"Green ports or green paradox? Empirical evidence from Norwegian port municipalities"

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GREEN PORTS OR GREEN PARADOX? EMPIRICAL EVIDENCE FROM NORWEGIAN PORT MUNICIPALITIES

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Abstract

This study investigates whether public investment in green maritime infrastructure and transportation projects contributes to CO_2 emission reductions in Norwegian port municipalities. Using panel data for 28 coastal municipalities from 2016 to 2023, the analysis assesses the temporal effects of maritime-supported projects, technology development (TransMar) and infrastructure (InfraMar), on local maritime emissions. A two-stage empirical strategy combines lagged panel regressions (OLS, FE, and RE) with unsupervised clustering to uncover structural heterogeneity in port activity and investment profiles. The results reveal that transport-related investments exhibit statistically significant emission-reducing effects with lags of three to five years, supporting the long-term decarbonization potential of targeted funding. In contrast, green infrastructure presence correlates positively with emissions, likely reflecting higher port activity and policy targeting in high-emission areas. Clustering analysis confirms that municipalities differ substantially in activity levels, investment patterns, and emission profiles, reinforcing the case for differentiated policy strategies. The findings contribute to environmental economics and maritime policy by offering new micro-level evidence on the effectiveness and temporal dynamics of green investments. This paper extends previous literature by integrating spatial clustering with dynamic investment modeling, providing novel insights into how policy timing and local industrial structure shape emission outcomes. The results have direct implications for designing adaptive, region-specific maritime decarbonization programs and guiding future EU-aligned infrastructure strategies.

Keywords green maritime investment, decarbonization, sustainable transport policy, maritime energy transition, port activity and emissions

JEL Classification Q58, L92, H54

INTRODUCTION

Maritime transport remains the backbone of global trade, carrying approximately 90% of the world's freight volumes. While global maritime routes continue to be shaped by legacy infrastructure – such as the Suez Canal (1867) and Panama Canal (1914) – the geography of maritime logistics has shifted significantly over the past three decades. Traditionally dominated by Western economies such as the United States, the United Kingdom, Germany, and France, the epicenter of maritime logistics has moved toward the Asia–Pacific region. Today, nine of the ten largest container ports globally are in Asia, with seven in China, and the remaining two in Singapore and Busan. Rotterdam remains the sole Western representative in this elite group, underscoring a dramatic shift in global shipping power (Norwegian Confederation of Enterprise, 2024).

The maritime and port sectors are undergoing a profound transformation to align with climate goals and decarbonization targets. The "green shift" encompasses both reductions in emissions from ships and port operations, as well as the deployment of sustainable energy infrastructure. In this evolving context, ports are increasingly expected not only to manage cargo flows but also to serve as nodes for clean energy distribution, electrification, and low-emission logistics.

Ports are emerging as pivotal facilitators in the global energy transition – frequently referred to as the "arteries of the energy transition" (DNV, 2020b). Once primarily logistical nodes, ports today are increasingly tasked with supporting decarbonization through infrastructure development, clean energy distribution, and sector coupling. In this context, maritime transport – responsible for nearly 3% of global greenhouse gas emissions – faces growing pressure to reduce its environmental footprint while enabling economic resilience and trade connectivity.

This transition demands large-scale infrastructure readiness in ports, including fuel storage, bunkering facilities, and hydrogen electrolysis capacity (DNV, 2024c). The strategic repositioning of ports also creates opportunities and vulnerabilities. On the opportunity side, ports can act as hydrogen hubs, especially when located near offshore wind farms and industrial clusters. Ports such as Rotterdam are already positioning themselves as green hydrogen distributors, leveraging proximity to gas infrastructure and refineries. In Norway, projects like Northern Lights demonstrate emerging roles for ports in carbon capture and storage (CCS) logistics, linking onshore emitters with offshore storage reservoirs under the North Sea (Equinor, n.d.).

More than 6% of Europe's maritime greenhouse gas (GHG) emissions originate from port operations, which are also a significant source of harmful air pollutants such as sulphur oxides (SOx) and fine particulate matter (PM). Reducing these emissions is critical for enhancing air quality and protecting public health in coastal urban areas. In response, the European Union has introduced a mandate requiring major ports to implement Onshore Power Supply (OPS) systems by 2030 (European Commission, 2025). This initiative aims to replace the use of polluting auxiliary ship engines during berthing with cleaner electrical grid connections, thereby significantly lowering emissions at port. For instance, cruise ships (due to their extended port stays) are responsible for significantly more emissions at berth than container vessels: Carnival's Azura (a 3,500-passenger cruise ship) emitted 22,800 tons of CO_2 in European ports in 2023 alone. Connecting to shore power during dockings could eliminate nearly all of these emissions, reducing the ship's total annual emissions by up to 20% (Transport & Environment, 2025). However, EU port readiness remains insufficient: of the OPS infrastructure required by 2030, only 20% has been installed or contracted (DNV, 2024b).

Under the FuelEU Maritime Regulation, starting in 2030, seagoing passenger vessels, including ferries and cruise ships, as well as container ships over 5,000 gross tonnages (GT), will be required to use OPS or equivalent zero-emission technologies while docked for more than two hours at ports within the Trans-European Transport Network (TEN-T). From 2035, this requirement extends to all ports equipped with OPS. Exemptions apply to brief or unscheduled port calls, or when OPS is unavailable or poses a risk to grid stability. Complementing this, the Alternative Fuels Infrastructure Regulation (AFIR) requires core and comprehensive TEN-T maritime ports to install OPS facilities sufficient to serve at least 90% of annual calls by the relevant ship types. Inland TEN-T ports must also comply, with core ports required to have at least one OPS connection by January 2025 and all inland ports by January 2030 (Transport & Environment, 2025).

Norway, with its extensive coastline and reliance on coastal shipping, presents a particularly relevant case. Over 3,000 ports and port facilities are essential to regional development and industrial supply chains. Norwegian policy initiatives, particularly ENOVA's funding programs, have prioritized green investments in maritime infrastructure and low-emission technologies. These investments aim to support emission reduction through the deployment of shore power, ferry charging stations, alternative fuels (e.g., LNG, methanol), and digital optimization of port operations (Enova, 2023). However, the degree to which these measures translate into measurable reductions in CO_2 emissions at the municipal level remains insufficiently investigated.

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In Norway, the green shift began with the introduction of shore power systems at the Port of Oslo in 2011, serving Color Line ferries. LNG and biogas infrastructure soon followed, and today hydrogen and ammonia-based solutions are under development. Recently, ports have also expanded their role as charging and refueling points for land-based transport, aligning with broader decarbonization strategies. Norwegian authorities have launched multiple regulatory and incentive-based initiatives to support this transition:

- Environmental Ship Index (ESI): offers port fee discounts based on a vessel's emissions performance. Ships scoring above 50 points benefit from full pilotage discounts, thereby promoting the adoption of shore power technology and transparent CO_2 reporting (ESI, n.d.).

- Environmental Port Index (EPI): behavior-based system tracks actual emissions from vessels during port stays. Fees are dynamically adjusted based on performance, with some ports now imposing surcharges of up to 150% on high-emission ships (EPI, n.d.).

- Mandatory Shore Power Requirements: certain ports require vessels exceeding a specified berth duration to connect to onshore electricity. In addition, national ferry contracts increasingly mandate the use of shore power where infrastructure is available (Norwegian Environment Agency, 2020).

- EU Policy Instruments: Norway is aligned with broader European initiatives such as the Trans-European Transport Network (TEN-T), the FuelEU Maritime Regulation, and the EU Emissions Trading System (ETS).

Yet despite these developments, Norway still lacks a coherent national strategy for safeguarding and leveraging critical port infrastructure. The absence of national redundancy plans and climate-resilience standards across the port sector raises important questions, and not only about the security and robustness of maritime logistics, but also about the coordination and long-term effectiveness of green investment initiatives (Office of the Auditor General, 2025).

Against this backdrop, this study investigates whether the current investments in maritime infrastructure and transportation projects are effective in reducing local CO_2 emissions in Norwegian port municipalities, hence the main research question is:

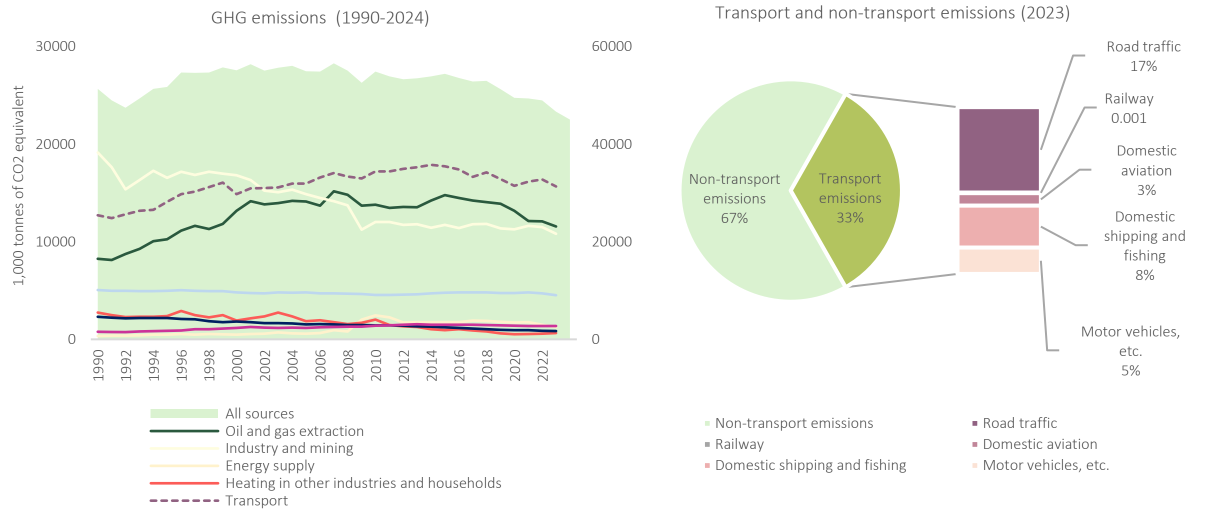
Does investment in maritime infrastructure and transportation contribute to reductions in local CO_2 emissions, and how is this relationship moderated by factors such as local economic activity and the availability of green port infrastructure?

Before proceeding with analysis, it is essential to map the current landscape of maritime activity, emissions trends, investment flows, and the presence of green infrastructure across Norwegian ports, and to review the existing literature on maritime decarbonization transition, environmental public investment and regional path dependence theory.

1. BACKGROUND

1.1. The green transition in maritime transport and ports: Status and innovation

Preliminary figures from Statistics Norway (SSB) show that greenhouse gas (GHG) emissions in Norway were 1.6 million tons lower in 2024 than the previous year (Statistics Norway, n.d.a). A total of 45 million tons of CO_2 equivalents were emitted in 2024. Compared to 1990, there has been a decrease of 12.4 percent (Figure 1). Although greenhouse gas emissions from aviation, shipping, and construction machinery declined by nearly 2.7% in 2024 compared to 2023, these sectors have still experienced a cumulative increase of approximately 40% in emissions since 1990 (Norwegian Environment Agency, 2025).



