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Invited research paper

How port governance shapes living labs for energy transitions

Sonia Yeh [a,*], Christopher Dirzka [b], Aleksandr Kondratenko [a], Frans Libertson [a], Benedicte Madon [c], Veronika Slakaityte [a]

[a] Chalmers University of Technology, Gothenburg, Sweden
[b] Copenhagen Business School, Copenhagen, Denmark
[c] Universidad de Sevilla, Seville, Spain

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ABSTRACT

Ports are increasingly central to decarbonisation, energy-system integration, and resilience, yet less is known about how port governance shapes experimentation and whether learning becomes embedded in organisational practice. Living Labs (LLs)—organised forms of multi-actor experimentation in real-life settings—offer a promising approach, but are often treated as governance-neutral. This study develops and applies a governance–LL fit framework linking governance conditions to four LL pillars: co-creation, real-life setting, iterative learning, and institutional embedding. We compare two Nordic ports that are both wholly municipally owned companies but differ in their dominant governance configurations and in asset control, operational responsibilities, and decision authority: the Port of Aalborg (Denmark) and the Port of Trelleborg (Sweden). The analysis draws on capacity-building workshops, stakeholder engagement materials, and project documentation, using a proposed energy community in Aalborg and a Green Corridor in Trelleborg as case anchors. The comparison shows that prospective uptake pathways reflect both governance conditions and the scope of the initiative. Aalborg's intra-port energy community could draw on contractual, procurement, and partnership interfaces within the port ecosystem, whereas Trelleborg's corridor-level initiative would require coordination and commitment across several autonomous organisations and jurisdictions. Across the cases, the analysis indicates that institutional uptake depends on aligning stakeholders, decision authority, and available organisational instruments with the scope of the transition challenge. Because the evidence captures early-stage LL development rather than completed pilots, the findings concern prospective pathways rather than demonstrated long-term outcomes.

1. Introduction

Maritime and inland ports are critical nodes in global transport and trade networks, enabling the movement of goods, energy, and people while supporting regional and national economies. They are also increasingly recognised as important arenas for energy and sustainability transitions, including the electrification of transport and port operations, renewable-energy integration, digitalisation, and supply-chain resilience (Monios et al., 2024). Although resources and scale are often assumed to explain differences in transition capacity (Monios et al., 2024; Lam and Notteboom, 2014; Munim et al., 2020), governance arrangements are also central to understanding this variation. What matters is not only who ultimately owns the port, but how control of land, infrastructure, operations, budgets, and contractual relationships is allocated among port authorities, terminal operators, municipalities, utilities, and other stakeholders. These arrangements shape how ports coordinate investment and respond to changes in energy and digital infrastructure.

Port governance therefore affects more than operational efficiency and investment decisions. It also shapes who can authorise experiments, commit resources, engage external actors, and translate learning into contracts, procedures, and investments (Sornn-Friese, 2024). Existing port studies document numerous sustainability and digitalisation initiatives (Acciaro et al., 2014; Lam and Notteboom, 2014; Fruth and Teuteberg, 2017), but provide less explanation of how governance affects the pathway from experimental activity to durable organisational change.

In this context, Living Labs (LLs) have emerged as an approach for organising multi-actor experimentation in complex socio-technical settings. In this study, LLs are understood as organised forms of experimentation in which public actors, firms, researchers, and, where relevant, users or civil-society organisations collaborate to frame problems, test options in real-life settings, and refine solutions through iterative learning (European Network of Living Labs et al., 2025; Engels et al., 2019). This distinguishes LLs from consultation processes

* Corresponding author.
E-mail address: sonia.yeh@chalmers.se (S. Yeh).

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that do not involve experimentation and from technically focused test beds primarily concerned with validating a technology. However, LLs should not be assumed to be governance-neutral. Their organisation and capacity to influence subsequent practice depend on the legal and organisational structures in which they are embedded, including the distribution of authority, responsibilities, resources, and accountability (Voorwinden et al., 2023).

