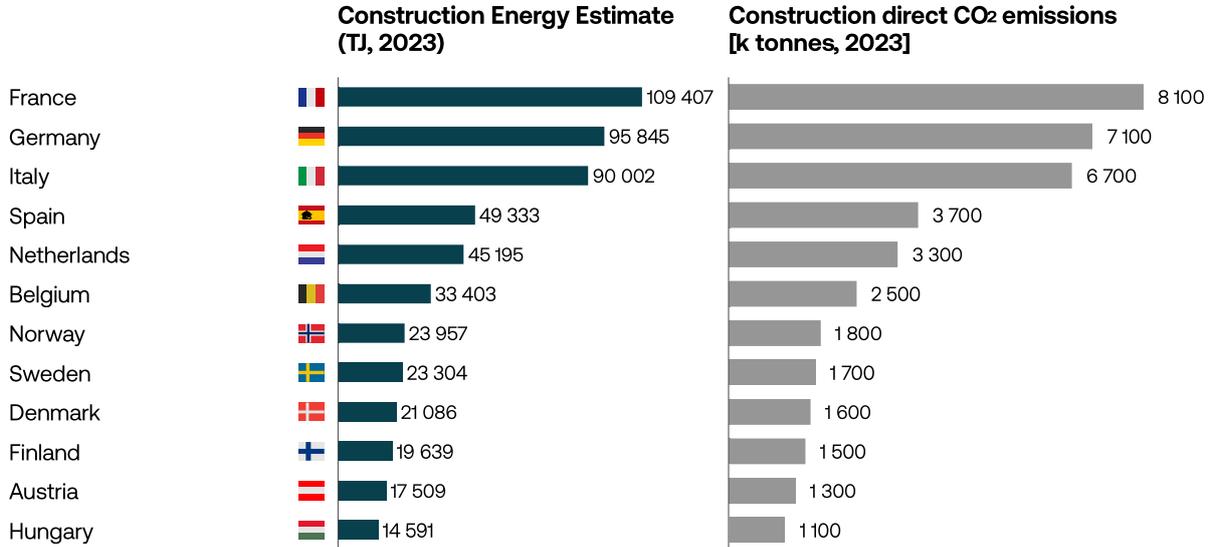


Figure 13: Energy estimate and direct CO₂ emissions for non-road mobile machinery (NRMM) and auxiliary site equipment in construction only (Eurostat AEA 2023, NACE F).

1.2 Status for zero-emission construction in Europe

In Europe, the landscape of zero-emission construction sites (ZEMCON) is uneven from several perspectives. The first relates to the geographical distribution of adoption for this construction approach. Most of ZEMCON's established activities take place in the Nordics, with a notable exception being the Netherlands. Second, the level of ambition in policies varies significantly. Some areas are already enforcing ambitious ZEMCON requirements in their procurement specifications. Others have committed to roadmaps or are still exploring ZEMCON through pilot projects.

1.2.1 Access to zero-emission machinery and equipment

When we discuss the market maturity of zero-emission construction, we need to consider two parallel aspects: regional markets and the level of demand for zero-emission machinery on the one hand, and the availability of supply in those markets on the other.

In terms of the zero-emission machinery supply, it has exponentially grown in recent years, driven by the decarbonisation of the economy. According to a mapping done by SINTEF, there exists more than 170 electric models of different machinery over 8 tons globally, and more than 350 models of smaller machinery as shown in Figure 14 (SINTEF, 2025). At Bauma, the world's largest trade fair in the construction industry, which is held every three years, the increase in zero-emission machinery shown by manufacturers has been evident, from tens of models in 2019 to hundreds shown in 2025. Some manufacturers, including European manufacturer Volvo, chose to showcase a fully electric line-up, of machinery of various segments and sizes, clearly indicating that the future of the sector is zero-emission. Chinese and Japanese manufacturers were also prominent at Bauma 2025, with many zero-emission models in exposition. At Bauma, [a Memorandum of Understanding](#) was also signed by leading manufacturers, such as Komatsu, Volvo CE, Liebherr and VDL ETS, who have recently

published recommendations towards the creation of standards on various design aspects of larger electric machines. The objective is to enable easier adaptation by end users in the European markets.

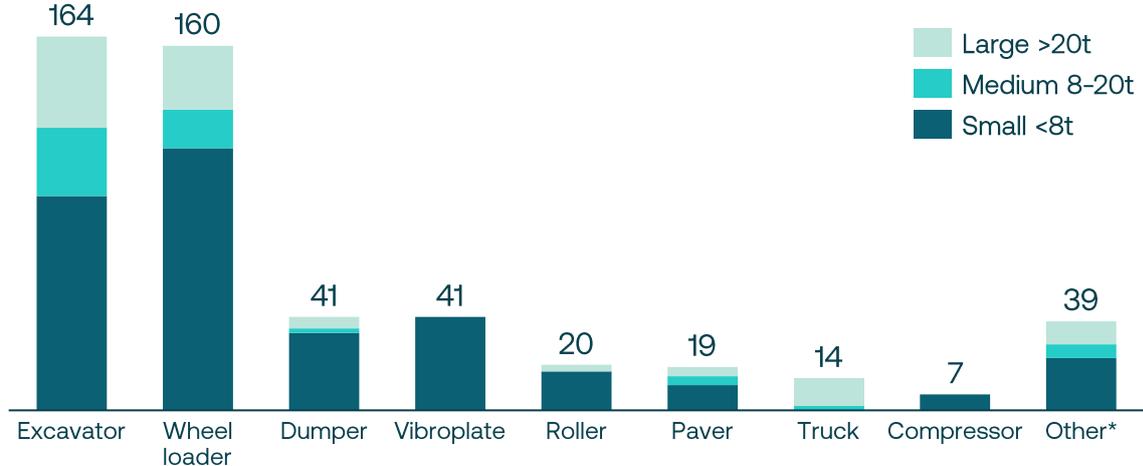


Figure 14: Number of available electric machinery models by September 2025 based on a mapping by SINTEF and Bellona (SINTEF, 2025). **Other** includes: Demolition robot, heater and dryer, grader, asphalt cutter, concrete truck, concrete truck mixer, carrier machine for slurry wall construction and chipper.

In terms of country-specific machinery supply, several stakeholders interviewed expressed differences in the availability outlook. In countries or regions where the demand signal is clear, such as Norway or the Netherlands, manufacturers, dealers and leasing companies are already delivering the requested equipment, leading to the early establishment of markets for zero-emission machinery and charging equipment. Similarly, cities with pilot projects have not expressed any difficulty in purchasing or leasing equipment, only concerns that the European supply might not be able to grow at the same rate as the demand, once public roadmaps and targets have been set.

As demand grows, however, the question is whether said demand will be met by European-based suppliers or whether imports will be necessary due to the European industry’s slower transition in comparison to Asian market. This has several underlying reasons, such as vertically integrated value chains in China, as well as Europe’s long tradition of internal combustion engines manufacturing. However, global trends tilt towards the increasing supply and product diversification of zero-emission machinery, prompted by accelerating electrification rates, synergies with the automotive sector, and a growing pool of interested European and international manufacturers.

1.2.2 Zero-emission construction ambitions and maturity in European markets

The development of zero-emission construction sites across Europe is progressing unevenly. Nordic countries and the Netherlands are leading the way in adoption, while progress in other areas is slower and often limited to pilot projects. In Central-Eastern and Southern Europe, Budapest and Barcelona are the only cities with a declared plan, although their implementation remains slow.

National landscape

National governments play an important role in the transition to zero-emission construction. At the national level, subsidies remain the main policy tool. In Norway and the Netherlands,

financing schemes are designed for procuring authorities to cover the additional costs associated with zero-emission construction sites. This is particularly relevant as municipal budgets are often limited and cannot absorb the higher costs associated with the initial adoption of ZEMCON. Additionally, both countries have subsidy schemes in place to support the private sector's purchase of zero-emission construction machinery.

The Netherlands have a high zero-emission machinery uptake and extensive policies

A clear example of national involvement is that of the Netherlands, which stands out for its comprehensive strategy for zero-emission construction sites. The primary government objective is to significantly reduce air pollutants, including nitrogen oxides (NO_x) and fine particulate matter, by 2030. Additionally, the Dutch strategy aims to curb CO₂ emissions from mobile machinery and construction logistics by 0.4 Mt by 2030, compared to 2019 (Ministry of Infrastructure and Water Management, 2023).

To meet these objectives, in 2024 the Netherlands have promoted the Voluntary Agreement on Clean and the Zero-Emission Construction initiative. This agreement establishes a roadmap with interim targets for the procurement of construction machinery, to which the signatories commit to respecting. Signatories of the agreement are ministries, provinces, municipalities, state agencies, and business networks.

Additionally, the Dutch government has launched two incentive schemes to mitigate the initial premium of emission-free construction machinery. The Clean and Emission-Free Construction Incentive Scheme for Fellow Authorities (SPUK SEB) and the Subsidy for Clean and Zero Construction Equipment (SEEB). The first scheme is designed for procuring authorities, such as provinces and municipalities, to assist them in covering additional costs arising from ZEMCON (Netherlands Enterprise Agency, n.d.). The second scheme, on the other hand, targets the private sector and seeks to promote the purchase of zero-emission machinery, the conversion of diesel machinery, and research and development (Netherlands Enterprise Agency, n.d.). All these measures have led to an increased number of zero-emission construction sites throughout the country.

The Nordic countries lead the way though targets and financing schemes

Finland has also taken steps to promote zero-emission construction sites nationwide. In 2020, it launched the National Green Deal for the non-road mobile machinery sector. Under this voluntary agreement, construction sites operated by co-signing cities, municipalities, agencies, and other public organisations will be required to be fossil fuel-free by the end of 2025. By 2030, at least half of construction machinery and site transport must run on electricity, biogas or hydrogen (Ministry of the Environment, 2024) (Ministry of the Environment, 2024).

Norway has launched several subsidy programmes to support zero-emission construction sites. The *Klimasats programme* helps municipalities cover the additional costs associated with zero-emission construction sites and other measures to increase the use of zero-emission machinery. Similarly, the Enova programme provides funding for the purchase of electric construction machinery and battery containers. The Ministry of Transport also operates a support scheme for pilot projects for zero-emission construction sites in the transport sector.

Political discussions are ongoing regarding further measures. Under discussion is a possible ban on the sale of new construction machinery with combustion engines from 2035.

Additionally, municipalities could be given the authority to enforce the use of zero-emission solutions and biogas on private construction sites (Klima- og miljødepartementet, 2025).

City landscape

Nevertheless, most of the planning takes place at the city level with an increasing number of European cities recognising the benefits of zero-emission construction, such as cleaner air, reduced noise and lower greenhouse gas emissions. At the local level, public procurement mandates are the most common tool for promoting the uptake of zero-emission construction solutions. The preparedness observed is however uneven across European cities. Some cities, like Oslo, already require 100% zero-emission for public construction projects. Other cities have set intermediate targets to phase out fossil fuels by transitioning to fossil-free and then moving to zero-emission construction sites. These targets are often expressed through percentages of zero-emission machinery in public projects. Alternatively, they are defined as targets for engine power categories, as the approach followed in the Netherlands.

Nordic cities have high ambitions and often strict requirements

Preliminary research indicates that the Nordic countries are home to the largest number of cities implementing ZEMCON requirements. In Norway, Oslo have already introduced requirements for the use of zero-emission construction machinery in public projects and plan to extend the requirement to private construction sites from 2030 (Oslo Municipality, 2024). Trondheim also has a clear roadmap, allowing fossil-free construction sites from 2025 and applying ZEMCON to city projects from 2030 (Trondheim Municipality, 2024).

Copenhagen stands out for its ambitious programme. From 2024, all municipal civil engineering projects will have to operate 100% without fossil fuels, supported by a bonus system for the use of zero-emission machinery. The city has allocated DKK 81.9 million for the period 2023–2026 to support this transition and is converting municipal machinery to run on alternative fuels by 2025 (Copenhagen Municipality, 2022).

In Finland, Helsinki, Turku, Espoo and Vantaa are showing a strong commitment by following the National Green Deal targets for the non-road mobile machinery sector (Ministry of the Environment, 2024).

Networks, agreements and roadmaps pave the way for ZEMCON across European cities

European and international city networks also play an important role in setting the level of ambition and aligning objectives. A clear example is the European Commission's Big Buyers Working Together (BBTW) initiative. In 2022, Barcelona, Bodø, Copenhagen, Helsinki, Oslo and Vantaa signed the Joint Declaration of Demand from the Working Group on Zero-Emission Construction Sites, under the BBTW project. The declaration sets a common minimum target of fossil-free construction sites by 2025, with interim targets of 20% zero-emission machinery in 2025 and 50% in 2030 (Big Buyers for Climate and Environment', 2022). Notably, Bodø and Oslo have surpassed the ambitions outlined in the Joint Declaration.

In the Netherlands, several municipalities have signed the Voluntary Agreement for Clean and Zero-Emission Construction Sites. These cities can pursue alternative ZEMCON roadmaps: the “basic tier,” which aims to phase out diesel machinery by 2035, and the “ambitious tier,”

which seeks to phase out diesel machinery by 2030. One of the frontrunners is the city of Amsterdam, which began procuring light machinery (<19 kW) in 2023, will extend the requirements to machinery up to 56 kW in 2025, and aims to ban the use of non-zero-emission machinery in public projects by 2030 (Gemeente Amsterdam, 2024).

In November 2025, at COP30 in Belém, the Climate and Clean Air Coalition, the International Council on Clean Transportation, and C40 Cities launched a global strategic partnership to transition to zero-emission non-road mobile machinery, with a strong initial focus on construction equipment, and aiming to raise awareness about zero-emission construction equipment and establish it as a key part of the global climate agenda. This partnership will bring together governments, international organizations, researchers, and civil society to offer expertise on promoting ZEMCON adoption worldwide (The ICCT, 2025).

Cities all over Europe launch zero-emission pilot projects

Pilot activities have been launched in other European cities. These include Paris (EODev, 2023) (France), Bönningheim (Kunz, 2024) and Schemmerhofen (Netzpraxis, 2023) (Germany), Vienna (Stadt Wien, 2025) (Austria), Zurich (Schweizerischer Baumeisterverband, 2025) (Switzerland), Stockholm (Stockholms Stadt, 2025) and Östersund (Östersund Kommun, 2025) (Sweden). In some instances, long-term plans accompany pilot projects. That's the case of Barcelona (Spain), which, having signed the Joint Declaration of Demand by the Working Group on Zero-Emission Construction Sites, aims to require the use of fossil-free machinery in public projects from 2025, with at least 20% of machinery being zero-emission, a percentage that will rise to 50% by 2030 (Big Buyers for Climate and Environment', 2022). Similarly, the Swiss canton of Basel-Stadt plans to electrify 80% of the fleets of its civil engineering and urban gardening departments by 2030 and implement ZEMCON public procurement rules by 2037 (Kanton Basel-Stadt, 2024).

To date, Budapest is the only city in Central and Eastern Europe identified with a plan for zero-emission construction sites. As a signatory to the C40 Declaration on Clean Construction, it has committed to consulting with suppliers to assess the availability of zero-emission solutions. Its roadmap included pilot projects for indoor construction sites starting in 2022 and for outdoor sites starting in 2025 (C40 Cities, 2021). However, no sources other than the C40 declaration have been found, raising doubts about its actual implementation.

	ZEMCON market maturity	Comment
Germany	 ● Low	Early pilots, no formal ZEMCON policy
Italy	 ● Low	Early pilots, no formal ZEMCON policy
France	 ● Low	No identified ZEMCON policies or pilots
Spain	 ● Low	Past piloting stage, national roadmap and local requirements
Netherlands	 Advanced	Early pilots, future requirements announced
Belgium	 ● Low	Early pilots, no formal ZEMCON policy
Sweden	 ● Moderate	Several pilot projects, municipal goals
Austria	 ● Low	200+ projects, national goals and municipal requirements
Norway	 Advanced	Early pilots, no formal ZEMCON policy
Finland	 ● Moderate	Several pilot projects, municipal goals
Denmark	 ● Moderate	Several pilot projects, municipal goals
Hungary	 ● Low	Declarations and roadmaps, limited implementation

Figure 15: Summarizing ZEMCON maturity in different European markets

Chapter summary and implications

This baseline analysis highlights a construction sector that is both economically significant and environmentally impactful, while also being structurally heterogeneous across Europe. Across the twelve analysed markets, construction activity is highly concentrated in a small number of large economies, with Germany, Italy and France alone accounting for a substantial share of total turnover, energy use and emissions. At the same time, some smaller markets—particularly in the Nordic countries and the Netherlands—are emerging as frontrunners in the deployment of zero-emission construction sites (ZEMCON), despite representing a smaller share of overall activity.

The environmental baseline shows that construction machinery remains overwhelmingly fossil fuel-based. Direct CO₂ emissions from construction activities across the analysed countries amount to more than 40 Mt annually, alongside substantial emissions of NO_x and PM_{2.5} that are released at ground level in urban areas. In cities that have already made progress in reducing emissions from road transport and buildings, construction machinery increasingly represents a visible and politically salient share of remaining local air pollution. This makes construction sites a strategically important intervention point for both climate and air quality policy.

At the same time, the baseline assessment reveals that technical readiness for ZEMCON is advancing rapidly. The supply of zero-emission machinery has expanded significantly in recent years, and frontrunner markets report few short-term constraints on access to equipment for pilot projects and early roll-out. The remaining barriers are therefore less about technology availability and more about market organisation, policy ambition, procurement practices and the ability of public clients to absorb or offset higher upfront costs.

Variation between countries and cities can largely be explained by a set of structural characteristics. These include overall market size and composition, the share of public procurement in construction activity, the strength of national climate targets, local air quality pressures, and the existence of coordinated policy frameworks and financial support schemes. Cities with high public procurement shares, strong local climate mandates and clear long-term roadmaps, such as Oslo, Copenhagen and Amsterdam, have been able to move

faster and create early lead markets for zero-emission solutions. In contrast, cities with fragmented governance, lower public leverage or less immediate air quality pressure remain of the pilot phase, if they have started piloting at all.

Establishing this baseline is critical for properly understanding the results of this report, as it defines both the scale of the challenge and the starting conditions for transition. It clarifies where emissions and energy use are concentrated, where early gains are most likely, and where structural constraints may slow adoption. Without a clear understanding of current market conditions, environmental impacts and readiness levels, it is not possible to credibly assess either the potential benefits or the costs of large-scale electrification of construction sites.

This baseline therefore provides the foundation for the impact assessment throughout the report. The next chapter translates national-level patterns into city-level contexts and examines how today's conditions shape the impacts of ZEMCON on costs, energy systems and environmental performance. The findings also frame the legal and governance context. Understanding these baseline conditions is therefore essential for assessing how current legal instruments and policy responsibilities at EU, national and local level can be applied to the transition towards zero-emission construction.

2

Impact assessment

This chapter assesses the potential impact of a large-scale transition to zero-emission construction (ZEMCON) across Europe. Building on the baseline established in Chapter 1, it examines how such a transition could affect construction costs, energy systems, and environmental performance, as well as the broader implications for European competitiveness. The analysis focuses on a set of representative city markets selected for their diversity in geography, market maturity, and industrial profile, providing a foundation for understanding regional differences and transition pathways.

The chapter begins with an overview of the selected focus cities, describing the characteristics of each city and the current status of their construction sectors, including activity levels, electrification maturity, and emission profiles. It then assesses the consequences of electrification across three key dimensions: cost implications, energy system impacts, and environmental implications. Finally, the chapter concludes with a discussion of the strategic implications of large-scale electrification, considering what this transition could mean for the European construction industry, its competitiveness, and its role in achieving broader decarbonisation goals.

2.1 Current situation and the construction sector's impact today

To assess the impact of a large-scale transition to zero-emission construction across Europe, a set of focus regions has been selected as a representation of different types of European cities. The purpose of identifying specific city markets is to capture the diversity of conditions that influence how electrification and zero-emission practices can be scaled in the construction sector. The criteria for selecting the focus cities are described in more detail in A.2 Methodology.

The selected cities represent different types of European markets with varying ZEMCON maturity, geographical location, market size, industrial profile, and climate ambitions. Together, they illustrate the range of opportunities and challenges that European cities face when transitioning to zero-emission construction.

All selected cities are part of the NetZeroCities programme, which gathers European cities committed to achieving climate neutrality by 2030. This ensures that the focus regions already have strong local climate agendas, while also providing access to networks and data that make comparison and knowledge exchange possible.

The analysis therefore includes both large and medium-sized cities, northern and southern regions, and markets with differing levels of technological maturity. Oslo is used as an analytical reference case, where empirical experience and indicative calculations provide a baseline for comparison across the selected cities. Oslo represents one of the most advanced markets for zero-emission construction in Europe, and the rationale for its selection as the reference city is further explained in the box below.



Case study | Zero-emission construction in Oslo

Oslo is used as the reference city in this study due to its advanced regulatory framework, high level of implementation experience, and a largely electrified energy system. Among European cities, Oslo represents one of the most mature markets for zero-emission construction, providing a realistic upper benchmark for what is currently technically, institutionally, and commercially achievable.

In 2016, Oslo adopted a target to reduce direct greenhouse gas emissions by 95% by 2030 compared to 2009, identifying construction activity as a priority sector for early action. This was formalised through a citywide objective for all construction sites to be zero-emission by 2030. In 2019, Oslo implemented what is considered the world’s first fully zero-emission construction site, demonstrating feasibility in dense urban environments. Since then, the city has scaled from pilot projects to approximately 180 zero-emission construction sites across a wide range of project types. From January 2025, all municipal construction projects are required to be zero-emission. (City of Oslo, 2025)

Over this period, data has been collected from zero-emission construction projects in Oslo, including documented implementation experience and mappings of available electric machinery and charging infrastructure (Bellona, SINTEF, MGF). This empirical material has been complemented by analytical and scenario-based assessments, including cost estimates and indicative calculations of power demand under full electrification (Oslo Economics, Hafslund Rådgivning). Together, these inputs form the basis for the impact assessment in this report and are used as a reference for other European cities.

Approx. number of ongoing construction projects per year in the city:

Hafslund Rådgivning has estimated the annual number of ongoing construction projects based on empirical input collected from contractors and industry actors, as part of power demand assessment related to climate actions.



Project size	Infrastructure	Building	
Large (50+ machines)	6	4	
Medium (15 machines)	80	20	
Small (5 machines)	130	60	
Total	216	84	300

As the impact of electrification is shaped by current market conditions, this section outlines key characteristics of the selected cities today, covering both general conditions and construction sector-specific factors relevant for zero-emission construction. As a baseline, the following pages present city profiles for each focus city, providing a structured overview of current conditions relevant for zero-emission construction. The profiles summarise key indicators, including population size, estimated construction activity, city-level CO₂ emissions, and air quality metrics (NO_x and PM_{2.5}), alongside brief qualitative descriptions of market characteristics, energy system conditions, and climate-related factors.

The indicators are intended to support comparison across diverse urban contexts and should be interpreted as indicative rather than exhaustive. Each of the indicators shown is further elaborated and discussed in the subsequent sections and sub-chapters of the impact assessment, where underlying assumptions, scaling approaches, and analytical implications are described in more detail.

Oslo



Reference city

👤 718 k 🏢 ~300 projects/year ☁️ CO₂ 0.9 Mt 🌫️ NO_x 19.7 µg/m³ 🌫️ PM_{2.5} 7.5 µg/m³

Medium-sized capital city with strong population growth and a high level of construction activity

Climate target Net-zero emissions by 2030. Reduce direct GHG emissions with 95% by 2030 compared to 2009.

ZEMCON maturity ● ● ●

Market characteristics Strong public sector involvement, active local suppliers, and established value chains for zero-emission construction. Experience with 180+ ZECS.

Energy system characteristics Main source of energy is electricity. Moderate grid capacity. >90% of power production is emission-free.

Climate characteristics Cold Nordic climate with strong seasonal variations.

Stockholm



👤 990 k 🏢 ~410 projects/year ☁️ CO₂ 1.2 Mt 🌫️ NO_x 18 µg/m³ 🌫️ PM_{2.5} 5.2 µg/m³

Large Nordic capital with high population density and strong urban development

Climate target Net-zero emissions by 2030. By 2030, the City must phase out fossil fuels from its procurement.

ZEMCON maturity ● ● ○

Market characteristics Well-developed construction sector with both national and international actors, growing focus on electrification, several ZEMCON pilot projects.

Energy system characteristics Main source of energy is electricity. Limited grid capacity. >90% of power production is emission-free.

Climate characteristics Cold Nordic climate with strong seasonal variations.

Eindhoven



👤 373 k 🏢 ~160 projects/year ☁️ CO₂ 0.9 Mt 🌫️ NO_x 19 µg/m³ 🌫️ PM_{2.5} 10.6 µg/m³

Medium-sized city in the Netherlands, known as a technology and innovation hub (Brainport region).

Climate target Net-zero emissions by 2030. 50% cleaner air in 2030 (compared to 2016). Follow the NL roadmap.

ZEMCON maturity ● ● ●

Market characteristics Strong high-tech and manufacturing industry. Growing focus on clean technology solutions. Experience with several ZEMCON projects.

Energy system characteristics Limited grid capacity. The city's power system is relatively small, relying on local connections, which requires careful energy planning for construction activities.

Climate characteristics Moderate maritime climate with mild winters and relatively stable temperatures.

Munich



1 489 k
 ~620 projects/year
 CO₂ 7.9 Mt
 NO_x 26.3 µg/m³
 PM_{2.5} 9.9 µg/m³

Large Nordic capital with high population density and strong urban development

Climate target	Net-zero emissions by 2030.
ZEMCON maturity	● ○ ○
Market characteristics	Strong industry focus, well-developed construction sector, modest focus on electrification in construction, a few ZEMCON pilot projects, host Bauma.
Energy system characteristics	Moderate grid capacity. ~60% of power production is emission-free.
Climate characteristics	Central European continental climate with cold winters and warm summers.

Barcelona



1 730 k
 ~870 projects/year
 CO₂ 3.4 Mt
 NO_x 24.7 µg/m³
 PM_{2.5} 15.1 µg/m³

Large Nordic capital with high population density and strong urban development.

Climate target	Net-zero emissions by 2030.
ZEMCON maturity	● ● ○
Market characteristics	Well-developed construction sector with both national and international actors, growing focus on electrification, a few ZEMCON pilot projects.
Energy system characteristics	Moderate grid capacity. Considering using “temporary connection points” that the city already owns. >70% of power production is emission-free.
Climate characteristics	Warm Mediterranean climate with mild winters and hot summers.

Budapest



1 774 k
 ~890 projects/year
 CO₂ 6.1 Mt
 NO_x 26.6 µg/m³
 PM_{2.5} 11.7 µg/m³

Large capital city in Central Europe, experiencing steady urban growth.

Climate target	Net-zero emissions by 2030.
ZEMCON maturity	● ○ ○
Market characteristics	Large construction market, limited experience with ZEMCON.
Energy system characteristics	Limited grid capacity. >70% of power production is emission-free.
Climate characteristics	Continental climate with hot summers and cold winters, requiring flexible energy management on site.

2.1.1 Focus cities characteristics overview

The selected cities display a wide range of characteristics in terms of city size, construction activity, ZEMCON maturity and environmental challenges. Together, these differences provide insight into where climate-related pressures are most pronounced, whether linked to greenhouse gas emissions, local air quality or both, and how these pressures interact with local ambition levels and policy frameworks.

ZEMCON activity is most advanced in the Nordic cities and in Eindhoven. As described in Part 1, Oslo and Eindhoven stand out as frontrunner markets with experience from a substantial number of zero-emission construction projects and established policy frameworks supporting electrification. Other cities in the sample are characterised by more limited pilot activity and, in some cases, less clearly defined ambitions or regulatory drivers related to zero-emission construction.

The cities also differ significantly in terms of environmental indicators such as CO₂ emissions, NO_x and PM_{2.5} concentrations. While these indicators reflect emissions from multiple sectors beyond construction, they provide an indication of where climate and air quality challenges are most acute. Among the focus cities, cities such as Munich and Budapest stand out with relatively high total CO₂ emissions and elevated NO_x concentrations and are also among the cities with the highest CO₂ emissions per capita. By contrast, Eindhoven shows the highest combined levels of CO₂ emissions and NO_x and PM_{2.5} concentrations on a per capita basis, while Oslo also exhibits relatively high air quality indicators. In cities with higher emission levels or poorer air quality, zero-emission construction may therefore play a more visible role as part of a broader portfolio of mitigation measures.

Construction activity also varies across the focus cities. Estimated annual construction activity is derived using Oslo as a reference case, with approximately 300 projects per year, and scaled to each city based on population size and adjusted for differences in overall construction intensity. Due to limited availability of comparable data across cities, and despite interviews with city representatives, estimates have been applied for annual project composition, this is further elaborated in A.2 Methodology.

Figure 16 provides an overview of key characteristics across the focus cities. The individual parameters and their relevance for the subsequent impact assessment are described in more detail in the following sections.

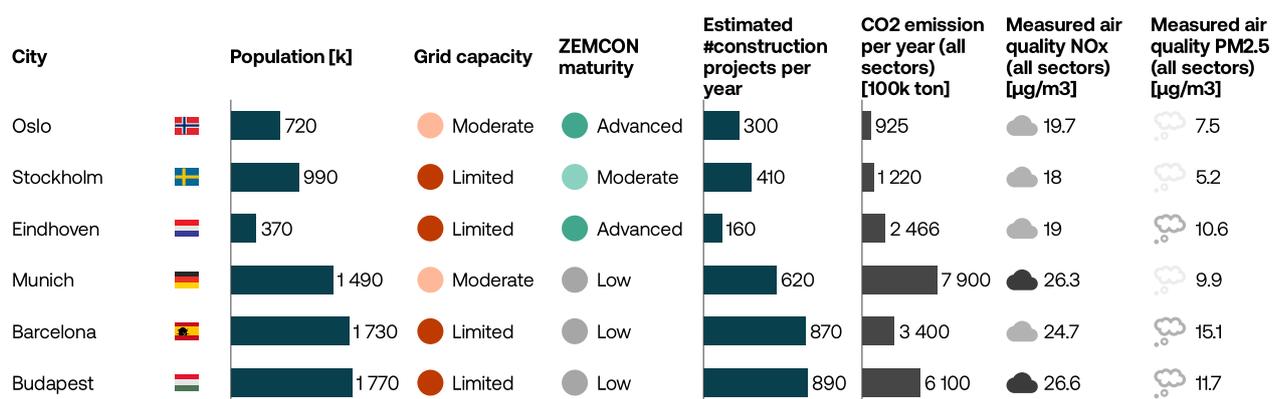


Figure 16: Market characteristics for selected European cities. The overview includes city population, evaluations of grid capacity (chapter 2.1.3 Energy system context and implications for electrification impacts) and ZEMCON maturity (chapter 2.1.4 Status for zero-emission construction), estimated number of ongoing construction projects per year (A.2 Methodology), annual CO₂ emissions (*Net Zero Cities, 2025*) (Norwegian Environment Agency, 2024) (*Ajuntament de Barcelona, 2020*), measured air quality (EEA, 2022)

2.1.2 Environmental impacts from current construction industry

The construction industry today poses significant environmental impacts when it comes to air pollution, noise and GHG emissions. The following paragraphs will elaborate on the environmental impacts from today’s sector in the focus cities.