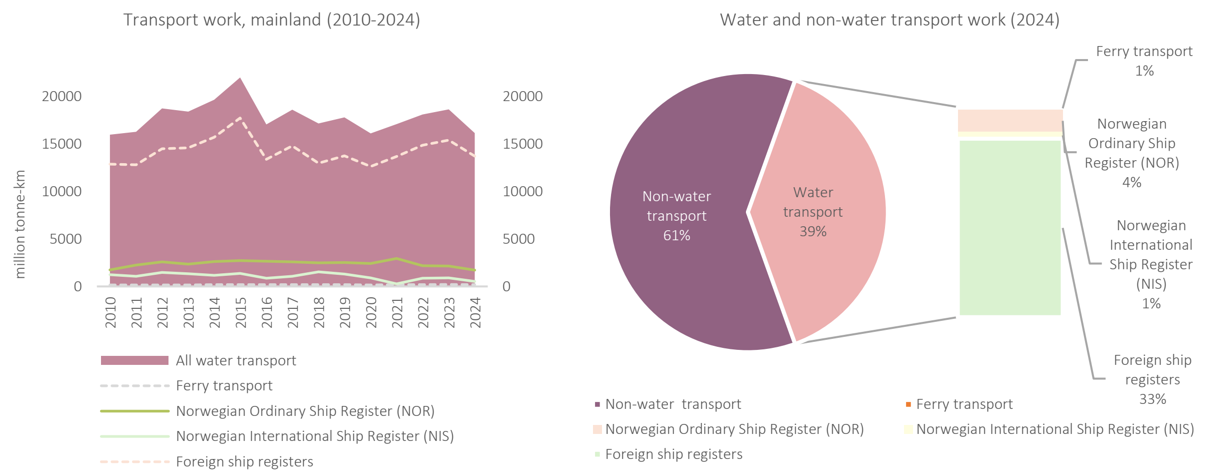
Note: Left: dynamic from all sources, 1990–2024. Right: structure of emissions from the non- and transport sectors, 2023.

Figure 1. Domestic greenhouse gas emissions of CO2 equivalents from Norwegian activity

At the same time, projected growth in Norway's GDP and freight volumes is expected to stimulate increased activity in both domestic shipping and the fisheries sector. National transport policy promotes a modal shift from road to sea – particularly for freight – as a strategy to lower overall emissions.

However, while such a shift may reduce total system emissions, it could simultaneously result in localized increases in emissions from maritime transport. According to the Norwegian Confederation of Enterprise (2024), the maritime sector is well equipped to handle additional freight capacity. This view is supported in the Norwegian Coastal Administration's National Transport Plan (NTP, 2014–2023), which highlights that Norway faces no substantial capacity limitations in either port facilities or navigable waterways (Norwegian Government, 2013). Nevertheless, despite these optimistic assessments and the ambitious goals outlined in the NTP, the anticipated modal shift has largely failed to materialize. Road transport continues to dominate domestic freight logistics (Figure 2).

Figure 2 shows that rail freight holds a modest 4.5% market share – significantly lower than



Note: Left: dynamic of transport mainland activity, 2010–2024. Right: structure of non- and water transport work, 2024.

Figure 2. Domestic transport work including cabotage[1] transport

1 Cabotage transport is the commercial transport of a load between collection points located in a country other than that in which the carrier is established.

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road transport at 56% and sea transport at 39% – while air freight remains marginal at just 0.02% (Statistics Norway, n.d.b). As previously noted, the Norwegian government aims to cut greenhouse gas emissions from domestic shipping and fishing by 50% by 2030 compared to 2005 levels (Norwegian Government, 2019). This equates to reducing emissions from 4,440 kilotons of CO_2 to 2,220 kilotons (DNV, 2020a).

To track progress toward this target, DNV has published an annual "barometer" of the green transition in Norwegian shipping since 2019. This report, commissioned by the Ministry of Climate and Environment, evaluates key indicators related to decarbonization efforts in the sector. The barometer assesses the rate of decarbonization in the maritime sector through an indicator known as "transition pressure." It has been published annually in updated editions, including DNV (2019a), 2020 (DNV, 2020a), 2021 (DNV, 2022), 2022 (DNV, 2023), 2023 (DNV, 2024a), and most recently in 2024 (DNV, 2025a). Although Statistics Norway reports domestic emissions based on fuel sales, DNV developed an alternative emissions model as part of the Green Shipping Action Plan (Norwegian Government, 2019) and the Klimakur 2030 initiative (Norwegian Environment Agency, 2020). It combines data on ship design speed, observed speed from the Automatic Identification System (AIS), and engine characteristics to accurately calculate engine load and fuel use for vessels conducting transport work. For auxiliary systems and other energy uses, the model relies on typical values and statistical relationships based on predefined ship type and size categories, derived from supporting data tables (DNV, 2020a). The "transition pressure" indicator in the barometer is based on a composite of key metrics. This annual assessment covers all commercial vessel segments[2], excluding recreational boats.

1.1.1. Emissions from domestic shipping

According to the barometer for 2024 (DNV, 2025a), there is a decrease in CO2 emissions from Norwegian domestic shipping from 2023 to 2024. Figure 3 illustrates that the primary contributors to emissions in domestic maritime sectors are fishing vessels (21%), offshore vessels (21%), and passenger vessels (17%).

On a more positive note, greenhouse gas emissions from domestic shipping declined by approximately 4.29% from 2023 to 2024. This reduction is largely attributed to decreased use of marine gas oils and the introduction of a new regulatory requirement mandating the blending of biofuels in marine fuels, which came into effect in 2023. Nevertheless, despite the reduction in CO_2 emissions observed over the past year, total emissions from domestic shipping in 2024 still amounted to 4,612 kilotonnes – approximately 42% above the level required to remain on track for the 2030 target of halving emissions relative to 2005 (DNV, 2025a).

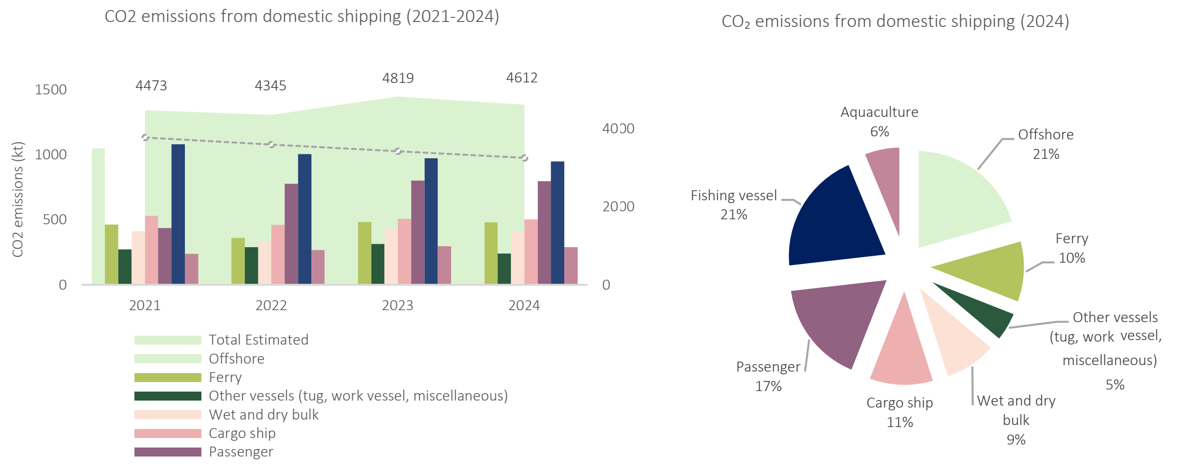


Figure 3. Estimated CO_2 emissions from Norwegian domestic shipping, by segment, 2021–2024

2 DNV has only considered measures on ships that spend more than 80 percent of the time in Norwegian waters, and it has been assumed that ships that mostly stay in Norwegian waters generally purchase their fuel in Norway.

1.1.2. Green technology in sailing ships

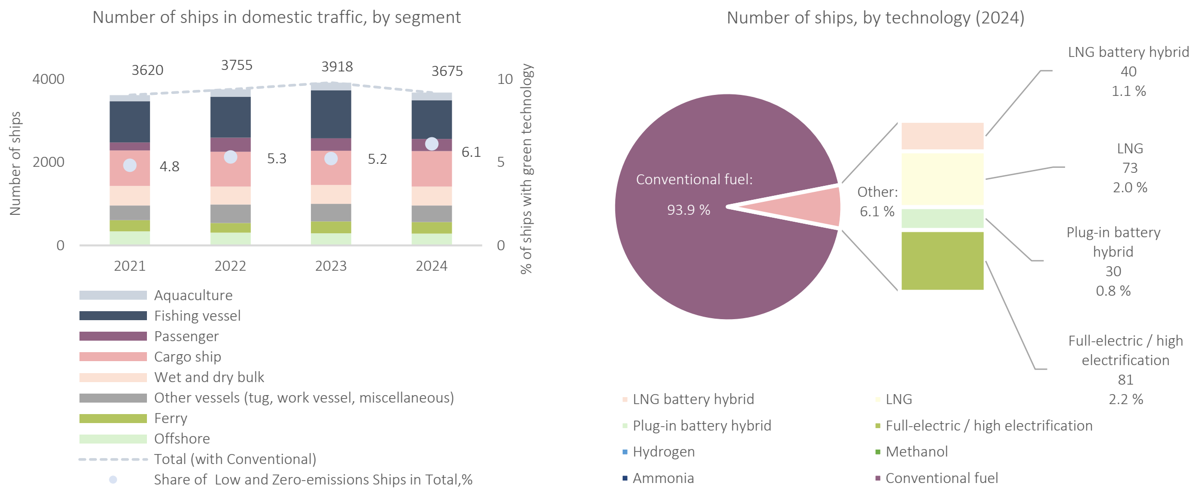
The term "green technology" encompasses two main categories:

1) low-emission technologies, including liquefied natural gas (LNG) propulsion and plug-in hybrid systems equipped with batteries that can be recharged via shore power; and

2) zero-emission technologies, which involve the use of hydrogen-based fuels such as hydrogen, ammonia, and methanol, as well as fully electric propulsion systems.

