Understanding the Interplay of Barriers and Facilitators in Port Decarbonisation: Evidence from the Nordic-Baltic Region

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Abstract. This study examines the barriers and facilitators shaping the energy transition in ports within the Nordic-Baltic region — a context characterised by notable asymmetries between Nordic and Baltic ports in institutional capacity, infrastructure maturity, and economic conditions. Using a qualitative expert focus group with 15 stakeholders from academia, policy, and industry across four countries, and analysed through thematic analysis, the findings identify two interrelated dimensions: enabling factors (regulatory frameworks, market-based mechanisms, technological advancements, and stakeholder collaboration) and constraining conditions (economic constraints, policy instability, technological uncertainty, infrastructure limitations, and workforce challenges). Critically, these factors interact dynamically — regulatory pressure drives change, yet policy instability undermines it; technological innovation creates opportunity, yet financial risk delays adoption. The study contributes region-specific empirical evidence to a literature that has largely overlooked Nordic-Baltic heterogeneity, and offers practical implications for differentiated policy support across the region.

1 Introduction

The transition towards low-carbon energy systems has become a central priority in global climate policy, particularly in sectors with high emissions such as maritime transport and port operations [1–2]. As critical nodes in global supply chains, ports play a dual role. They both contribute to greenhouse gas emissions and enable decarbonisation pathways through infrastructure development, regulatory implementation, and technological innovation [3–4]. Despite being one of the most energy-efficient modes of transport, maritime transport accounts for approximately 2.7–3% of global CO_2 emissions. Projections indicate continued growth if no substantial mitigation measures are implemented [5–6].

In response to these challenges, increasing regulatory pressure at both international and regional levels has sought to accelerate the decarbonisation of the maritime sector. The International Maritime Organization has set ambitious targets to reduce greenhouse gas emissions. At the same time, the European Union has introduced policy instruments such as the Monitoring, Reporting and Verification system and emissions trading mechanisms. These aim to promote transparency and incentivise emission reductions [7–8]. At the same time, ports are expected to act as facilitators of this transition. They do so by providing

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infrastructure for alternative fuels, enabling electrification, and supporting the integration of renewable energy systems [5,9].

However, despite this growing policy ambition, the implementation of decarbonisation measures in ports remains uneven and complex. Existing research highlights a range of technological, economic, and institutional challenges that hinder progress. These include high capital costs, uncertainty regarding future energy pathways, and fragmented regulatory environments [10–12]. Moreover, while much of the literature focuses on technological solutions and policy frameworks, less attention has been paid to how these challenges are experienced and addressed by practitioners operating within real-world contexts [13–14].

The Nordic-Baltic region provides a particularly relevant context for examining these dynamics. It is characterised by strong environmental governance, advanced policy frameworks, and active participation in regional cooperation initiatives. As a result, the region is often considered a frontrunner in energy transition efforts. Nevertheless, differences in economic capacity, infrastructure development, and national policy implementation create varying conditions for the adoption of decarbonisation measures across ports.

This study addresses these gaps by examining the barriers and facilitators of energy transition in ports through expert perspectives in the Nordic-Baltic region. To guide the analysis, the study is structured around the following research questions:
RQ1: What are the key barriers hindering the energy transition in ports in the Nordic-Baltic region?
RQ2: What factors facilitate the implementation of decarbonisation measures in ports?
RQ3: How do barriers and facilitators interact in shaping the pace and direction of the energy transition?

2 Literature review

Decarbonisation has become a central objective in global climate policy. This is driven by the urgent need to reduce greenhouse gas emissions and mitigate climate change [1–2]. The maritime sector plays a critical role in this transition due to its contribution to global emissions and its importance in international trade [5–6].

Ports are increasingly recognised as key actors in enabling the energy transition. They contribute to emissions through ship operations and infrastructure. At the same time, they act as potential energy hubs integrating renewable energy systems and low-carbon technologies [9]. The concept of green ports reflects this dual role and focuses on sustainability through technological innovation and governance [15–16].

The literature identifies three main pathways for decarbonisation. First, technological solutions such as renewable energy integration, electrification, and alternative fuels are widely emphasised [5]. Second, operational measures, including improved logistics and efficiency, offer cost-effective emission reductions [17–18]. Third, regulatory frameworks play a key role in driving change through targets and market-based instruments [7–8].