Air quality

Air quality is a key factor influencing public health and environmental well-being in urban areas. Exposure to elevated levels of nitrogen dioxide (NO₂) and fine particulate matter (PM_{2.5}) has clearly documented adverse effects on human health. The EU has therefore defined limit values for concentration of these air pollutants in directive EU2024/2881 (European Commission, 2025), and the current limit values have been suggested tightened by 2030 (Health Effects Institute, 2023). The WHO health guidelines offer an even stricter limit recommendation to ensure a healthy population. The following table summarizes the limit values and guidelines:

Table 1: European limit values for NO₂ and PM_{2.5} for today and 2030 and WHO guidelines

Pollutant	Limit type	Current limit	New limit 2030 (EU 2024/2881)	WHO guideline
Fine particles (PM _{2.5})	Annual	20 µg/m ³	10 µg/m ³	5 µg/m ³
Nitrogen dioxide (NO ₂)	Annual	40 µg/m ³	20 µg/m ³	10 µg/m ³

As shown in the Table 1, the annual EU limit value for NO₂ is 40 µg/m³ and for PM_{2.5} is 25 µg/m³ under current Directive 2008/50/EC. All cities studied have air quality levels within the current limitations. However, the EU is now moving to tighten these significantly to 20 µg/m³ for NO₂ and 10 µg/m³ for PM_{2.5} by 2030. The EUs goal for 2050 is to reach the WHO guidelines, where the concentrations are again halved compared to the 2030 goals. While air quality in Europe has improved notably in recent decades for most pollutants, many areas across the EU still experience pollutant levels that exceed current EU limits and exceed the stricter guidelines set by the WHO. The health risks associated with concentrations above these thresholds include increased incidence of respiratory and cardiovascular diseases, higher risk of stroke, and reduced life expectancy (EEA, 2025).

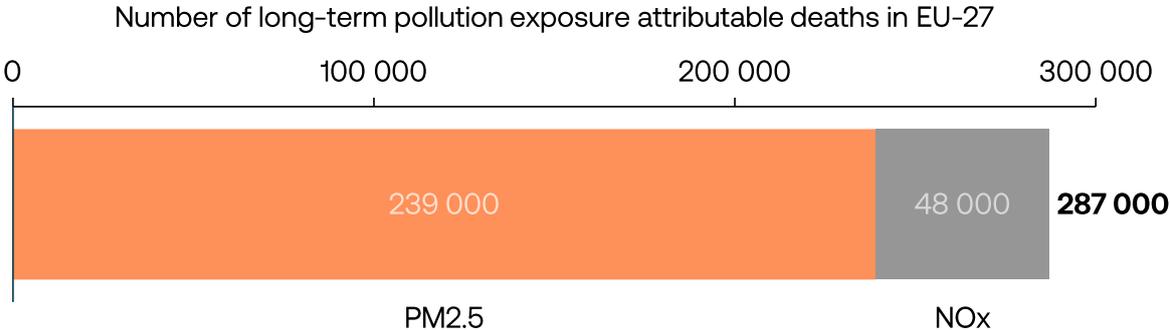


Figure 17: Number of deaths attributable to long-term pollution exposure for PM_{2.5} and NO_x

In 2022 the number of attributable deaths in EU-27 due to long-term exposure to key air pollutants were 239 000 deaths from PM_{2.5} and 48 000 deaths from NO₂ exposure.

(European Environment Agency, 2024), illustrated in Figure . This is linked to pollution both in countries with poor air quality, but also in countries with air quality levels well within the current and coming EU limits. For example, the number of estimated deaths due to air pollution in Sweden in 2019 was 6 700. Additionally, the associated costs of health effects of air pollution were estimated to 168 billion SEK (15 BEUR) per year (Gustafsson, Lindén, Forsberg, Åström, & Johansson, 2022). The results from this study are illustrated in the example below. The cost and number of deaths is especially high considering that the air quality in Sweden is good compared to many other countries and indicates a high health related cost in other countries.

Example | The health and cost impacts of low air quality

Although almost the entire Swedish population is exposed to air pollution levels better than the current EU environmental standards, a 2022 study ((Gustafsson, Lindén, Forsberg, Åström, & Johansson, 2022) estimates that approximately **6,740 premature deaths per year** in Sweden are attributable to poor air quality.

The health impacts linked to exposure to NO₂ and PM_{2.5} are conservatively estimated to result in **socio-economic costs of around SEK 168 billion** in 2019, equivalent to around **EUR 15.5 billion**. Absence from work and education alone is estimated to account for approximately 0.02% of Sweden's GDP.

The study further estimates that 82% of the Swedish population is exposed to PM_{2.5} and 11% to NO₂ concentrations that exceed WHO guideline values, which are thresholds that all cities included in our impact assessment also exceed. This widespread exposure helps explain the significant health burden and associated economic costs.

Costs [bn SEK]

168 bn SEK

Air pollution associated health costs

Air pollution levels in several focus cities exceed the coming EU limits and WHO guidelines
 Among the cities included in this study, there is significant variation in measured concentrations of both NO_x and PM_{2.5} over a year, as shown in Figure 18 and Figure 19 below (EEA, 2022). The numbers reflect both geographic conditions and differences in local policy, transport systems, and degree of electrification.

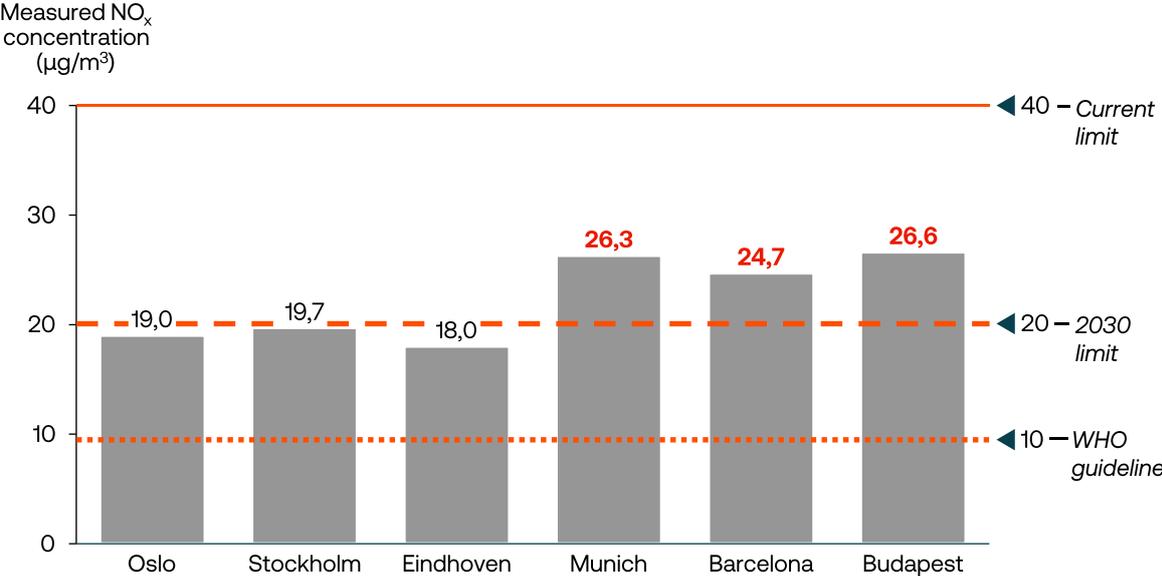


Figure 18: Measured average annual NO_x levels in the focus cities (average of all measure points in each city) (EEA, 2022). Current and future EU limit values and WHO guidelines are indicated on the right.

For NO_x, Budapest and Munich show the highest levels, at 26.6 and 26.3 µg/m³ respectively, which is still within current EU limits, but well above the updated 2030 targets and WHO guidelines. The cities exceeding the coming limits are marked in red on the figure. Barcelona also shows elevated concentrations, with 24.7 µg/m³ NO_x, indicating a need for further mitigation measures. In contrast, Oslo, Eindhoven, and Stockholm report lower concentrations. They are all below the coming EU limit of 20 µg/m³ NO_x. However, all focus cities show air quality levels that are poorer than the recommended WHO guideline of 10 µg/m³, which is the EU goal for 2050.

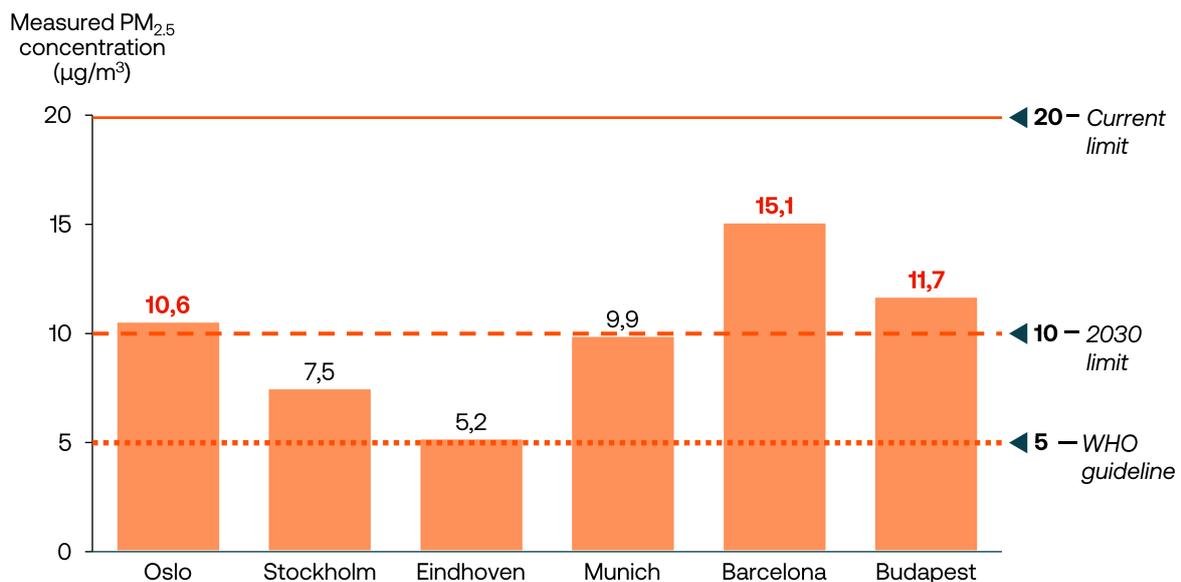


Figure 19: Measured average annual PM_{2.5} levels in the focus cities (average of all measure points in each city) (EEA, 2022). Current and future EU limit values and WHO guidelines are indicated on the right.

For PM_{2.5}, Barcelona, Budapest and Oslo have levels of PM_{2.5} above the coming EU limit. Munich, Eindhoven, and Stockholm have PM_{2.5} levels below, yet near, the current EU threshold of 10 µg/m³. However, all cities are above the recommended WHO guideline of 5 µg/m³.

These are average values throughout the year, and there are several days also in these cities that are above the recommended levels, especially for PM_{2.5}. A known example is that air pollution is high in Oslo on cold windless days, due to still air and wood burning. In colder climates, air pollutants also tend to persist longer in the atmosphere, particularly during winter months when temperature inversions and limited air circulation can trap emissions close to the ground. This can lead to higher local concentrations of pollutants such as NO_x and PM_{2.5}, even when overall emission levels are moderate. Cities like Oslo and Stockholm are especially affected by these conditions and have strong variation in air pollution levels throughout the year due to colder winter temperatures over long periods of time.

Many cities have taken active steps to reduce air pollution. For example, Barcelona implemented a ringroad- low emission zone and reinforced sustainable mobility measures; according to the city council, air pollution in Barcelona has declined by more than 30 % since 2015 (Localised, 2023).

There are regulations that limit emissions from non-road mobile machinery (NRMM), however a recent study from TNO (TNO, 2025) in the Netherlands have investigated actual NO_x and PM emissions from fossil NRMM and found that the emissions are higher under lower loads such as while idling, and that the emissions are only measured under high load situations to comply with regulations. Most of the machines on average emitted less than the limits, but some also exceeded these when considering the low load use. The machines are run at lower intensity levels than the catalysts are designed for in up to 30% of the time, and the emission during this time accounts for up to over 90 % of the total emissions.

Parts of the population are affected by local air pollution above general air quality levels

From an occupational perspective NO_x and PM emissions are a severe problem for the workers surrounded by heavy machinery using fossil fuels throughout the workday. Exposure to diesel motor exhaust has been associated with increased risk of lung cancer and heart disease, and for tunnel construction workers a paper from 2011 showed that the level can be more than 300 µg/m³ (Lewné, Plato, Bellander, Alderling, & Gustavsson, 2011), where the EU air quality standards (European Commission, 2025) for 1 hour exposure is 200 µg/m³.

Employees at construction sites are, in fact, systematically within close reach of diesel exhaust fumes, which the [International Agency for Research on Cancer classifies as a Group 1 human carcinogen](#), meaning there is sufficient evidence linking exposure to an increased risk of lung cancer (International Agency for Research on Cancer, 2012). This risk is confirmed by sector-specific [empirical evidence](#), which shows that after five years in the construction industry, workers face a high risk of developing lung cancer, comparable to individuals with a personal or family history of cancer (Dement, Ringen, Hines, Cranford, & Quinn, 2020).

Additionally, people living or working close to construction sites may be exposed to substantially higher concentrations of air pollutants than the general urban population, as emissions from mobile sources tend to decrease sharply with distance from the source. For pollutants such as NO_x, elemental carbon, and PM_{2.5}, the spatial extent of elevated concentrations typically ranges from 100 to 500 metres, depending on pollutant type, background levels, meteorological conditions, and the surrounding physical environment (Zhou & Levy, 2007). For particulate matter (PM) mass and elemental carbon, the spatial extent is typically around 100–400 m; for nitrogen oxides (NO_x/NO₂), it is often in the range 200–500 m. This means that a construction site can create a localised exposure “hotspot,” affecting nearby residents, office workers, and passersby, particularly in dense urban areas. This effect is illustrated in Figure 20 below.

Because urban air quality is usually reported as a citywide average, these localised exposure peaks are often underrepresented in official data. This can lead to an underestimation of the actual health risks faced by people in direct proximity to construction activity.

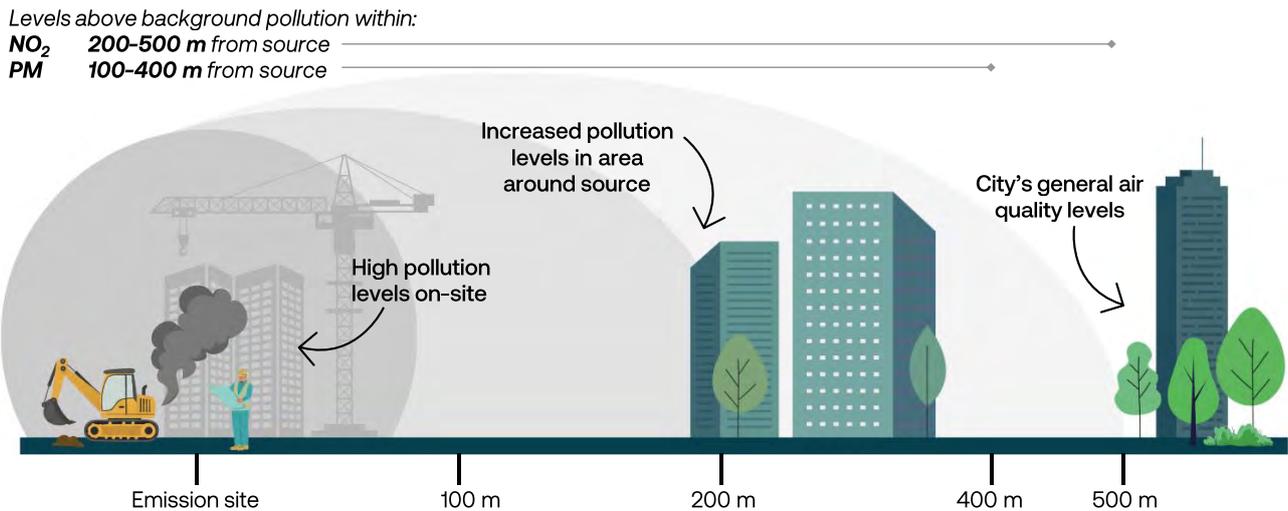


Figure 20: Illustration of concentration of pollutant levels around the source of pollution.

Noise

Noise from construction sites can be both bothersome and, in some cases, harmful to people living and working in adjacent areas. This issue is especially pronounced on long-running sites and in densely populated urban contexts. According to the Directive 2002/49/EC (Environmental Noise Directive, END), “environmental noise” is defined as unwanted or harmful outdoor sound created by human activities (European Commission, 2002). Prolonged exposure to environmental noise is a recognized public health concern in the EU, linked to serious illnesses such as cardiovascular disease, sleep disturbance, and cognitive impairment. In the EU, more than 12 000 premature deaths are caused by long-term exposure to environmental noise, and more than 22 million people suffer from chronic high annoyance (European Commission, 2024). A special report on urban pollution in the EU, from the European Court of Auditors concludes that the cities are still too noisy (European Court of Auditors, 2025). The report also underlines that there are no common specific European targets for noise reduction and that these levels are decided nationally.

Construction sites represent an important and continuous source of environmental noise

In the EU, environmental noise levels above 55 dB Lden (day-evening-night level) are generally considered bothersome and exposure to noise levels exceeding this over time is linked to adverse health effects (European Environment Agency, 2025). Today, most construction machinery largely exceed these noise levels when in use during the day (Illingworth & Rodkin Inc., 2022) and, although only in use during daytime, will contribute to a significant increase in the average day-evening-night noise levels as well.

Noise from construction sites is sometimes not addressed to the same extent as other noise sources, such as road traffic or railways, because individual sites are temporary in nature. However, in urban areas with continuous redevelopment and infrastructure upgrades, construction activity is nearly constant, and many projects go on for years. While each site may only operate for a limited period, the cumulative effect is that parts of the population are regularly exposed to bothersome levels of construction noise.

Noise pollution from construction sites affects many people every year

To assess the effect of noise from construction sites in each focus region, we estimated the probable number of people exposed to harmful or bothersome noise levels. Our approach applies typical decibel levels for construction machinery and equipment, adjusts for sound attenuation over distance and calculates average noise levels over 24 hours. The methodology is further described in *A.2 Methodology: Environmental implications*.

Based on these assumptions, we define a 100-metre radius around each construction site as the area where noise levels likely reach or exceed 55 dB on average over 24 hours, and a 50-metre radius where levels likely reach or exceed 60 dB on average over 24 hours. These thresholds were used to estimate the total impacted area and, by extension, the number of people likely affected in each city. For the purposes of this study, we consider average noise levels at or above 55 dB over 24 hours to be bothersome, and levels at or above 60 dB to be potentially harmful when experienced over time. These categories are simplifications, as the health impact of noise increases gradually with each additional decibel. The assumed affected areas are illustrated in Figure 21 below.

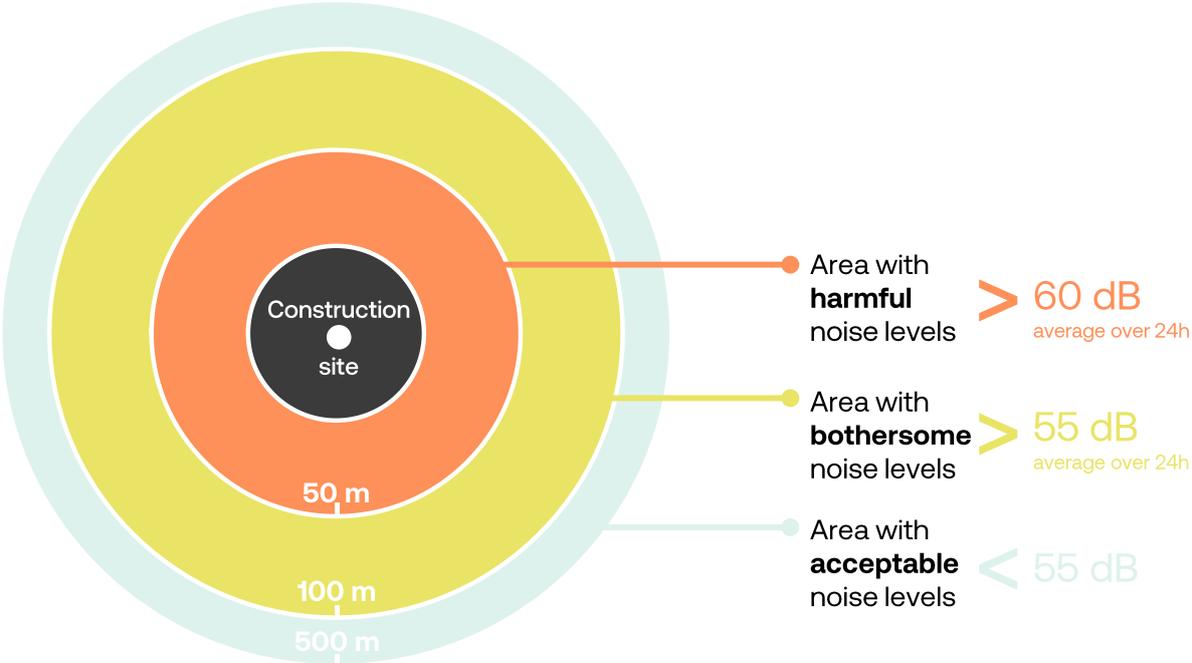


Figure 21: Illustration of estimated affected areas by noise levels over longer time periods. The area and decibel estimations are described in *A.2 Methodology*.

The extent of the impacted area will vary depending on the characteristics of each construction site, including the equipment used, the duration of operations, and the surrounding urban environment. Surrounding buildings, vegetation, and local topography can also significantly reduce the propagation of sound, leading to substantial variation in noise exposure. The radiuses are therefore approximations intended to indicate the probable scale of noise effects. Based on our assumptions of noise levels and distances, the following number of people is estimated to experience harmful levels of noise from construction sites:

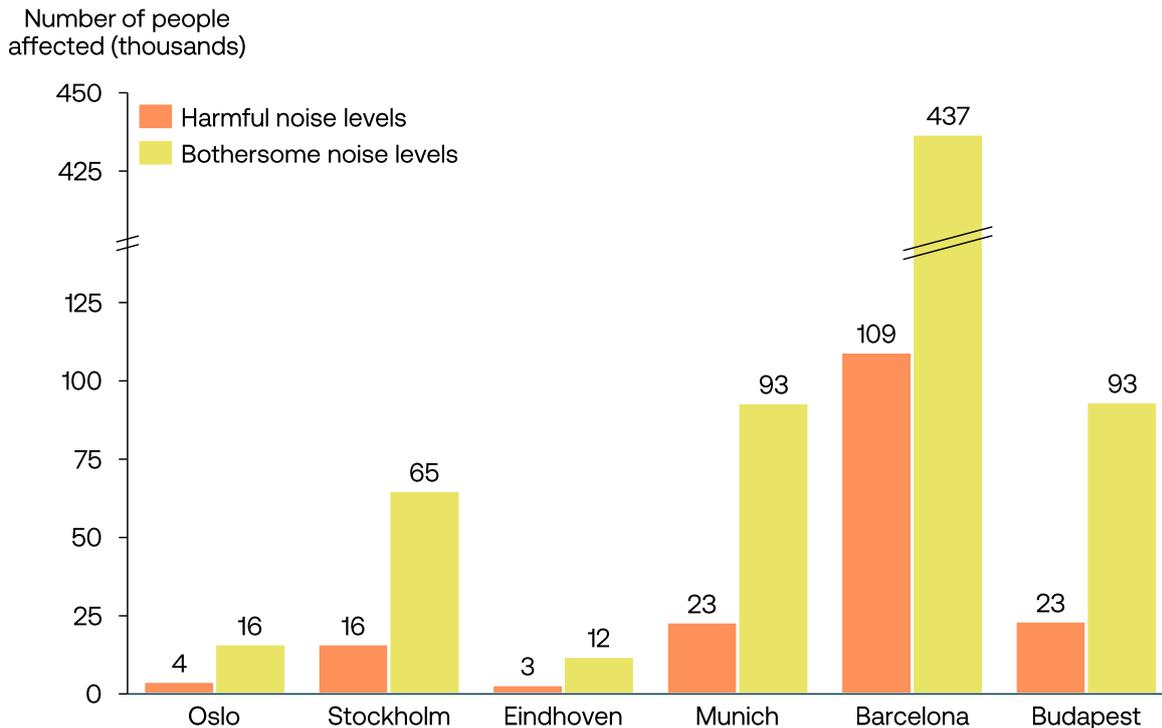


Figure 22: Estimated number of people experiencing bothersome and harmful noise levels in each focus city.

As shown in Figure 22, the estimated number of people affected by construction noise is highest in Barcelona, Munich, and Stockholm. In Barcelona, over 90 000 people are estimated to be exposed to harmful noise levels, while more than 360 000 are potentially experiencing bothersome levels. Munich and Stockholm also show substantial numbers, each with tens of thousands of residents likely affected. In contrast, cities such as Eindhoven and Oslo show significantly lower numbers.

These differences come from two key factors: the number of active construction projects and the population density in each city. Compact cities, like Barcelona, will have more people living within proximity to construction activity. This increases the likelihood that residents are exposed to elevated noise levels. While Eindhoven and Oslo also have a considerable number of projects, their more dispersed urban form results in fewer people being exposed per site.

CO₂ emissions

Construction activity currently emits substantial amounts of greenhouse gases in terms of CO₂ in all focus cities. Many European cities today have high levels of emissions at the city level that must be reduced to meet climate targets and achieve a better urban environment. Among the focus cities, Munich, Budapest and Barcelona have the highest CO₂ emissions with 3-8.3¹ millions of tons per year per city (Net Zero Cities , 2025). In total the focus cities amount to more than 21¹ million tonnes of CO₂ per year.

Construction sites have emissions that cannot be reduced simply by lowering activity levels. Cities depend on continuous construction activity to deliver buildings, infrastructure and maintenance. Emission reductions must therefore come from changes in how construction work is carried out rather than from reduced volumes. Construction machinery is also

¹ Emissions originate from the Climate City Contracts, reference year 2018 for Eindhoven and Munich, 2019 for Barcelona, 2020 for Oslo and Stockholm, 2022 for Budapest

particularly well suited for electrification, as zero-emission alternatives to conventional diesel-powered construction machinery are already commercially available.

Direct CO₂ emissions from construction machinery are estimated to account for almost 450 thousand tonnes across the six cities based on the assumptions on the number and composition of projects. These emissions accounts for a relatively small share of total city-wide CO₂ emissions, around 2%, but has a major impact on the direct emissions in the city which negatively affect residents and construction workers. The estimates can be shown in Figure 23, and are derived bottom-up by mapping current construction activity, assigning representative diesel-powered machinery, and calculating associated fuel consumption and emissions (see A.2 Methodology for more details). For Oslo, the results have been validated against official statistics from the Norwegian Environment Agency, providing confidence in the methodology. This highlights the considerable potential for emission reductions through a shift to zero-emission machinery.

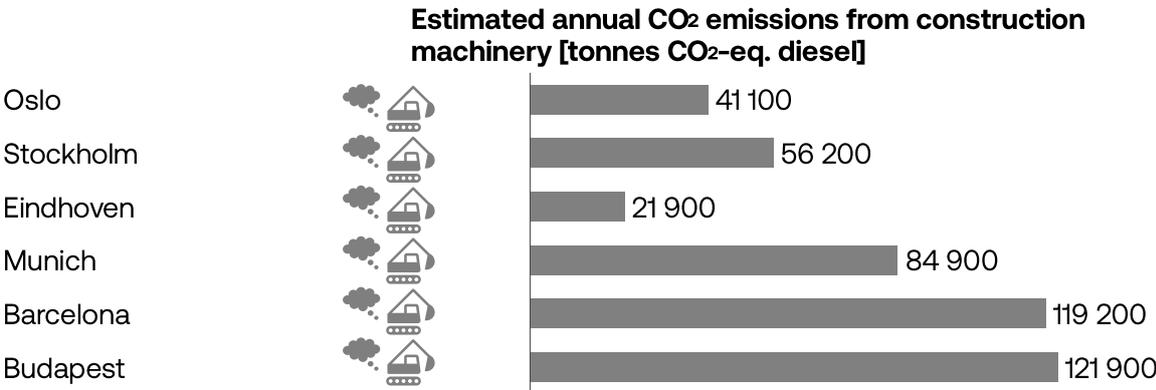


Figure 23: Estimated yearly direct CO₂ emission from construction machinery per city based on energy consumption of diesel and CO₂ equivalents for diesel as 2,66 kg CO₂/litre

2.1.3 Energy system context and implications for electrification impacts

Differences in energy system characteristics and local grid conditions across the focus cities create different conditions for the electrification of construction activities and for the resulting reductions in greenhouse gas emissions. Both the composition of power generation and the availability of grid capacity influence how quickly electrification can be implemented and how large the climate impact will be in each city.

Differences in energy mix across markets lead to varying emission reduction impacts today and greater impacts over time as power systems decarbonise

The current situation illustrates substantial variation between markets, with the Nordic countries standing out due to their high share of renewable and emission-free power generation. At the same time, the increasing focus on renewable energy sources across Europe is expected to reduce these differences over time. As more countries expand their share of renewable power generation, an increasing number of markets will develop energy system conditions that are favourable for achieving significant emission reductions through electrification of construction and civil engineering activities.

Figure 24 shows the status for composition of the energy system in the focus cities (based on two datasets compiled by Our World in Data, (Our World in Data, 2025), and (Ember; Energy Institute - Statistical Review of World Energy, 2025). The Nordic countries are almost completely without fossil fuels in power generation, and the share of electricity used

compared to the total energy consumption is close to 50 %, at the other end of this scale we find the Netherlands with 54 % emission free power generation and an electrification share of 15 %. In the years to come all countries will move towards the right when decarbonizing power generation and move upwards as the use of electricity expands to other sectors.