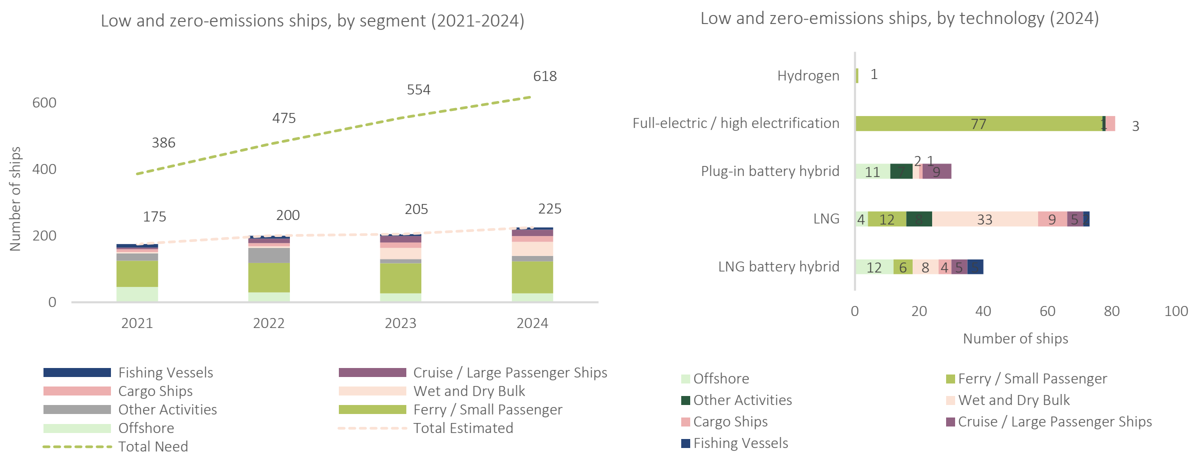
Although the total number of domestic vessels in Norway has shown a declining trend in recent years (with fishing and cargo vessels remaining the dominant segments), there has been a noticeable increase in the share of green ships within the active fleet. During 2021–2024, the proportion of green vessels rose from 4.8% to 6.1% (Figure 4).

Figure 5 illustrates that there were 225 green ships registered in the domestic fleet in 2024. Among the green ships, a total of 82 vessels were classified as zero-emission. Of these, 81 were fully electric or highly electrified, and one vessel operated on hydrogen technology. These zero-emission ships were primarily ferries or smaller passenger vessels, with 77 fully electric and one hydrogen-powered. In contrast, the offshore segment is composed exclusively of low-emission technologies and currently has no zero-emission vessels. This segment



Note: Left: by segment, 2021-2024. Right: by segment and type of green technology, 2024.

Figure 4. Total number of ships in the sailing fleet



Note: Left: by segment, 2021–2024. Right: by segment and type of green technology, 2024.

Figure 5. Number of ships with green technologies in the sailing fleet

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includes 12 LNG-battery hybrid vessels, 4 operating solely on LNG, and 11 plug-in battery hybrid vessels. As for the share of zero-emission ships relative to the total number of green ships, there was a slight decline from 37% to 36% (2023–2024). Zero-emission operations (fully electric, high levels of electrification, or hydrogen-based propulsion) are observed primarily in the ferry segment – most notably *MF Hydra*, which utilizes hydrogen technology, and three zero-emission cargo vessels: *Yara Birkeland* (operated by ASKO) and the two autonomous sea drones *Marit* and *Therese*.

1.1.3. Green technology in the order book

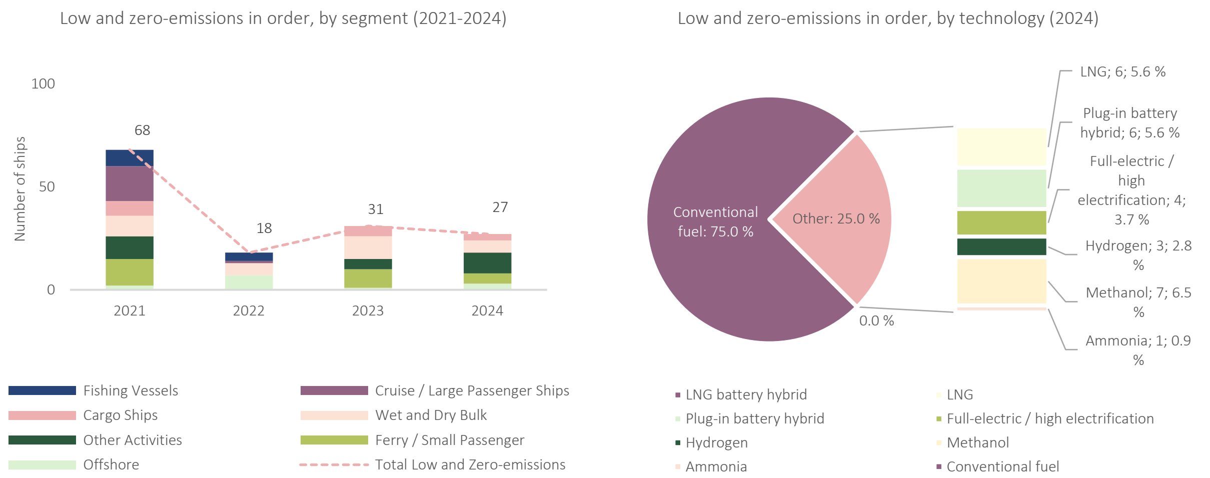
The development of green technology in Norway's shipbuilding order book shows a concerning trend (Figure 6). During the period, the number of low- and zero-emission ships on order declined by 13%, from 31 ships in 2023 to 27 in 2024.

Three hydrogen ships listed in the order book are the same as in 2023: two ferries ordered by Torghatten Nord and a workboat ordered by Salmar. The methanol-fueled vessels include three cable-laying ships, two container ships, one construction support vessel (CSV), and one subsea construction vessel (ESCV). A notable addition in 2024 is Eidesvik's *Viking Energy*, which is to be retrofitted to operate on ammonia. Nevertheless, such statistics are far from sufficient: to meet the national climate targets for 2030, based on the reference scenario, in the sailing fleet by 2028 should be 981 vessels, with 225 currently in operation, with only 27 green ships in the order book; this translates into a gap of approximately 96% between the target and the current trajectory. Globally, 2024 marked a record-breaking year for the maritime industry: a total of 515 such vessels were ordered, representing a 38% increase compared to 2023 (DNV, 2025b).

1.1.4. Infrastructure

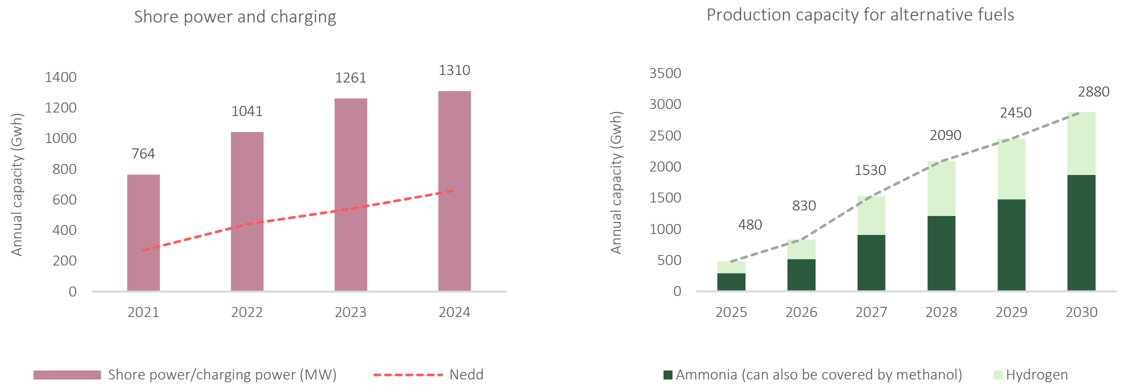
Emission reductions from green vessels rely heavily on the availability of appropriate fuel types. This green transition is heavily dependent on two key aspects of infrastructure: availability of shore power/charging capacity and production capacity for alternative fuels (hydrogen, ammonia, and methanol). The estimated demand for green energy for ships provides a benchmark for assessing whether current and planned infrastructure is sufficient to meet the 2030 target (Figure 7).

Norway has made strong progress in expanding shore power and ferry charging stations. For shore power and battery charging, the projected demand by 2025 is 770 GWh as of December 2024, supported infrastructure has a capacity of 1,310 GWh, indicating that development is on track. However, capacity does not guarantee universal availability due to limited access for various ship types and port uses. Additionally, future demand may increase with advances in battery technol-



Note: Left: by segment, 2021-2024. Right: by segment and type of green technology, 2024.

Figure 6. Order book of low and zero-emissions ships

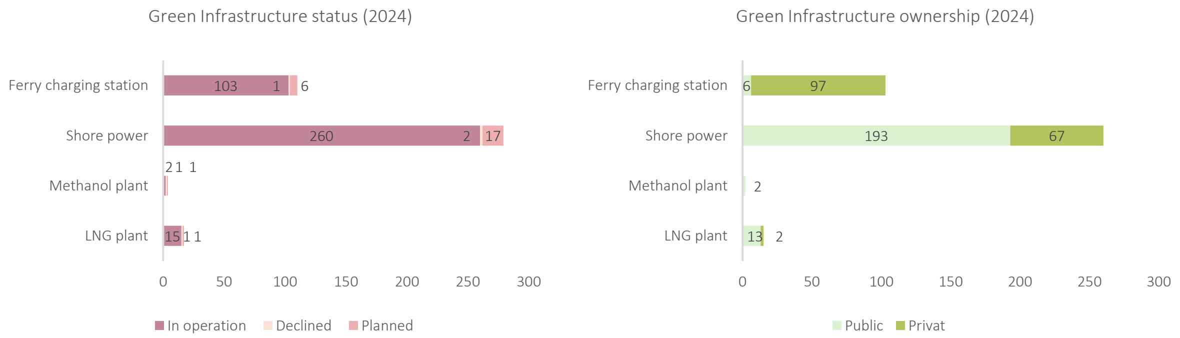


Note: Left: shore power and charging capacity. Right: production capacity for alternative fuels.

Figure 7. Shore power and charging capacity and production capacity for alternative fuels

ogy and the electrification of larger vessels. The Norwegian Coastal Administration has prepared an overview of shore power plants and charging facilities for quays and ferries. Figure 8 shows that for ferry charging stations, the number is 97 private and 6 public, which includes low-voltage and high-voltage plants. There are thus a total of 193 public shore power plants in Norway (Norwegian Coastal Administration, n.d.).

Production of hydrogen, ammonia, and methanol remains limited. As of December 2024, Norway has four operating hydrogen plants (totaling 37 GWh), three of which produce green hydrogen. One green ammonia plant is in operation with a planned capacity of 107 GWh. Additional projects with final investment decisions could raise hydrogen and ammonia production to 1,021 GWh by 2028 (less than half of the estimated 2,090 GWh needed). It is important to note that most projects will not serve the maritime sector exclusively. For instance, GreenIron has contracted Norwegian Hydrogen for green hydrogen to be used in steel production, which alone accounts for 42% of Norway's hydrogen output today. Matching the types of fuel produced with what maritime shipping requires remains a challenge. For example, current hydrogen ships operate on liquid hydrogen, which is not compatible with the compressed hydrogen produced in Norway – forcing reliance on imports from Germany. Moreover, a public support mechanism remains a strong issue. In 2024 alone, Enova provided over NOK 3 billion in support for hydrogen and ammonia projects, a threefold increase from the previous year (Kystens Næringsliv, 2025). Yet, confidence in these fuels among shipowners appears weak. The Norwegian Shipowners' Association's outlook (2025) reports a growing skepticism toward hydrogen and ammonia, with many projects cancelled despite state subsidies. Only a small number of shipowners currently consider green ammonia a viable primary fuel. These disconnects between available support schemes and industry confidence highlight the need for better alignment of infrastructure planning, vessel design, fuel development pathways, and underscore the dynamic nature of Norway's maritime energy transition.