However, the transition remains complex. No single solution exists, and ports require tailored strategies that combine multiple measures [10]. Economic barriers, including high investment costs and uncertainty, continue to hinder progress [11–12]. Furthermore, coordination among stakeholders is essential but difficult to achieve [13].

The literature highlights that while technological and policy pathways are well understood, less attention has been given to how these factors interact in practice. This gap is particularly pronounced at the regional level. Studies focusing specifically on the Nordic-Baltic context remain limited. Existing research tends to treat the region either as a uniform frontrunner in sustainability governance or conflates the Nordic and Baltic sub-regions. This occurs despite their distinct institutional capacities, infrastructure maturity, and economic conditions [3–4].

The Nordic countries benefit from well-established green port frameworks, long-standing carbon pricing mechanisms, and higher capital availability. In contrast, Baltic ports face greater financing constraints, less developed alternative fuel infrastructure, and more fragmented national policy environments. This divergence creates region-specific dynamics in how barriers and facilitators manifest and interact. These dynamics are not captured in generic European-level analyses.

This study addresses this gap by exploring stakeholder perspectives on barriers and facilitators of energy transition across both sub-regions. It enables a contextually grounded analysis of how enabling and constraining forces operate under varying institutional and economic conditions.

This study is positioned within the broader literature on socio-technical transitions and sustainability transformations in infrastructure systems. Existing frameworks, such as multi-level perspective approaches, emphasise the interaction between technological innovation, institutional structures, and market dynamics in shaping transition pathways. However, much of this literature adopts a generalised perspective and often overlooks regional heterogeneity and context-specific dynamics. By focusing on the Nordic-Baltic region, this study contributes to these frameworks. It demonstrates how transition processes are mediated by asymmetries in institutional capacity, economic resources, and infrastructure development. In doing so, it highlights the importance of spatial and institutional differentiation in understanding energy transition in port systems.

3 Methodology

This study employs a qualitative research design to examine the barriers, opportunities, and policy gaps associated with energy transition in the Nordic-Baltic region. The study is part of a broader research programme investigating the macro-environmental conditions shaping regional energy governance; however, it adopts an epistemologically distinct approach. Rather than mapping structural conditions through secondary sources, this study seeks to capture the collective knowledge and lived expertise of practitioners and policymakers actively engaged in the field, prioritising participant-driven insights over pre-defined analytical categories.

An expert focus group discussion was conducted as the primary data collection method. Focus group methodology is particularly suited to policy-oriented research, as it enables participants to articulate, refine, and collectively validate their perspectives through deliberative interaction [19-20]. Unlike individual interviews, this format allows emergent consensus and points of elaboration to surface organically [21]. Expert focus groups are recognised as effective for examining complex governance challenges [22].

A purposive sampling strategy ensured diversity across roles and countries. The focus group included 15 participants from Latvia, Finland, Sweden, and Estonia, representing academics, policymakers, and project managers (See Table 1).

Table 1. Focus Group Respondent Profile

Country	Region	Role	Experience
Estonia	Northern Europe	Researcher	0–5 Years
Estonia	Northern Europe	Senior management	20+ Years
Finland	Northern Europe	Researcher / academic	6–10 Years
Finland	Northern Europe	Researcher / academic	0–5 Years
Finland	Northern Europe	Researcher / academic	20+ Years
Finland	Northern Europe	Researcher / academic	6–10 Years
Finland	Northern Europe	Operations	20+ Years
Finland	Northern Europe	Researcher / academic	11–20 Years

Finland	Northern Europe	Researcher / academic	0–5 Years
Finland	Northern Europe	Policy / regulatory	6–10 Years
Latvia	Northern Europe	Researcher / academic	6–10 Years
Latvia	Global Operations	Senior management	20+ Years
Latvia	Eastern Europe	Researcher / academic	0–5 Years
Latvia	Eastern Europe	Other	11–20 Years
Sweden	Northern Europe	Policy / regulatory	0–5 Years

The session lasted approximately 60 minutes and was recorded with consent. A verbatim transcript was produced and analysed using thematic analysis following Braun and Clarke (2006) [23]. The analysis involved inductive coding and grouping of themes, with a focus on collective sensemaking [24].

Credibility was ensured through audit trail and member checking.

4 Results and Discussion

The thematic analysis identified two overarching dimensions shaping the energy transition in ports: facilitators and barriers. These dimensions emerged inductively from the focus group discussion and reflect the collective sensemaking of participants across policy, research, and industry domains. Importantly, the findings indicate that these factors are not independent but form a dynamic system in which enabling and constraining forces interact to shape decision-making and implementation processes. The summary of the barriers and facilitators are shown in Table 2.