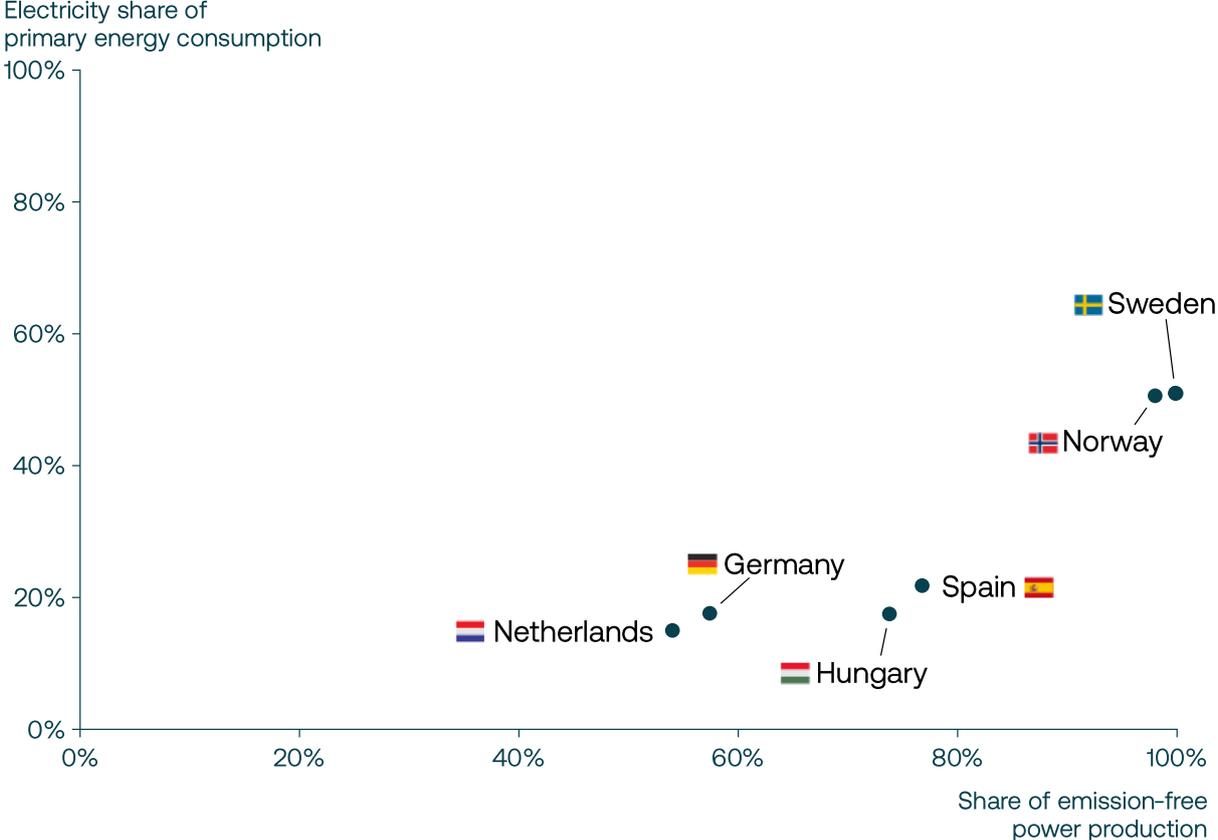


Figure 24: Electricity share of primary energy consumption together with share of emission-free electricity production per country (Our World in Data, 2025) (Ember; Energy Institute - Statistical Review of World Energy, 2025).

The European power system has been developed throughout the 20th century, and every nation originally built their infrastructure based on their local preconditions and available resources. Later the power grid has expanded, and today we face a more interconnected continent. The focus on lowering greenhouse gas emissions has just been present during the last couple of decades and has accelerated after the Paris accord in 2015.

To reach the ambitions of the European Climate Law of net zero emissions by 2050, two developments will take place. One being that the power system today will be decarbonized, and the other is that the use of electricity needs to expand to abate emissions from other sectors. The consequence of this is that when considering the reductions of greenhouse gas emissions today from a full transition to electric ZEMCON is that the reductions will be even greater in the future when the power generation has been decarbonized.

Grid constraints may shape early implementation but are unlikely to be a long-term barrier
 Several cities in this study, especially Eindhoven, Barcelona, Stockholm and Budapest, face challenges in securing new high-power grid connections. In the Netherlands, and particularly in the Brainport region around Eindhoven, grid capacity is a major challenge. More than 80,000

companies are currently waiting for a connection, and it can take up to two years to connect to the grid.

These constraints can affect project implementation and infrastructure costs in the short term, particularly for larger or fully electrified construction sites. However, grid limitations should be understood in the context of a broader electrification trend across multiple sectors. Construction is not electrifying in isolation, and grid reinforcements and system developments are already planned and underway in many European countries to accommodate increased electricity demand from transport, industry and buildings.

Moreover, electrification of construction is expected to occur gradually rather than through an immediate shift to fully electrified sites. Early projects typically involve partial electrification and relatively modest power demands, reducing the need for high-capacity grid connections. Where grid access is limited, temporary solutions such as mobile batteries and mobile charging units can support operations without halting project activity. Cities with more readily available grid capacity, such as Oslo, benefit from lower connection costs and simpler integration of charging infrastructure, but over time differences in grid-related constraints are expected to narrow as power systems develop.

2.1.4 Status for zero-emission construction

Some of the focus cities are more advanced today and past the piloting phase. This is particularly true for Dutch cities such as Eindhoven, and cities in the Nordics, such as Oslo.

Other cities have increased focus on ZEMCON the past few years. This is the case of Stockholm, which is conducting its first projects and has committed to making the [majority of its construction-site operations emission-free by 2030](#). Another city where this is happening is Barcelona, where three pilots have been undertaken, and the municipality is preparing the groundwork to introduce regulatory measures mandating the partial use of zero-emission machinery starting in 2030.

However, most European cities are in a very early phase with lack of specific goals and just a few piloting projects, or none. Nonetheless, momentum in Europe is growing, and with the increased focus on electrification, pollution reduction, competitiveness and resilience, the outlook is favourable.



Case study | Barcelona – third pilot project

Barcelona provides an example of a large Southern European city progressively mainstreaming zero-emission construction practices. In the framework of its broader sustainability, air-quality and climate objectives, the city has already completed three pilot projects assessing the feasibility, performance and impacts of electric construction machinery in urban worksites.

The third pilot, carried out during the re-urbanisation of the Jardins de les Tres Xemeneies in the Sants-Montjuïc district, represents a mature and comprehensive test case. The project involved a range of construction activities, including demolition, earthworks, material handling, concrete placement and urban furniture installation. A significant share of these operations was performed using electric machinery, such as the dumper, a forklift, and electrically powered hand tools supplied via external battery packs, with only limited use of diesel equipment for tasks where no market-ready electric alternative was available.

The results of the pilot confirm that electric machinery can be deployed in real urban construction conditions with a high level of operational reliability. Energy consumption remained modest, overall operating costs were low, and the machinery met performance expectations for this type of project. Importantly, site operators reported a smooth adaptation process and highlighted improvements in working conditions, particularly due to the absence of exhaust fumes and the elimination of heat emissions from machines, which is particularly relevant in southern European regions that reach extremely high temperatures during the summer months.

From an environmental perspective, the pilot demonstrated clear benefits. Noise monitoring showed no measurable increase in ambient noise levels attributable to construction activities, confirming advantage of reduced disturbance in urban areas. CO₂ emissions associated with machinery use were significantly reduced compared to conventional diesel equipment, and thermal measurements confirmed improved comfort for workers operating near the machines.

Beyond technical performance, the pilot also provided valuable institutional learning. The main challenges identified were not related to machinery capability, but to administrative and procedural aspects, particularly the time required to secure temporary electricity connections. These findings have helped the municipality identify concrete areas where coordination between public authorities, utilities and contractors can be improved to facilitate wider deployment. The municipality is currently exploring next steps in the transition.

2.2 Impact assessment for electrifying construction sector

Europe is already cutting emissions and increasing its energy independency through electrification of several sectors. The EU Climate Law entered into force in 2021, making the 2050 climate neutrality commitment binding for all member states. To be able to reach these ambitions, the use of low-carbon electricity in as many sectors as possible is a precondition. To meet the needs, challenges and opportunities that come from electrification of the construction sector, we need an overview of the implications the transition will have, both locally and for Europe as a whole. Only then can we ensure a just transition with minimal challenges, extended benefits and positive ripple effects.

The impact assessment is performed to shed light on some of the possibilities and challenges to expect during the transition to zero emission construction. The transition will not take place overnight, but in the evaluation of the consequences we have considered future developments in both the power system and with regards to the technology and equipment maturity.

Overall, the electrification of the sector both provides benefits and temporary challenges. In a transition period, construction costs may increase, and the demand for electrical power will in some regions be significantly higher. At the same time, emissions, local air pollution and noise pollution will decrease and provide benefits for the environment, climate, health and life quality.

Additionally, we can expect broader economic and strategic impacts in a European level. In the following parts, each of the implications are evaluated and discussed.

2.2.1 Environmental implications

Urban environmental issues are shaped by emissions from multiple sectors, like transport, energy use, and construction. Road traffic is a major contributor to both greenhouse gas (CO₂) emissions and local air pollution, particularly nitrogen oxides (NO_x), particulate matter (PM) and noise in cities. These environmental challenges can be addressed through a combination of electrification, traffic reduction, improved public transport, and urban planning measures.

Construction activity, however, is less flexible. It cannot be reduced through behavioural or modal shifts in the same way as road transport. Construction is a necessary and ongoing function in all urban areas, linked to housing, infrastructure upgrades, and climate adaptation measures. As such, the sector's environmental impacts must be addressed through a technological transition rather than a reduction in activity. Moving to zero-emission solutions is therefore the only way to reduce CO₂-emissions, air pollutants, and noise from construction sites. This transition is essential not only for achieving climate targets but also for improving air quality and reducing the health burden of environmental noise in cities.

Air quality

Transitioning to zero-emission construction machinery has the potential to significantly improve urban air quality by removing a key local source of nitrogen oxides (NO_x) and particulate matter (PM). While construction activity is temporary, its emissions impact both workers and people living or working near active sites. Replacing diesel-powered equipment with electric alternatives eliminates tailpipe emissions and reduces exposure to harmful pollutants in the immediate surroundings. This section outlines the expected air quality benefits of a full transition to zero-emission machinery in urban construction.

Zero-emission machinery can significantly reduce emissions of air pollutants in the cities

The transition to zero-emission construction machinery will lead to significant reductions in NO_x, PM_{2.5} and other pollutants in the construction sector. While alternative climate neutral fuels such as biodiesel also reduce CO₂ emissions, they do not eliminate emissions of NO_x and fine particulates.

To assess the potential in the transition, we have estimated how much air pollution reduction could be achieved if the construction sector were fully electrified, based on the number of projects in each city and the emission intensity of different machinery stages. The methodology is described further in Environmental implications. The table below summarizes the total annual emission reductions for both NO_x and PM_{2.5} from electrification of the sector. For the cities where we have the total air pollutant emissions, the reduction in percent is specified in parentheses.

Table 2: Estimated reductions in NO_x and PM_{2.5} emissions in each of the focus cities. Decrease compared to today's level in parentheses where applicable.

City	NO_x reduction (tonnes)	PM_{2.5} reduction (tonnes)
Oslo	97	6,1
Stockholm	396 (18%)	4,4 (5%)
Eindhoven	153 (11%)	15,9
Munich	929	43,3
Barcelona	1482 (13%)	67,4
Budapest	1516	68,9

The estimated reduction in air pollutants from full electrification of the construction sector varies between the cities, reflecting the differences in construction activity and machine fleet age. Overall, the analysis demonstrates that zero-emission construction machinery can contribute to substantial reductions in local pollutants, which again will lead to improved air quality. As previously described, idling and other low-intensity uses of machinery significantly contributes to emissions, and this problem will be eliminated after a transition to electrical machinery. Given higher pollution levels during the winter months in colder climates, electrifying construction machinery not only reduces overall emissions but also helps mitigate the seasonal build-up of pollution that can pose increased health risks for residents and workers during cold weather.

While greenhouse gas emissions such as CO₂ have a global impact, local air pollutants like nitrogen oxides and particulate matter vary widely in concentration from one location to another and have direct, short-term effects on human health and local air quality. The local differences are therefore important to consider when it comes to air quality, and cutting local pollutants delivers immediate benefits to the health and well-being of people living and working near the source. The effect on some of the selected focus cities are elaborated below.

Budapest and Barcelona show the largest absolute reductions, with potential decreases of approximately 1 520 tonnes of NO_x and 69 tonnes of PM_{2.5} in Budapest, and 1 480 tonnes of NO_x and 67 tonnes of PM_{2.5} in Barcelona. Barcelona currently has annual NO_x emissions of approximately 11 100 tonnes today (Ajuntament de Barcelona, 2020). Full electrification of construction machinery is estimated to reduce this by around 13%, representing a substantial contribution toward lowering overall pollution levels. This reduction could play a role in helping the city meet the stricter air quality limits set to take effect in 2030, which are currently not being met. Given the city’s high population density and large number of active construction sites, reducing emissions from this sector offers not only climate benefits but also direct improvements to public health in some of the most exposed urban areas. Although total particulate matter emissions for Barcelona have not been available for this project, and we therefore cannot quantify the reduction as a percentage, a comparable effect on PM emissions can be expected from the electrification of construction machinery.

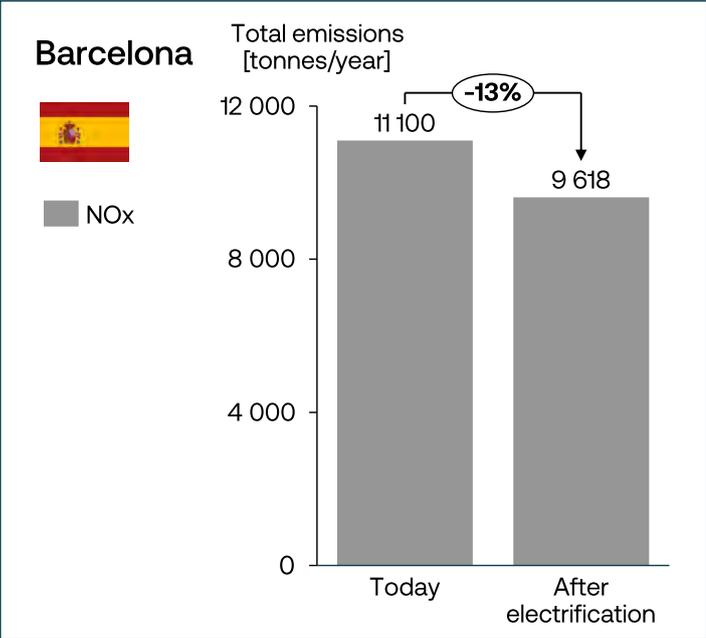


Figure 25: Estimated reduction in total NO_x emissions in Barcelona from electrification of all construction machinery.

Eindhoven has estimated annual NO_x emissions of around 1 400 tonnes (National Institute for Public Health and the Environment - Netherlands, 2025). Electrifying construction machinery in the city could reduce this by approximately 153 tonnes, or 11% of total emissions. While the absolute reduction is smaller than in larger cities, the relative impact is still significant, especially in an urban environment where local exposure can be high. This reduction would support Eindhoven’s broader efforts to improve air quality. Moreover, because background pollution levels in smaller cities often are lower, avoided emissions can have a greater marginal effect on local air quality. Reducing NO_x and particulate emissions from construction therefore contributes not only to meeting EU air quality targets, but also to improving health outcomes in specific neighbourhoods.

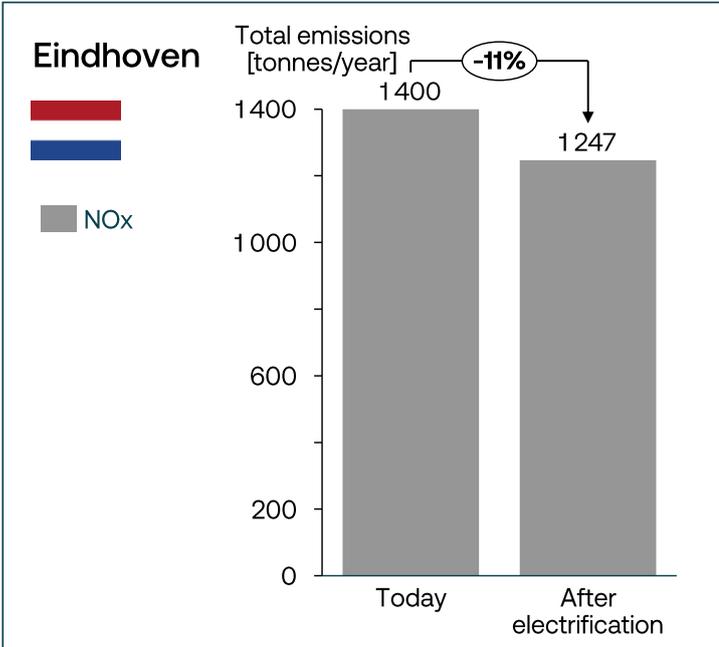


Figure 26: Estimated reduction in total NO_x emissions in Eindhoven from electrification of all construction machinery.

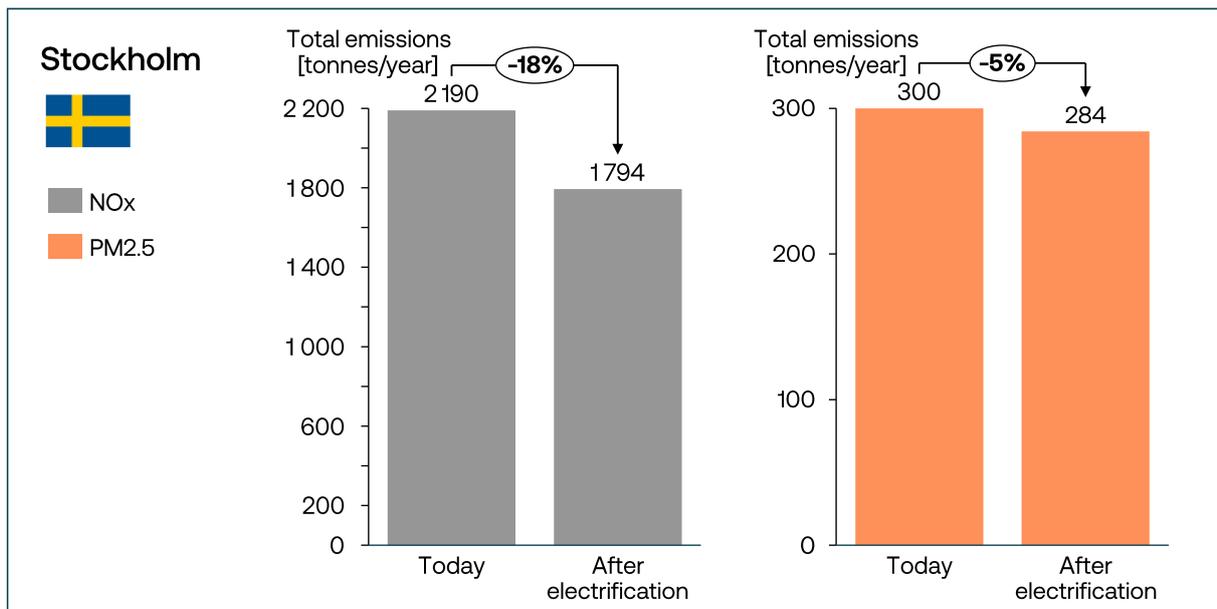


Figure 27: Estimated reduction in total NO_x emissions (left) and PM_{2.5} emissions (right) in Stockholm from electrification of all construction machinery.

The city of Stockholm has provided information (interview, 2025) that the annual emissions in 2024 were 2190 tonnes NO_x, and 300 tonnes PM. In Stockholm, electrifying construction machinery is estimated to reduce NO_x emissions by approximately 396 tonnes per year, representing 18% of the city's total NO_x emissions. For PM_{2.5}, the reduction is around 4.4 tonnes, or 5% of total emissions. These figures indicate that construction activity is a significant source of air pollution in the city, particularly for NO_x. Given Stockholm's ambitions for clean urban environments and its relatively low background levels of air pollution, reducing construction-related emissions can have a measurable effect on both air quality and public health, especially in areas with dense development and ongoing infrastructure projects.

The potential benefits of electrification are even more relevant in colder climates like Stockholm's, where winter weather conditions can cause pollutants to linger longer in the air. This means that emissions from construction sites may have greater health impacts during the winter, especially for people living or working nearby. Reducing emissions at the source through zero-emission machinery is therefore a highly effective way to improve urban air quality year-round, but particularly during the winter.

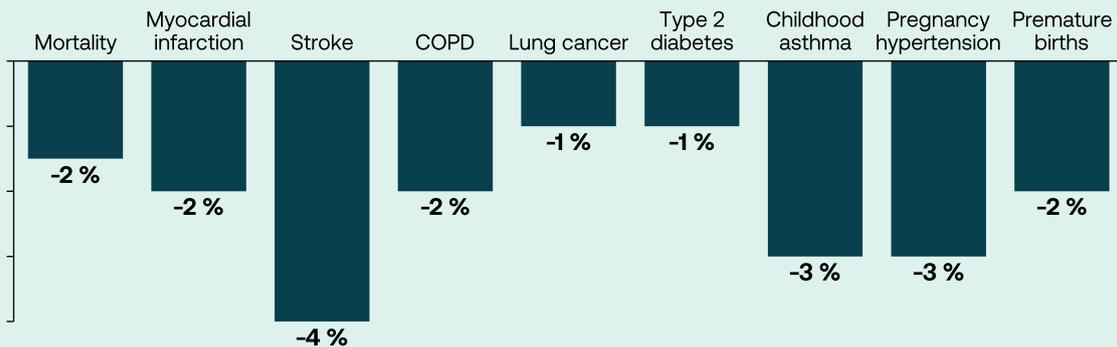
These findings show that construction activity is a significant and often underestimated contributor to urban air pollution. While the scale of impact varies across cities, the potential for improvement through electrification is clear. Reducing NO_x and PM emissions at the source, particularly in densely populated areas, will not only help cities meet stricter EU air quality standards, but also deliver direct health and environmental benefits to those most exposed. This will again lead to fewer pollution related deaths and lower public health costs. The example box below illustrates findings from a study about the Swedish population (Oudin, Flanagan, & Forsberg, 2024), assessing the public health benefits linked to improved air quality. The study illustrates how even small improvements in air quality can lead to measurable public health benefits across the population. The findings highlight the strong connection between reduced exposure to NO₂ and PM_{2.5} and lower rates of disease and premature death. If the associated costs of health effects of air pollution were avoided in their entirety, Sweden could for example redirect the estimated cost of 168 billion SEK (15 BEUR) per year (Gustafsson, Lindén, Forsberg, Åström, & Johansson, 2022) to other critical parts of the national budget.



Example | The impact of improved air quality

A 2024 study (Oudin, Flanagan, & Forsberg) assessed the potential health benefits of improving air quality in Sweden, using a representative population sample and exposure-response functions. The analysis examined the effects of a modest reduction in air pollution of only $1 \mu\text{g}/\text{m}^3$ $\text{PM}_{2.5}$ and NO_2 . The results showed that even such a small improvement in air quality could lead to substantial public health gains. The projected benefits of a modest reduction in $\text{PM}_{2.5}$ emissions is illustrated below:

Reduced occurrence of health challenges given a $1 \mu\text{g}/\text{m}^3$ reduction in $\text{PM}_{2.5}$



Noise

Zero-emission construction machinery will have a positive effect on noise pollution

A transition to zero-emission construction machinery would reduce the numbers for people affected by both harmful and bothersome noise levels. Electrification lowers the overall noise from machinery, especially by eliminating continuous engine noise. This will in turn reduce the size of the impacted area around each site and lower the number of people exposed. Several reports about the learnings from pilot projects, such as the ones in Gran (Statens Vegvesen, 2025) and Olav Vs gate, Oslo in Norway (Agency for Urban Environment in Oslo, 2020), report lower noise levels. This in turn is reported to lead to a more comfortable work environment on the sites and less bothersome noise for nearby offices and shops.

While a shift to zero-emission construction machinery will significantly reduce noise related to engine operation, it will not eliminate all construction-related noise. Activities such as drilling and ground works will still produce intermittent high-decibel noise. However, electric machinery operates almost entirely silently when not in active contact, leading to reduced noise and fewer prolonged exposure events. Given that continuous noise exposure is considered more harmful to health than sporadic high-noise events, this transition represents a significant improvement.

Electrification of construction machinery will significantly improve the working environment for the construction workers by reducing constant engine noise on site. For workers, this will provide better overall working conditions, lower stress levels, and reduced risk of long-term hearing damage. This was reported in the pilot projects both in Gran and Oslo referenced above.

Overall, people living and working near construction sites will experience a tangible improvement in quality of life as the sector transitions to zero-emission machinery. Lowered noise and reduced air pollution both benefit those near construction activity. With less engine

noise and fewer local emissions, residents and workers will be exposed to fewer health risks and less daily disturbance. This is especially important in dense urban areas, where construction is often carried out close to homes, schools, and offices, and where background levels of noise and pollution may already be high.

Since reducing construction activity is not a realistic option in growing and evolving cities, electrification stands out as the only viable way to achieve meaningful reductions in emissions and noise, without compromising development, maintenance or urban growth.

CO₂ emissions

Electrifying construction activity provides a substantial reduction in greenhouse gas emissions. Reaching net-zero emissions in European cities requires deep decarbonisation across multiple sectors, and construction is no exception. Since the emission from construction sites cannot be reduced by simply reducing activity, the necessary cuts must come from how construction work is carried out and from replacing fossil fuels with low-carbon electricity.

Electrification effectively eliminates almost all direct CO₂ emissions from construction machinery (Scope 1). However, the net climate impact also depends on indirect emissions associated with electricity generation and the energy mix of the country (Scope 2). As a result, the emission reductions presented in this section account for electricity-related emissions based on national power generation mixes and therefore differ from the total current diesel-based emissions from construction machinery.

The climate impact of electrification depends primarily on two factors: the carbon intensity of electricity generation (Ember, 2025) and the overall scale of construction activity in each city. As shown in chapter 2.1.3 Energy system context and implications for electrification impacts, Norway and Sweden have among the lowest electricity-related emissions in Europe, with power systems dominated by hydropower, wind and nuclear generation. Their emission intensities are below 40 g CO₂e per kWh. At the other end of the scale, countries such as Germany and the Netherlands still rely on coal, gas and oil in power generation, resulting in emission intensities above 250 g CO₂e per kWh. Consequently, the net emission reductions achieved through electrification are greatest in cities with highly decarbonised electricity systems.

Net emission reductions reflect the difference between emissions from conventional diesel-based construction and the emissions associated with producing the electricity needed to operate electric machinery. As the European power system becomes more decarbonised, these reductions will grow and gradually approach zero once electricity generation itself becomes fully low-carbon.

Across the focus cities, we estimate that, based on today's power generation mixes, the transition to zero-emission construction would reduce indirect emissions (Scope 2) by more than 330 thousand tonnes of CO₂ per year, equivalent to approximately 165 thousand passenger cars. At the same time, the transition is estimated to eliminate approximately 445 thousand tonnes of direct emissions (Scope 1) from diesel-powered construction machinery. These avoided direct emissions represent the full on-site mitigation potential of electrification and illustrate the level of emission reductions that could be realised as electricity systems across Europe become increasingly decarbonised. The estimates are based on energy consumption calculations as described in A.2 Methodology.

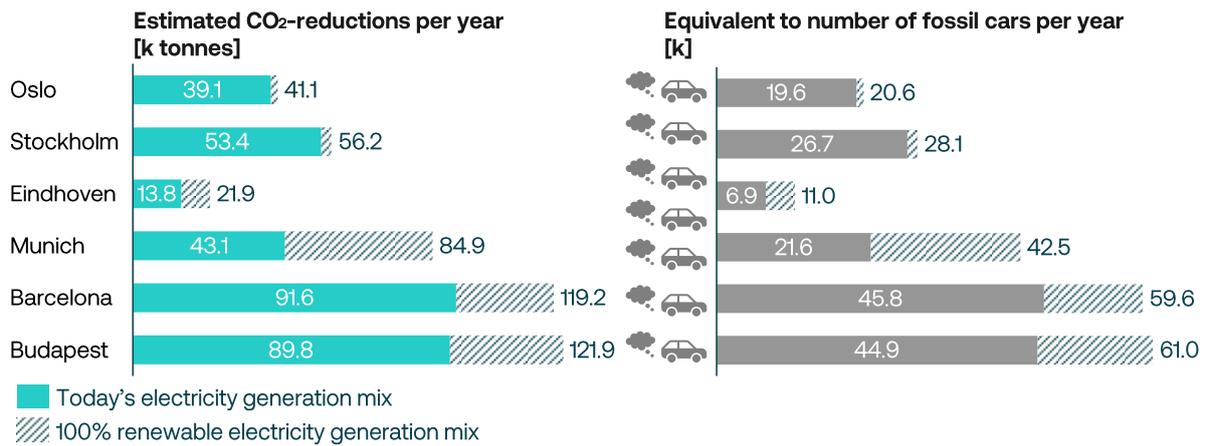


Figure 28: Estimated annual indirect CO₂ emission reduction from construction machinery per city and estimated equivalent from passenger cars in the EU based on 12 000 km/year and 170g/km

The relative impact varies across cities. Cities with low-carbon electricity benefit most on a per-project basis, while cities with higher total emissions experience a smaller relative effect despite large absolute reductions. For example, Oslo has annual emissions of around 1.3 tonnes of CO₂e per capita, compared with more than 5 tonnes per capita in Munich. A full transition to zero-emission construction therefore produces a larger relative reduction in Oslo, even though Munich also achieves substantial absolute cuts.

At the European level, construction activity today accounts for approximately 27 million tonnes of CO₂ per year, equivalent to nearly 14 million passenger cars (VTT Technical Research Centre of Finland, 2024) and (Transport & Environment, 2024). As electricity production continues to decarbonise, the emissions associated with zero-emission construction will fall further. In the long term, near-zero emissions from the construction sector are therefore achievable as part of a broader transition toward a fully decarbonised energy system.

2.2.2 Energy system impact

The electrification of construction activities increases demand for electricity from the grid, and this can be challenging in urban areas where grid capacity is already constrained. However, the construction sector is only one of several sectors that will place greater pressure on the electricity system in the years ahead. Europe is entering a broad energy transition, and the demand for electricity is expected to grow rapidly across multiple segments of society. According to the most recent Ten-Year Network Development Plan from (ENTSO, 2025), electricity consumption in EU27 in the “Distributed Energy” scenario is projected to increase by 42 percent by 2040 compared with 2019 (see Figure 29). This growth is driven primarily by the electrification of transport, which alone is expected to increase electricity use by a factor of 15 to 17, as well as by the expansion of heat pumps in buildings, increased electricity use in industry and more limited growth in agriculture and other sectors.

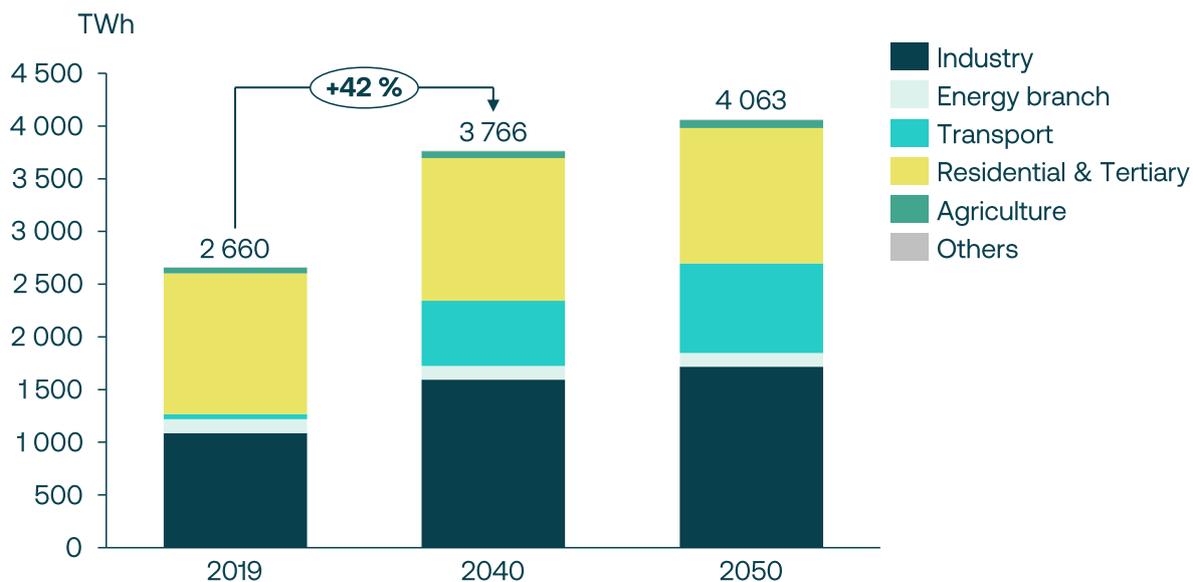


Figure 29: Expected scenario-based electricity demand from different sectors in 2040 in Europe, for Distributed Energy scenario (ENTSO, 2025). This scenario is characterized with a decentralised energy transition driven by high energy efficiency, strong direct electrification, and widespread local renewable generation, with consumers and prosumers playing a central role.