Note: Left: status of infrastructure. Right: ownership type, 2024.

Figure 8. Availability of green maritime infrastructure and port coverage in Norway

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1.2. Investment needs, governance, and instruments

Achieving a 50% reduction in greenhouse gas (GHG) emissions from domestic maritime transport by 2030 – a national goal set by the Norwegian government – requires a rapid and large-scale transformation of the maritime sector. This transition demands substantial investment in both low- and zero-emission vessels and the supporting energy infrastructure required to operate them.

According to Erraia et al. (2024), reducing emissions from maritime transport will require an average annual investment of NOK 7.3 billion. This investment corresponds to the additional costs of choosing low- and zero-emission alternatives for ships and developing the necessary onshore infrastructure:

1) ship-related investments: includes retrofitting existing vessels and the additional costs of constructing new green ships, estimated at NOK 5.1 billion per year;

2) land-based investments: involves infrastructure for charging and bunkering zero-emission fuels, as well as production facilities for such fuels. These investments are estimated at NOK 2.2 billion per year.

DNV (2025a) estimated the total investment needs for realizing the 2030 decarbonization scenario at NOK 99.4 billion by 2030 (Table 1).

Table 1. Accumulated investment needs in Norwegian domestic shipping, MNOK (2022–2030)

Year	Investment need for land-based infrastructure	Investment need for low- and zero-emission ships	Total
2022	1,000	3,900	4,800
2023	1,200	7,800	8,900
2024	1,400	11,600	13,000
2025	3,800	23,600	27,500
2026	5,700	35,700	41,300
2027	9,100	47,700	56,800
2028	12,000	59,700	71,600
2029	13,800	71,700	85,400
2030	15,700	83,700	99,400

This estimate excludes vessels already in operation (e.g., certain battery-electric ferries) and assumes that new builds will operate primarily (≥ 80%) in Norwegian waters. It also includes the cost differentials associated with installing green technologies on vessels and building the infrastructure to produce, store, and supply alternative fuels such as green hydrogen, ammonia, and methanol. Despite these projections, the actual level of investment between 2022 and 2024 remains significantly below target. Apart from some progress in shore power and ferry charging stations, many planned investments have either been delayed or have not materialized.

1.3. Energy infrastructure needs and instruments

By 2030, the accumulated investment in infrastructure alone (excluding ship technology) is estimated at NOK 15.7 billion, reflecting the capital costs of constructing shore power facilities, bunkering terminals, and fuel production plants for hydrogen and ammonia (DNV, 2025a). Norway currently has the highest number of shore power plants in Europe, supported significantly by Enova, which has distributed over NOK 660 million since 2016 to 93 shore power plants since 2016 (Norwegian Confederation of Enterprise, 2024).

The development of green maritime infrastructure focuses on three critical stages in the value chain:

1) production of green fuels;

2) distribution;

3) bunkering (fueling infrastructure).

This system faces a classic "chicken-and-egg" dilemma, where the fleet cannot be converted until it has access to alternative fuels, while at the same time one does not dare to invest in the production of alternative fuels until demand is secured and customers are in place. In practice, this means that a completely new value chain must be built at the same time (KLP, 2023).

For institutional investors, market risk, including uncertainty related to future carbon pricing, is the greatest challenge. If shipping companies or cargo owners are also not willing and/or able to assume this risk through long-term customer contracts for the purchase of green fuels, we will probably not achieve the necessary scaling of new green maritime infrastructure in Norway. Hence, political support, adapted public instruments, and price competitiveness are critical factors to the further development of climate-friendly energy technologies and infrastructure; these are also central to attracting capital. Figure 9 represents an overview of main support schemes for green transition in the maritime industry. Such support is divided into three main parts:

1) research and development support;

2) investment support;

3) loans and guarantees.

Some support schemes offer both development and investment support. For instance, Research Council of Norway works to promote R&D activities; Innovation Norway provides various support schemes like grants and loans to supports innovative business projects. Figure 9 illustrates that green maritime infrastructure generally relies on more mature technologies than those traditionally supported by Norwegian funding schemes. Among these, Enova stands out by providing investment support even beyond the demonstration phase, despite operating in immature markets. Other relevant Norwegian instruments include (Norwegian Government, 2019): Eksfin, offering guarantees for export-oriented climate investments (its mandate was expanded in 2022 to include green projects within Norway); Gassnova and the CLIMIT program, targeting CCS technologies; NOx Fund, which has supported maritime emission reduction projects, measures typically involve reduced fuel consumption or a shift to cleaner energy sources.

These above mentioned that decarbonization of shipping in Norway depends not only on infrastructure rollout and technological availability, but also on policy incentives, demand stimulation, and coordination across the maritime value chain.

2. LITERATURE REVIEW

This study draws upon two theoretical lenses: environmental public investment theory and regional path dependence theory.

Public investment theory posits that targeted infrastructure spending, especially in public goods such as ports, can generate positive externalities, including technological spillovers, productivity gains, and reduced environmental harm (Song & van Geenhuizen, 2014). Ports, while increasingly commercialized, often require foundational investments that may not yield direct financial returns but are

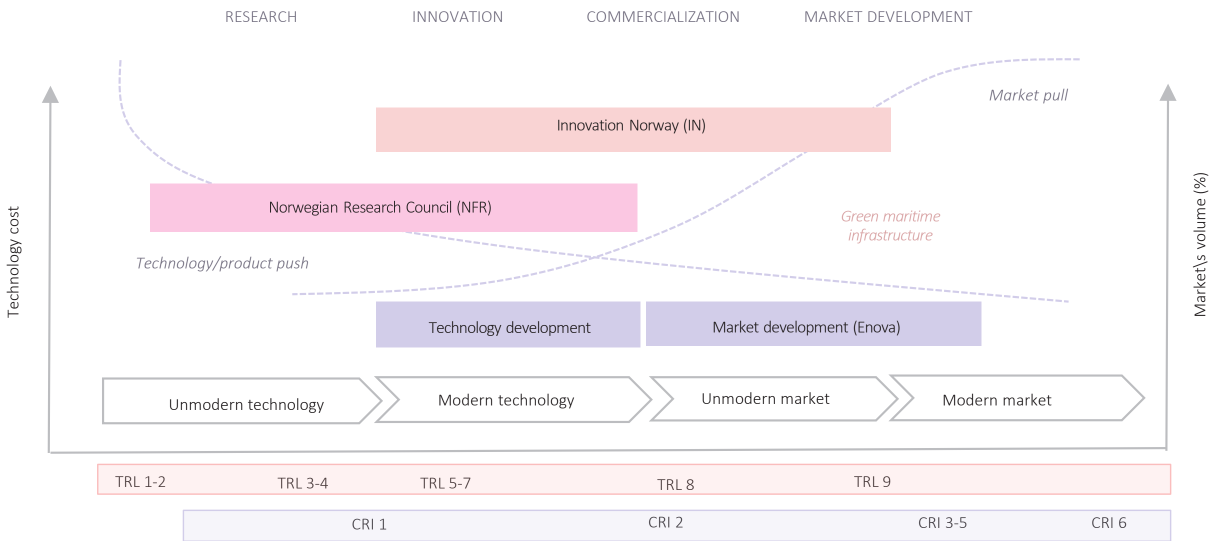

Figure 9. Categorization of government instruments targeting climate-friendly energy technology by Technology maturity level (TRL) and Commercial readiness index (CRI)

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critical for enabling green transitions. These include shore power systems, ammonia bunkering terminals, and hydrogen storage facilities. As Sotnychenko and Sivan (2021) argue, ports frequently face the paradox of financing low-return but socially vital infrastructure, making public subsidies and strategic investment mechanisms essential. Recent paper by Sang and Pan (2024) on Chinese cities provides valuable methodological insight by demonstrating that green infrastructure investment (GII) can have significant carbon reduction effects, with a noted time-lag of impact, showing the strongest results three periods after implementation. Their dynamic panel threshold model also reveals nonlinear relationships, where technological progress moderates the impact of GII on emissions, highlighting the importance of absorptive capacity and innovation systems.

Furthermore, Grytten et al. (2020) and Koilo (2019) prove that leadership, active investment in new technologies and energy efficiency policies contribute to decoupling economic growth from emissions. This highlights the importance of regional and sector-specific analyses when applying environmental Kuznets curve theory to port and maritime infrastructure transitions. Green energy investment literature further emphasizes the importance of public-private partnerships, risk-sharing mechanisms, and adaptive governance in fostering resilient energy transitions (Koilo, 2021, 2024). These mechanisms are critical for aligning short-term investment decisions with long-term decarbonization goals, particularly when dealing with uncertain technological pathways and high upfront costs.

Mohite and Mathew (2025) found that upgrading port infrastructure, such as fuel bunkering for ammonia and hydrogen, shore power systems, and waste management, is essential for supporting next-generation green vessels; however, these upgrades face financial, regulatory, and technical barriers. Their research recommends aligning infrastructure investments with sustainability goals and highlights case studies such as Rotterdam, Gothenburg, and Singapore, which illustrate feasible pathways through integrated policy, public funding, and stakeholder engagement. Tagawa et al. (2025) contribute insights on governance, showing that strategic cooperation between ports, rather than isolated investments, enhances port competitiveness and environmental performance. Their case study of Osaka and Kobe ports supports the idea that collaborative approaches can improve network structure and facilitate shared sustainability transitions. Daniel et al. (2025) underscore the need for holistic transformation frameworks, cross-border cooperation, and context-sensitive approaches to unlock the full potential of port-based critical energy infrastructure in meeting sustainability goals. Complementing these perspectives, Sogut and Erdoğan (2022) propose a holistic framework for green port transition based on energy and environmental sustainability. Their results highlight that green port development is not only a technical challenge but also a matter of strategic management and stakeholder coordination within circular economic systems.

Recent evidence from broader European transition studies highlights that sustainable mobility and renewable energy investments yield substantial long-term environmental benefits, though with notable time lags between policy action and measurable outcomes (Khaustova et al., 2024; Vasa et al., 2024). These findings are relevant for the Norwegian maritime context, where policy frameworks and infrastructure funding play a decisive role in local emission outcomes. Public investment can stimulate technology uptake, green port operations, and networked innovation. Moreover, major geopolitical events can further influence energy-transition dynamics – for example, disruptions from the war in Ukraine have been shown to accelerate systemic change in energy systems (Koilo, 2025).