4.1 Facilitators of Energy Transition

A key facilitator identified by participants is the role of regulatory frameworks, particularly at the European level. Experts consistently emphasised that regulatory pressure acts as a primary driver of decarbonisation. It compels both ports and shipping companies to adopt greener practices. This finding aligns with previous studies that highlight regulation as a central mechanism for driving environmental change in the maritime sector [10]. However, the findings also suggest that regulation is most effective when it is stable, clearly communicated, and supported by complementary mechanisms. In the absence of these conditions, its impact may be limited.

Closely related to regulatory drivers are market-based mechanisms, which participants identified as particularly influential. Instruments such as emissions pricing and carbon trading schemes were seen as effective because they directly affect financial performance. As a result, they influence operational decision-making. This supports the argument that economic incentives can significantly enhance the effectiveness of environmental policies by aligning sustainability objectives with business interests [8]. Unlike purely regulatory approaches, market-based mechanisms create continuous incentives for improvement rather than minimum compliance.

Technological developments also emerged as a major facilitator of energy transition. Participants highlighted advancements in alternative fuels, electrification, and energy systems as key enablers of decarbonisation. In particular, developments in the shipping sector were seen as driving change within ports because they create demand for new infrastructure and services. This interdependency between ship and port systems has been recognised in previous research [9]. However, the findings further indicate that technological innovation alone is insufficient unless it is supported by financial and institutional conditions that enable implementation.

Another important facilitator identified in the discussion is stakeholder collaboration. Participants emphasised the importance of coordination between ports, shipping companies, policymakers, and energy providers. Collaborative approaches were seen as essential for reducing uncertainty, sharing risks, and aligning investments. This finding reinforces existing literature that highlights the importance of governance and coordination in complex infrastructure transitions [13]. In this context, ports play a critical role. They function not only as infrastructure providers, but also as facilitators of broader system-level coordination.

4.2 Barriers to Energy Transition

Despite the presence of these facilitating factors, the findings reveal a number of significant barriers that constrain the pace and effectiveness of energy transition in ports. Among these, economic constraints were identified as the most critical. Participants highlighted the high capital intensity of investments in decarbonisation technologies, combined with long and uncertain payback periods. These financial risks create strong disincentives for investment, particularly in an environment characterised by market volatility and uncertainty. This finding is consistent with previous research that identifies economic barriers as a key limitation in maritime decarbonisation [11–12].

Policy instability was also identified as a major barrier. While regulation is a key driver of change, participants expressed concerns about frequent policy changes, lack of long-term clarity, and inconsistencies across jurisdictions. These factors create uncertainty and complicate strategic planning, particularly for long-term infrastructure investments. This highlights a critical tension within the policy environment. Regulation can both enable and constrain transition, depending on its design and implementation.

Technological uncertainty represents another significant barrier. Participants noted that there is currently no clear consensus on which alternative fuels or technologies will dominate in the future. This lack of clarity creates risks of stranded investments. It also leads to hesitation among port authorities and investors. This finding aligns with broader literature on energy transitions, which emphasises the challenges associated with technological uncertainty and path dependency [25]. In the port context, these challenges are particularly acute due to the long lifespan of infrastructure assets.

Infrastructure limitations further compound these challenges. Many ports currently lack the necessary infrastructure to support large-scale adoption of alternative fuels and electrification technologies. Upgrading existing infrastructure requires substantial investment and long-term planning. Both are difficult to achieve under conditions of uncertainty. This reflects the structural nature of the transition, where legacy systems and existing investments create barriers to change.

In addition to these structural and economic barriers, participants also identified workforce-related challenges. The transition towards new energy systems requires specialised knowledge and skills. These are not yet widely available. This highlights the importance of human capital in enabling energy transition, an aspect that is often underrepresented in the literature.

Finally, market and competitive pressures were identified as a constraining factor. Ports operate in highly competitive environments and are often reluctant to invest in decarbonisation measures unless there is a clear competitive advantage. This results in a "wait-and-see" approach, where actors delay investment decisions until greater certainty emerges. Such behaviour reflects broader coordination problems commonly observed in large-scale transitions.