Norway anticipates a similar development in demand for electricity as in Europe. The Norwegian Water Resources and Energy Directorate estimates a 28 percent increase in national electricity consumption by 2040 (Norwegian Water Resource and Energy Directorate (NVE), 2025). For Stockholm we use the projections by Energimyndigheten and their scenario “Local environmental concerns (Lokala miljöhensyn)” of 29 percent (Swedish Energy Agency, 2025). Oslo and Stockholm have already come relatively far in the electrification of transport, buildings and industry. Figure 29 shows current peak load together with the assumed increase in peak load towards 2040 based on this trajectory. For the remaining cities, we apply the Distributed Energy scenario with an increase of 42 percent, reflecting the expected rise in electricity demand in EU27 as electrification accelerates. Since electricity consumption refers to total annual energy use, it is reasonable to expect that peak power demand will increase even more sharply than the energy demand. The figures used here should therefore be regarded as conservative estimates of expected peak capacity needs in 2040.

Oslo Municipality has assessed the expected peak-load impact from electrifying the construction sector as it operates today (Hafslund Rådgivning, 2025). The sector is developing rapidly, and significant technological improvements are anticipated in the coming years. Machinery that currently relies on high-power fast charging during the workday is expected to shift towards overnight charging at lower capacity as battery performance improves. This will reduce daytime peak demand and move the remaining peak towards the end of the working day. The industry also reports a clear trend toward battery-electric machinery rather than cable-powered equipment, although some machine categories, such as compressors and drilling rigs for energy wells, will continue to require high power and are best suited for cable operation.

Based on this technological outlook, we estimate that the future peak load associated with electrifying Oslo’s construction sites is around 60 MW (see Figure 30 below). This estimate is based on the already assessed peak-load impact from electrifying the construction sector, reduced by 10% to exclude demand from site huts and 20% to reflect the change from fast

charging to overnight charging (more details in A.2 Methodology). This number corresponds to roughly 2 percent of the city’s current peak power demand and represents only around 9 percent of the expected total increase in peak demand towards 2040. The construction sector is therefore not a dominant driver of future grid needs in Oslo. The estimated peak power demand from electrifying construction machinery for the other focus cities are derived from adjusting the Oslo estimate with the estimated number of ongoing projects per year (A.2 Methodology).

Among the focus cities, Oslo and Stockholm have the highest electric share of total energy usage, as shown in Chapter 2.1.3 Energy system context and implications for electrification impacts. These differences are reflected in the relative peak-load contributions from construction. For example, Budapest may see a 12 percent increase in peak load from construction activities, yet an additional 29 percent increase is expected from other sectors. Although this growth will challenge grid capacity in several cities, the construction sector on its own is not the primary source of pressure. The broader electrification of transport, heating and industry is the main driver, and it will require substantial reinforcement of the European electricity system as well as expanded use of mobile energy solutions.

Peak-load/power demand needs on construction sites can in many cases be managed with on-site battery systems. This is already common in Oslo and especially in Eindhoven, where grid constraints are significant, this is a setup that is commonly used in ZEMCON-projects. When assuming overnight charging, with a lower instant power demand, a 500 kWh battery system per project can reduce peak load by approximately 14 percent in Oslo, with larger units enabling even greater reductions. Effective solutions already exist to manage power demand on construction sites (e.g. batteries, hydrogen fuel cells, solar panels), and in the wider context of expected growth in electricity use across all sectors, the electrification of construction is unlikely to pose a major standalone challenge for urban energy systems in Europe.

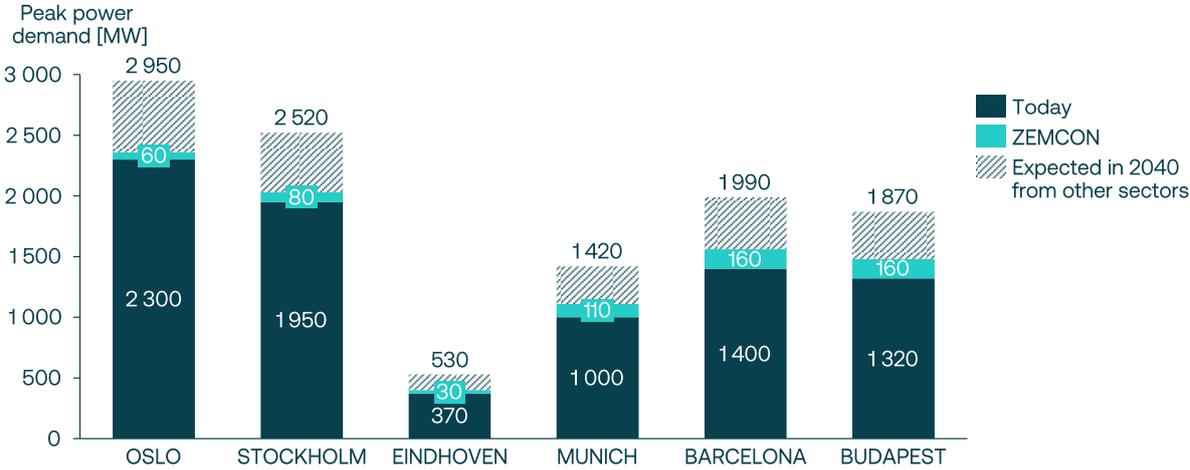


Figure 30: Peak power demand for electricity today (Blokhuis, Brouwers, van der Putten, & Schaefer, 2011) (Norwegian Water Resources and Energy Directorate, 2025) (Stadtwerke München, 2024) (Endesa, 2025) (ENTSO-e, 2025), estimated demand from 100% ZEMCON and expected demand from other sectors in 2040 for each focus city (ENTSO, 2025) (Norwegian Water Resource and Energy Directorate (NVE), 2025) (Swedish Energy Agency, 2025)

While electrification increases electricity consumption in the construction sector, its contribution to overall energy demand remains relatively modest compared with other sectors. As shown in Figure 31, the expected rise in annual electricity use from construction is around 1 percent in Oslo and approximately 3 percent in Budapest. These increases are small relative to the broader electrification trends in transportation, heating and industry, which together account for the dominant share of future electricity demand growth.

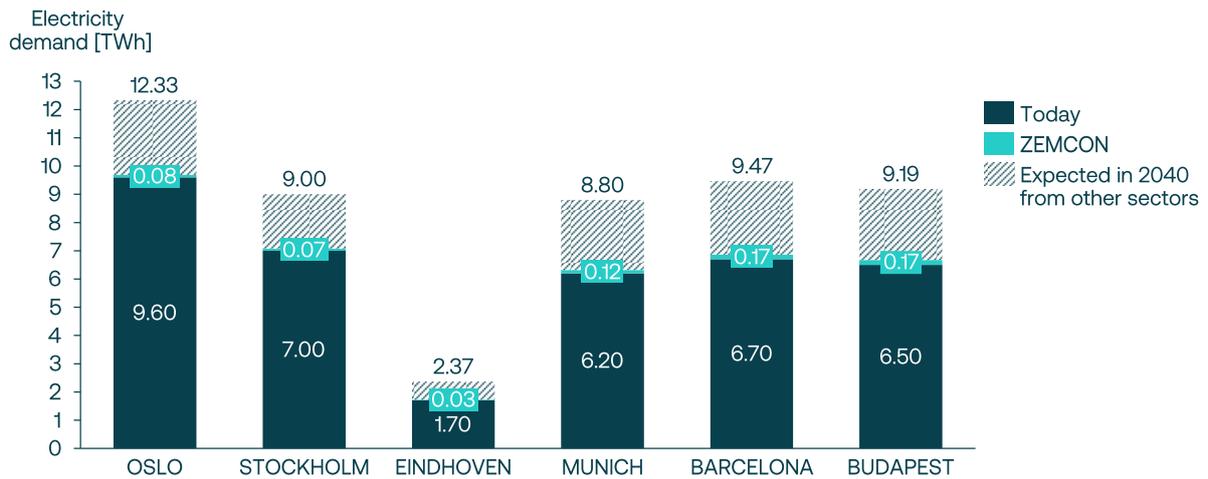


Figure 31: Energy demand for electricity today, estimated demand from 100% ZEMCON and expected demand from other sectors in 2040 for each focus city (ENTSO, 2025) (Norwegian Water Resource and Energy Directorate (NVE), 2025) (Swedish Energy Agency, 2025)

The relationship between peak load and average hourly electricity use illustrates why construction has a limited impact on total energy consumption but a more noticeable effect on peak power demand. In Oslo, electricity demand from construction sites is highly uneven. Peak power demand is around 6.6 times higher than the average hourly demand, meaning that most of the electricity use is concentrated in short periods during the working day. This reflects how construction sites operate: power-intensive activities occur intermittently, while demand is very low outside active working hours. By comparison, the overall Oslo electricity system has a peak-to-average ratio of about 2.1, typical for an urban load profile dominated by households, commercial buildings and electric heating, where electricity demand is more evenly distributed over time.

Taken together, these findings show that while the construction sector can influence local peak load conditions, its role in the wider energy system remains limited. The overall impact on electricity demand and grid development will be determined far more by the broader electrification of transportation, heating and industry than by construction alone. In this wider context, the contribution from zero-emission construction represents only a small share of the total transformation facing the European energy system.

2.2.3 Cost assessment

Zero-emission construction offers several environmental benefits, but current evidence shows that fully electrified projects still involve a moderate cost premium compared to conventional fossil-based operations. Importantly, empirical evidence indicates that this premium is smaller than often perceived and is expected to decline rapidly as technology matures and markets develop.

Early-market experience from Oslo, one of Europe's most advanced zero-emission construction markets, indicates an average cost increase of around 5% of the total contract value, though the premium varies considerably with access to grid capacity, machinery composition, project mobility, duration, and site-specific conditions (Oslo Economics, Hafslund Rådgivning, 2025). These factors determine how demanding it is to operate an all-electric machinery fleet and to establish suitable charging infrastructure. Since the first pilot projects in 2019, Oslo has implemented more than 180 zero-emission construction projects by 2025, providing a strong empirical basis for assessing cost development over time. (City of Oslo, 2025)



Case study | Cost calculations for Oslo

To assess the cost implications of electrifying construction activity, early-phase projects in Oslo are used as a reference. A bottom-up methodology is applied, covering two project types, building construction and infrastructure, across three project sizes (5, 15, and 50 machines). The analysis is based on real conventional projects that are hypothetically converted to fully electric operations by replacing the machinery fleet and adding the necessary electrical infrastructure. Cost data were collected from Norwegian industry actors in autumn 2024 as part of a study conducted for the Norwegian Environment Agency (Oslo Economics and Hafslund Rådgivning, 2025).

Additional costs are calculated as a share of total project value and used as input to represent pilot-phase conditions. While early pilot projects in Oslo incurred higher costs, rapid technological development suggests that cities entering the pilot phase today are likely to face lower costs; the estimates are therefore treated as representative pilot costs.



The cost assessment in this study is based on lessons learned from fully electrified construction projects in Oslo and Norway, often piloting newly developed machinery and energy supply solutions still in a very early stage of commercialisation. Adopting zero-emission construction to other countries and cities will most likely be a gradual, with increasing shares of electric machinery rather than immediate full conversion. The estimates presented here should therefore be understood as a conservative upper bound for near-term projects. With

partial electrification and the use of available support schemes, actual project costs are likely to be lower.

Although current cost levels reflect a market in its early phase, both technological development and market learning are progressing rapidly. Recent projects demonstrate that several electric machine models can now operate for a full working day without intermediate charging, representing a marked improvement compared to earlier generations that managed only a few hours. Improvements in battery capacity, machine reliability and charging solutions, combined with increasing contractor experience and more mature supply chains, have already reduced operational constraints and are expected to drive significant cost reductions over the coming years.

As markets gain experience and technologies become more standardised, zero-emission construction is expected to move from an early pilot phase into a development phase, characterised by more predictable performance, lower risk premiums and declining cost differentials compared to diesel-based solutions. Cost trajectories will nevertheless differ across European markets due to variation in technological maturity, grid connection conditions and access to temporary power.

Figure 32 illustrates the estimated development of additional costs for 100% zero-emission construction over time, expressed as a share of total project cost (contract value for the main contractor), using Oslo as a reference market. The estimates are based on conservative assumptions and exclude support schemes as well as potential additional benefits from extended equipment lifetime. Table 3 summarises the characteristics of the different market phases and the assumptions applied to illustrate cost development scenarios. Further elaboration on the assumptions and calculation methodologies used are summarized in A.2 Methodology.

The first stage represents the pilot phase and draws on cost experience from projects delivered in Oslo to date (Oslo Economics, Hafslund Rådgivning, 2025). In this phase, high investment prices for electric machinery, typically two to three times the cost of conventional equipment, combined with extensive charging needs and operational challenges result in a noticeable cost premium. As the market develops, machinery prices are expected to decline, fewer required infrastructure components, and the absence of additional construction time are expected to reduce this premium significantly.

For leading markets such as Oslo, rapid technology and market development indicates that zero-emission construction can reach a development phase already by around 2030, where electric projects are competitive compared to conventional fossil-operation. The pace and scale of cost reductions will vary across markets, reflecting differences in technological maturity, grid conditions and local market characteristics.

Table 3: Characteristics of different market maturity phases and cost development scenarios used in the case study for cost calculations in Oslo

	Market characteristics	Cost characteristics
 Pilot	Early-stage market, low predictability, limited equipment availability. Prototype machinery, immature charging, need for fast charging and mobile batteries. Frequent operational challenges and inefficiencies.	Machines 2–3x cost, high infrastructure costs, risk premiums and cost of operational challenges (OC)
 Development	Emerging market, growing demand. More stable machinery, larger batteries enabling overnight charging. OC largely removed.	Machine price equal to diesel machine 20 % increased diesel price (carbon pricing) 35% lower infrastructure cost 100% lower OC costs
 Mature	More mature market, broader uptake, stronger supply chains. Serial machinery and charging equipment production, high operational efficiency.	Machine price 20% lower than diesel machine 40 % increased diesel price (carbon pricing) 50% lower infrastructure cost 100% lower OC costs

Estimated additional cost for 100% ZEMCON relative to project cost

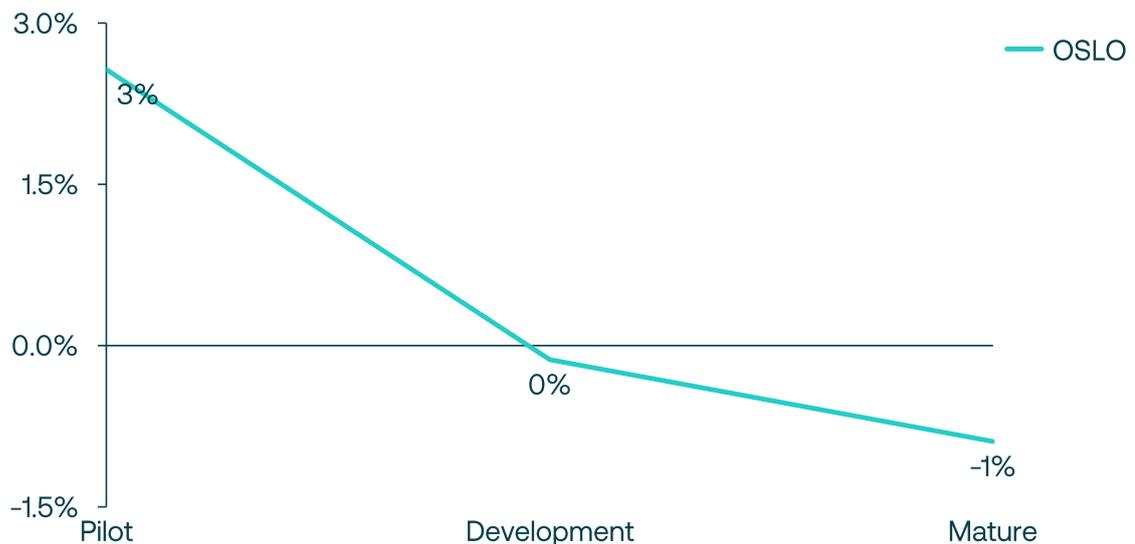


Figure 32: Estimated additional cost relative to project cost for different market maturity phases, as described in the table above, using Oslo as a reference market

New and less mature markets are likely to experience reduced and shorter-lived pilot phase cost premiums because of accumulated learning and rapid technological development

In an early market phase dominated by pilot projects, the transition to zero-emission construction is typically characterised by limited competence, ongoing experimentation, and immature or unproven technologies. The shift from conventional to fully electric construction operations represent a substantial operational change, requiring early planning, new forms of project coordination, and closer interaction between contractors, clients, and energy system actors.

Some markets, such as Oslo and Eindhoven, have already progressed several years into this transition, allowing important lessons to be drawn from first movers. While these experiences

are transferable to other cities, each local market will nonetheless undergo its own initial phase, during which additional costs are likely to arise for fully zero-emission construction projects.

However, these early cost premiums are not inherent or persistent. Gradual implementation strategies, targeted support schemes, and systematic knowledge sharing can significantly reduce both the magnitude and duration of the pilot phase. As zero-emission construction is adopted across a growing number of markets, accumulated learning effects, technological maturation, and cross-border transfer of experience are expected to shorten this phase and lower associated costs for new and less mature markets.

To provide a balanced assessment of cost impacts, it is important to recognise that electrification introduces both additional costs and structural cost advantages compared to diesel-based construction. While early-phase projects may face higher upfront investment and transitional challenges, electric machinery benefits from lower energy costs, reduced maintenance needs and fewer operational losses related to fuel logistics. As a result, several cost components already favour electric solutions, even in relatively immature markets.

Using Oslo as a reference case, the cost assessment therefore distinguishes between temporary cost premiums linked to market immaturity and more persistent cost drivers shaped by technology and energy system characteristics. For analytical clarity, the additional cost of fully electrified construction projects is divided into four main categories, representing the main sources of cost variation when transitioning to zero-emission construction:

- **Machine cost:** differences in investment and maintenance costs between electric and diesel-powered machinery, assessed over the equipment lifetime and allocated to the relevant project period.
- **Energy cost:** the change in operating energy costs resulting from a switch from diesel to electricity.
- **Infrastructure cost:** the cost of renting charging infrastructure, grid connections, cabling, and energy storage systems needed to support the transition.
- **Operational challenges:** additional costs related to technology immaturity, limited user experience, or reduced productivity in early implementation phases.

The relative importance of these cost components varies across markets and project types. However, the Oslo case demonstrates that several cost advantages materialise early, while remaining cost premiums are primarily linked to transitional factors that are expected to decline as technologies mature, and market experience accumulates. The applied methodology is described in the A.2 Methodology, and the following paragraphs discuss the main cost drivers by category and comparing with the other focus cities.



Case study | Cost calculations for Oslo

Oslo is used as an illustrative case. Cost estimates are based on industry data collected in autumn 2024 for the Norwegian Environment Agency (Oslo Economics and Hafslund Rådgivning, 2025). Assumptions and parameters for the pilot phase is summarised below.

Pilot phase	
 <p>Annualising investment costs of machinery (excl. subsidies) over lifetime and allocated to project duration. 2-3x higher investment.</p> <p>Machinery lifetime 8 years Operating hours 1800 h/year Discount rate 6% Residual value Zero Maintenance Cost per hour</p>	 <p>Rental prices for infrastructure components, batteries and chargers.</p>
 <p>Estimated energy consumption per machinery multiplied with energy price.</p> <p>Diesel price 1.14 EUR/L Electricity price 0.10 EUR/kWh</p>	 <p>Estimated additional cost related to issues with technology immaturity, reduced productivity and limited user experience, based on shared experiences from industry actors.</p>

Development phase

- Machine price = diesel machine
- 20 % higher diesel price (carbon pricing)
- 35% lower infrastructure cost
- 100% lower OC costs

Mature phase

- Machine price 20% lower than diesel
- 40 % higher diesel price (carbon pricing)
- 50% lower infrastructure cost
- 100% lower OC costs

Estimated additional cost for 100% ZEMCON relative to project cost



Machine costs

In an early-stage market in Norway, both rental rates and investment costs for electric construction machinery are currently estimated to be two to three times higher than for comparable diesel-powered equipment. These estimates are based on market data collected in a study conducted for the Norwegian Environment Agency in 2024 (Oslo Economics, Hafslund Rådgivning, 2025). At present, pricing reflects limited production volumes, constrained availability and risk premiums associated with uncertain demand.

At the same time, electric machinery benefits from lower maintenance requirements and fewer mechanical components compared to diesel equipment, reducing lifetime maintenance costs. Rapid technological development is also improving cost competitiveness, with an increasing number of electric machine models entering the market, including small-series production with prices approaching those of diesel equivalents. According to SINTEF, more than 115 electric models of wheel loaders and excavators over 8 tons are currently available globally (SINTEF, 2025). Smaller machine categories, as well as equipment types that have already undergone electrification in other applications, such as lifts, are in many cases already price-competitive with diesel alternatives.

As Norway remains part of an early-stage global market, current rental and investment prices still reflect prototype characteristics and conservative pricing assumptions. However, as production volumes increase, supply chains mature and market demand becomes more predictable, these risk premiums are expected to decline. Consequently, machine-related cost differentials are primarily driven by transitional market conditions rather than structural disadvantages of electric machinery. This also represents advantages that other markets can benefit from and that can help reduce initial start-up costs despite lower market maturity.

Energy cost

Energy costs represent one of the clearest economic advantages of zero-emission construction. Operating electric machinery is generally far cheaper than running diesel equipment, as electricity prices are typically lower than the equivalent cost of diesel consumption. Current price levels illustrate this gap: diesel prices across the studied cities range from 1.14 to 1.56 EUR/L, while electricity prices vary more widely, from 0.10 EUR/kWh in Oslo to 0.23 EUR/kWh in Munich. This advantage is particularly strong in markets with low electricity prices, such as Oslo and Stockholm, where the cost gap between the two energy sources is substantial. In cities with higher electricity prices, such as Munich, Eindhoven, and Budapest, the advantage is smaller but still present.

Diesel prices remain relatively uniform across Europe, while electricity prices vary widely due to differences in energy mix, taxation, and grid tariffs. As a result, the relative savings from electrification differ between markets but consistently represent a downward pressure on total project costs. If CO₂ taxation on diesel increases in the coming years while electricity prices remain stable, the economic benefit of electrified operation will grow further, strengthening the long-term cost competitiveness of zero-emission construction.

Infrastructure costs

Infrastructure costs depend primarily on project scale and the number of machines operated electrically. Larger and fully electrified sites require more charging capacity and energy storage, while smaller projects or partial electrification solutions can be supported with simpler

setups. As electrification is expected to be introduced gradually in most markets, infrastructure requirements and associated costs are naturally reduced in early phases.

In an early-stage market such as Norway, specialised infrastructure, particularly high-capacity chargers and mobile battery systems, is still characterised by small-series production and limited standardisation, resulting in higher prices. By contrast, conventional components such as cabling, power cabinets and temporary substations rely on mature technologies already widely used in the construction sector, leading to more predictable costs. As standardisation increases and markets scale, costs for specialised infrastructure are expected to decline. This is an advantage that other markets entering the transition at a later stage will be able to benefit from.

Grid conditions also influence infrastructure costs, and current conditions vary across the focus cities. Some cities face more constrained access to high-capacity grid connections, while others benefit from greater available capacity and shorter connection timelines. These differences can affect infrastructure choices and short-term project costs, particularly for larger or fully electrified construction sites.

At the same time, the transition to zero-emission construction is expected to be gradual. Early projects typically involve partial electrification and smaller power demands, reducing the need for immediate high-capacity grid connections. Where grid access is limited, temporary solutions such as mobile batteries, mobile charging units and other on-site energy systems can support operations without major cost escalation. Over time, as described in Chapter 2.2.2 *Energy system impact*, continued electrification across sectors is expected to drive grid reinforcement and system development across Europe. As a result, differences in infrastructure-related costs between markets are likely to narrow, despite varying grid conditions today.

Operational challenges costs

In early-phase markets dominated by pilot projects, additional costs related to operational challenges are expected. Operational challenges arise from immature technology and limited experience in early-phase zero-emission construction. Pilot projects often face unforeseen technical issues, longer planning and setup times and reduced productivity as new routines are established. These costs reflect the learning curve associated with shifting from conventional to electric operation.

Early experience from Oslo shows that such challenges were most pronounced when prototype machinery and charging equipment were used, making higher costs in the initial phase a natural and temporary outcome. Experience from Oslo shows that such costs fall quickly as experience builds. Improved machine reliability, improved charging solutions and established planning practices reduces both uncertainty and productivity losses. Similar trends are likely to be experienced in similar developing markets as Eindhoven. For new markets, some additional operational costs can therefore be expected initially but learning effects across markets and rapid technology development are likely to significantly shorten this phase.

Market maturation and improved technology reduce costs as adoption increases

As markets mature, both technological progress and accumulated operational experience are expected to reduce the additional cost of zero-emission construction substantially. In the early pilot phase, high rental prices and investment costs for electric machinery, extensive

infrastructure needs and limited operational experience all contribute to a marked cost premium. Over time, these drivers evolve in ways that narrow the cost gap. The first years of market development are likely to bring more predictable technology, more stable supply chains and increased familiarity among contractors, which collectively reduce both risk premiums and the need for costly contingency solutions.

As machinery technology evolves and battery capacities increase, daily operations are expected to rely more on overnight charging and less on high-power daytime charging. Smaller charging components are also cheaper to develop and are likely to enable more machinery to charge via standard temporary site power connections. Based on the reference assumptions applied for Oslo, this development alone is estimated to reduce total infrastructure-related costs by approximately 35%. In addition, mobile battery systems are expected to become more affordable as battery technologies mature and as the zero-emission construction market scales. At this stage, operational challenges are expected to be largely resolved, as contractors gain experience and standardised routines are established.

At the same time, broader adoption across multiple markets enables economies of scale through series production of electric machinery, charging equipment and supporting infrastructure. Higher production volumes, more standardised designs and more mature supply chains are expected to lead to substantial reductions in investment costs. Within a few years, these effects may allow fully electric construction projects to become cost-competitive, or potentially more cost-effective, than conventional diesel-based solutions. Importantly, cost reductions are not driven by the construction sector alone. Electrification across transport, industry and buildings contributes to declining battery and power electronics costs, from which zero-emission construction directly benefits.

In parallel, changes in the regulatory framework are expected to further improve the relative cost position of electric solutions. Rising carbon pricing towards 2030 is likely to increase diesel prices, with estimates suggesting increases in the range of 15–25%, and potentially higher under more ambitious scenarios (Volvo Trucks, 2025). This development strengthens the long-term cost advantage of electrification and accelerates the transition from early-stage cost premiums to structural cost benefits in mature markets.

The pace at which these cost reductions materialise will vary across markets, reflecting differences in current maturity, grid conditions, supply chains and institutional experience. In practice, the transition to zero-emission construction is also expected to be gradual rather than characterised by an immediate shift from conventional to fully electrified projects. Early projects typically involve partial electrification, allowing cost improvements to materialise progressively as experience is built, technologies mature and infrastructure solutions are optimised. As a result, the initial cost premium faced by new markets is likely to be lower than what would be implied by a hypothetical scenario of immediate full-scale electrification.

To illustrate this point (see case study below), the analysis includes an example of the estimated additional cost in a market that is currently less mature, assuming a full transition to zero-emission construction under today's conditions. The example compares Budapest with Oslo as a reference case, using conservative assumptions to reflect differences in market maturity and energy system conditions. While a less mature market such as Budapest is likely to face higher costs in an initial phase, particularly related to infrastructure and operational factors, these costs are expected to decline rapidly as experience is transferred across markets and technologies continue to develop. Differences in grid conditions may also affect infrastructure costs in the short term, but these effects are likely to diminish over time as electrification progresses gradually, and power systems are reinforced.

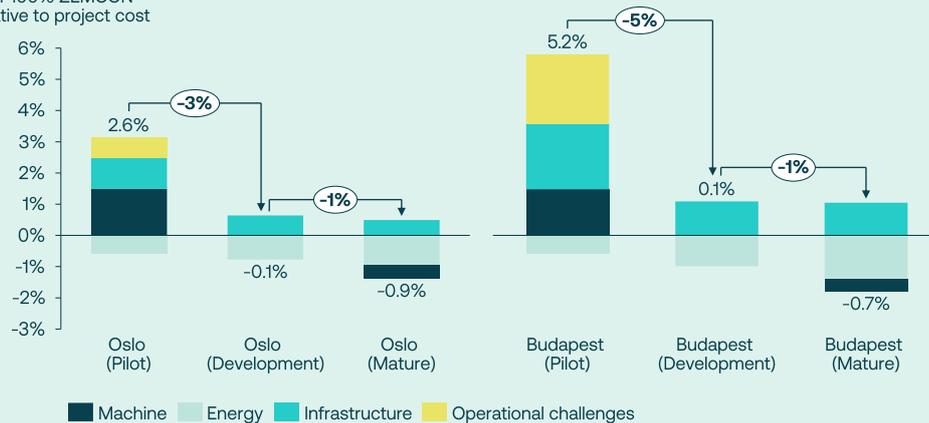


Case study | Additional cost for 100% ZEMCON in different markets

Assumed differences between Budapest and Oslo:

- Machine cost: Lower prices in general
- Energy cost: 20% higher diesel prices, 2x electricity prices
- Infrastructure cost: Higher due to limited grid capacity issues
- OC cost: Higher due to less experience with ZEMCON

Estimated additional cost for 100% ZEMCON relative to project cost



2.2.4 Strategic implications

The strategic implications of the transition towards zero-emission construction sites are significant. The [Draghi report on the future of European competitiveness](#) makes clear that decarbonisation is no longer a peripheral environmental objective but a central condition for Europe's long-term economic strength, security and political relevance. EU Commission President Ursula von der Leyen [has stated](#) that the EU's green transition is a central pillar of strengthening the bloc's competitiveness, including through an active industrial policy aimed at increasing the share of EU companies in the global clean technology market.

In this context, zero-emission construction should be understood as a strategic lever within a wider industrial and energy transformation, rather than as a narrow sectoral initiative.

European competitiveness

The Draghi report argues that Europe's competitiveness challenge is inseparable from its climate and energy transition. Persistently high energy costs, technological dependence and slow deployment of clean solutions risk eroding Europe's industrial base. Construction is a foundational sector for infrastructure, housing and industrial investment; failure to decarbonise its operations would lock in inefficiencies, expose projects to volatile fossil-fuel prices and undermine the credibility of Europe's broader net-zero strategy.

Conversely, accelerating ZEMCOM can contribute to lowering operational energy costs over time, stimulating demand for clean technologies and reinforcing Europe's position as a rule-setter in sustainable industrial practices. Not acting risks widening the competitiveness gap with regions that are already scaling clean construction technologies and standards.