However, the degree of efficiency and emission impact varies by regional capacity and industrial structure. As noted by Naumenkova et al. (2025), fiscal and financial mechanisms remain central to sustaining long-term environmental transformations, especially in capital-intensive sectors such as shipping and port infrastructure.

Regional development theory, particularly path dependence frameworks, underscores how historical industrial activities, infrastructure legacies, and institutional arrangements shape present-day environmental and economic trajectories. Moreover, empirical evidence suggests that port infrastructure planning must account for regional disparities in capacity, demand, and technology adoption. Sang and Pan (2024) further demonstrated that the output elasticity of green infrastructure investment varies significantly by location, influenced by technological readiness and economic maturity. Similarly, Cholidis et al. (2025) propose a scalable framework for transitioning ports into nearly zero-energy ecosystems by integrating hybrid renewable energy systems (HRES), energy storage systems (ESS), and smart grid technologies. Their case-based simulation confirms that systemic planning and modular HRES implementation can significantly reduce emissions and enhance port resilience. In addition, Rodrigue et al. (2017) highlight the inherently political nature of green logistics, emphasizing that institutional capacity at the regional level is essential for implementing effective environmental strategies. They argue that minimizing transport movements through spatial integration of industrial activities and strong land use planning, rather than increasing shipment frequency, offers a more sustainable pathway. This reinforces the importance of regional governance structures in managing logistics networks and maritime infrastructure transitions toward environmental sustainability.

In sum, the literature review reveals that the transition to low-emission maritime transport requires substantial infrastructure investment across port regions, vessel technologies, and fuel supply chains. Prior research has established that infrastructure development contributes to emission mitigation in multiple sectors, including transportation and energy (Munim & Schramm, 2018). In the maritime domain, the focus has largely centered on port electrification (Sæther & Moe, 2021), sustainability indicators (Koilo, 2020), and decarbonization trajectories outlined by international agencies like the IMO (2023). Despite this, there remains a notable gap in empirical research addressing the subnational or municipality-level effects of such investments, particularly in coastal and industrial port towns. By focusing on the municipality-level dynamics in Norway, this study seeks to contribute to filling a critical empirical gap in the existing body of research.

3. METHODOLOGY

This study investigates the relationship between investments in green maritime infrastructure and emission reductions across Norwegian port municipalities. Using a mixed-method approach, the paper combines panel data econometrics with unsupervised clustering to analyze 28 coastal municipalities from 2016 to 2023.

3.1. Research objective

The overarching objective is to assess whether investments in green maritime projects contribute to the decarbonization of port-related activities in Norway. Specifically, the study aims to:

- Quantify the link between maritime investments and local CO_2 emissions.
- Identify regional heterogeneity through unsupervised clustering (coastal municipalities with different port activity vary in investment, infrastructure, and emission outcomes).
- Evaluate the effect of green infrastructure on emission trends in high-activity port municipalities.

3.2. Research hypotheses

The following hypotheses are tested:

H1: *Public maritime investments reduce local CO_2 emissions.*

H_0: *$\beta_1 = 0$ – No impact of maritime investments on CO_2 emissions.*

H_1: *$\beta_1 < 0$ – Investments are associated with emission reductions.*

H2: *Green investment has a lagged impact.*

H_0: *$\beta_2 = 0$ – No lag effect.*

H_1: *$\beta_2 < 0$ – Emission reductions follow the adoption of green technology and infrastructure after a delay.*

H3: *Green infrastructure moderates the emissions relationship.*

H_0: *$\beta_3 = 0$ – No interaction effect.*

H_1: *$\beta_3 < 0$ – Emission reductions are stronger in municipalities with green infrastructure (e.g., shore power).*

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H4: Port activity increases emissions.

H₀: $\beta_4 = 0$ – Port calls and tonnage are unrelated to emissions.

H₁: $\beta_4 > 0$ – More port activity leads to higher emissions.

H5: Clustering reveals spatial mismatches.

H₀: Clusters do not differ systematically.

H₁: Clusters vary in investment, infrastructure, and emission outcomes.

3.3. Data sources and variable overview

A novel dataset was compiled from multiple official and industry sources. It includes metrics related to emissions, investments, infrastructure, and port performance (Table 2):

3.4. Analytical approach

3.4.1. Correlation and regression analysis

The main dependent variable is the maritime-related CO_2 emissions for each municipality (2016–2023). Independent variables:

- maritime activity: *PortCall, PortGross;*
- public investments: *TransMarFunding, InfraMarFunding, TransMarProjects, InfraMarProjects* (projects are binary variables: 1 if ≥ at least two green projects, 0 if less projects);
- infrastructure availability: *GreenInfrastructure;*
- economic indicators: *EmployMar, TurnMar, ValueMar.*

The regression equation was specified as:

$$\begin{aligned}\ln CO2_{it} &= \beta_0 + \sum_{k=1}^{5}\beta_{1k}\ln TransMarFunding_{i,t-k} \\ &+\sum_{k=1}^{5}\beta_{2k}\ln InfraMarFunding_{i,t-k} \\ &+\sum_{k=1}^{5}\beta_{3k}\,\text{bin}\, TransMarProject_{i,t-k} \\ &+\sum_{k=1}^{5}\beta_{4k}\,\text{bin}\, InfraMarProject_{i,t-k} \\ &+\beta_5 GreenInfrastructure_{it} \\ &+\beta_6\ln PortsCall_{it} + \beta_7\ln PortGross_{it} \\ &+\beta_8\ln EmployMar_{it} + \beta_9\ln TurnMar_{it} \\ &+\beta_{10}\ln ValueMar_{it} + \varepsilon_{it},\end{aligned} \tag{1}$$

where ε – error term; *ln* – natural logarithm; *bin* – binary indicator; *i* – index for municipality (or observational unit); *t* – index for year (time period); *k* – lag order, going from 1 to 5.

3.4.2. Cluster analysis

To explore spatial heterogeneity, unsupervised cluster analysis (e.g., K-means) was conducted using emission trajectories, investment profiles, infrastructure availability, port throughput (tonnage) to group municipalities into typologies based on their alignment with decarbonization patterns and identify mismatches between investment levels and outcomes. All statistical analyses were performed using Stata 19.0, following the mixed-methods framework.

Table 2. The measurement and data source of explanatory variables

Indicator Group	Variable Name	Description	Source
CO_2 Emissions	CO2Mar	Maritime CO_2 emissions per municipality (tonnes)	Norwegian Environment Agency (n.d.)
Port Activity	PortCalls, PortGross	Annual port calls and vessel gross tonnage	Statistics Norway (n.d.c)
Green Infrastructure Access	GreenInfrastructure	Count of publicly accessible installations (shore power, LNG, ferry charging)	Norwegian Coastal Administration (n.d.)
Green Infrastructure Investment	InfraMarFunding, InfraMarProject	ENOVA-supported shore power, bunkering, and charging infrastructure[3]	Enova (n.d.)
Green Transport Investment	TransMarFunding, TransMarProject	ENOVA funding for green vessel projects	Enova (n.d.)
Maritime Economic Performance	EmployMar, TurnMar, ValueMar	Employment, turnover, and value added in the maritime sector	Maritime Forum (n.d.)

3 This study focuses specifically on Enova support, as it supports both domestic shipping and infrastructure investments.

4. RESULTS

4.1. Regression results

To evaluate the relationship between green maritime investments and CO_2 emission trends across 28 Norwegian port municipalities (2016–2023), pooled OLS, fixed effects (FE), and random effects (RE) models were applied.

4.2. Descriptive statistics and correlation analysis

The study begins with basic descriptive statistics for key variables across 224 observations (28 municipalities over 8 years), presented in Table 3.

The dependent variable, log-transformed maritime CO_2 emissions (*ln_co2mar*), has a mean of 10.30 (SD = 0.93). Key funding variables, including *ln_transmarfunding* and *ln_inframarfunding*, exhibit positive skewness.

Correlation analysis revealed significant positive correlations among key variables (Table 4).

4.2.1. Multicollinearity and OLS diagnostics

An initial pooled OLS regression was conducted without lags of maritime transport and infrastructure funding variables (Table A1 in Appendix A). Variance Inflation Factor (VIF) analysis reveals high multicollinearity among control variables, particularly *ln_employmar* (VIF = 10.6) and *ln_turnmar* (10.2), in line with correlation analysis warning. These first two variables were dropped in subsequent models to improve model stability.

Other diagnostics of the POL model included:

1. Heteroskedasticity test (Breusch-Pagan/Cook-Weisberg): $\chi^2(1) = 35.57$; $p = 0.000$.

Result: Strong evidence of heteroskedasticity. This suggests that the error variance is not constant

Table 3. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ln_co2mar	224	10.30	0.93	7.07	11.77
ln_transmarfunding	224	0.72	1.39	0.00	5.01
ln_inframarfunding	224	0.50	0.99	0.00	4.41
bin_transmarprojects	224	0.28	0.45	0.00	1.00
bin_inframarprojects	224	0.30	0.46	0.00	1.00
greeninfrastructure	224	7.11	8.17	0.00	36.00
ln_portcall	224	7.25	1.04	3.40	9.46
ln_portgross	224	15.89	1.19	11.82	18.64
ln_employmar	224	6.56	1.31	3.26	9.04
ln_turnmar	224	7.92	1.70	2.94	11.62
ln_valuemar	224	6.75	1.83	0.00	10.53

Table 4. Correlation insights

Variable	ln_co2 mar	ln_ transmar funding	ln_ inframar funding	bin_ transmar projects	bin_green infrastruc-ture	bin_ inframar projects	ln_port call	ln_port gross	ln_ employ mar	ln_turn mar	ln_value mar
ln_co2mar	1	–	–	–	–	–	–	–	–	–	–
ln_transmarfund	0.33	1	–	–	–	–	–	–	–	–	–
ln_inframarfund	0.24	0.31	1	–	–	–	–	–	–	–	–
bin_transmarproj	0.36	0.83	0.30	1	–	–	–	–	–	–	–
greeninfrastruct	0.58	0.31	0.19	0.36	1	–	–	–	–	–	–
bin_inframarproj	0.25	0.38	0.77	0.39	0.24	1	–	–	–	–	–
ln_portcall	0.57	0.50	0.30	0.52	0.61	0.35	1	–	–	–	–
ln_portgross	0.53	0.52	0.27	0.49	0.51	0.31	0.86	1	–	–	–
ln_employmar	0.67	0.51	0.28	0.45	0.62	0.31	0.65	0.59	1	–	–
ln_turnmar	0.68	0.53	0.28	0.45	0.56	0.28	0.64	0.65	0.93	1	–
ln_valuemar	0.56	0.51	0.21	0.40	0.53	0.24	0.56	0.59	0.88	0.88	1

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across observations. Therefore, standard errors from the OLS model may be biased, necessitating the use of robust standard errors in estimation.