Table 2. Barriers and facilitators of port decarbonisation: categories, sources, and interplay mechanisms

Category	Barriers	Facilitators
Economic	• High capital intensity of decarbonisation investments with long and uncertain payback periods Source: [11–12], Focus Group Discussion ↔ *Undermines technological facilitator: innovation exists but cannot be adopted without financing* • Absence of accessible funding mechanisms for smaller ports; EU instruments disproportionately benefit larger, strategically significant terminals ↔ *Neutralises ETS as a facilitator when revenues are not reinvested at port level* *Source:* Focus Group Discussion	• Market-based mechanisms (e.g. EU ETS) creating direct financial incentives for emission reductions. Source: [8] Focus Group Discussion ↔ *Conditional: enabling only where national institutional capacity ensures reinvestment* • Efficiency-driven cost reductions generating economic co-benefits for decarbonisation Source: [17–18], Focus Group Discussion
Policy	• Regulatory instability and frequent policy reversals increasing investment risk and deferral behaviour. Source: [10] · Focus Group Discussion ↔ *Directly negates regulatory facilitator; creates self-defeating policy cycle* • Inconsistent implementation of EU regulations across national jurisdictions Focus Group Discussion • Misalignment between ETS revenue collection and reinvestment into port infrastructure. Source: Focus Group Discussion	• EU regulatory frameworks (MRV, ETS, IMO GHG targets) compelling adoption of greener practices. Source: [7–8], Focus Group Discussion ↔ *Effective only under stable, harmonised implementation conditions* • Regional harmonisation potential through Baltic Sea cooperation initiatives. Source: Focus Group Discussion
Technological	• Absence of consensus on dominant alternative fuel pathway, creating stranded asset risk. Source: [25] · Focus Group Discussion ↔ *Compounds economic barrier: uncertainty × capital risk produces "wait-and-see" lock-in* • Infrastructure gap for alternative fuels and electrification, particularly in smaller Baltic ports. Source: [10], Focus Group Discussion ↔ *Creates intra-regional competitive divergence — well-equipped ports attract traffic at others' expense*	• Advancements in alternative fuels and battery technology creating new infrastructure demand. Source: [5,9] · Focus Group Discussion • Ship-side innovation (e.g. hybrid/battery propulsion) generating pull-through demand for port upgrades Source: Focus Group Discussion ↔ *Requires coordinated port response; uncoordinated adoption risks route redistribution*
Institutional	• Competitive market pressures discouraging first-mover investment without guaranteed advantage Source: [13] · Focus Group Discussion • Global shipping dynamics limiting regional policy reach; EU rules affect only part of traffic flows. Source: Focus Group Discussion	• Stakeholder collaboration among ports, shipping companies, policymakers and energy providers Source:[13] Focus Group Discussion • Ports as system coordinators enabling broader network-level transition alignment. Source: [3–4]
Human capital	• Shortage of specialised skills and trained workforce for new energy systems and technologies. Source: Focus Group Discussion	• Growing awareness and community pressure in municipally-owned or community-adjacent ports Source: Focus Group Discussion

Sources: Bracked References and expert focus group (March 2026, n=15, Latvia · Finland · Sweden · Estonia). ↔ denotes interplay mechanism identified in section 4.3.

4.3 Interplay Between Barriers and Facilitators

A key contribution of this study lies in demonstrating the interdependence between barriers and facilitators. The findings show that these factors interact in complex and sometimes contradictory ways. For example, while regulatory frameworks act as a primary driver of decarbonisation, their effectiveness is reduced by policy instability and lack of harmonisation. Similarly, technological innovation creates opportunities for transition, but its adoption is constrained by financial risk and infrastructure limitations.

A particularly significant interactional mechanism identified in the discussion concerns the relationship between regulatory stability and investment behaviour. Participants highlighted that long-term infrastructure decisions, typically spanning ten to fifteen years, are highly sensitive to policy continuity. When regulatory frameworks are subject to frequent revision, the risk profile of decarbonisation investments increases substantially. This leads port operators to defer commitment until greater certainty emerges. This dynamic is self-reinforcing. Instability in the policy environment undermines the very investment that regulation is designed to stimulate, effectively neutralising its enabling function. The automotive sector was referenced as an analogous case. In that sector, early adopters of green technology lost competitive advantage following subsequent regulatory reversals. Participants considered this pattern directly relevant to port infrastructure planning.