Global competition and the role of China

The report explicitly warns that Europe is at risk of falling behind in key clean-technology value chains, particularly vis-à-vis China. China's rapid advances in electrification, batteries, power electronics and industrial equipment pose a direct challenge to Europe's technological leadership. In the construction sector, this risk is especially acute: if Europe delays the ZEMCON transition, it may become dependent on imported zero-emission machinery and systems developed elsewhere. Proactively supporting ZEMCON allows Europe to anchor innovation, manufacturing and standards-setting domestically, reducing exposure to external technological dependencies and strengthening its position in global markets.

Supporting the European battery industry through zero-emission construction

The transition towards zero-emission construction sites can directly support the development of Europe's domestic battery industry. As highlighted in the Draghi report, clean technologies are among the fastest-growing global markets, with battery manufacturing expected to absorb roughly two-thirds of the global clean-technology manufacturing investment needed to reach climate neutrality by 2050. The transition to zero-emission construction sites will rely extensively on battery-based solutions, including electric construction machinery, on-site energy storage and mobile charging infrastructure, creating sustained and diversified demand beyond the passenger vehicle sector.

By linking ZEMCON deployment with European battery production, the EU can strengthen industrial competitiveness and reduce strategic dependencies in a critical technology. Construction applications require robust, high-performance batteries, offering European manufacturers opportunities for innovation and specialisation.

European machinery producers and ripple effects from city-level transitions

A shift towards ZEMCON has significant upstream implications for European machinery and equipment manufacturers. As large cities move first, often driven by air-quality regulations, public procurement rules and climate targets, they create early markets for zero-emission construction machinery, power systems and digital site management solutions. These city-level transitions can generate positive ripple effects: scaling demand, driving learning curves, reducing costs through serial production and enabling European manufacturers to become global leaders in electric, hydrogen-based and digitally integrated construction equipment.

Not only that, but by demonstrating the various ways in which this transition can be made possible at local level, with the many side benefits in cities of various sizes, as highlighted in this report, they start to generate enough critical mass to drive the transition across the block. In turn, regional markets become transnational, eventually driving down prices.

However, if Europe fails to support this transition, domestic producers risk losing first-mover advantages to non-European competitors, with long-term consequences for industrial employment, innovation capacity, export potential and safety.

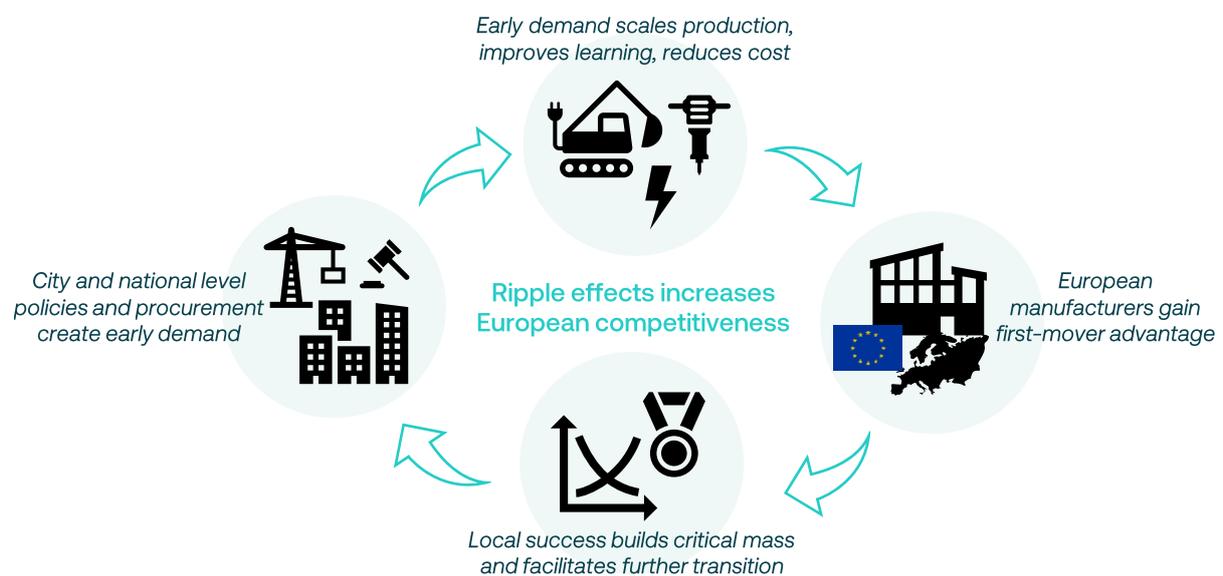


Figure 33: Illustration of zero-emission construction could lead to ripple effect and increase European competitiveness

Robustness, safety and strategic autonomy

The Draghi report places strong emphasis on resilience, security and reduced dependencies. ZEMCON contribute to these objectives by supporting greater reliance on locally produced and European energy sources, particularly electricity from renewables, rather than imported fossil fuels. Electrified and digitally connected construction sites also raise new considerations around surveillance, data integrity and critical infrastructure protection, but they simultaneously offer opportunities to strengthen European standards for safety, cybersecurity and system reliability.

Embedding ZEMCON within a European industrial and energy ecosystem can enhance robustness by shortening supply chains, improving monitoring of critical assets and reinforcing strategic autonomy in both energy and machinery production.

Furthermore, recent geopolitical events have exposed the dangers of relying on imports of fossil fuels, particularly oil, as [the EU imports 98% of the oil it consumes](#). The Draghi report also [highlights](#) this issue, where it says Europe has a relative lack of natural resources, compared to the United States. The switch to renewable-powered construction would strengthen the EU's resilient and strategic autonomy, becoming less dependent on volatile energy prices.



The cost of inaction

Failing to advance towards zero-emission construction sites would have detrimental effects: continued exposure to fossil-fuel price volatility, loss of industrial competitiveness, increased dependency on non-European technologies, and weakened credibility of EU climate policy. As highlighted by the Draghi report, climate action and competitiveness must move together. ZEMCON represent a concrete, visible and economically meaningful arena where this alignment can be realised; or, if neglected, where Europe's strategic vulnerabilities could deepen.

3

Policy and Legal Options

In this chapter, the report explores the legal and policy framework that shapes the conditions for the deployment of zero-emission construction sites across Europe. It examines how existing environmental, health and safety, and energy-related legislation – while not originally designed to promote zero-emission construction – already provides a strong and often underutilised legal basis for action by municipalities, regions and Member States.

Given the EU's multi-level governance structure, in which requirements are set at European, national and local levels according to the distinct competencies of each, public procurers face a complex task when identifying the legal basis for setting targets or requirements for the uptake of zero-emission machinery (see Figure 34 below). With this overview, the report aims to contextualize the possibilities to promote uptake of zero-emission machinery within this broader framework, as well as to demonstrate that the transition is not only compatible with current law but, in many cases, directly supported or even required by it.

The chapter first outlines the constitutional, human and labour rights, and EU law foundations of environmental protection, with a particular focus on air quality, noise pollution and occupational health. It then analyses how binding EU directives, such as the Ambient Air Quality Directive and the Environmental Noise Directive, translate high-level commitments into concrete obligations at the local level, creating both duties and opportunities for authorities to act.

Building on this legal baseline, the chapter subsequently identifies policy gaps and emerging opportunities across EU legislation and initiatives, such as those from electrification, grid planning and industrial regulation to public procurement and carbon pricing that could accelerate the uptake of zero-emission construction machinery.

Throughout these chapters, the report highlights existing examples from national legislation, legal cases, roadmaps, and financial incentives, which are proof that, while measures can and should be taken at all levels of governance to ease the transition, the possibility of advancing is already embedded within the existing policies. This report shines a light on the available options and hopes to provide certainty to public procurers of the legal soundness of ZEMCON.

A more detailed explanation of the interaction between EU, national and local policy frameworks, and of the distribution of competences across EU, national and local levels can be found in Annexes A.3 and A.4 respectively.

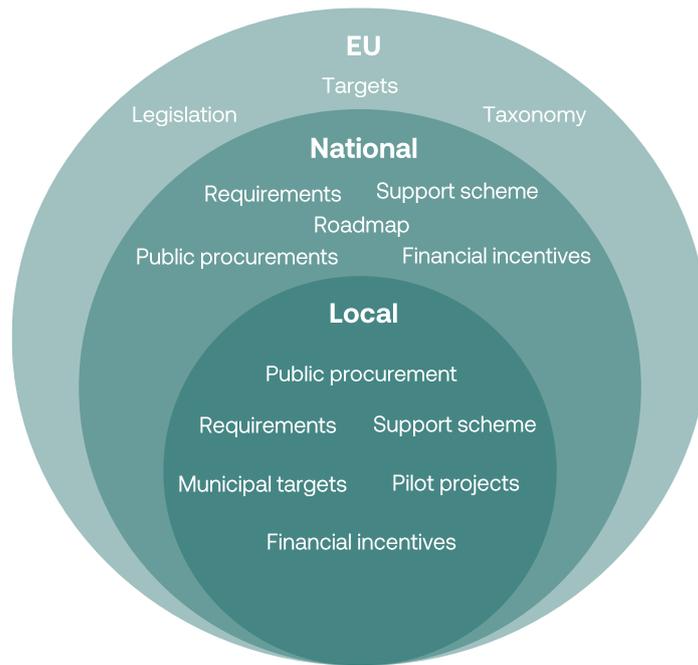


Figure 34: Illustration of the different levels of policy options and legal frameworks on different levels of influence

Figure 35 below summarizes the mapped policies and legal frameworks on EU, national and local levels for the focus cities that are existing today. The figure also outlines an evaluation of the policy and legal framework impact to transition to ZEMCON. The different instruments are described in the following pages.

Type	Policy/Instrument	Level	Impact
Collaborative Governance	Voluntary Agreement	🇳🇱 National	Low
	Private-public market dialogue	🇳🇱 National	Medium
	Joint Statements/Declarations	🇳🇱 National	Medium
Economic	Financing schemes for municipal support	🇳🇱 National	High
	Subsidies for zero-emission machinery	🇪🇺 EU	High
	ETS2 & Energy Taxation Directive	🇪🇺 EU	Medium
	GBER	🇪🇺 EU	Medium
	Support schemes for machinery and infrastructure	🇳🇱 Local/National	High
Energy	Electrification Action Plan	🇪🇺 EU	Medium
	European Grids Package	🇪🇺 EU	Medium
Public Procurement	Public Procurement Directive	🇪🇺 EU	High
	Clean Vehicles Directive	🇳🇱 National	Medium
	Zero-emission requirements in public procurement	🇳🇱 Local/National	High
	Pilot projects	🇳🇱 Local	Medium
Regulatory	NRMM Regulation	🇪🇺 EU	High
	Ambient Air Quality Directive	🇪🇺 EU	High
	Plans, goals and roadmaps for ZEMCON transition	🇳🇱 Local/National	Medium
	Air quality plans and roadmaps	🇳🇱 Local/National	Low
	Environmental Noise Directive	🇪🇺 EU	Medium
	EPBD	🇪🇺 EU	Medium
	Directives on workers protection	🇪🇺 EU	Medium
	Taxation and fees on fossil machinery and fuels	🇳🇱 National	High
	Municipal targets	🇳🇱 Local	Medium

Figure 35: Policy and legal options on different levels and with an evaluation of their potential impact

Figure 35 shows a non-extensive list of political and financial instruments at different levels of governance. The impact has been estimated according to the instrument's effectiveness when it comes to enabling ZEMCON. As the Figure shows, the highest impact comes from both financial instruments (such as subsidies and taxation) and political instruments (such as the directives on air quality and public procurement, and supply-side regulations such as the NRMM regulation). Non-binding voluntary agreements as well as plans and roadmaps have a low impact on their own, without binding requirements to enact them – they are, nonetheless, valuable tools, particularly at the early stages of the transition.

3.1. Introduction to Legal Framework

In European countries, numerous legal provisions aim to ensure a safe and healthy environment. Although these provisions were not designed with the specific goal of favouring the adoption of ZEMCON, they provide a solid legal foundation for municipalities to mandate the use of zero-emission machinery within their administrative borders.

To understand municipal legal rights and obligations regarding air and noise pollution, it is essential to identify the commitments these countries have made. These commitments often stem from international agreements, national constitutional law, and EU secondary law.

Although legal provisions are often referred to national authorities, due to its complex nature, environmental pollution management requires coordination among various levels of governance. As such, local authorities are often responsible for designing air and noise pollution policies within their constituencies.

Based on this division of responsibilities, the following section examines the laws currently in place. By outlining the main rules governing air quality and noise control, it shows how existing legislation can already give local authorities a legal basis for requiring the use of zero-emission machinery, both for publicly and privately owned construction sites.

3.1.1. Constitutional and human rights foundations of environmental protection in the EU

All residents of the [European Union have the human right to a "safe, clean, healthy, and sustainable environment." This right is an integral part of the constitutional law in at least 18 EU countries.](#) In other countries, it is incorporated into secondary national legal frameworks (UN Special Rapporteur on Human Rights and the Environment, 2019). As signatories to the [1998 Aarhus Convention](#), the EU and its Member States are obligated to ensure that residents can access information, participate in decision-making, and seek justice regarding matters related to environmental protection (European Commission, n.d.).

The right of European citizens to a healthy environment finds additional grounds in Article 8 of the European Convention on Human Rights – *Right to respect for private and family life and home* (European Court of Human Rights, 2024).

Law case | Environmental pollution and human rights

According to the European Court of Human Rights (ECHR), prolonged exposure to endangering levels of air and noise pollution may constitute a prejudice to the rightful enjoyment of this right. In its decision for [Greenpeace E.V. and others v. Germany 18215/06](#), the ECHR observed that "Article 8 is applicable in case of severe environmental pollution" and it noted "that soot and respirable dust particles can have a serious detrimental effect on health, in particular in densely populated areas with heavy traffic".

Similarly, in the litigation case [Deés v. Hungary 2345/06](#), the ECHR stated that prolonged exposure to excessive noise from the motorway limited the applicant's right to the enjoyment of their private life.

Again, in [Kapa and Others v. Poland 75031/13](#), the Court made clear that a violation of Article 8 may occur even in the case of temporary disturbances. This provided that these disturbances result from public authorities' failure to adopt mitigating measures to reduce individuals' exposure to excessive noise.

3.1.2. EU law mandates local action on air and noise pollution

When it comes to local authorities' obligations to ensure healthy and safe environments for their residents, they largely stem from EU secondary law. The most important pieces of legislation that limit the harmful effects of air and noise pollution are the Ambient Air Quality Directive (AAQD) and the Environmental Noise Directive (END). These directives are central to the Zero Pollution Action Plan, which was adopted by the European Commission in 2021 and aims to reduce the negative impacts of air and noise pollution on human health and biodiversity.

The Revised Ambient Air Quality Directive 2024/2881

As stated in Article 1(1), the [Ambient Air Quality Directive 2024/2881](#) is to reduce air pollution "to levels no longer considered harmful to human health, natural ecosystems and biodiversity, as defined by the best available and most up-to-date scientific evidence, thus contributing to a toxic-free environment at the latest by 2050".

It does so by setting intermediate limit values and targets for 2026 and 2030 for a diverse range of air pollutants. Among others, the directive set targets for particulate matter and nitrogen dioxide, for which diesel-powered construction machinery and non-road mobile machinery in general are a key source of emissions (see Part 2).

The targets and limit values specified in Annex I of the Directive are mandatory, and Member States must fulfil these obligations by taking all necessary measures to ensure air pollution levels meet EU standards.

For areas where limit values and targets exceed the Directive's provisions, competent authorities must draft air quality plans and air quality roadmaps to meet EU standards. These are strategic environmental pollution management and planning instruments that outline the

policies and strategies needed to reduce pollution levels to the safety standards set by EU legislation.

Air quality plans and roadmaps must be drafted for “zones” and “agglomerations.” The first geographical units, “zone,” are territories designated by the Member States for assessing and managing air quality. The other units, “agglomeration,” refer to areas where at least 250,000 people live or to regions with a specified population density, for which Member States are to establish the normative population density. These areas often match those of medium- and large-sized cities, making local authorities responsible for designing and implementing measures tailored to local challenges.

It is important to emphasize that drafting these plans and roadmaps is mandatory when emission levels of one or more air pollutants exceed EU standards, but also that simply drafting them does not mean that authorities have met their legal obligations. In fact, plans and roadmaps must help reduce air pollution to normative levels as quickly as possible. Furthermore, when emissions of one or more air pollutants exceed the “alert threshold” outlined in the Directive, competent authorities must develop short-term plans that outline emergency measures to address the exceedance.

Finally, the Directive grants EU residents and civil society organizations the right to challenge the adequacy of air quality plans, roadmaps, and short-term plans before national courts. For example, this has occurred in Brussels, Munich, and Budapest, where the measures taken by local and regional authorities were found insufficient to meet the provisions of the AAQD.

Similarly, the Directive establishes that individuals whose health has been harmed by exposure to excessive values of air pollution have the right to seek compensation from public authorities responsible for failing to meet the required standards.

Table 4: Comparison of air quality limit emissions between WHO guidelines and the EU AAQD

Pollutant	WHO 2021 (health guideline)	New EU Directive 2030 (EU 2024/2881) https://eur-lex.europa.eu/eli/dir/2024/2881/oj/eng
PM_{2.5} (annual)	5 µg/m ³	10 µg/m ³
PM_{2.5} (24-h)	15 µg/m ³ (3-4 exceedance days per year)	25 µg/m ³ EU daily limit; max 18 exceedance days
PM₁₀ (annual)	15 µg/m ³	20 µg/m ³
PM₁₀ (24-h)	45 µg/m ³ (3-4 exceedance days/year)	45 µg/m ³ , max. 18 days/year
NO₂ (annual)	10 µg/m ³	20 µg/m ³
NO₂ (24h / short)	25 µg/m ³ (3-4 exceedance days/year)	EU keeps short-term metrics (hourly=200 µg/m ³ , daily=50 µg/m ³); plus Average exposure indicator obligations. EEA

The table above shows that the updated EU Directive, even though [a huge step forward from its previous version](#), still sets less stringent limits than those recommended by the World Health Organization. However, according to the [Zero Pollution Action Plan](#), the European Commission aims to meet WHO limit values by 2050.

The Environmental Noise Directive 2002/49/EC

The [Environmental Noise Directive 2002/49/EC](#) is a piece of legislation that seeks to reduce noise pollution across EU cities and to allow public access to environmental noise data. The directive requires Member States to draft, every five years, noise maps and noise management action plans for major airports, railways, roads, and agglomeration areas with over 100.000 inhabitants.

As for the AAQD, the END indicates that EU countries are to designate the relevant authorities responsible for collecting noise data and drafting noise management action plans. As per the AAQD, this duty often falls to local authorities.

However, unlike the AAQD, the Directive does not mandate targets for noise pollution. Instead, it recommends indicative, non-mandatory maximum values that should be met. According to the [Special Report of the European Court of Auditors](#), the lack of compulsory limit values stands as a significant weakness in the approach, resulting in disincentives to the timely and comprehensive drafting of effective noise management action plans (European Court of Auditors, 2025).

[As noted by the Commission itself](#), without more decisive action, the goal to reduce by 30% the number of people exposed to harmful transport noise by 2030 is unlikely to be achieved. This policy target, however, should not be treated as a desirable extra, given the critical health impacts of excessive noise pollution on human health and the environment (European Commission, 2022).

Despite the lack of compulsory limits, however, the END still obliges Member States to gather information and take measures to limit noise pollution in major affected areas. This obligation was reaffirmed in [Commission v. Poland \(C-602/21\)](#), where the European Court of Justice held that failing to adopt noise management action plans constitutes a breach of EU law.

Explanation | Zero Pollution Action Plan

Environmental pollution remains a leading threat to public health in the European Union. According to the European Environment Agency, [around 357,000 people](#) in the EU died in 2022 due to chronic exposure to particulate matter, nitrogen dioxide, and ozone. High levels of air pollution in cities and major traffic areas are major contributors to lung cancer, cardiovascular disease, childhood asthma, and diabetes. Noise pollution adds to this burden, causing approximately [66,000 deaths and 50,000](#) new cases of cardiovascular disease each year.

In response to this health crisis, the European Commission launched the [“Towards Zero Pollution for Air, Water and Soil” action plan](#) in 2021, as part of the European Green Deal. The plan aims to reduce environmental pollution by 2050 to levels considered safe for human health and natural ecosystems, while also establishing intermediate targets to be achieved by 2030:

- Reduce premature deaths from air pollution by 55%.
- Lower the number of people systematically exposed to transport noise by 30%.
- Reduce by 25% the areas of EU ecosystems where air pollution poses a threat to biodiversity.
- Improve water quality by halving marine litter, reducing overall waste, and lowering microplastic emissions by 30%.
- Improve soil health by decreasing nutrient runoff and cutting the use of chemical pesticides by 50%.
- Substantially decrease waste generation and cut residual municipal waste by half.

While the Zero Pollution Action Plan sets important targets for pollution reduction, it is important to note that it is not legally binding. It functions as a strategic framework that sets policy direction and quantitative targets for 2030 and 2050, guiding revisions of directives (like the AAQD) and shaping future funding and policy instruments. However, it cannot be directly enforced before national courts.

The revised AAQD is fully legally binding, as it sets enforceable limit values, intermediate targets, mandatory air quality plans and roadmaps, and procedural rights for citizens to challenge inadequate measures or claim compensation. Member States – and by extension regional and local authorities – must adopt all necessary measures to meet these standards within strict deadlines, making the AAQD the strongest regulatory driver for action on pollution from transport, heating, traffic and non-road mobile machinery, including diesel-powered construction machinery.

In contrast, the END establishes binding obligations on monitoring, mapping, action planning and public information, but does not impose binding noise limit values. This means authorities must assess and manage noise strategically but are not legally compelled to reach specific maximum noise thresholds.

As a summary: the AAQD imposes hard legal obligations, the END imposes binding monitoring and planning duties without mandatory limits, and the Zero Pollution Action Plan provides non-binding strategic direction. For municipalities, this means that compliance with the AAQD is a strict legal requirement with direct accountability, whereas noise management and long-term pollution-reduction goals rely more on strategic planning, political commitment and voluntary measures – at least until the existing directives are revised to incorporate binding standards.

3.1.3. Construction workers' right to a safe and healthy work environment

Construction workers are particularly vulnerable to occupational disease caused by chronic exposure to excessive air and noise pollutants.

European law is aware of the risk to which these workers are exposed. For this reason, the 2019 amendment to [Directive 2004/37/EC on the protection of workers from carcinogens and mutagens at work](#) sets the 8-hour exposure limit for diesel exhaust at 0.05 mg/m³ (50 µg/m³). This value, however, applies only as long as it is not technically feasible to adopt alternative substances or processes. On this matter, the Directive clarifies that, **when a technological process allows it, the workers' exposure to cancerogenic substances must be eliminated**, or, if elimination is not possible, minimized to the greatest extent technically achievable.

Workers at construction sites report an [above-average risk of developing hearing loss as an occupational disease](#) (Masterson & Themann, 2025). As per the exposure to exhaust fumes, EU law obliges employers to minimise the risk to workers by ensuring that health and safety equipment is available on site. In the case of construction workers, reducing exposure to high noise levels is often achieved by utilising personal hearing protectors.

Hearing protectors, however, pose additional risks at construction sites. They can endanger workers' safety by reducing their ability to hear alarms and warning signals that could prevent life-threatening accidents. In addition, workers at a construction site often need to communicate with each other, often over significant distances. As such, they don't wear ear protection gear continuously, raising the risk of developing hearing impairment and other occupational illnesses associated with prolonged exposure to high noise levels.

This is why, as highlighted by [Directive 2003/10/EC](#), “Taking account of technical progress and of the availability of measures to control the risk at source, the risks arising from exposure to **noise shall be eliminated at their source** or reduced to a minimum [...]”.

As enabling conditions for upscaling the deployment of zero-emission construction machinery become fully established across the different EU geographies, it is evident that EU law provides a strong legal foundation for requiring contractors to gradually adopt electric construction equipment, regardless of whether construction sites are publicly or privately owned.

Example | Occupational health concerns from heat

Construction workers' exposure to high temperatures

Temperature, while outside the scope of the study, is a relevant aspect in the transition to ZEMCON.

Exposure to high temperatures is an increasingly pressing **occupational health concern** for outdoor workers, including construction crews, municipal street cleaners, and other public service employees. As global temperatures rise and heatwaves become more frequent and intense due to climate change, workers who spend long hours outdoors face serious risks—ranging from heat exhaustion and dehydration to heatstroke and even death.

In cities like Barcelona, where temperatures can reach extremely high levels (in August 2025, a maximum temperature of 38.9 °C [was registered](#)), it has become painfully evident the need to mitigate the risk to which workers are exposed. One way to do so is via the use of zero-emission machinery.

Traditional diesel-powered equipment not only emits pollutants but also adds local waste heat and radiant thermal loading around operators and nearby workers. Diesel engines generate substantial heat through combustion and cooling systems, which can contribute to elevated microclimate temperatures on site.

By contrast, electric and zero-emission construction machinery produce much less waste heat at the point of use, since electric motors convert electrical energy into mechanical work far more efficiently than combustion engines, meaning less energy is lost as heat.

Explanation | Directive 2004/37/EC

The Dutch Labour Inspectorate approach to diesel emissions from construction machinery

The Dutch Labour Inspectorate made it clear that aligning with Article 4(1) of the Directive requires the phased-in introduction of zero-emission machinery, as this is the only way to protect workers from exposure to diesel engine emissions.

*The employer shall reduce the use of a carcinogen, mutagen or reprotoxic substance at the place of work, **in particular by replacing it, in so far as is technically possible**, by a substance, mixture or process which, under its conditions of use, is not dangerous or is less dangerous to workers' health or safety, as the case may be*

The Labour Inspectorate indicated that, in the future, [merely retrofitting machinery with filters won't comply](#) with EU law (Bouwend Nederland, 2024). This is because filters alone don't provide sufficient protection, as there is no safe level of exposure to diesel exhaust gases, as emphasised by the International Agency for Research on Cancer.

For this reason, the limit value **of 0.05 mg/m³ (elemental carbon)** set in Annex III of Directive (EU) 2019/130 must be considered as an absolute minimum level, to be applied **only when no other technically feasible solutions are available**.

In the Netherlands, national, regional, and local authorities collaborate with the private sector to increase the availability of zero-emission machinery and ensure that supporting infrastructure is in place.

This means that as the Roadmap for Zero Emission Construction Equipment advances, there will be no overly complex technical barriers preventing private sector employers from fully protecting construction workers from chronic exposure to diesel exhaust fumes, as required by EU law.

Law case | Munich's diesel bans and their legal basis in EU Ambient Air Quality Law

Munich's approach to air pollution management has been shaped by a decade-long legal battle initiated by NGOs Deutsche Umwelthilfe (DUH), Verkehrsclub Deutschland (VCD), and ClientEarth. The subsequent rulings at regional, national, and European levels have highlighted the legal importance of ambient and air quality plans, as well as the rights of natural and legal persons to demand compliance with European air pollutant limit values.

2012: DUH [wins a legally binding court order](#) requiring the City of Munich to amend its air quality plan to meet EU limit values for NO₂. – annual average limit of 40 µg/m³

2015: Since NO₂ levels remain dangerously high, [DUH files a second complaint](#) demanding enforcement and the imposition of a coercive fine. At the same time, [VCD files its own complaint](#) requiring an amendment of the air quality plan.

2016: The Bavarian Administrative Court in Munich [orders the city to enforce the 2012 ruling](#) and threatens the imposition of coercive fines if the Bavarian government does not revise the air quality plan within one year.

2018: The [Bavarian Environment Minister is fined for the third time](#) due to continued failure to produce an adequate air quality plan and to address illegal levels of air pollution. The court sets a four-month deadline for compliance and warns that further delays could result in a [prison sentence](#).

2019: The [Court of Justice of the European Union](#) in Case C-752/18 rules that:

- *Imprisonment of public officials* for refusing to comply with air-quality court orders is not incompatible with EU law, provided human-rights safeguards are upheld.
- However, before considering imprisonment, national authorities should impose effective coercive measures, such as substantial and recurring fines, unlike the fines imposed on the Bavarian Ministry of Environment, which were not significant.

2022: The [City of Munich, DUH, and VCD reach a settlement](#) incorporating a three-stage diesel driving-ban plan.

2024: In 2023, DUH and VCD sued the Munich municipality again over the city's decision to postpone the diesel ban for Euro 5 vehicles. [In its 2024 ruling, the Bavarian Administrative Court mandates the municipality to enforce traffic restrictions in areas where monitoring stations recorded values exceeding the limits set by Directive 2008/50.](#)

[As of 2024, NO₂ levels in Munich appear to comply with the provisions of Directive 2008/50.](#) However, the 2024 revision of the Ambient Air Quality Directive anticipates reducing the annual average limit from 40 µg/m³ to 20 µg/m³ by 2030 at the latest.

3.2. Policy gaps and opportunity analysis

In this section, the report aims to go beyond the core legal basis as outlined in the previous section and explore the related policies at various levels of governance that can also set a valuable case for the uptake of zero-emission construction sites across Europe. Since the cities and regions that are the focus of this study are part of the European Union (with the exemption of Oslo) a thorough review of the European legislation is performed.

EU dimension

There is a large focus in industrial decarbonisation and on resilience and competitiveness in Europe, which is intimately related to decreasing dependencies on fossil fuels. ETS2 is being delayed, which will likely have negative implications on TCO estimations for European electric machinery manufacturers. The Environmental Noise Directive and the Air Quality Directive, though extremely relevant, have been addressed in the previous section.

Electrification Action Plan (EAP)

The European Commission's **Electrification Action Plan (EAP)** will be an EU-wide strategy explicitly focused on accelerating the shift from fossil fuels to electricity across all sectors of the economy. While the Plan does not specifically address construction sites, it creates a supportive policy environment for electric non-road mobile machinery (NRMM) by:

1. Prioritising electrification as the most efficient decarbonisation pathway

The EAP identifies electrification as a “no-regrets” option for industry, transport, and buildings. This provides a strong policy basis for extending electrification targets to construction machinery, which remains one of the few major sectors without a decarbonisation trajectory or dedicated EU standards.

2. Supporting flexibility and smart charging

The EAP promotes demand-side flexibility, smart charging, vehicle-to-grid (V2G) applications, and the integration of mobile battery systems. This is highly relevant to zero-emission construction machinery, which could eventually shift charging to high-renewable periods, use smart load management on construction sites, and participate in future flexibility markets.

European Grids Package

The upcoming **European Grids Package** is expected to play a critical role in upgrading and expanding grid infrastructure to support the rapid electrification, by focusing on the technical and regulatory reforms needed to build a modern, flexible, and expanded electricity network across Europe. Without these upgrades, connection delays will grow, renewable deployment will slow, and electrification will remain stagnant, therefore showing its clear relevance to ZEMCON sites deployment.

1. EU-level infrastructure planning: ensuring future-proof electricity networks

The Package strengthens long-term system planning by requiring operators to anticipate new and temporary high-load need. Measures such as planning for mobile substations, temporary high-capacity connections, and flexible access arrangements ensure that ZEMCON sites can be integrated without costly delays.