2. Normality of residuals (Shapiro-Wilk Test): W = 0.9715; $p = 0.00017$.

Result: The null hypothesis of normally distributed residuals is rejected. While this deviation from normality may not severely affect coefficient estimates in large samples, it can impact inference in small samples.

These results highlight the importance of choosing the correct model specification and estimation technique, especially when addressing heteroskedasticity and non-normality.

4.2.2. Panel estimation and model selection

To ensure both estimation efficiency and robustness, three types of panel regression models were applied (with lags of maritime transport and infrastructure funding variables): pooled OLS, fixed effects (FE), and random effects (RE). The regression results are presented in Table A2, where Model 1 corresponds to the pooled OLS specification, Models 2 and 3 represent the FE and RE estimations, respectively, and Models 4–6 include cluster-robust standard errors.

Importantly, the model incorporates lag structures for the key policy-related variables, including funding and project interventions. This lagged specification allows for the temporal delay between maritime investment efforts and their potential impact on CO_2 emissions, thus enhancing the economic and policy interpretation of the results. By capturing effects distributed over multiple periods, the estimation more accurately reflects real-world implementation lags and cumulative responses.

Several diagnostics were implemented to choose the best model, which included:

1. The Breusch-Pagan Lagrangian Multiplier (LM) test was used to determine whether RE is preferred over pooled OLS. The test statistic ($\chi^2 = 59.75$, $p = 0.000$).

- Since $p < 0.01$, the null that Var(u) = 0 (i.e., no panel effect) is rejected. Thus, RE is better than pooled OLS.

2. The Hausman test compared FE and RE estimators. The test yielded $\chi^2(23) = 0.64$, $p = 1.000$.

- Since $p = 1.000$, the null hypothesis is not rejected. This means that there is no statistically significant difference between FE and RE coefficients.

Hence, based on specification following Hausman and Breusch-Pagan tests, the random effects model was selected as the preferred. Table A2 presents the regression results for RE model including lag structures for maritime transport and infrastructure funding variables. Based on it, can be derived the following:

- The coefficients of *ln_transmarfunding* are negative and statistically significant (mostly at the 1% level) across FE and RE models for all five lag periods. The estimated effect magnitude increases over longer lags, suggesting a persistent reduction in CO_2 emissions following transport-related investments.
- The *bin_transmarprojects* variable shows positive and significant coefficients for the first and second lags, followed by insignificant effects in later periods.
- The variables related to infrastructure funding and projects (*ln_inframarfunding, bin_inframarprojects*) are statistically insignificant in all model specifications.
- The *greeninfrastructure* variable was excluded from the FE model due to perfect collinearity but appears positive and significant in the RE model with clustered standard errors.
- The control variable *ln_portgross* is positive and statistically significant in both FE and RE estimations, while *ln_portcall* remains statistically insignificant.

Overall, the model results demonstrate strong robustness across specifications, with consistent significance patterns and expected signs for most key variables.

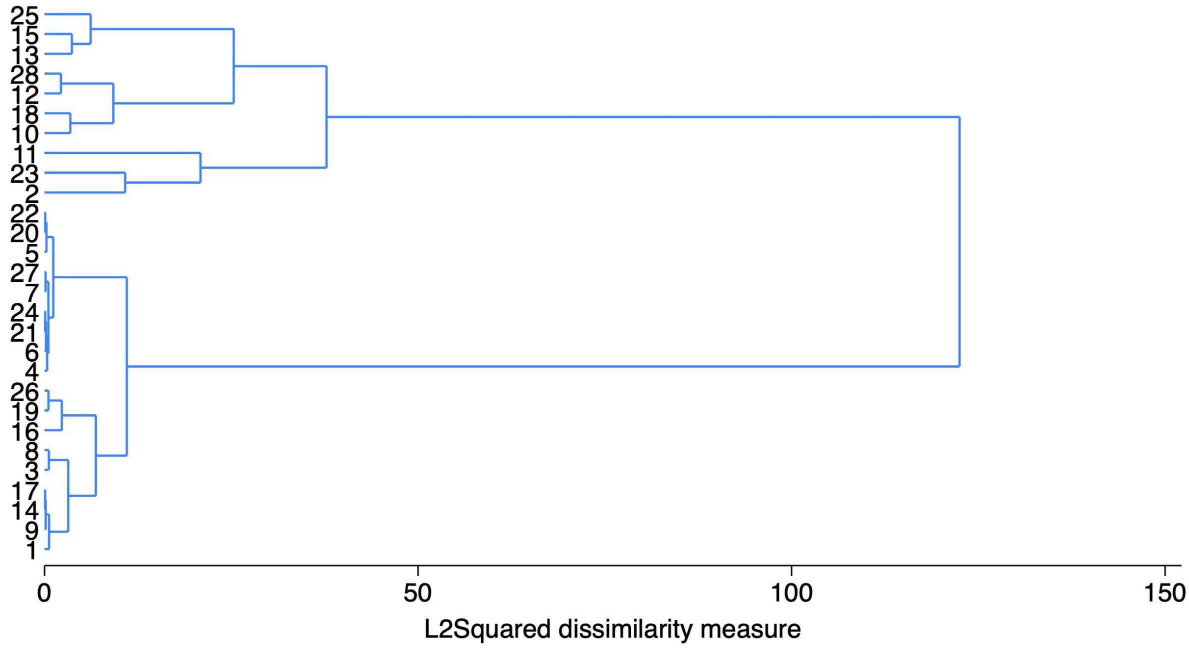

Figure 10. Dendrogram for HR cluster analysis

Table 5. Three distinct municipal typologies

Cluster	Description	Size	Examples
1	Low emissions, low activity, few green projects	13	Alstahaug, Brønnøy, Drammen, Eigersund, Fredrikstad, Harstad, Larvik, Narvik, Rana, Sandefjord, Sauda, Sør-Varanger, Tønsberg
2	Moderate investment and infrastructure with mid-range emissions	7	Bodø, Hammerfest, Kristiansand, Molde, Moss, Porsgrunn, Trondheim
3	High port activity, significant green funding, high emissions	8	Bergen, Haugesund, Kinn, Kristiansund, Oslo, Stavanger, Tromsø, Ålesund

4.3. Cluster analysis

To uncover spatial heterogeneity, unsupervised K-means clustering ($k = 3$) was applied based on standardized values of emissions, investment levels, green infrastructure, and port activity. Results suggest three distinct municipal typologies presented in Table 5.

Ward's linkage with Euclidean distance confirmed cluster structure. The dendrogram highlights distinct groupings and inter-cluster dissimilarities (Figure 10).

The dendrogram gives a visual sense of how similar municipalities are. For example: nodes that merge early are more similar, large vertical jumps = greater dissimilarity → meaningful cluster breaks. Better visual presentation of municipalities explains such clustering approach (Table B1 and Figures B1-B4) in Appendix B.

5. DISCUSSION

The results support the hypothesis that public investments in maritime transport lead to long-term reductions in CO_2 emissions, while infrastructure-related effects remain delayed. This finding is consistent with broader evidence on sustainability transitions, where the environmental impact of green funding becomes significant only after technological and institutional maturity is reached (Versal & Sholoiko, 2022; Plastun et al., 2023).

The negative and significant coefficients of *ln_transmarfunding* across lag periods confirm that transport-oriented funding yields long-term emission reductions, consistent with environmental public investment theory and findings from Sang and Pan (2024). These lagged effects reflect the delayed realization of benefits due to the time needed for technology adoption, fleet renewal, and operational adjustments.

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In contrast, the initial positive association of *bin_transmarprojects* with emissions in the early years likely reflects transitional phases involving construction, retrofitting, or increased activity during project implementation. This pattern aligns with the "green transition paradox" observed by Mohite and Mathew (2025), where short-term increases precede long-term gains.

The lack of statistical significance for *ln_inftamarfunding* variables suggests that port infrastructure improvements – such as shore power and charging stations – may require longer observation periods to exhibit measurable effects. These investments often depend on complementary vessel technologies and user adoption rates.

The positive coefficient for *green infrastructure* in the RE models should not be interpreted as causation but rather as an indication that high-emission ports are the primary recipients of such investments. This pattern underscores policy targeting, as infrastructure development is concentrated in active ports with high throughput and emissions intensity.

The positive and significant *ln_portgross* coefficient confirms that higher port activity remains a dominant factor in emission levels. This finding highlights the dual challenge of balancing economic activity and environmental objectives within maritime policy.

Finally, the clustering results reveal distinct municipal typologies, confirming spatial heterogeneity across Norwegian ports. High-activity ports combine advanced infrastructure with higher emissions, while smaller ports show limited investment and lower emission intensity.

Table 5 shows the following:

- Cluster 1: These municipalities exhibit lower levels of maritime emissions and economic activity, with limited investment in green infrastructure or maritime transport projects. This cluster likely represents smaller or less industrialized port regions, where policy and investment effects may be marginal or slow to materialize.
- Cluster 2: Represents a middle category, where some investment in infrastructure and maritime activity is present, along with moderate CO_2 emissions. These municipalities may be in transition, starting to show measurable impacts from maritime funding or projects, but still not fully industrialized.
- Cluster 3: Includes large, industrial port cities with high throughput, emissions, and green infrastructure activity. These municipalities are key drivers of national-level maritime emissions and likely receive targeted funding for mitigation.

These results align with Rodrigue et al. (2017) and Sogut and Erdoğan (2022), emphasizing that governance capacity, regional cooperation, and adaptive policy instruments are crucial for achieving effective decarbonization.

5.1. Hypothesis summary

Hence, this study tested five hypotheses related to the impact of maritime investments, green infrastructure, and port activity on local CO_2 emissions. The results provide robust support for several core assumptions.

H1: *Public maritime investments reduce CO_2 emissions → Reject H_0 ($\beta_1 \neq 0$): The null hypothesis is rejected, with statistically significant negative effects found, particularly through lagged green maritime transport funding.*

H2: *Green investment has a lagged impact → Reject H_0 ($\beta_2 \neq 0$): The emission-reducing effects of green investments exhibit a lag structure, with impacts becoming more pronounced 3–5 years after implementation. This supports the hypothesis of delayed environmental benefits.*

H3: *Green infrastructure moderates the emissions relationship → Fail to reject H_0 ($\beta_3 = 0$): The positive and statistically significant coefficient suggests that building of green infrastructure tends to increase emissions in port municipalities. Thus, we fail to reject the null hypothesis.*

H4: *Port activity increases emissions → Reject H_0 ($\beta_4 \neq 0$): Increased port activity (measured by port calls and cargo throughput) is positively and significantly correlated with higher emissions, confirming that port operations remain a key driver of local CO_2 intensity.*

H5: *Clustering reveals spatial mismatches → Reject H_0 ($\beta 5 \neq 0$): The cluster analysis revealed systematic spatial variation across municipalities in both investment levels and infrastructure rollout. This confirms that the effects are not uniformly distributed geographically.*

5.2. Implications

For policymakers, the results underscore the need to design investment programs with sufficient lead time for implementation and impact realization. Moreover, infrastructure planning must be integrated with local port activity forecasts and fuel supply systems to avoid mismatch. Municipalities with low baseline capacity may require tailored support mechanisms beyond one-size-fits-all national subsidies. These findings call for differentiated policy tools. Ports with high emissions and infrastructure may benefit from operational regulations (e.g., OPS mandates), while smaller ports may require capacity-building and co-investment schemes.