A second interactional mechanism relates to the compounding effect of technological uncertainty and infrastructure limitations. The absence of a clear consensus on which alternative fuel pathway will prevail places port authorities in a structurally difficult position. Investment in any single fuel infrastructure carries the risk of stranded assets should the dominant technology shift. This uncertainty is particularly acute for smaller ports with limited capital reserves. In such cases, a misaligned infrastructure investment may foreclose future options and erode competitive position relative to better-resourced ports in the region. The findings therefore suggest that technological uncertainty and economic constraints do not merely coexist as separate barriers. Rather, they mutually reinforce one another, producing a combined constraining effect that exceeds their individual impacts.

A third dynamic concerns the uneven distribution of market-based facilitators across the region. Instruments such as emissions trading were identified as effective in principle. However, their enabling impact was found to be contingent on institutional capacity at the national level. Where revenues generated through such mechanisms are not systematically reinvested into port decarbonisation infrastructure, their function as a facilitator is significantly diminished. This is particularly the case for smaller Baltic ports that lack alternative financing pathways. This asymmetry suggests that the same policy instrument can operate as a facilitator in one institutional context and as a missed opportunity in another. Its effect depends on the administrative and financial conditions surrounding implementation.

This interplay suggests that the energy transition in ports is not limited by the absence of solutions. Rather, it is constrained by the misalignment between policy ambition, market conditions, and implementation capacity. In other words, the challenge is not only technological. It is also systemic, requiring coordinated action across multiple domains.

4.4 Synthesis of Findings

The findings indicate that decarbonisation in ports is shaped by a dynamic balance between enabling and constraining forces. Regulatory pressure, technological innovation, and market incentives create strong momentum for change. However, their impact is significantly moderated by economic constraints, policy instability, and structural limitations. This highlights the need for integrated approaches that align policy frameworks, financial mechanisms, and technological development.

From a policy perspective, the results suggest that greater emphasis should be placed on stability, coordination, and long-term planning. From an industry perspective, collaboration and strategic alignment are essential for reducing uncertainty and enabling investment. Without such alignment, the transition risks being slowed by fragmentation and uncertainty, despite the availability of viable solutions.

5 Conclusion

This study examined the barriers and facilitators shaping the energy transition in ports within the Nordic-Baltic region. The findings reveal that economic constraints, policy instability, technological uncertainty, and infrastructure limitations represent key barriers. At the same time, regulatory frameworks, market incentives, technological advancements, and collaboration act as facilitators. Importantly, these factors interact dynamically and create tensions that influence decision-making and implementation.

The study makes several contributions to the literature. First, it provides empirically grounded insights into the systemic nature of energy transition in ports. It demonstrates that the challenge is not primarily technological, but stems from misalignment between policy ambition, market readiness, and implementation capacity. Second, and more distinctively, it contributes region-specific evidence from the Nordic-Baltic context. This is an area underrepresented in the port decarbonisation literature, despite its strategic relevance as a testing ground for EU maritime climate policy. The findings reveal that Nordic and Baltic ports do not experience barriers and facilitators uniformly. Nordic participants emphasised policy harmonisation and long-term investment certainty as the primary bottleneck. Baltic participants, in contrast, foregrounded financial constraints and infrastructure deficits as the binding limitations. This asymmetry has direct implications for regional policy design. It suggests that one-size-fits-all approaches to maritime decarbonisation governance are unlikely to be effective across the region.

From a policy perspective, the findings indicate that differentiated support mechanisms are required to account for regional asymmetries between Nordic and Baltic ports. For Nordic ports, where institutional frameworks and financial capacity are relatively well developed, policy efforts should prioritise regulatory harmonisation, long-term policy stability, and coordination across shipping routes. These measures would reduce uncertainty and enable large-scale investments. In contrast, Baltic ports require more targeted financial support mechanisms. These include improved access to EU funding instruments, dedicated investment schemes for smaller ports, and support for infrastructure development related to alternative fuels and electrification. Additionally, ensuring that revenues generated through market-based instruments such as emissions trading are effectively reinvested into port infrastructure is critical for enhancing their enabling function across the region. These differentiated approaches would help address structural inequalities and accelerate a more balanced regional transition.

Despite limitations related to sample size and scope, the study provides valuable insights into real-world transition challenges. Future research should expand empirical analysis and explore specific implementation strategies. Overall, achieving port decarbonisation requires coordinated action and alignment across multiple dimensions to ensure an effective and timely transition.

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