2. Permitting and grid connection times.

Future reforms to grid-connection procedures, which the forthcoming Grids Package is expected to prioritise should aim to streamline and accelerate access to the network. This could include more standardised connection requests, clearer timelines from DSOs and TSOs, fewer administrative steps, and fully digitalised processes. For ZEMCON sites, these reforms reduce uncertainty, providing greater predictability and improve the viability of using electric machinery.

3. Enabling flexibility markets to complement grid development

By promoting flexibility, the European Grids Package could be particularly relevant for electric machinery. This will make it easier for temporary work sites to participate in demand-response schemes, allowing electric machinery to act as flexible loads, and potentially to offer grid support via bidirectional charging. This is a major opportunity: large machinery fleets could eventually serve as distributed storage, supporting grid stability and absorbing renewable electricity surpluses.

4. Strengthening distribution-level networks and DSO–TSO coordination

Most electric construction machinery will connect at the distribution level, making local grid readiness critical. The Package seems like it will put greater emphasis on distribution grid reinforcement, digital monitoring, and harmonised planning between DSOs and TSOs. Better coordination across voltage levels helps ensure that local bottlenecks are identified early and that distribution grids are equipped.

Thus, it becomes evident that a strong and well-defined electrification policy framework can strengthen the case for zero-emission machinery in Europe. The upcoming policies are a crucial opportunity to address some of the hurdles that machinery procurers and users are facing, particularly uncertainties around electricity supply, and to bring down the total cost of ownership (TCO) of construction machinery.

Non-Road Mobile Machinery Regulation

In the EU, air pollutant emissions from construction machinery have been regulated since 1997 by the [Non-Road Mobile Machinery Regulation \(EU 2016/1628\)](#). Over the years, the aim of this regulation has been to control emissions of carbon monoxide, hydrocarbons, oxides of nitrogen, and particulate matter, with the overall goal of “stimulating innovation, improving air quality, reducing health costs, and increasing life expectancy.” With its 2016 revision, the NRMM Regulation established Stage V emissions standards, which took full effect in 2022 after delays caused by pandemic-related supply chain disruptions.

The current NRMM regulation appears ill-suited to achieving the broader environmental and social goals of the European Union. The regulation does not establish CO₂ emissions standards, despite off-road machinery accounting for nearly 3% of GHG emissions in the EU, two-thirds of which corresponds to agricultural and construction machinery, leaving this source of climate risk unaddressed (Transport & Environment, 2024). Additionally, while Stage V standards' air pollutant limits are strict, the zero-emission construction equipment industry will eliminate local air pollutant emissions entirely, effectively supporting key EU strategies such as the Zero Pollution Action Plan. Similarly, transitioning to alternative powertrains and fuels can aid the union's goal of reducing noise pollution in urban areas.

It is important to note that these EU objectives cannot be achieved solely through switching to fossil-free NRMM, which do not provide the same benefits regarding air and noise pollution mitigation, and for which long-term environmental and economic sustainability remains debated.

Finally, the regulation only applies to newly produced NRMM. However, depending on the type and use of the machinery, most of the machinery produced starting in 2022 will still be operating for at least 10 to 20 years. This means that, in its current prescriptions, the NRMM Regulation entirely misaligns with the EU 2030 and 2050 climate and environmental goals. In addition, the regulation risks undermining the competitiveness of EU original equipment manufacturers (OEMs). In fact, European machinery manufacturers are already at risk of losing ground to Chinese competitors, who are rapidly scaling up production of electric construction equipment.

When it comes to the NRMM Regulation, this central piece of legislation appears not suited to address the challenges the EU is facing. For this reason, we suggest that the EU adopts a comprehensive approach and regulates NRMM emissions standards while duly considering the environmental, climate, and competitiveness benefits of zero-emission off-road.

Example | National roadmap

Dutch Roadmap for Zero Emission Construction Equipment (SSEB)

The Dutch Ministry of Infrastructure and Water Management developed an [Agreement](#) on Clean and Zero Emission Construction Equipment, which was signed by over 150 parties. The Roadmap towards zero-emission construction equipment was developed in collaboration with representatives of the construction sector, governmental organisations (central/regional) and knowledge institutes, and it targets mobile machinery, vehicles and floating machinery used in construction.

It provides a clear and uniform approach on how to reach a more sustainable deployment of construction equipment, step by step, and sets out emission requirements from 2023 until 2030 and beyond, depending on machinery sizes.

Mobile Machinery – Basic tier

	2023–2024	2025–2027	2028–2029	2030 and beyond
Light (19–56 kW)	Stage IIIa/IIIb	Stage IIIa/IIIb	Zero-emission	Zero-emission
Medium and Heavy (56–560 kW)	Stage IIIb	Stage IV with soot filter	Stage IV with soot filter	Stage IV with soot filter (2030) Zero-emission (from 2035)
Specialized and >560 kW	No requirements	No requirements	Catalytic converter and soot filters	Catalytic converter and soot filters (2030) Zero-emission (from 2035–2040)

The Roadmap presents a clear pathway forward, and is supported with subsidy schemes (see last chapter). This roadmap has been welcome by industry and public procurers alike, and has put the Netherlands at the forefront of the transition.

However, this Roadmap remains voluntary, as there are no real possibilities to enforce the use of ZE-construction equipment through national regulation. The Ministry notes that the total market share of construction equipment the Netherlands is not sufficient to stimulate international market of NRMM manufacturers, and that harmonised efforts at European and international level are needed.

Experiences such as the Dutch **Roadmap for Zero Emission Construction Equipment** offer a valuable starting point for the EU in planning the gradual introduction of zero-emission construction machinery. The Dutch roadmap was designed for public purchasers to include in their procurement criteria and for OEMs and contractors to plan their operations. We believe the same step-by-step approach could, in principle, also be operationalised for the supplying industry. This would allow manufacturers to gradually shift production to machines with more powerful engines or higher-performance batteries. At the same time, this would give

policymakers across Europe the space to ensure that the necessary infrastructure and energy planning are in place.

This phased approach would also deliver early and tangible benefits. In fact, it would allow for reducing air pollution from smaller-engine construction machinery early on. The impact would be significant, as the [large amount of light construction machinery in use suggests a greater contribution to total environmental pollution](#) (Desouza, Marsh, Beevers, Molden, & Green, 2024).

On the other hand, updating the NRMM Regulation to gradually phase in zero-emission machinery will help sustain European leadership in construction equipment and prevent the competitiveness challenges faced by the automotive industry due to their delayed investments in electrification. A clear EU roadmap phasing out diesel construction machinery would send strong market signals, align Member States with climate, air quality, and worker safety goals, support European manufacturers in scaling production, and ensure ZEMCON sites becomes the default by 2040.

Energy Performance of Buildings Directive (EPBD)

Under the Energy Performance of Buildings Directive (EPBD), EU Member States are required to integrate whole-life carbon (WLC) considerations into national building policies for the first time. By 2027, each Member State must develop a national WLC roadmap outlining how emissions from all stages of the building life cycle (from material extraction and manufacturing to construction, operation, renovation, and end-of-life) will be progressively reduced. In addition, the EPBD mandates the introduction of limit values for whole life-cycle global warming potential (GWP) for new buildings, applicable from 2030 onwards, with an explicit requirement that these thresholds follow a downward trajectory over time.

This approach is highly relevant for zero-emission construction sites because WLC accounting explicitly includes emissions generated during the construction phase, such as those from non-road mobile machinery, on-site generators, and transport associated with construction activities. While it has not been yet decided how these limit values will be addressed, the current methodology recommends that emissions from the construction phase are included in all Member States, which hold the responsibility to set out which lifecycle modules should be included under a WLC limit. As a result, construction machinery emissions become an integral part of the carbon performance of buildings. This creates a significant political and regulatory opportunity: Member States may use WLC methodologies and upcoming GWP limits to set ambitious national requirements that indirectly (or directly) incentivise the phase-out of fossil fuel-powered machinery in favour of zero-emission alternatives. In doing so, the EPBD becomes not only a building-energy policy but also a powerful lever for accelerating ZEMCON adoption across Europe.

While the Commission draft guidelines for calculating the global warming potential (GWP) are promising, [there are concerning aspects](#). As the draft stands, the guidelines leave the choice to the Member States on which life-cycle stages and modules will be covered by limit values. For the EPBD to be a meaningful tool of reducing emissions from construction, Member States must require the disclosure of the emissions from construction machinery.

Clean Vehicles Directive (CVD)

The Clean Vehicles Directive (CVD) (Directive (EU) 2019/1161) is one of the EU's central policy instruments for driving the uptake of zero-emission technologies in public procurement. Although its current scope focuses primarily on road vehicles and does not directly cover non-

road mobile machinery (NRMM) such as construction equipment, it is nonetheless highly relevant for zero-emission construction sites. Firstly, by requiring public authorities to procure increasing shares of zero-emission buses, vans and trucks, the CVD accelerates the deployment of charging infrastructure, depot electrification, smart energy management systems, and grid upgrades, all of which are foundational components of electric construction sites. Secondly, as public works contractors increasingly operate electric support vehicles to meet CVD requirements, the transition creates natural spill-overs into adjacent machinery categories used on the same urban construction projects.

Importantly, the upcoming revision of the CVD, announced in the European Commission's Greening Freight Package and 2040 climate target communication, is expected to expand the scope to additional vehicle or machinery categories. Several Member States and NGOs have explicitly called for the revision to include non-road mobile machinery, particularly construction machinery, because diesel-powered NRMM constitutes a major source of NO_x and PM emissions in cities and is currently not subject to any zero-emission procurement obligation. Adding NRMM to the Directive, or creating a parallel regulatory mechanism under the same framework, would send a strong market signal and could significantly accelerate the uptake of electric excavators, wheel loaders, compressors, and site generators across Europe.

Even if the upcoming revision stops short of fully integrating NRMM, it is expected to strengthen the link between public procurement, air quality compliance, and climate objectives, creating new opportunities for municipalities to justify ZEMCON sites policies under EU law and to integrate zero-emission machinery requirements into tenders for public construction works.

Public Procurement Directives: status and revision

Public procurement is one of the most powerful tools available to public authorities for accelerating the uptake of zero-emission construction technologies. Nevertheless, across Europe, procurement remains an underutilised instrument for achieving climate policy goals.

The legal foundation for such an approach is already in place. The EU Public Procurement Directive (Directive 2014/24/EU) provides robust support for embedding environmental considerations in public tenders. It enables contracting authorities to award contracts based not only on the lowest price but on the "most economically advantageous tender" (MEAT), which emphasises the best price-quality ratio. This framework accommodates criteria such as life-cycle costing, technical performance, environmental impact, and social value.

Nonetheless, many Member States continue to default to awarding contracts on the basis of the lowest price. Data from the European Commission shows that 55% of all EU tenders still rely exclusively on this criterion, thereby missing opportunities to incentivise sustainable innovation or account for wider societal benefits.

The absence of mandatory environmental or social criteria limits the strategic use of procurement for climate and environmental objectives. This gap is especially relevant in the construction sector, where public buyers represent a substantial share of demand for major building projects.

From a ZEMCON sites standpoint, this landscape presents both obstacles and possibilities. Procurement procedures remain under-exploited in many areas, yet the legal basis for transformative action already exists.

Municipal authorities already including environmental criteria in their construction tenders lament that they alone do not carry the sufficient demand power to enable market

transformation. However, if Member States and local authorities consistently applied the MEAT approach, placing emission reductions and climate alignment at the centre of award criteria, they could generate substantial demand for zero-emission construction machinery, clean energy infrastructure, and low-carbon logistics by granting preferential market access to cleaner bids.

Achieving meaningful ZEMCON sites deployment requires both clear, ambitious harmonised targets and the integration of these targets into public procurement processes to create lead markets of sufficient size for greener bids, unlocking substantial revenue opportunities for projects that choose zero-emission machinery.

Example | National legislation

Legal certainty in clean machinery procurement in Norway

The April 2025 regulation on emissions from construction sites (FOR-2025-04-03-594) has materially changed the uncertainty landscape for both public and private actors in Norway. By explicitly authorising municipalities, under Section 9 of the Pollution Control Act, to require zero-emission solutions and biogas through local regulations, it resolves earlier doubts about whether general climate requirements could lawfully be imposed on all construction sites, including private projects. For Oslo municipality, this provides a clear and robust legal basis for developing a local regulation on zero-emission construction sites, which has now been sent to public consultation. This reduces legal and political risk and allows climate, air-quality, and noise objectives to be pursued through a coherent, municipality-wide framework rather than only via procurement and individual planning decisions.

For the private sector, the regulation reduces uncertainty about direction while shifting the focus towards implementation details. Contractors, developers, equipment suppliers and financiers can now treat zero-emission and biogas requirements as a credible, long-term regulatory trend and adjust fleet investments, pricing, and project planning accordingly. At the same time, there is remaining uncertainty around how quickly different municipalities will operationalise this new legal authority, how strict their phase-in schedules will be, and how exemptions will be applied in practice. Oslo's ongoing public consultation is therefore an important signal to the market: it provides an early example of how the new national legal basis may be operationalised and offers a reference point for other Norwegian municipalities considering similar measures.

ETS2 & Energy Taxation Directive

Most of the most polluting NRMM categories benefit from low-tax diesel, because the Energy Taxation Directive (ETD) allows Member States to charge below-minimum rates or even fully exempt diesel used in construction. [Revising the ETD to phase out these exemptions would level the playing field for zero-emission machinery, accelerate market uptake, and support the growth of a competitive European clean technology sector.](#)

Despite being covered by the Effort Sharing Regulation, [climate emissions from NRMM remain largely unregulated](#). Today, only the rail sector, which is already highly electrified, is affected by the EU ETS, since the ETS only covers electricity use.

The new ETS2 will apply a carbon price to fuels used by construction, industry, and commercial NRMM, and represents a meaningful step toward internalising the climate costs of fossil fuels in the sector. However, the recently announced delays to ETS2 implementation are a setback, as they reduce the expected economic signal. This particularly affects frontrunners who had counted on lower total cost of ownership to accelerate investments in zero-emission machinery.

3.3. Economic implications & cost mitigation options

The additional cost of zero-emission construction compared to conventional practices is primarily associated with the higher up-front cost and rental prices of electric machinery and the cost of supporting infrastructure. Electric machines are more energy efficient, electricity is generally cheaper than diesel, and with expected increases in CO₂ taxation on diesel, the relative economic advantage of electric alternatives is likely to grow in the coming years.

Achieving cost competitiveness depends on reducing the cost of electric machinery. This requires both lower production costs and reduced investment risk. Production costs are expected to fall as battery technologies improve and as manufacturers shift from prototype-based development to serial production. Battery technology development is largely driven by other sectors and is therefore expected to progress independently of developments in the construction segment. Serial production, however, depends directly on the global market uptake of electric machinery. Small-scale serial manufacturing already exists in parts of the Chinese market for selected machine types, but a substantial reduction in unit costs, from two to three times the cost of conventional machines to competitive levels, requires broader scale-up.

In an early market phase, as seen in most European markets today, investment risk can be mitigated through clear governmental targets and regulatory trajectories that signal future market demand for electric machinery. Direct subsidies for both producers and purchasers (typically rental companies and contractors) can further reduce upfront risk. A combination of long-term policy signals and targeted financial support reduces the barrier to early investment while also securing future demand.

Infrastructure expenses are currently significantly higher for zero-emission construction sites than for conventional operations. This is largely due to the need for high-capacity charging solutions for machinery and mobile battery systems. As machinery technology evolves and battery capacities increase, overnight charging is expected to be sufficient in many applications, with less need for expensive high-power daytime charging. Smaller charging components are also cheaper to develop and are likely to enable more machinery to charge via standard temporary site power connections. In addition, mobile battery systems are

expected to become more affordable as battery technologies mature and as the zero-emission construction market scales.

As with machinery, subsidies can play an important role in the early market phase for actors investing in charging infrastructure, whether contractors or rental companies. Clear regulatory direction can further reduce investment risk and ultimately lower rental prices for charging equipment – this is an area where the Electrification Action Plan could play a mitigating role. Infrastructure-related cost reductions therefore depend on three parallel developments: improved machinery technology, more cost-efficient charging technologies, and increased market demand.

Funding the transition

Transitioning construction sites and machinery to zero-emissions requires targeted public support to bridge upfront costs (machines, batteries, chargers), fund site electrification and grid upgrades, and de-risk early adopters. Public finance can accelerate market formation, but to be durable and defensible, subsidy design should respect international (WTO) rules and EU internal-market constraints while maximising environmental, social and industrial benefits.

EU-level instruments that can finance ZEMCON transition

Although the next EU Multiannual Financial Framework (MFF) for 2028–2034 has not yet been approved, the European Commission and several Member States have made clear that the next cycle will undergo major restructuring. Early political signals suggest the next MFF will consolidate funding streams, strengthen strategic autonomy, and significantly expand support for clean technologies.

The Commission’s 2024–2025 strategic foresight and the Communication on the “Long-term competitiveness strategy” emphasise that the next MFF will likely prioritise:

- **clean industrial manufacturing**, including electric machinery and batteries
- **energy system modernisation**, particularly distribution grids
- **strategic net-zero technologies**, aligned with the Net-Zero Industry Act
- **urban transition**, including clean mobility, building renovation, and local emissions reduction

This signals that electrified construction and ZEMCON sites could be eligible for multiple funding windows, even if specific programmes have not yet been designed.

Some of the former financing lines that are relevant:

- Innovation Fund (EU ETS revenues)
- Connecting Europe Facility – Energy (CEF-E):
- InvestEU
- LIFE Programme
- Cohesion Policy Funds (ERDF / CF)

Ongoing political discussions indicate new or reshaped tools may emerge in the next MFF, including:

- A European Sovereignty Fund (or equivalent) to reduce reliance on non-EU manufacturing, which would be highly relevant given electric construction machinery’s emerging global competition with China.

- Expanded Just Transition Mechanisms to ensure workers and SMEs can adapt to clean industrial requirements, potentially covering training and upskilling for ZEMCON sites operation.
- A dedicated EU Electrification Facility (proposed by multiple think tanks), providing stable support for grid investments, flexible connections, and demand-side electrification, including machinery.

EU state-aid rules and national subsidies

In the EU/EEA, the [General Block Exemption Regulation \(EU\) 651/2014 \(GBER\)](#) is the EU's main legal framework enabling national, regional, and local authorities to provide subsidies for zero-emission construction machinery, charging infrastructure, electrified site power, and related innovation.

While in the EU, state aid is generally prohibited, exemptions are foreseen when addressing market failures. In such cases, the European Commission still needs to approve a state aid scheme to ensure it doesn't distort competition. Nevertheless, in some instances, aid schemes below the given thresholds can be implemented without the need to notify the Commission beforehand. These are the exemptions regulated by the GBER.

Under GBER, several aid categories directly or indirectly cover investments relevant to zero-emission construction machinery, including support for environmental protection, energy efficiency, renewable energy, and innovation.

Notably, Article 36 (*Investment aid enabling undertakings to go beyond Union standards for environmental protection or to increase the level of environmental protection in the absence of Union standards*) regulates the conditions to grant investment aid for the acquisition of equipment that reduces pollution beyond EU standards. Zero-emission excavators, electric site loaders, hybrid cranes, and battery-powered NRMM all fit these criteria when they deliver environmental performance improvements beyond the baseline diesel technologies. This means **national or municipal authorities can grant purchase subsidies, tax reductions, or accelerated depreciation schemes to construction firms adopting cleaner equipment without requiring case-by-case State-aid clearance.**

Explanation | Subsidy rules

For construction machinery, governments cannot subsidise investments that simply ensure compliance with future EU standards already adopted (e.g., NRMM exhaust Stage VI, if it were adopted). However, they can subsidise investments that go beyond any existing or upcoming standard (e.g., switching from diesel NRMM to *zero-emission* machinery, which is not required by any EU standard today).

This is why electric construction machinery subsidies are allowed under Article 36, because there is no EU obligation to electrify construction machinery, and because moving to electric goes well beyond any Union standard. Therefore, the general prohibition does not block aid.

Example | Subsidy programme

Enova subsidy programme: Zero-emission construction machinery

The Enova 2025 subsidy programme for zero-emission construction machinery utilises [Article 36 of the General Block Exemption Regulation](#). This regulatory framework allows Enova to run the programme flexibly and transparently, while supporting Norway's transition to more sustainable construction practices.

The Norwegian state-owned enterprise has been supporting electric construction machinery for several years and, in this way, has played a key role in encouraging early adoption of zero-emission equipment. Initially, the programme offered broad support for a wide range of electric machinery. In recent years, however, the programme has narrowed its focus to specific types of machinery and adopted a competition-based model. Under this system, funding is not guaranteed to all applicants. Rather, projects are evaluated based on criteria of cost efficiency and environmental impact, and only the best proposals receive grants.

Article 36 of the GBER also enables financial support for charging and refuelling infrastructure, which is essential for the commercial viability of electric and hydrogen construction machinery.

Key enabling framework considerations are also covered in Articles 41 (*Investment aid for the promotion of energy from renewable sources*) and 48 (*Investment aid for energy infrastructure*) which regulate aid rules for the rollout of recharging infrastructure and smart grids, permitting public co-funding for both public and private charging points on or near construction sites. This includes stationary charging stations, mobile battery containers, grid upgrades, and temporary power systems that replace diesel generators at construction sites. As long as the aid intensity thresholds and eligible-cost definitions are respected, Member States can design fast-track programmes to remove infrastructure bottlenecks and reduce total project costs for contractors.

In addition, GBER provides strong flexibility for innovation and demonstration projects, which is highly relevant for a sector where zero-emission technologies are still emerging. Articles 25–30 allow funding for experimental development, pilot deployment, testing, and upscaling of new machinery types or site-management systems. For example, public authorities can support OEMs developing next-generation battery packs for heavy NRMM, contractors piloting all-electric construction sites, or digital systems for optimising energy use in machinery fleets. Such aid measures do not require prior notification as long as they meet the specific criteria on eligible costs, collaboration requirements, and maximum funding intensities.

Example | Subsidy programme

Netherlands — SSEB (Schoon en Emissieloos Bouwmaterieel).

The [Dutch SSEB](#), aside from setting out the roadmap presented in the previous section, includes a purchase subsidy that provides support for buying or leasing zero-emission construction equipment and retrofits, which directly reduces upfront cost barriers for contractors and rental companies. This scheme demonstrates how a focused national purchase subsidy accelerates fleet turnover.

The subsidy scheme includes a variety of programmes including subsidies for innovation, purchasing and retrofitting.

Practical incentives and subsidy instruments suited to ZEMCON

Subsidies and financial incentives, paired together with a clear political mandate, have proven instrumental to the transition in some of the selected cities. Below is a non-exhaustive, representative list of potential incentives that could be set in place by public authorities.

- **Purchase subsidies (grants or vouchers) for electric NRMM.** These reduce upfront price gaps and accelerate fleet turnover. Best practice: run open, transparent voucher schemes, apply technology-neutral performance criteria (e.g., minimum operating hours, emissions per kWh), cap per-unit amounts, and avoid domestic-sourcing conditions. Such schemes fit within GBER categories if designed as environmental investment support.
- **Investment tax incentives.** Tax measures can reduce effective capital cost and accelerate investment in zero-emission technologies.
- **Innovation & system demonstration grants.** Support R&D, piloting of bidirectional charging, battery swapping, retrofits and standardisation. While the technology is already proven, grants that allow municipalities to set up and test the necessary administrative and technological mechanisms would certainly speed up the transition, especially if lessons learned are shared afterwards with other regions.
- **Public procurement & aggregated demand-pull mechanisms.** Public authorities can use procurement award criteria to require or reward ZE machinery. Aggregating demand across municipalities reduces price premium over time and enables industry to have a long-term demand signal.
- **Charging & grid infrastructure grants.** Granting funds for temporary and permanent site electrification, mobile substations, and depot chargers is strongly defensible as public infrastructure. Infrastructure funding should be designed to be open-access where technology allows and follow transparent procurement for works.

- **Battery leasing & OPEX support.** Because batteries drive upfront cost, public support for battery leasing programmes (where batteries are owned by third-party lessors) reduces CapEx and can be structured as market-based services rather than direct purchase subsidies, which can be particularly helpful for small contractors.

Example | Subsidy programme

Early-mover incentive from the Swedish Transport Agency

Infrastructure bodies at national level are promoting the transition. The Swedish Transport Agency has set up an early-mover financial incentive, where [they award a bonus in all new contracts of SEK 2.50 per kWh of electricity used for heavy vehicles and work machines in our contracts](#). It is now being introduced in all new construction contracts and is valid until 2029.

While this bonus does not cover the entire cost, it is a strong incentive for the transition. With the bonus as a basis, the Swedish Transport Administration intends to create the conditions for being able to set requirements for heavy, zero-emission vehicles and work machines, from 2030 at the latest.

The zero-emission bonus is one of several steps and needs to be supplemented with research, development and demonstration projects with the aim of building knowledge and highlighting measures that are currently not profitable, or where there are other obstacles to introducing them.

The first step in this is the RFI, Request For Information, that the Swedish Transport Administration has for heavy zero-emission trucks in basic road maintenance, winter road maintenance. More system demonstrations are expected in the future.

Final remarks on policy and legal options

The analysis above demonstrates that Europe already possesses a strong legal and policy foundation capable of supporting a rapid transition towards zero-emission construction sites. While existing constitutional guarantees, EU directives, and worker-protection standards were not originally designed with construction decarbonisation in mind, they unmistakably place clear duties on public authorities to reduce air and noise pollution and protect the health of both residents and workers. The revised Ambient Air Quality Directive stands out as the most powerful driver of near-term action, imposing binding obligations on Member States (and by extension, regions and municipalities) to meet strict pollutant limits. Complemented by worker-safety legislation, the regulatory landscape creates a compelling rationale for phasing out diesel machinery and for promoting electric alternatives as the most effective means of protecting public health.

At the same time, significant policy gaps persist. The current NRMM Regulation does not address climate emissions, the Clean Vehicles Directive still excludes construction machinery, and the delay in ETS2 weakens the economic signal that frontrunners relied upon to justify

early investments in zero-emission machinery. Yet these gaps also represent major opportunities. The Electrification Action Plan, the European Grids Package, the revision of the Clean Vehicles Directive and of the Public Procurement Directives, and the introduction of whole-life-carbon requirements under the EPBD all have the potential to bring construction-phase emissions firmly into the core of EU climate and industrial policy. Taken together, these upcoming reforms could create the clarity and market certainty needed for zero-emission machines to scale, improve competitiveness for European OEMs, and align public procurement practices with long-term environmental goals.

To fully realise this potential, **public authorities at all levels of governance have a decisive role to play.**

Municipalities can integrate ZEMCON sites requirements into air-quality planning, noise-management strategies, and tenders for public works, demonstrating compliance with EU law while activating substantial local demand. Regions can coordinate grid planning, permitting, skills programmes, and financial incentives that lower risk for early adopters. Member States can establish ZEMCON-aligned national WLC roadmaps under the EPBD, remove fossil-fuel tax exemptions under the Energy Taxation Directive, mandate MEAT-based procurement, and advocate for stronger EU-level standards for non-road mobile machinery. At the EU level, legislators can close remaining regulatory gaps, set a clear timeline for phasing out fossil-fuel NRMM, and design funding instruments that accelerate electrification, infrastructure upgrades, and industrial scaling.

Ultimately, achieving zero-emission construction sites is not only technologically feasible but fully aligned with Europe's legal obligations, public-health goals, and industrial competitiveness agenda. The tools already exist; what remains is for public authorities to apply them consistently and ambitiously. By coordinating action across governance levels, Europe can turn construction sites from overlooked sources of pollution into visible milestones of urban sustainability, cleaner air, safer working conditions, and a resilient, future-proof industrial base.

Annexes

A.1 About collaborating consultancy teams

A.2 Methodology

A.3 Interaction between EU, national and local policy frameworks

A.4 Distribution of competences across EU, national and local levels



A.1 About the collaborating consultancy teams



Hafslund Rådgivning

Hafslund Rådgivning is a consulting division within Hafslund, the second largest renewable energy producer in Norway. Hafslund has more than 120 years of experience with renewable power generation. The company plays a central role in developing a renewable, smart, and fully electrified zero-emission energy system in Norway.

Hafslund Rådgivning was established to ensure that the expertise and experience accumulated within the group are available for sharing. Climate goals and significant electrification targets in the coming years will impose new requirements on various players across different industries. Hafslund Rådgivning is a consultancy firm that assists public and private entities with challenges related to transitioning to emission-free solutions. The team aims to simplify, streamline, and make the transition profitable, aiding the most forward-thinking market players. Hafslund Rådgivning has supported major transport operators, ports, contractors, and municipalities in reducing emissions, becoming more energy-efficient, and operating fully electric.

Hafslund Rådgivning employs individuals with deep insight into the technical, economic, and regulatory challenges faced by various businesses, drawn from operational experience across multiple industries and relevant expertise in climate policy from the public sector. As part of the Hafslund group, Hafslund Rådgivning can leverage internal development expertise and connect clients with business developers to swiftly implement profitable initiatives.

Visit Hafslund Rådgivning's website [here](#).



Bellona

The Bellona Environmental Foundation is an international, science-based, non-profit organization with offices in Oslo, Brussels, Berlin & Vilnius. Founded in 1986 as an action and protest group, Bellona has evolved into a recognized technology- and solution-oriented organization with offices in Oslo, Brussels, Berlin, and Vilnius. Today, more than 70 engineers, ecologists, physicists, chemists, economists, political scientists, and journalists work at Bellona. The foundation strives to identify and implement sustainable solutions to the world's most pressing environmental issues. Its main goals are to combat the climate crisis, environmental degradation, pollution-induced hazards to human health, and the ecological consequences of economic development strategies.

Bellona's work is rooted in a firm belief that it is possible to address environmental challenges in a constructive and progressive manner, and that industry and business can adapt to new challenges provided they have the right long-term and predictable framework conditions.

Thus, Bellona aims to be a bridge between industry and decision-makers, working closely with the former to help them respond to environmental challenges within their fields and proposing policy measures that accelerate the deployment of new technology with minimal impact on the environment. Bellona is accredited and has observer status in the UNEP Governing Council, UNFCCC, and IMO.

Visit Bellona's website [here](#).

A.2 Methodology

Part 1: Baseline assessment methodology

Part 1 of the assignment focuses on establishing a baseline assessment for the European construction sector and is carried out as Work Package 1. The work package is designed to provide a European-level baseline across regions, with emphasis on market characteristics, energy use, emissions, and other environmental impacts. The resulting deliverable will inform the selection of regions for subsequent work packages and create a shared evidence base for the transition to ZEMCON. Methodologically, Work Package 1 follows a structured approach consisting of four main activities: kick-off and scope alignment, sector profiling, environmental performance mapping, and comparative maturity and scoping.

Activity A1.1: Kick-off and scope alignment

The team arranged a kick-off meeting, first internally and then together with NetZeroCities and the City of Oslo. In the meeting with the client, we agreed on the scope, timeline, and deliverables. We discussed the approach to Work Package 1 and reviewed the key focus areas to ensure the project delivers the desired outcomes. We also received input on potential data sources to be used and agreed that stakeholder involvement will be essential and must be planned early. The meeting further clarified the division of roles between the different parties.