5.3. Limitations and future study

Several limitations should be acknowledged. First, the study is constrained by data availability and aggregation; for instance, the green infrastructure variable lacks temporal variation, limiting its interpretability in panel models. Second, omitted variables, such as vessel-level fuel type or real-time port activity, may bias estimates.

Thus, disaggregating maritime CO_2 emissions by vessel segment could help clarify how port activity and ship type influence emission patterns. Segment-specific analyses would also provide better guidance for targeting infrastructure investments and regulatory interventions. Additionally, a comparative cross-country study, contrasting Norwegian port municipalities with similar port regions in other European countries subject to the FuelEU Maritime and TEN-T regulations, could offer broader insights into the relative effectiveness of different green shipping strategies.

CONCLUSION

This study aimed to evaluate whether public investments in green maritime transport and infrastructure contribute to CO_2 emission reductions in Norwegian port municipalities. Using a panel dataset of 28 coastal municipalities from 2016 to 2023, the results demonstrate that green transport investments have statistically significant emission-reducing effects, particularly after a lag of three to five years, confirming their long-term contribution to maritime decarbonization. Conversely, the presence of green infrastructure, such as shore power and charging stations, is positively associated with emissions, suggesting concentration of such facilities in high-activity, high-emission ports rather than immediate mitigation effects. Clustering analysis further revealed strong spatial heterogeneity in investment patterns, infrastructure readiness, and emission intensity, emphasizing the need for tailored rather than uniform policy approaches. These findings highlight that while targeted funding can drive emission reductions over time, policy efficiency depends on regional capacity, coordination, and infrastructure maturity. Future research should extend this analysis to other European port regions and integrate vessel-level data to better capture technology adoption dynamics and cross-border policy diffusion effects.

AUTHOR CONTRIBUTIONS

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APPENDIX A

Table A1. Regression results (Main specification and extended controls)

Variables	Extended Model	Main Model
ln_transmarfunding	−0.127**	−0.108
	(−2.09)	(−1.63)
ln_inframarfunding	0.023	0.077
	(0.33)	(1.05)
bin_transmarprojects	0.290	0.294
	(1.60)	(1.50)
bin_inframarprojects	0.004	−0.048
	(0.02)	(−0.29)
greeninfrastructure	0.025***	0.031***
	(3.50)	(4.11)
ln_portgross	0.058	0.067
	(0.75)	(0.85)
ln_valuemar	−0.124**	0.143***
	(−2.28)	(4.03)
ln_employmar	0.106	–
	(1.00)	
ln_turnmar	0.318***	–
	(3.95)	
Constant	6.460***	6.937***
	(7.84)	(8.51)
Observations	224	224
R-squared	0.553	0.468
Adj. R-squared	0.532	0.449
Root MSE	0.638	0.692

Note: t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A2. The regression results of POLS, RE, FE model

Variable	POLS	FE	RE	POLS_Clustered	FE_Clustered	RE_Clustered
ln_transmarfunding_k-1	−0.177	−0.102***	−0.099***	−0.177	−0.102***	−0.099***
	(−1.54)	(−3.15)	(−3.47)	(−1.48)	(−4.02)	(−4.16)
ln_transmarfunding_k-2	−0.041	−0.084***	−0.079***	−0.041	−0.084***	−0.079***
	(−0.38)	(−3.19)	(−3.41)	(−0.40)	(−3.59)	(−3.20)
ln_transmarfunding_k-3	0.026	0.09911	−0.050**	0.026	−0.053***	−0.050***
	(0.17)	(−1.87)	(−1.99)	(0.20)	(−3.26)	(−2.99)
ln_transmarfunding_k-4	0.002	−0.101**	−0.094***	0.002	−0.101**	−0.094**
	(0.01)	(−2.65)	(−2.80)	(0.01)	(−2.27)	(−2.40)
ln_transmarfunding_k-5	−0.191	−0.112***	−0.106***	−0.191	−0.112**	−0.106***
	(−1.11)	(−3.02)	(−3.24)	(−1.34)	(−2.71)	(−2.81)
ln_inframarfunding_k-1	0.077	−0.052	−0.046	0.077	−0.052	−0.046
	(0.59)	(−1.58)	(−1.58)	(0.90)	(−1.25)	(−1.17)
ln_inframarfunding_k-2	0.050	0.025	0.026	0.050	0.025	0.026
	(0.42)	(0.68)	(0.80)	(0.48)	(0.97)	(1.09)

http://dx.doi.org/10.21511/ee.16(4).2025.07

Table A2 (cont.). The regression results of POLS, RE, FE model

Variable	POLS	FE	RE	POLS_Clustered	FE_Clustered	RE_Clustered
ln_inframarfunding_k-3	0.184	−0.004	0.001	0.184	−0.004	0.001
	(1.20)	(−0.09)	(0.02)	(1.19)	(−0.13)	(0.03)
ln_inframarfunding_k-4	−0.005	0.009	0.013	−0.005	0.009	0.013
	(−0.02)	(0.21)	(0.34)	(−0.03)	(0.23)	(0.38)
ln_inframarfunding_k-5	0.095	0.005	0.010	0.095	0.005	0.010
	(0.59)	(0.11)	(0.29)	(0.99)	(0.13)	(0.34)
bin_transmarprojects_k-1	0.261	0.302***	0.293***	0.261	0.302***	0.293***
	(0.83)	(4.14)	(4.54)	(0.82)	(5.19)	(5.41)
bin_transmarprojects_k-2	0.160	0.238***	0.227***	0.160	0.238***	0.227***
	(0.48)	(3.41)	(3.68)	(0.54)	(3.31)	(3.28)
bin_transmarprojects_k-3	0.036	0.097	0.100	0.036	0.097	0.100
	(0.07)	(1.07)	(1.25)	(0.11)	(1.45)	(1.52)
bin_transmarprojects_k-4	−0.067	0.106	0.102	−0.067	0.106	0.102
	(−0.11)	(1.02)	(1.10)	(−0.15)	(0.72)	(0.74)
bin_transmarprojects_k-5	0.808	0.088	0.093	0.808**	0.088	0.093
	(1.59)	(0.87)	(1.03)	(2.18)	(1.07)	(1.15)
bin_inframarprojects_k-1	−0.017	0.011	0.012	−0.017	0.011	0.012
	(−0.07)	(0.17)	(0.21)	(−0.08)	(0.17)	(0.19)
bin_inframarprojects_k-2	0.006	0.009	0.012	0.006	0.009	0.012
	(0.03)	(0.12)	(0.18)	(0.03)	(0.11)	(0.15)
bin_inframarprojects_k-3	0.080	0.046	0.040	0.080	0.046	0.040
	(0.26)	(0.52)	(0.52)	(0.28)	(0.50)	(0.45)
bin_inframarprojects_k-4	0.341	0.142	0.127	0.341	0.142	0.127
	(0.56)	(1.12)	(1.15)	(0.54)	(1.03)	(0.99)
bin_inframarprojects_k-5	−0.065	0.004	−0.009	−0.065	0.004	−0.009
	(−0.15)	(0.03)	(−0.10)	(−0.22)	(0.03)	(−0.10)
greeninfrastructure	0.031**	omitted	0.032	0.031**	omitted	0.032**
	(2.22)		(1.52)	(2.09)		(2.28)
ln_portcall	−0.028	0.134	0.137	−0.028	0.134	0.137
	(−0.13)	(0.77)	(0.97)	(−0.10)	(0.66)	(0.73)
ln_portgross	0.216	0.447***	0.417***	0.216	0.447**	0.417**
	(1.56)	(3.91)	(4.40)	(1.26)	(2.55)	(2.56)
ln_valuemar	0.116	−0.022	−0.020	0.116	−0.022	−0.020
	(1.64)	(−0.91)	(−0.94)	(1.03)	(−1.44)	(−1.40)
Constant	5.76***	2.19	2.41	5.76*	2.19	2.41
	(3.33)	(1.17)	(1.73)	(1.78)	(0.90)	(1.19)
R-squared	0.6116	0.6226	0.4888	0.6116	0.6226	0.4888

Note: *t* statistics in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

APPENDIX B

Table B1. Variation in maritime CO_2 emissions, green investments, and port activity across port municipalities. 2016–2023

Municipality	Maritime emissions, average	Green Infrastructure, unit	Green TransMar. Investment, total	Green InfraMar. Investment, total	Green TransMar. Projects, total	Green InfraMar. Projects, total	Port Calls, average	Port gross tonnage, average
Sauda								
Rana								
Drammen								
Brønnøy								
Sandefjord								
Sør-Varanger								
Eigersund								
Fredrikstad								
Trondheim								
Tønsberg								
Alstahaug								
Haugesund								
Narvik								
Porsgrunn								
Harstad								
Larvik								
Oslo								
Molde								
Kristiansund								
Kristiansand								
Moss								
Bodø								
Hammerfest								
Ålesund								
Tromsø								
Bergen								
Kinn								
Stavanger								

Note: Min Max.