The meeting also confirmed that the baseline assessment will focus on European markets at the country level, while subsequent work packages will shift the focus towards European cities as target markets. The geographical scope of the baseline assessment, i.e. European countries to include, were selected according to the following criteria:

- Construction market size
- Expected growth of construction machinery sector and the extent to which the country has a focus on European industry that can contribute to building an industry in Europe
- Existing ZEMCON projects, pilots or initiatives present in the country
- Geographical representation (at least one country representing Southern Europe and Central Easter Europe)
- Data availability

Activity A1.2 Sector profiling

As part of the baseline assessment, we conducted sector profiling to provide a comparative analysis of construction activity across European countries. The profiling considered market size (turnover, employment, procurement), and the role of public sector purchasing power. Where available, data on lead markets for zero-emission machinery and ownership models were also examined. This step was essential for identifying structural differences across countries that affect the potential for ZEMCON adoption.

The baseline assessment was conducted through desk research and data collection from publicly available sources. We compiled the best available quantitative data on construction sector metrics from sources such as Eurostat, the European Construction Sector Observatory, and FIEC (European Construction Industry Federation) reports. Macroeconomic indicators (e.g. national construction output, GDP contribution, procurement volumes) and employment figures were obtained to characterise market size.

Employment data for the construction sector (NACE Rev. 2, F classification) were collected from two sources. First, we used the data mapper of the European Construction Observatory (ECOSO), which provides employment levels in EU Member States up to 2021. To estimate employment for 2023 and 2024, we relied on the Labour Input in Construction database from Eurostat, using the indicator “*number of persons employed.*” This database provides quarterly labour indexes for construction across Member States up to 2025 (based on a 2021 baseline). Quarterly employment figures for 2023 and 2024 were calculated from these indexes, and annual employment estimates were derived by averaging the quarterly values.

To estimate the volumes and shares of public procurement in European countries (excluding Norway), we relied on the 2024 study by Wyns, Kalimo, and Khandekar, titled “Public Procurement of Steel and Cement for Construction: Assessing the potential of lead markets for green steel and cement in the EU”. The report adopted a bottom-up approach based on public data from 2019, including FIEC (2022) and Euroconstruct (2021) reports on public investment in civil engineering and non-residential construction, as well as Eurostat data on investment in public housing and gross capital formation in the construction sector (Tomas Wyns, 2024).

We then proceeded with qualitative assessment of ZEMCON's preparedness in various European cities by examining policy documents, official communications, and media sources. The analysis focused on identifying and summarising data on cities that have implemented or announced zero-emission construction site requirements, incentives, pilot projects, or defined targets. We also engaged with EU city networks, such as the Big Buyers Working Together Community of Practice on Zero-Emission Construction Sites and gathered input from procurement officials (via meeting minutes or targeted surveys to members of the Community of Practice).

Data Gaps identified:

- Absence of integrated employment data platform.
- Differences in data over time highlight a gap in temporal comparability.
- Noise pollution associated to construction.
- Country-level non-road mobile machinery air pollution (NO_x, PM_{2.5}) is currently best described for construction and manufacturing together from Eurostat. Future work should aim to split these.

Activity A1.3 Environmental performance mapping

As part of the baseline assessment, we mapped environmental performance indicators related to construction activity across the selected countries. The analysis focused on greenhouse gas (GHG) emissions, air pollutant emissions, energy use, and noise. Together, these provide a cross-country comparison of the environmental footprint of the construction sector and its potential implications for zero-emission construction machinery.

The environmental performance assessment was conducted through desk research and data collection from official statistical sources. For greenhouse gas and air pollutant emissions, we relied primarily on Eurostat datasets. Greenhouse gas estimates were taken from the 2023 Air Emissions Accounts (AEA), which attribute emissions to the construction sector (NACE F: buildings, civil engineering, and specialised construction) on a residence-based basis. Air pollutant data (NO_x, PM_{2.5}) were drawn from [Eurostat's 2023 inventory](#) under NFR 1A2gvii, which covers mobile combustion in manufacturing industries and construction, including non-

road mobile machinery (NRMM) such as off-road construction equipment. These two datasets therefore represent distinct but complementary system boundaries: the AEA provides a sectoral perspective on total construction-related emissions, while the NFR dataset isolates pollutants from construction and manufacturing machinery. Both were the latest available sources at the time of analysis.

To contextualise construction-related emissions within national energy systems, we linked sectoral CO₂ estimates with country-level electricity generation data. National electricity statistics were obtained from Our World in Data's 2024 energy database, which provides harmonised, cross-country figures on generation levels and fuel mixes. Construction energy use was estimated indirectly by converting reported CO₂ emissions from the sector into energy demand. We applied the default IPCC (2006) emission factor for diesel combustion (74,100 kg CO₂/TJ), assuming diesel as the representative fuel, and expressed results in terawatt hours (TWh) using the IPCC AR6 Annex II conversion factor (1 TJ = 0.0002778 TWh). This approach links environmental and energy statistics to approximate the construction sector's theoretical electricity-equivalent demand, which was then benchmarked against national electricity generation levels.

Each country's energy system was further characterised by generation mix. Sources were grouped into three categories: Baseload (nuclear, coal, and 65% of gas), Flexible (hydro—75% considered dispatchable—plus the remainder of gas, bioenergy, geothermal, and oil), and Intermittent (wind, solar, and the non-dispatchable share of hydro). Where no single category exceeded 50%, or where two categories were close in share (within 10 percentage points, with the top ≥40%), the system was classified as Mixed. This provides a consistent rule-based framework for interpreting the interplay between construction energy demand and electricity supply characteristics.

Noise pollution was also considered, but no pan-European dataset exists that consistently isolates construction-specific noise. Under the Environmental Noise Directive (END), noise reporting typically covers road, rail, aircraft, and large industrial sources, but not construction separately. At country level, the European Environment Agency (EEA) provides strategic noise maps, country fact sheets, and the Noise Observation & Information Service for Europe (NOISE). These resources will inform further work at city level, where construction noise data may be more readily assessed.

Data gaps identified:

- Lack of construction-specific noise datasets at the European level.
- Current pollutant data for non-road mobile machinery (NO_x, PM_{2.5}) combine construction and manufacturing; disaggregation would improve accuracy.
- Construction energy demand can only be approximated indirectly via CO₂ emissions and assumed fuel factors, limiting precision.
- Differences in system boundaries between GHG (AEA) and pollutant (NFR) datasets may affect comparability across indicators.

Activity A1.4 Comparative maturity and scoping

The maturity matrix was established using data collected and structured in Excel, with a visual representation developed in Grunt. Grunt retrieves data directly from the Excel file, ensuring that the matrix can be easily updated as new information becomes available. The matrix combines quantitative data and qualitative assessments to provide a consolidated overview. It summarises the status in each country while highlighting NetZeroCities with ZEMCON

activities, thereby creating a foundation for the subsequent selection of markets in the next work package.

Part 2: Road mapping and impact assessment methodology

Part 2 of the assignment focuses on assessing the impacts of a large-scale transition to zero-emission construction (ZEMCON) across Europe and is carried out as Work Package 2. The work package aims to evaluate technical feasibility, cost implications, and strategic relevance for the EU, building on the regional baseline established in Work Package 1. Methodologically, the work follows a structured analytical process consisting of four main components: selection of focus regions and regional assessment, cost assessment, energy system impact analysis, and strategic and environmental implications.

Each analytical component combines quantitative and qualitative methods to provide a comprehensive understanding of the transition potential in selected regions. The analysis integrates market data, expert interviews, and scenario-based modelling to assess how ZEMCON solutions may affect construction practices, costs, and energy systems at the city and regional level.

Activity A2.1 Selection of focus regions

As part of the project, a key task was to identify a set of 5–10 priority regions for further analysis. In agreement with the City of Oslo and NetZeroCities, it was decided to focus on a smaller number of regions to enable a more in-depth assessment.

During Work Package 1, an initial market screening was conducted at the country level. Based on this, it was agreed that subsequent work packages would focus on target markets at the city level. Following this approach, five regions (or city markets) were selected, with Oslo serving as a reference case.

The selected cities represent a diversity of market contexts, in terms of construction activity, city size, and maturity of ZEMCON practices. The selection was guided by the following criteria:

- Different levels of ZEMCON maturity
- Participation in the NetZeroCities programme
- A mix of larger and smaller cities
- Focus on the European construction industry
- Geographical distribution of cities

Cities participating in NetZeroCities were prioritised not only because of their climate ambitions, but also due to their accessibility through established networks closely connected to the project. This facilitates validation of findings and supports the generation of insights that are relevant and transferable across different urban contexts.

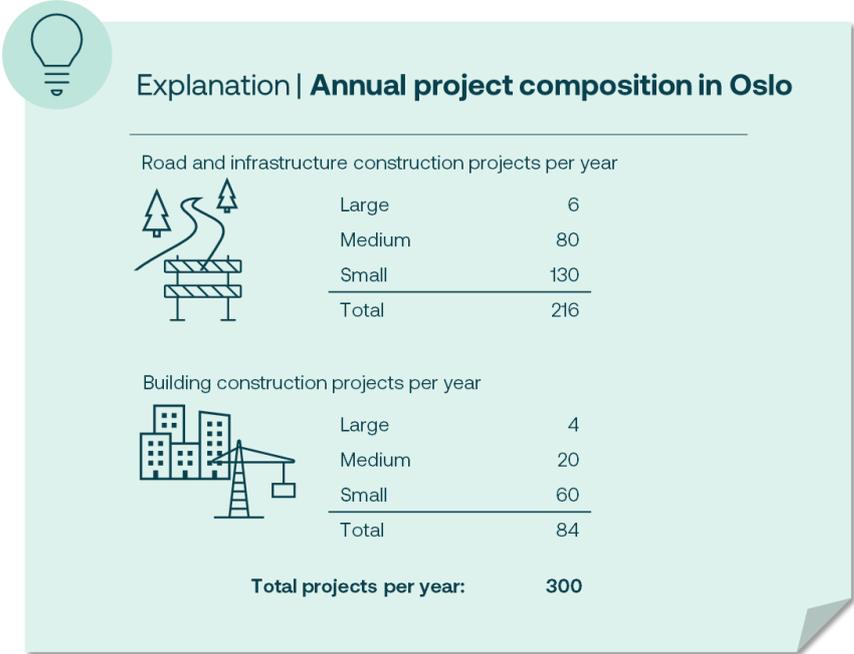
Activity A2.2 Cost assessment

We apply a cost assessment methodology consistent with the approach developed for the Norwegian Environment Agency (Oslo Economics, Hafslund Rådgivning, 2025). The analysis estimates both the short- and long-term cost implications of transitioning to zero-emission machinery and construction practices across European cities. Oslo is used as the reference case, and costs are then adjusted according to the market characteristics of each selected city to obtain city-relative estimates.

The total cost is broken down into four main components: machine cost, energy cost, infrastructure cost, and operational challenges. A bottom-up approach is used to create the reference case for Oslo, with one reference project for building construction and one for

infrastructure construction. The composition of projects (small, medium, and large) for building and infrastructure construction is based on market insights from a study done for the City of Oslo by Hafslund Rådgivning in 2025 (*Power demand for climate actions*), corresponding to approximately 300 projects per year.

Machine costs, energy costs and project cost is adjusted from the reference projects to each project size by the number of machines for a typical project (small – 5 machines, medium sized – 15 machines, large – 50 machines). Infrastructure costs and operational challenges costs are not proportional to the number of machines due to advantages with larger fleet of machinery. One can use the infrastructure components more effectively and can reduce the amount of operational challenges with less equipment and more potential from learning by using more equipment.



The additional cost per project and project size is calculated, multiplied by the total number of projects, and then averaged to obtain the additional cost for a typical project in Oslo. This cost is then expressed as a share of the total project cost (i.e., enterprise contract value).

Machine cost

Machinery investment prices are collected from Norwegian equipment operators, and the machine fleet is based on the reference projects for Oslo (Oslo Economics, Hafslund Rådgivning, 2025). It is assumed that an electric machine has a retail price that is 2-3 times more expensive compared to a diesel machine, which was the case when the study for Norwegian Environment Agency was conducted (Oslo Economics, Hafslund Rådgivning, 2025). While this may not yet be the case in all countries, it is expected that market maturity and increased production volumes will reduce this gap before full electrification takes place. A machinery price factor is calculated to adjust for the difference in machinery price in different markets based on Eurostat machinery investment index (Eurostat, 2025) and market characteristics.

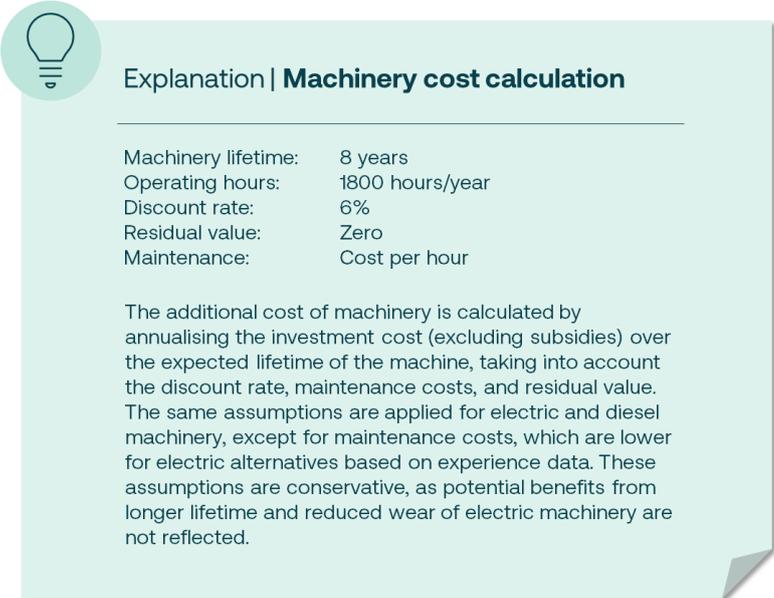


Table 5: Machine price factor per market based on Eurostat machinery investment index (Eurostat, 2025) and market characteristics.

	Machine price factor
Oslo - Reference	1,0
Stockholm	0,9
Eindhoven	0,8
Munich	0,8
Barcelona	0,7
Budapest	0,6

Energy cost

Energy consumption is estimated based on a bottom-up approach with reference projects in Oslo (Oslo Economics, Hafslund Rådgivning, 2025), adjusted for the project size based on typical number of machinery. The energy cost is then calculated by multiplying energy consumption by local electricity and diesel prices in each country.

Table 6: Energy prices per market for diesel and electricity (Cargopedia, 2025) (Eurostat, 2025)

	Diesel price [EUR/L]	Electricity price [EUR/kWh]
Oslo - Reference	EUR 1,14	EUR 0,10
Stockholm	EUR 1,37	EUR 0,11
Eindhoven	EUR 1,56	EUR 0,20
Munich	EUR 1,44	EUR 0,23
Barcelona	EUR 1,41	EUR 0,18
Budapest	EUR 1,36	EUR 0,21

Infrastructure cost

Rental prices and equipment costs for charging infrastructure are collected from Norwegian suppliers. Adjustments are made for each city based on assessments of grid capacity. The time required to obtain a grid connection is not included in the infrastructure cost, but is assumed to be resolved prior to project implementation.

Table 7: Infrastructure characteristics and price factor per market

	Grid capacity	Infrastructure price factor
Oslo - Reference	Moderate	1,0
Stockholm	Limited	1,3
Eindhoven	Limited	1,0
Munich	Moderate	1,3
Barcelona	Limited	1,3
Budapest	Limited	1,3

Operational challenges

Operational inefficiencies and productivity losses are estimated as 10% of the additional cost observed in the reference project for Oslo (Oslo Economics, Hafslund Rådgivning, 2025). This factor is adjusted for each city based on the assessed ZEMCON market maturity.

	ZEMCON maturity
Oslo - Reference	Advanced
Stockholm	Moderate
Eindhoven	Advanced
Munich	Low
Barcelona	Low
Budapest	Low

Additional cost as share of total project cost

The additional cost for an average project is then calculated for each city. To determine the share of this additional cost relative to the total project cost, the baseline project cost for Oslo is adjusted to reflect local market characteristics. These adjustments are based on an assessment of cost drivers such as regulatory environment, material and labour costs, and geographical factors (e.g. cold climate or mountainous terrain). The cost drivers are evaluated as either High, Moderate or Low based on the market characteristics. The adjustment factor is then calculated by using the value 5 for High, 4 for Moderate and 3 for Low. The results for the market adjustment factor are compared against the Purchasing Power Parity (PPP) Index from Eurostat (Eurostat, 2025), which provides a measure of end-user purchasing power, though not always representative of construction cost differences. For example, city popularity may increase end-user prices without a proportional rise in construction costs.

	Regulations	Materials	Manpower	Geographical
OSLO	High	High	High	High
STOCKHOLM	High	Moderate	High	High
EINDHOVEN	Moderate	High	High	Moderate
MUNICH	High	Moderate	Moderate	Moderate
BARCELONA	Moderate	Moderate	Moderate	Low
BUDAPEST	Low	Low	Low	Low

Finally, the additional cost is expressed as a percentage of the total project cost by multiplying the Oslo reference project cost by the city-specific market adjustment factor and dividing the calculated additional cost by this value.

Additional cost for different market maturity phases

The additional cost for the different market maturity phases are calculated by using the cost characteristic scenarios as explained in chapter 2.2.3 Cost assessment. These characteristics are adjusted for

Activity A2.3 Energy system impact

To assess how a full transition to zero-emission construction affects the energy system in each of the selected cities, the analysis combines publicly available data with project-level calculations and explicitly stated assumptions where required. Energy system impacts are assessed along two dimensions: power demand and energy demand. The applied methodology is aligned with the approach used in the cost assessment to ensure internal consistency across analyses.



Explained | **Power vs. Energy – What's the difference?**

Power (Watt, kilowatt (kW), megawatt (MW), etc)

Power tells us *how fast* electricity is being used or produced right now. Think of it as the speed of energy flow — like how quickly water runs through a hose.

Power is the most important factor when considering available capacity in the power grid as every grid component has an upper limit of how much power it can transmit at any given time.

Energy (kilowatt-hours (kWh), megawatt-hours (MWh), etc)

Energy is the *total amount of electricity used or produced over time*. Think of it as the amount of water that has accumulated after running through a hose. Energy is the integral of instantaneous power over time.

Example: If a heater with a power of 1 kilowatt (kW) runs for 3 hours, it uses 3 kilowatt-hours (kWh) of electricity.

Power demand

Power demand is estimated as the aggregated peak demand required to operate electrified construction sites within each city. The calculation is based on the estimated number of construction projects per year multiplied by an average project-level power demand.

The reference power demand per project is derived from the lower-bound estimates developed by Hafslund Rådgivning for the City of Oslo in 2025 (Power demand for climate actions). These estimates are based on empirical input from contractors and industry actors currently operating zero-emission construction sites and include electricity demand for both construction machinery and site huts. Power demand is differentiated by project type and size, covering small, medium-sized and large projects within building, road and infrastructure construction, and accounts for the expected number of projects operating simultaneously.

To reflect more realistic future conditions, several adjustments are applied to the reference estimates. Total power demand is reduced by 10% to exclude demand associated with site huts, and by an additional 20% to reflect a shift from fast charging during daytime operation towards increased use of overnight charging. Furthermore, accumulated experience and improved planning are assumed to reduce conservative over dimensioning of grid capacity, as industry experience indicates that many projects currently reserve more power than is ultimately utilised.

As a consistency check, the results are validated against simplified bottom-up estimates. Assuming an average charging power of 40 kW per machine, eight machines per project, simultaneous peak demand in 50% of projects, and approximately 300 active projects per year in Oslo, the implied peak demand is around 48 MW. This is broadly consistent with the modelled estimate of approximately 55 MW.

Energy demand

Annual energy demand is estimated using a bottom-up approach focusing exclusively on electric construction machinery. Other equipment and heavy-duty vehicles are excluded from the analysis. The methodology builds on detailed project-level data developed by Hafslund Rådgivning for the Norwegian Environmental Agency (Oslo Economics, Hafslund Rådgivning, 2025), covering two representative reference projects: one building construction project and one road construction project, and as explained in the cost assessment methodology.

Energy consumption is first calculated on a per-project basis, accounting for the higher efficiency of electric machinery compared to diesel-powered alternatives. Annual energy

demand is then derived by combining energy use per project with estimates of the number of projects per year, differentiated by construction type and project size. Scaling factors are applied based on typical machinery composition, assuming an average of five machines for small projects, fifteen machines for medium-sized projects, and fifty machines for large projects.

The estimated number of construction projects per year in each city is based on Oslo as a reference case, with an annual volume of approximately 300 projects. This figure was then scaled for each city according to population size. In addition, an adjustment was made to reflect differences in construction activity between cities, drawing on a ranking from Expert Market Research that compares construction activity levels across major European urban areas. Based on this, the number of projects was adjusted upwards for Barcelona and Budapest. Interviews with city representatives have been conducted, but due to limited availability of data on construction activity and a lack of accessible sources, estimates have been used for the annual project composition.



The calculated electric energy use due to ZEMCON, is compared to the expected electricity as of 2040 based on estimates on power consumption from ENTSO-e. As emissions from power production varies significantly between the countries this will also have an impact on the associated greenhouse gas emissions from power production and the net reduction in emissions. The net reductions in GHG-emissions are calculated by comparing emissions from the use of fossil fuels to emissions from power production in the different countries.

A list of sources used are provided in the table below:

Parameter	Sources
Electricity price (incl. tax and levies, non-household consumers)	Eurostat
National power system data	ENTSO-e statistical factsheet 2024
Carbon intensity of power generation	Our World in Data
Electricity consumption per city	Statistics Sweden , Stadtwerk München , Energia Barcelona , Hungarian Statistical Office , Klimaatmonitor NL

Activity A2.4: Strategic and environmental implications

Environmental implications

The environmental implications of the transition to ZEMCON include reductions in greenhouse gas (GHG) emissions, decreased air pollution and improved air quality, as well as noise reduction. The methodology applied for each of these aspects combines quantitative bottom-up calculations with a qualitative discussion of existing statistics and the observed impacts of the ZEMCON transition in the selected cities. The specific methodology applied for each calculation is described below.

CO₂

The reductions in CO₂ emissions are calculated by estimating emissions from the use of fossil diesel (emission factor of 2,66 kg CO₂/litre) where the diesel volume originates from the average project from Oslo (referred to in the above section) times the number of estimated projects in each city. These fossil emissions are then compared to the emissions from power generation of the equivalent projects using electric machinery. The CO₂ emissions from power production is based on the emission intensity factor (g CO₂/kWh electricity) of electricity production in each country (Ember Energy Research CIC, 2025). The reduction in GHG emissions is the difference between these results. Our estimates for Oslo is validated by comparing the result with numbers shared by the Norwegian Environment Agency. Our estimates shows total CO₂ emissions as 41 thousand tonnes, while numbers from the Norwegian Environment Agency shows emissions of 45 thousand tonnes (Norwegian Environment Agency, 2024).

For commenting on the environmental implications of these emission reductions in each city, the reduction is compared to the average emissions from a car to show the equivalent number of cars. There is no single source stating the greenhouse gas emissions of all the investigated cities, so the numbers used for the calculations is a mixture of public statements from local officials and governments, and where such statements were unavailable the emissions has been calculated based on emissions per capita in each respective country, some statements might be older than others so that the absolute numbers should just be used as an indication.

Air quality and pollution

The reduction in emissions of NO_x and PM_{2.5} was estimated through a bottom-up analysis based on energy use in representative construction projects. Emission factors were sourced from EU regulations for different engine stages (ICCT, 2016), and we applied city-specific assumptions for the distribution of engine types in use. These assumed shares, along with the corresponding emission factors for each engine stage, are presented in the tables below.

Table 8: Assumed share of different stages for NRMM in each city

City	Share of machinery by stage in city			
	II	III (A+B)	IV	V
Eindhoven	0 %	30 %	30 %	40 %
Oslo	0 %	0 %	30 %	70 %
Stockholm	0 %	30 %	30 %	40 %
Munich	0 %	30 %	30 %	40 %
Barcelona	10 %	30 %	30 %	30 %
Budapest	10 %	40 %	30 %	20 %

Table 9: Emissions of NO_x and PM_{2.5} per kWh for different stages for NRMM

Stage	II	III (A/B)*	IV	V
NO _x (g/kWh)	7	3	0,4	0,4
PM _{2.5} (g/kWh)	0,4	0,1125	0,025	0,015

*Average of emissions for stage IIIA and IIIB used.

The total emissions were then calculated by multiplying the emission factors by the estimated energy consumption per typical project and the number of relevant projects in each city, as described above.

Noise

To provide a general indication of the current impact of construction noise in the selected cities, we estimated the number of people affected by noise exceeding European thresholds from construction sites. The EU noise thresholds under the Directive are set at 55 decibels (dB) for the day-evening-night period (L_{den}) (EEA, 2025), and noise exceeding this threshold over time is considered bothersome and can in cases with higher noise levels or longer time periods be harmful. The assessment used a typical decibel level for construction machinery of 86 dB at approximately 15 m (Illingworth & Rodkin Inc., 2022), combined with a general sound attenuation model, where the noise level decreases by 6 dB per doubling of distance from it for a point source in free space. In this study we define average noise levels at 55 dB or above as bothersome, and average noise levels that exceed approximately 60 dB as harmful.

This gives an approximate noise level of 75 dB at 50 m from the source and 70 dB at 100 m from the source. To calculate the average noise levels over 24 hours we have assumed the following distribution of noise levels throughout the day, including ten hours of construction activity:

Noise source	Noise level (dB)	# of hours per 24h
Construction site	76 (50 m)/69 (100 m)	10
Evening, background	55	4
Night, background	45	10

This gives the following average noise levels at 50 m and 100 m:

Average noise level at 50 m	60 dB
Average noise level at 100 m	57 dB

Further reductions in noise levels at 100 m were assumed due to the presence of buildings and vegetation, and the radius of the affected area for bothersome noise levels (55 dB) was therefore kept at 100 m. The final assumed radius of bothersome and harmful noise levels then gives an affected area of approximately 31 400 m² and 7 850 m². The affected area was then multiplied by the number of construction projects and local population density to estimate the number of people currently exposed to bothersome levels of construction noise in each city. The following population density was used for each city:

Table 10: Population densities per city

City	Population density (capitas/km²)
Eindhoven	2 394
Oslo	1 699
Stockholm	5 012
Munich	4 736
Barcelona	15 991
Budapest	3 337

Strategic implications

Strategic implications of the ZEMCON transition in Europe is done through a qualitative assessment.

Part 3: Policy and legal options methodology

Part 3 of the report investigates the legal frameworks (A.3.1) that enable the adoption of zero-emission construction machinery, policy recommendations (A.3.2) at different levels of governance to promote the rapid scaling of ZEMCON sites, provides a map for stakeholder engagement (A.3.3), and outlines economic implications and cost-mitigation strategies for the large-scale deployment of ZEMCON sites (A.3.4).

For activity **A.3.1**, an analysis of international treaties, constitutional provisions, European primary and secondary law, and Europe-wide case law was conducted. Additionally, there was extensive desk research of official communications from European and national courts, as well as from environmental civil society organisations, regarding concluded and ongoing litigation.

For activity **A.3.2** the assessment covers the analysis of national and local best practices for geographies characterised by the early-adoption of targeted incentives, regulatory measures, and public-sector mandates for zero-emission construction machinery. Their approaches served as reference points for identifying scalable and transferable policy measures. We then linked these best practices to the existing EU policy framework. Desk research on relevant regulations and directives, as well as communications and strategies, was conducted, with a keen focus on policies concerning public procurement, industrial strategy, clean mobility, and environmental and climate legislation. Finally, the analysis identified practical policy levers and pitfalls and highlighted actionable opportunities for policymakers at all levels.

Activity **A.3.3** focused on the outreach for the validation of findings on municipal ambitions, policy instruments, and ongoing zero-emission construction pilots across Europe. Information collected through this outreach is organised into a comparative matrix. Further, two semi-structured interviews were conducted with two selected municipal authorities. These interviews explored in more detail how cities design and operationalise policies for zero-emission construction sites, the challenges they encounter, and the types of support they consider necessary. The final component involves engagement with city networks and relevant civil society organisations. This engagement prepares a dissemination event to share the report's results.

To complete activity **A.3.4**, desk research of the latest European Union's communications regarding the Multiannual Financial Framework was undertaken, as well as of national examples of subsidies for zero-emission machinery. Furthermore, a legal analysis of the EU's state aid rules and exemptions was performed.

A.3 Interaction between EU, national and local policy frameworks

EU policy interacts with national and local policies through a system of shared, complementary and hierarchical responsibilities, designed to ensure common objectives across the Union while allowing flexibility in implementation. Understanding this interaction is key to interpreting how EU goals—such as environmental protection or decarbonisation—translate into concrete action on the ground.

At the EU level, policies are set through treaties, regulations, directives and strategies. Regulations apply directly and uniformly in all Member States, without the need for national legislation. Directives, by contrast, define objectives and minimum standards that Member States are legally required to achieve, while leaving them discretion over how to implement those objectives. EU strategies and action plans (such as the Zero Pollution Action Plan) are not legally binding but shape legislative priorities, funding and future regulatory developments.

At the national level, governments are responsible for transposing EU directives into national law and for ensuring compliance with EU obligations. This often involves adopting legislation, defining enforcement mechanisms, and assigning responsibilities to regional or local authorities. National policies may go beyond EU minimum requirements, but they cannot fall below them. National authorities also act as intermediaries, translating EU-wide objectives into national strategies that reflect domestic administrative structures, economic conditions and political priorities.

At the local and regional level, authorities are typically responsible for implementation and enforcement. In areas such as air quality, noise management, urban planning and public procurement, EU law often explicitly requires action at the local level, for example through the adoption of air quality plans, noise action plans or procurement criteria. While local authorities must act within the framework set by EU and national law, they usually retain discretion to choose the most appropriate measures for their local context, including setting stricter requirements where legally permitted.

Overall, EU policy establishes a common direction and binding baseline, national policy translates this into enforceable domestic rules, and local policy delivers practical outcomes through planning, permitting, procurement and enforcement. Rather than operating in isolation, these levels are interdependent: EU law often relies on local action to achieve its objectives, while local authorities increasingly draw on EU obligations to justify ambitious measures, such as requirements for zero-emission construction sites.

A.4 Distribution of competences on EU, national and local levels

In the EU system, competences define which level of governance has the legal authority (“power”) to act in a given policy area. These competences are set out primarily in the EU Treaties and determine how responsibilities are shared between the EU, national governments and local authorities.

1. EU-level competences

The EU can act only within the competences conferred on it by the Treaties. These fall into three main categories:

1.1. Exclusive EU competences

Only the EU may legislate and adopt legally binding acts; Member States may act only if empowered by the EU.

Key examples include:

- Customs union
- Common commercial policy (trade)
- Competition rules for the internal market
- Monetary policy for euro-area countries

These competences rarely affect construction sites directly, but competition and state-aid rules can shape industrial policy and public procurement conditions.

1.2. Shared competences

Both the EU and Member States can legislate. Member States exercise their competence to the extent that the EU has not exercised its own.

This category is most relevant for zero-emission construction sites and includes:

- Environment and climate policy
- Energy
- Transport
- Internal market
- Public health (for certain aspects)

In these areas, the EU typically:

- Sets common objectives, minimum standards or limit values (e.g. air quality, emissions, noise),

- Defines procedural obligations (e.g. planning, monitoring, reporting), while Member States:
- Decide how to implement and enforce these rules nationally and locally,
- May adopt stricter measures, provided they are compatible with EU law.