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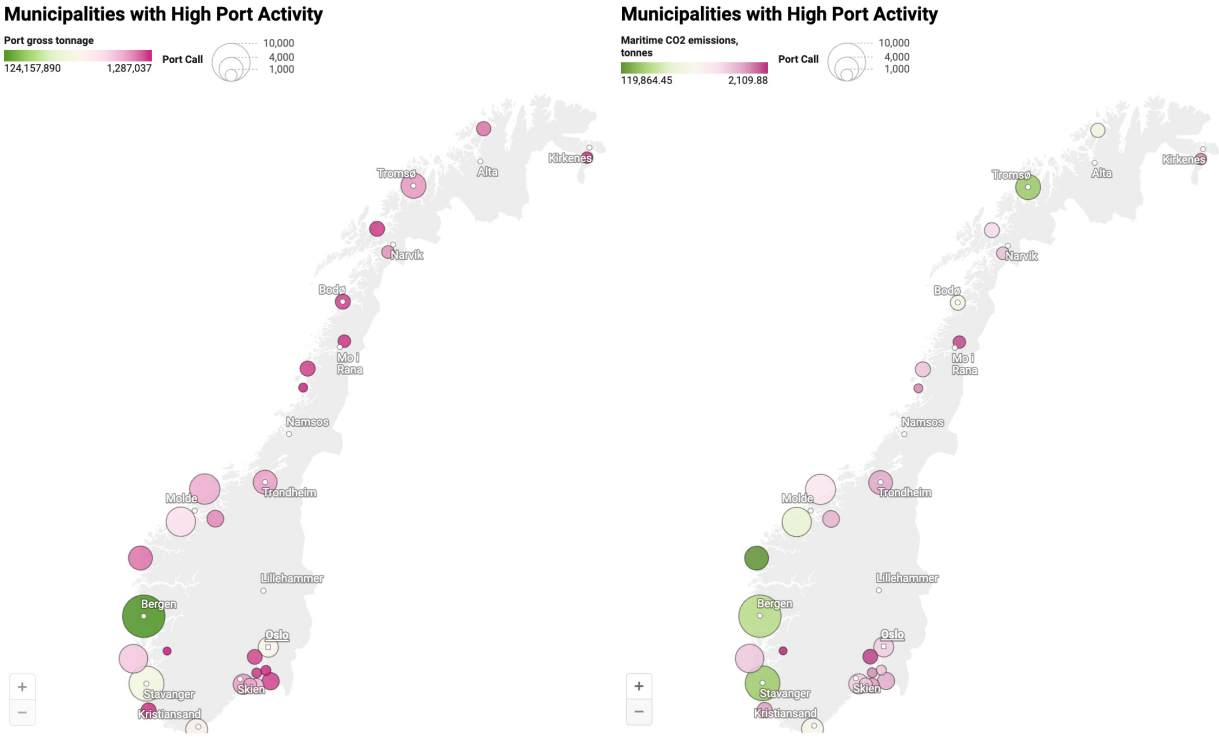
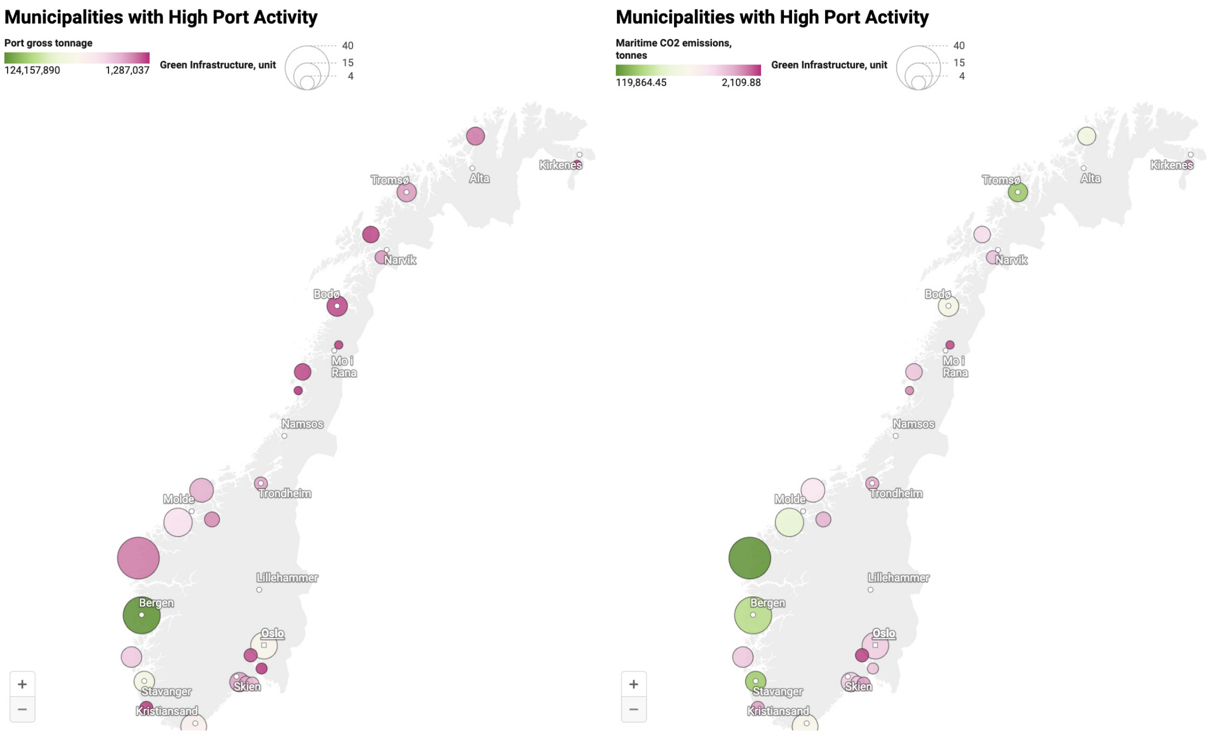


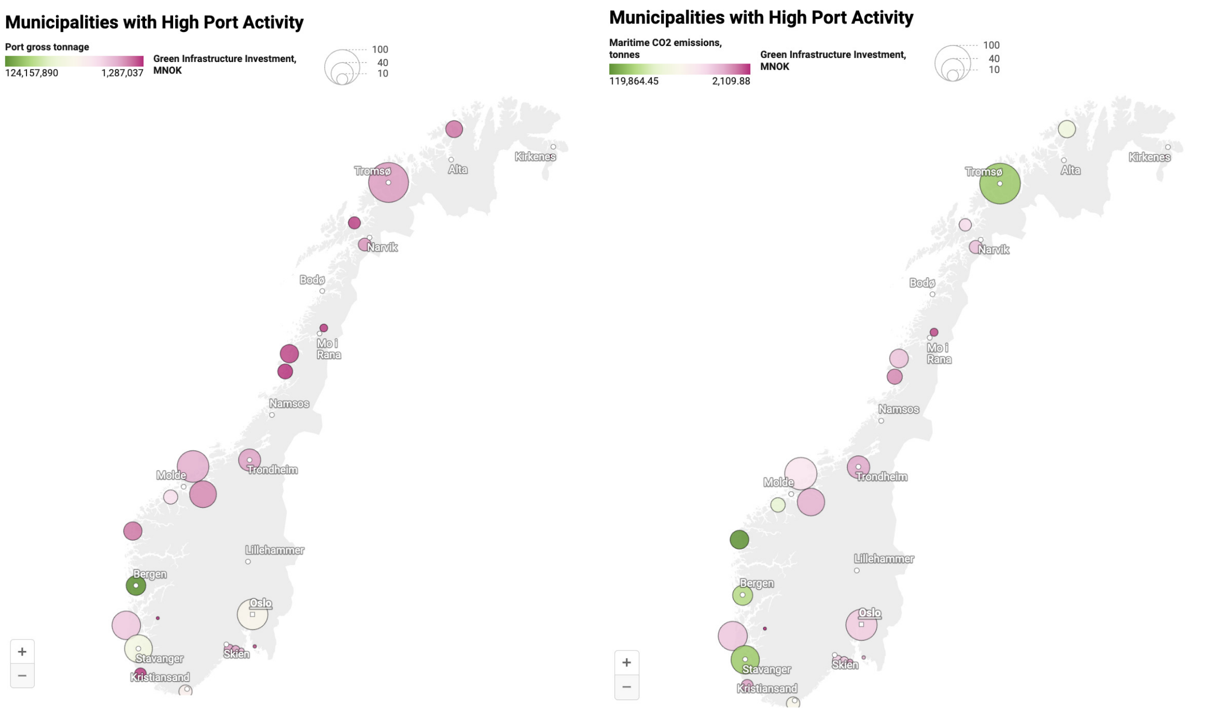
Note: Size of the circle – number of port calls, and color line is port gross tonnage (left), maritime related emission (right).

Figure B1. Norwegian port activity, 2023



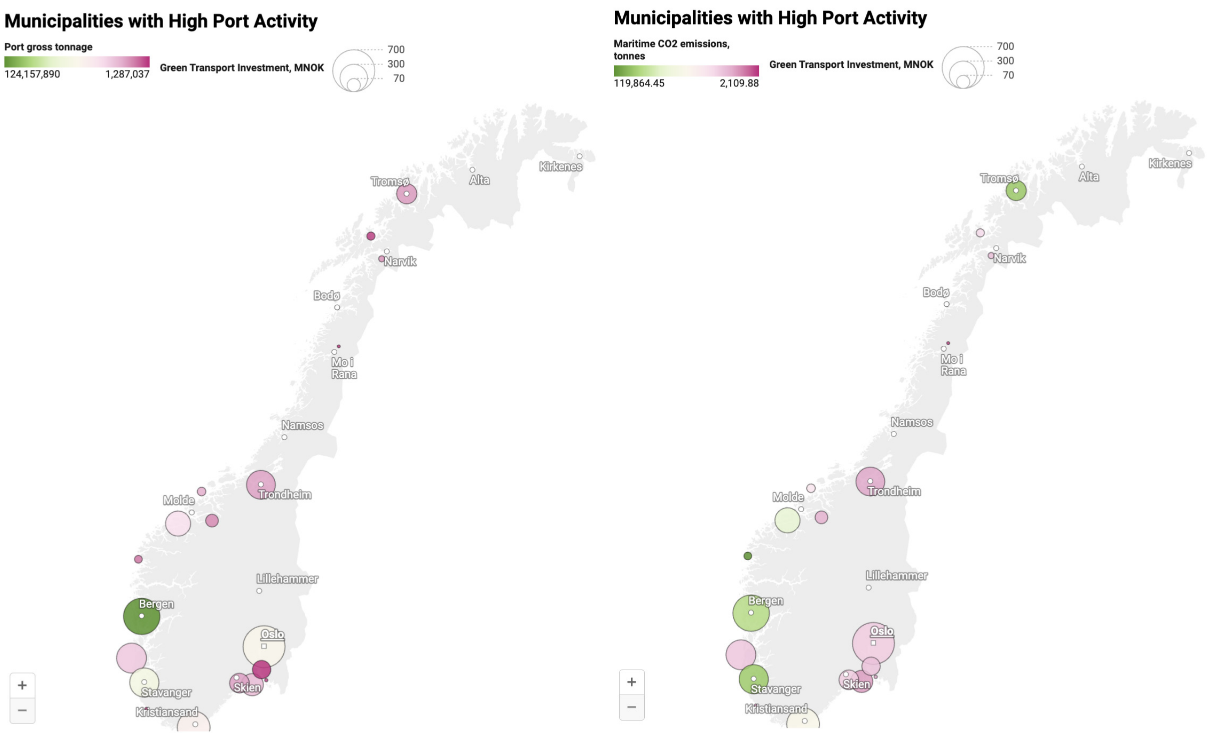
Note: Size of the circle – number of green terminals, and color line is port gross tonnage (left), maritime related emission (right).

Figure B2. Green infrastructure availability



Note: Size of the circle – Green infrastructure funding (2016–2023), and color line is port gross tonnage (left), maritime related emission (right).

Figure B3. Green maritime infrastructure funding, 2016–2023



Note: Size of the circle – Maritime transport funding (2016–2023), and color line is port gross tonnage (left), maritime related emission (right).

Figure B4. Green maritime transport funding, 2016–2023

http://dx.doi.org/10.21511/ee.16(4).2025.07