1.3. Supporting, coordinating or complementary competences

The EU cannot harmonise national laws but may support, coordinate or supplement national action.

Relevant examples include:

- Industry
- Public health (non-harmonised aspects)
- Research and innovation
- Education and training

Here, the EU mainly influences action through:

- Funding programmes (e.g. Horizon Europe),
- Guidance, strategies and recommendations,
- Coordination and best-practice exchange.

2. National-level competences

Member States retain primary authority over:

- The organisation of public administrations,
- Transposition and enforcement of EU directives,
- Taxation (within EU constraints),
- Labour law and occupational health and safety,
- Land use planning and building regulations,
- Allocation of powers to regions and municipalities.

National governments:

- Translate EU objectives into binding national law,
- Set enforcement mechanisms and penalties,
- Decide whether and how local authorities can adopt stricter environmental or procurement requirements.

In many countries, national law explicitly empowers municipalities to act on air quality, noise control and public procurement—areas directly relevant to ZEMCON sites.

3. Regional and local-level competences

Local and regional authorities derive their powers from national law, but they play a decisive role in implementation, especially in environmental and urban policy.

Typical local competences include:

- Air quality and noise management at city or regional level,
- Urban planning and zoning,
- Issuing permits for construction sites,
- Public procurement for public works,
- Local transport and traffic regulation,
- Enforcement and inspections.

Even where they do not legislate, local authorities often:

- Design and implement mandatory plans required by EU law (e.g. air quality or noise action plans),
- Set conditions in permits or public contracts,
- Adopt local ordinances or procurement criteria that go beyond minimum EU standards, where allowed.

4. How the competences interact in practice

In practice, the system works as follows:

- EU level sets binding goals and minimum standards (e.g. air quality limits, planning obligations),
- National level converts these into national law and allocates responsibilities,
- Local level delivers compliance through concrete measures, enforcement and procurement.

This means that while municipalities may not “make EU law,” they are often the key actors responsible for making EU law effective on the ground, including through measures such as requiring zero-emission construction machinery to meet air quality, noise or worker safety obligations.

List of Figures

Figure 1: Summary of the characteristics for 12 analysed national markets in Europe. The presented figures are elaborated in Chapter 1.1.....7

Figure 2: Market characteristics for selected European cities. The overview includes city population, evaluations of grid capacity (chapter 2.1.3) and ZEMCON maturity (chapter 2.1.4), estimated number of ongoing construction projects per year (A.2 Methodology), annual CO2 emissions (Net Zero Cities , 2025) (Norwegian Environment Agency, 2024) (Ajuntament de Barcelona, 2020), measured air quality (EEA, 2022)..... 8

Figure 3: Number of deaths attributable to long-term PM_{2.5} and NO_x exposure..... 8

Figure 4: Estimated reduction in total NO_x emissions (left) and PM_{2.5} emissions (right) in Stockholm from electrification of all construction machinery..... 9

Figure 5: Estimated number of people experiencing bothersome and harmful noise levels in each focus city.....10

Figure 6: Estimated annual indirect CO2 emission reduction from construction machinery per city and estimated equivalent from passenger cars in the EU based on 12 000 km/year and 170g/km..... 11

Figure 7: Peak power demand for electricity today (Blokhuis, Brouwers, van der Putten, & Schaefer, 2011) (Norwegian Water Resources and Energy Directorate, 2025) (Stadtwerke München, 2024) (Endesa, 2025) (ENTSO-e, 2025), estimated demand from 100% ZEMCON and expected demand from other sectors in 2040 for each focus city (ENTSO, 2025) (Norwegian Water Resource and Energy Directorate (NVE), 2025) (Swedish Energy Agency, 2025)..... 12

Figure 8: Illustration of zero-emission construction could lead to ripple effect and increase European competitiveness.....14

Figure 9: Policy and legal options on different levels and with an evaluation of their potential impact...15

Figure 10: Summary of the characteristics for 12 analysed national markets in Europe. ZEMCON market maturity reflects the level of zero-emission construction activity in each market, based on the number and type of implemented projects. Low maturity indicates few or no pilot projects, moderate maturity reflects multiple pilot projects, while advanced maturity represents markets with several projects approaching or entering commercial deployment. The presented indicators are further elaborated in the following pages, and the methodology is described in A.2 Methodology.....20

Figure 11: Net turnover, public procurement shares and size of lead markets for zero-emission machinery in European construction markets (FIEC, 2025) (Statistics Norway, 2023) (Brussels school of governance, 2024) 22

Figure 12: NO_x and PM_{2.5} emissions in thousand tonnes for Mobile combustion in manufacturing industries and construction (Eurostat, 2025).....23

Figure 13: Energy estimate and direct CO₂ emissions for non-road mobile machinery (NRMM) and auxiliary site equipment in construction only (Eurostat AEA 2023, NACE F).....24

Figure 14: Number of available electric machinery models by September 2025 based on a mapping by SINTEF and Bellona (SINTEF, 2025). **Other** includes: Demolition robot, heater and dryer, grader, asphalt cutter, concrete truck, concrete truck mixer, carrier machine for slurry wall construction and chipper.25

Figure 15: Summarizing ZEMCON maturity in different European markets29

Figure 16: Market characteristics for selected European cities. The overview includes city population, evaluations of grid capacity (chapter 2.1.3) and ZEMCON maturity (chapter 2.1.4), estimated number of ongoing construction projects per year (A.2 Methodology), annual CO2 emissions (Net Zero Cities , 2025) (Norwegian Environment Agency, 2024) (Ajuntament de Barcelona, 2020), measured air quality (EEA, 2022).....35

Figure 2: Number of deaths attributable to long-term pollution exposure for PM_{2.5} and NO_x.....36

Figure 18: Measured average annual NO_x levels in the focus cities (average of all measure points in each city) (EEA, 2022). Current and future EU limit values and WHO guidelines are indicated on the right..... 37

Figure 19: Measured average annual PM _{2.5} levels in the focus cities (average of all measure points in each city) (EEA, 2022). Current and future EU limit values and WHO guidelines are indicated on the right.....	38
Figure 20: Illustration of concentration of pollutant levels around the source of pollution.....	40
Figure 21: Illustration of estimated affected areas by noise levels over longer time periods. The area and decibel estimations are described in A.2 Methodology.....	41
Figure 22: Estimated number of people experiencing bothersome and harmful noise levels in each focus city.....	42
Figure 23: Estimated yearly direct CO ₂ emission from construction machinery per city based on energy consumption of diesel and CO ₂ equivalents for diesel as 2,66 kg CO ₂ /litre.....	43
Figure 24: Electricity share of primary energy consumption together with share of emission-free electricity production per country (Our World in Data, 2025) (Ember; Energy Institute - Statistical Review of World Energy, 2025).....	44
Figure 25: Estimated reduction in total NO _x emissions in Barcelona from electrification of all construction machinery.....	49
Figure 26: Estimated reduction in total NO _x emissions in Eindhoven from electrification of all construction machinery.....	49
Figure 27: Estimated reduction in total NO _x emissions (left) and PM _{2.5} emissions (right) in Stockholm from electrification of all construction machinery.....	50
Figure 28: Estimated annual indirect CO ₂ emission reduction from construction machinery per city and estimated equivalent from passenger cars in the EU based on 12 000 km/year and 170g/km.....	53
Figure 29: Expected scenario-based electricity demand from different sectors in 2040 in Europe, for Distributed Energy scenario (ENTSO, 2025). This scenario is characterized with a decentralised energy transition driven by high energy efficiency, strong direct electrification, and widespread local renewable generation, with consumers and prosumers playing a central role.....	54
Figure 30: Peak power demand for electricity today (Blokhus, Brouwers, van der Putten, & Schaefer, 2011) (Norwegian Water Resources and Energy Directorate, 2025) (Stadtwerke München, 2024) (Endesa, 2025) (ENTSO-e, 2025), estimated demand from 100% ZEMCON and expected demand from other sectors in 2040 for each focus city (ENTSO, 2025) (Norwegian Water Resource and Energy Directorate (NVE), 2025) (Swedish Energy Agency, 2025).....	55
Figure 31: Energy demand for electricity today, estimated demand from 100% ZEMCON and expected demand from other sectors in 2040 for each focus city (ENTSO, 2025) (Norwegian Water Resource and Energy Directorate (NVE), 2025) (Swedish Energy Agency, 2025).....	56
Figure 32: Estimated additional cost relative to project cost for different market maturity phases, as described in the table above, using Oslo as a reference market.....	59
Figure 33: Illustration of zero-emission construction could lead to ripple effect and increase European competitiveness.....	67
Figure 34: Illustration of the different levels of policy options and legal frameworks on different levels of influence.....	70
Figure 35: Policy and legal options on different levels and with an evaluation of their potential impact.....	70

List of Tables

Table 1: European limit values for NO₂ and PM_{2.5} for today and 2030 and WHO guidelines36

Table 2: Estimated reductions in NO_x and PM_{2.5} emissions in each of the focus cities. Decrease compared to today’s level in parentheses where applicable.....48

Table 3: Characteristics of different market maturity phases and cost development scenarios used in the case study for cost calculations in Oslo59

Table 4: Comparison of air quality limit emissions between WHO guidelines and the EU AAQD 73

Table 5: Machine price factor per market based on Eurostat machinery investment index (Eurostat, 2025) and market characteristics..... 101

Table 6: Energy prices per market for diesel and electricity (Cargopedia, 2025) (Eurostat, 2025)..... 101

Table 7: Infrastructure characteristics and price factor per market..... 101

Table 8: Assumed share of different stages for NRMM in each city106

Table 9: Emissions of NO_x and PM_{2.5} per kWh for different stages for NRMM106

Table 10: Population densities per city 107

References

- Agency for Urban Environment in Oslo. (2020). *Experiences with zero-emission machines in pilot project in Oslo (norwegian)*. Retrieved from https://www.klimaoslo.no/wp-content/uploads/sites/2/2024/04/BYM_Utslippsfri-anleggsplass.pdf
- Ajuntament de Barcelona. (2020). *Model de contaminació local de Barcelona - 2017*. Retrieved from https://ajuntament.barcelona.cat/qualitataire/sites/default/files/qa_balanscontaminaciolocal2017_0.pdf
- Big Buyers for Climate and Environment*. (2022, September 19). *Joint Statement of Demand of Zero Emission Construction Sites Working Group*. Retrieved September 10, 2025, from European Commission: <https://public-buyers-community.ec.europa.eu/resources/joint-statement-demand-zero-emission-construction-sites-working-group>
- Blokhuis, E., Brouwers, B., van der Putten, E., & Schaefer, W. (2011). Peak loads and network investments in sustainable energy transitions. *Energy Policy*, 6220–6233.
- Bodø kommune. (n.d.). *Klimamål - Bodø kommunes målsettinger for klimagassutslipp (Revidert etter bystyrevedtak 26.9.2024)*. Retrieved September 10, 2025, from Bodo kommune: <https://bodo.kommune.no/tjenester/natur-miljo-klima-og-naring/klima-og-barekraft/klimamal/>
- Bouwend Nederland. (2024, January 11). *Arbeidsinspectie verscherpt handhaving dieselmotoremissies*. Retrieved from Bouwend Nederland: <https://www.bouwendnederland.nl/nieuws/algemeen/arbeidsinspectie-verscherpt-handhaving-dieselmotoremissies>
- Brussels school of governance. (2024). *Public Procurement of Steel and Cement for construction*. Retrieved from <https://www.brussels-school.be/sites/default/files/2024-06/Public%20procurement%20construction%20steel%20and%20cement%20EU%20FINAL.pdf>
- C40 Cities. (2021). *Clean Construction Declaration*. C40 Cities.
- Cargopedia. (2025, October 6). *European Fuel Prices*. Retrieved from <https://www.cargopedia.net/europe-fuel-prices>
- City of Oslo. (2025, September 8). *Utslippsfri drift er den nye normalen*. Retrieved from <https://www.klimaoslo.no/utslippsfrie-byggeplasser-er-den-nye-normalen/>
- Copenhagen Municipality. (2022). *En ny retning for København. Aftaletekst for budget 2023 (revideret 6. oktober 2022)*. Copenhagen: Københavns Kommune. Retrieved from <https://www.kk.dk/sites/default/files/2022-10/Aftaletekst%20pa%CC%8A%20budget%202023%20rev%206%20oktober%2022.pdf>
- Dement, J. M., Ringen, K., Hines, S., Cranford, K., & Quinn, P. (2020). Lung cancer mortality among construction workers: implications for early detection. *Occupational and Environmental Medicine*(77), 207–213. doi:<https://doi.org/10.1136/oemed-2019-106196>
- Desouza, C., Marsh, D., Beevers, S., Molden, N., & Green, D. (2024). Emissions from the Construction Sector in the United Kingdom. *Emission Control Science and Technology*, 70–80.

- EEA. (2022). *Europe's Air Quality Status*. Retrieved from European Environment Agency: <https://www.eea.europa.eu/en/analysis/publications/europes-air-quality-status-2024?activeTab=2a0410b3-b135-49bc-8b05-224e316ddd45>
- EEA. (2025). *European Environment Agency*. Retrieved from <https://www.eea.europa.eu/en/newsroom/news/air-pollution-standards-still-not-fully-met-across-europe>
- EEA. (2025, June 24). *European Environment Agency: "More than 20% of Europeans exposed to harmful noise pollution levels"*. Retrieved from <https://www.eea.europa.eu/en/newsroom/news/europeans-exposed-to-harmful-noise-pollution-levels>
- EFFRA. (2025). Retrieved from The Made in Europe Partnership - EFFRA: <https://www.effra.eu/made-in-europe-state-play/>
- Ember. (2025). *Statistical Review of World Energy (2025)*. Retrieved from <https://ourworldindata.org/explorers/energy?tab=table&time=2000..2024®ion=Europe&country=NOR~SWE~NLD~ESP~DEU~HUN&tableFilter=selection&pickerSort=asc&pickerMetric=entityName&hideControls=false&Total+or+Breakdown=Total&Energy+or+Electricity=Electricity+>
- Ember Energy Research CIC. (2025, 11). *Ember Energy - Europe - Insights*. Retrieved from <https://ember-energy.org/countries-and-regions/europe/>
- Ember; Energy Institute - Statistical Review of World Energy. (2025). *Electricity as share of primary energy, 2024*. Retrieved from https://ourworldindata.org/grapher/electricity-as-a-share-of-primary-energy?tab=discrete-bar&time=latest&country=NOR~SWE~DEU~HUN~ESP~NLD&mapSelect=~OWID_WRL&globe=1&globeRotation=58.3%2C10.95&globeZoom=2.67&tableSearch=norwa
- Endesa. (2025, July). *Ara*. Retrieved from Endesa admits a peak in electricity demand due to the heat: https://en.ara.cat/economy/endesa-activates-generator-to-supply-electricity-to-507-barcelona-residents_1_5428831.html
- ENTSO. (2025, 2). *Ten Year Network Development Plan 2024*. Retrieved from <https://2024.entsos-tyndp-scenarios.eu/>
- ENTSO-e. (2025, March). *Statistical factsheet 2024*. Retrieved from https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2024_web.pdf
- EODev. (2023). *Travaux de voirie zéro-émission dans le centre de Paris*. (EODev) Retrieved September 15, 2025, from EODev: <https://www.eo-dev.com/fr/cas-dusages/travaux-de-voirie-zero-emissions-dans-le-centre-de-paris/>
- European Commission. (n.d.). *Buildings and construction*. Retrieved from https://single-market-economy.ec.europa.eu/industry/sustainability/buildings-and-construction_en
- European Commission. (2002). *Environmental Noise Directive*. Retrieved from https://www.era-comm.eu/Air%20quality%20and%20noise%20legislation/course/module_3/4_aim.html
- European Commission. (2022). *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions First 'zero pollution' monitoring and outlook 'Pathways towards cleaner air,*

- water and soil for Europe'*. Brussels: European Commission. Retrieved from EUR-Lex: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A674%3AFIN>
- European Commission. (2024, October 14). *Noise*. Retrieved from https://environment.ec.europa.eu/topics/noise_en
- European Commission. (2025). *EU air quality standards*. Retrieved from https://environment.ec.europa.eu/topics/air/air-quality/eu-air-quality-standards_en
- European Commission. (2025, 11 28). *EU air quality standards*. Retrieved from https://environment.ec.europa.eu/topics/air/air-quality/eu-air-quality-standards_en
- European Commission. (n.d.). *The Aarhus Convention and the EU*. Retrieved from European Commission Energy, Climate change, Environment: https://environment.ec.europa.eu/law-and-governance/aarhus_en
- European Court of Auditors. (2025). *Special report 02/2025: "Urban pollution in the EU – Cities have cleaner air but are still too noisy"*. Publications Office of the European Union.
- European Court of Human Rights. (2024, April). Factsheet - Environment and the European Convention on Human Rights. Strasbourg, France. Retrieved from https://www.echr.coe.int/documents/d/echr/fs_environment_eng
- European Environment Agency. (2024, 12). *Harm to human health from air pollution in Europe: burden of disease status, 2024*. Retrieved from <https://www.eea.europa.eu/en/analysis/publications/harm-to-human-health-from-air-pollution-2024>
- European Environment Agency. (2025). Retrieved from <https://www.eea.europa.eu/en/analysis/indicators/exposure-of-europe-population-to-noise>
- Eurostat. (2025). *Air pollutants by source sector*. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/env_air_emis__custom_19147581/default/table
- Eurostat. (2025). *Comparative price levels for investment*. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Comparative_price_levels_for_investment
- Eurostat. (2025, October). *Electricity prices for non-household consumers - bi-annual data (from 2007 onwards)*. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_205__custom_18329096/bookmark/table?lang=en&bookmarkId=2f326ed8-6ca3-4b80-bca0-8c737528b82d&c=1759930053000
- Eurostat. (2025, October). *Purchasing power parities (PPPs), price level indices and real expenditures for ESA 2010 aggregates*. Retrieved from Eurostat: https://ec.europa.eu/eurostat/cache/metadata/en/prc_ppp_esms.htm
- FIEC. (2025). *2025 FIEC Statistical Report*. Brussels: FIEC. Retrieved from <https://www.fiec.eu/library/publications/statistical-report>
- Gemeente Amsterdam. (2024). *Inkoopbeleid SEB Mobiele werktuigen – Verdiepende gesprekken markt mei '24*. Amsterdam: Gemeente Amsterdam. Retrieved from https://openresearch.amsterdam/en/media/inline/2024/8/23/202405_dilemmas_inko

opbeleid_seb_amsterdam_aftrap_verdiepende_gesprekken_markt_2.pdf?is_http_request=true

- GREENPEACE E.V. and others against Germany, 18215/06 (The European Court of Human Rights May 12, 2009).
- Gustafsson, M., Lindén, J., Forsberg, B., Åström, S., & Johansson, E. (2022). *Quantification of population exposure to NO₂, PM_{2.5} and*. Stockholm: IVL Swedish Environmental Research Institute Ltd.
- Health Effects Institute. (2023). Retrieved from <https://www.healtheffects.org/announcements/robust-scientific-evidence-supports-revision-eus-clean-air-standards>
- ICCT. (2016). *EUROPEAN STAGE V NON-ROAD EMISSION STANDARDS*. Policy Update, INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION. Retrieved from https://theicct.org/wp-content/uploads/2021/06/EU-Stage-V_policy-update_ICCT_nov2016.pdf
- Illingworth & Rodkin Inc. (2022). *Construction Noise and Vibration Assessment*. Retrieved from <https://www.paloalto.gov/files/assets/public/v/1/planning-amp-development-services/current-planning/uploads-for-website/new-folder-1/appendix-e-construction-noise-and-vibration-assessment.pdf>
- International Agency for Research on Cancer. (2012, June 12). IARC: Diesel Engine Exhaust Carcinogenic. Lyon, France.
- Kanton Basel-Stadt. (2024, October 14). *Klimaschutzstrategie "Netto-Null 2037"*. Retrieved September 18, 2025, from Offizielle Website des Kantons Basel-Stadt: <https://www.bs.ch/schwerpunkte/klima/klimaschutz>
- Klima- og miljødepartementet. (2025). Klimamelding 2035 – på vei mot lavutslippssamfunnet. (*Meld. St. 25 (2024–2025)*). Regjeringen. Retrieved from <https://www.regjeringen.no/contentassets/d51d0e3cc153440b9611cdece49f4549/no/pdfs/stm202420250025000dddpdfs.pdf>
- Kunz, J. (2024). Wenn Bagger und Lastwagen flüstern. *Bietigheimer Zeitung*. Retrieved from <https://www.bietigheimerzeitung.de/inhalt.boennigheim-wenn-bagger-und-lastwagen-fluestern.7901519e-6be7-4bd6-9055-000364c021b8.html>
- Lewné, M., Plato, N., Bellander, T., Alderling, M., & Gustavsson, P. (2011). Occupational exposure to motor exhaust in Stockholm, Sweden—Different grouping strategies using variability in NO₂ to create homogenous groups. *International Journal of Hygiene and Environmental Health*, 47-52.
- Localised. (2023). *LOCALISED EU Project*. Retrieved from <https://www.localised-project.eu/2023/04/26/air-pollution-in-the-city-down-by-more-than-30>
- Masterson, E. A., & Themann, C. L. (2025). Prevalence of hearing loss among noise-exposed U.S. workers within the Construction sector, 2010–2019. *Journal of Safety Research*, 158-165. doi:<https://doi.org/10.1016/j.jsr.2024.11.005>
- Ministry of Infrastructure and Water Management. (2023, November 23). Voluntary Agreement on Clean and Zero-Emission Construction. *Government Gazette*(no. 31167). Amsterdam: Government of the Netherlands. Retrieved from <https://www.opwegnaarseb.nl/documenten/2024/11/04/voluntary-agreement-czec>

- Ministry of the Environment. (2024). *Green Deal agreement on emission-free work sites has boosted efforts to phase out fossil fuels*. Finnish Government. Retrieved from <https://valtioneuvosto.fi/en/-/1410903/green-deal-agreement-on-emission-free-work-sites-has-boosted-efforts-to-phase-out-fossil-fuels>
- Ministry of the Environment. (2024, January 15). *Green Deal agreement on emission-free work sites has boosted efforts to phase out fossil fuels*. Retrieved from <https://valtioneuvosto.fi/en/-/1410903/green-deal-agreement-on-emission-free-work-sites-has-boosted-efforts-to-phase-out-fossil-fuels>
- National Institute for Public Health and the Environment – Netherlands. (2025). *National emissions database – Emissieregistratie*. Retrieved from <https://www.emissieregistratie.nl/>
- Net Zero Cities . (2025, 12). *Net Zero Cities Knowledge Repository – Climate City Contracts*. Retrieved from <https://netzerocities.app/knowledge>
- Netherlands Enterprise Agency. (n.d.). *Regeling stimuleren Schoon en Emissieloos Bouwen voor medeoverheden (SPUK SEB)*. (Netherlands Enterprise Agency) Retrieved September 15, 2025, from Netherlands Enterprise Agency: <https://www.rvo.nl/subsidies-financiering/spuk-seb#waarvoor-is-de-spuke-seb-bedoeld%3F>
- Netherlands Enterprise Agency. (n.d.). *Subsidy for Clean and Zero Emission Construction Equipment (SSEB)*. (Netherlands Enterprise Agency) Retrieved September 16, 2025, from Business.gov.nl: <https://business.gov.nl/subsidy/clean-and-zero-emission-construction-equipment-sseb/>
- Netzpraxis. (2023). *Netze BW testet die emissionsfreie Baustelle*. Netzpraxis. Retrieved from <https://www.energie.de/netzpraxis/news-detailansicht/nsctrl/detail/News/netze-bw-testet-die-emissionsfreie-baustelle>
- Norwegian Environment Agency. (2024). *Utslipp av klimagasser i kommuner og fylker*. Retrieved from <https://www.miljodirektoratet.no/tjenester/klimagassutslipp-kommuner/?area=10010§or=7>
- Norwegian Environment Agency. (2025, May 2). *Nitrogenoksider (NOx)*. Retrieved from <https://www.miljodirektoratet.no/ansvarsomrader/forurensning/luftkvalitet/lokal-luftkvalitet/nox/>
- Norwegian Environment Agency. (2025). *Total emissions to air in Norway*. Retrieved from <https://www.norskeutslipp.no/en/Frontpage/?SectorID=90>
- Norwegian Water Resource and Energy Directorate (NVE). (2025, June). *Long term power market analysis 2025 (Langsiktig kraftmarkedsanalyse 2025)*. Retrieved from <https://www.nve.no/energi/analyser-og-statistikk/langsiktig-kraftmarkedsanalyse/langsiktig-kraftmarkedsanalyse-2025/>
- Norwegian Water Resources and Energy Directorate. (2025, May). *Områdestudie Oslo*. Retrieved from PlanNett: <https://plannett.nve.no/omraadestudie/20250106>
- Oslo Economics, Hafslund Rådgivning. (2025). *Kostnader ved omstilling til nullutslipp på bygge- og anleggsplasser*. Retrieved from Norwegian Environment Agency: <https://www.miljodirektoratet.no/publikasjoner/2025/januar-2025/kostnader-ved-omstilling-til-nullutslipp-pa-bygg--og-anleggsplasser/>
- Oslo Harbour. (2018). *Oslo Havn som nullutslippshavn – Handlingsplan*. Oslo.

- Oslo Municipality. (2024). *Climate and environmental requirements Version 1.0*. Oslo: Oslo Kommune.
- Oudin, A., Flanagan, E., & Forsberg, B. (2024). Projected health benefits of air pollution reductions in a Swedish population. Retrieved from <https://pubmed.ncbi.nlm.nih.gov/39589000/>
- Our World in Data. (2025). *Electricity generation from fossil fuels, nuclear and renewables, 2024*.
- Reuters. (2025, September 9). *Spanish power utilities warn electricity grid is saturated*. Retrieved from <https://www.reuters.com/business/energy/spanish-power-utilities-warn-electricity-grid-is-saturated-2025-09-09/>
- Schweizerischer Baumeisterverband. (2025, July 29). *Flüsterleise Baustelle*. Retrieved September 14, 2025, from Schweizerischer Baumeisterverband: <https://baumeister.swiss/fluesterleise-baustelle/>
- Seger Säll, B. (-a. (2025, 11 5). Email: Contribution to impact assesment for electrification of construction in European cities. (I. (. Aamnes, Interviewer)
- SINTEF. (2025, September). *Electric construction machinery*. Retrieved from <https://www.klimaoslo.no/electric-construction-machinery/>
- Stadt Wien. (2025, March 8). *Stadt Wien, Wirtschaftskammer Wien und PORR starten Pilotversuch zur CO₂-neutralen Baustelle*. Retrieved September 16, 2025, from Stadt Wien: <https://presse.wien.gv.at/presse/2025/03/08/stadt-wien-wirtschaftskammer-wien-und-porr-starten-pilotversuch-zur-co2-neutralen-baustelle>
- Stadtwerke München. (2024). *Netzdaten*. Retrieved from <https://www.swm-infrastruktur.de/strom/netzstrukturdaten/netzdaten>
- Statens Vegvesen. (2025). *Learning report from pilot project at Gran (norwegian)*. Retrieved from <https://nva.sikt.no/registration/0199383afbc5-e27a8b2f-e5fc-47b5-b841-be89c4a2c85f>
- Statistics Norway. (2023). *National accounts*. Retrieved from <https://www.ssb.no/en/statbank/table/11189>
- Statnett. (2025, February). *Long term market analysis report (Langsiktig markedsanalyse) 2024-2050*. Retrieved from <https://www.statnett.no/for-aktorer-i-kraftbransjen/planer-og-analyser/langsiktig-markedsanalyse/>
- Stockholms Stadt. (2025, August 11). *1,240 new homes in eastern Södermalm*. Retrieved September 16, 2025, from Växer Stockholm: <https://vaxer.stockholm/en/projects/sodermalm/emission-free-construction-site-in-central-stockholm/#:~:text=Net%20Zero%20Persikan,machine%20pool%20in%20ground%20works.>
- Swedish Energy Agency. (2025, March). *Scenarier over Sveriges Energisystem*. Retrieved from <https://energimyndigheten.a-w2m.se/System/TemplateView.aspx?p=Arkitektkopia&id=1173312576a844f5a08e2c4a2005ccfb&l=t&cat=%2FPrognoser%20och%20Scenarier&lstqty=1>

- The ICCT. (2025). *Press Release: Global Partnership Aims to Accelerate the Electrification of Construction Machinery*. Retrieved from <https://theicct.org/pr-global-partnership-aims-to-accelerate-the-electrification-of-construction-machinery/>
- TNO. (2025, 3 7). Retrieved from <https://publications.tno.nl/publication/34644014/npoDBBy02/TNO-2025-R10466.pdf>
- Tomas Wyns, H. K. (2024). *Public Procurement of Steel and Cement for Construction: Assessing the potential of lead markets for green steel and cement in the EU*. Brussels: Brussels School of Governance.
- Transport & Environment. (2024). *Reducing emissions from non-road mobile machinery*. Brussels: T&E. Retrieved from <https://www.transportenvironment.org/articles/reducing-emissions-from-non-road-mobile-machinery>
- Transport & Environment. (2024, December). *Reducing emissions from non-road mobile machinery*. Retrieved from https://www.transportenvironment.org/uploads/files/202412_NRMM_briefing_final.pdf
- Trondheim Municipality. (2024). *Kommuneplanens arealdel 2022-2034 - Klimaveileder for plan- og byggesaker i Trondheim kommune*. Trondheim: Trondheim Kommune.
- UN Special Rapporteur on Human Rights and the Environment. (2019). *Report of the Special Rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and*. UNEP.
- Vantage Market Research. (n.d.). Retrieved 09 25, 2025, from <https://www.vantagemarketresearch.com/industry-report/electric-construction-equipment-market-2426>
- Volvo Trucks. (2025, June 13). *What the EU's carbon price means for transport companies*. Retrieved from <https://www.volvotrucks.vn/en-vn/news/insights/articles/2025/jun/what-the-eu-s-new-carbon-pricing-means-for-transport-companies.html>
- VTT Technical Research Centre of Finland. (2024). *Pathways for CO2 regulation in NRMM*. Helsinki: VTT Research Information Portal.
- Zhou, Y., & Levy, J. I. (2007). Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. *BMC Public Health*. Retrieved from <https://link.springer.com/article/10.1186/1471-2458-7-89>
- Östersund Kommun. (2025, August 14). *Avsiktsförklaring för fler utsläppsfria byggarbetsplatser*. Retrieved September 16, 2025, from Östersund.se: <https://www.ostersund.se/om-webbplatsen/nyhetsarkiv/nyhetsarkiv/2025-08-14-avsiktsforklaring-for-fler-utslapps fria-byggarbetsplatser.html>
- Östra Sveriges Luftvårdsförbund. (2025, 02 19). *Luftföroreningar i Östra Sveriges Luftvårdsförbund*. Retrieved from https://www.slbanalys.se/slb/rapporter/pdf8/slb2025_018.pdf

Generative AI (*ChatGPT, 2025*) is used to support drafting, language refinement and structural editing. The model did not generate original data or analysis. All interpretations and conclusions are those of the authors.

**NET
ZERO
CITIES**



Oslo



Hafslund
Rådgivning

BELLONA
EUROPA



Funded by
the European Union