This article examines how established port governance configurations—Public Service, Tool, Landlord, and Private Service—shape the feasibility and design of LL approaches for port energy transitions. We develop a governance–LL fit framework and apply it to two analytically contrasting cases: the Port of Aalborg (PoA), Denmark, operating under a Landlord-oriented configuration, and the Port of Trelleborg (PoT), Sweden, operating under a Tool/Public Service-oriented configuration. The analysis examines how asset control, operational responsibilities, and decision rights shape stakeholder participation, the feasible scope of energy-related experimentation, and the pathways through which LL learning might be incorporated into organisational practice.

The paper contributes to understanding port governance–LL fit in the context of energy transitions in three ways. First, it develops and operationalises a governance–LL fit framework for port energy transitions. The framework connects established port governance configurations and the allocation of assets, responsibilities, and decision rights to four LL pillars through four analytical dimensions: stakeholder dynamics, decision authority and embedding pathways, innovation scope, and institutional uptake mechanisms. Second, applying the framework to two contrasting ports shows how governance conditions interact with the organisational and geographical scope of an initiative to shape the actors, coordination requirements, and institutional pathways through which learning may be embedded. Third, the study derives practical implications for aligning port LL activities with decision authority and the instruments through which their results may influence routine practice. While developed in the context of port energy transitions, the framework may also offer relevant insights for other infrastructure-intensive settings in which asset control and decision rights shape collaborative experimentation and adoption.

1.1. Living Labs as an innovation-governance model

The European Network of Living Labs (ENoLL) defines LLs as "open innovation ecosystems in real-life settings, using iterative feedback processes throughout the innovation lifecycle to create sustainable impact" (European Network of Living Labs et al., 2025). This framing emphasises that LLs are not merely temporary project formats or collections of participatory methods. Rather, they are arrangements intended to connect research, industry, policy, and society in collaborative experimentation.

Recent scholarship has consequently conceptualised LLs as instruments of innovation governance in addition to spaces for co-creation. Engels et al. (2019), for example, describe test beds and LLs as experimental governance arrangements through which state and non-state actors test emerging socio-technical configurations under real-world conditions. LLs are also commonly associated with the *Quadruple Helix* model—public sector, industry, academia, and civil society or users—which emphasises that innovation depends on coordination across institutional spheres (Cavallini et al., 2016).

The governance of an LL is nevertheless shaped by its organisational setting. Legal form, institutional location, decision structures, and relationships with a host organisation influence how roles are assigned, resources are controlled, and collaboration is sustained (Voorwinden et al., 2023). This distinction is important for the present study: the LL is treated as an innovation-governance approach for addressing port energy-transition challenges, whereas workshops, stakeholder mapping, SWOT analysis, and related canvases are methods used to organise participation and generate evidence within that approach.

Governance in LLs is often described across three layers: macro, meso, and micro. The macro level concerns the broader LL constellation, including its partners, legitimacy, and position within the surrounding innovation ecosystem. The meso level concerns the governance of particular LL projects or interventions, while the micro level concerns the methods used to support co-creation, experimentation, and evaluation (Schuurman, 2015). In the port context, this vocabulary helps distinguish the wider constellation of authorities, firms, utilities, researchers, and other actors from particular pilots and the participatory methods used to develop them. We use the three-layer model as supporting terminology rather than as a separate analytical framework.

LLs can also act as *orchestrators* within regional innovation systems by aligning actors, facilitating collaboration, and connecting experiments to broader pathways of change (Fauth et al., 2024). However, the effects of an experiment do not automatically extend beyond its immediate participants or project period. Research on urban LLs distinguishes mechanisms through which experimental learning may be embedded in existing institutions, translated to new settings, or scaled more broadly (von Wirth et al., 2019). Related research on climate-governance experiments similarly emphasises that experimental outcomes must be mobilised, adapted, and anchored within the structures and practices of the organisations that adopt them (Sengers et al., 2021). Conversely, reliance on temporary projects can produce discontinuity and weak organisational learning when no durable institutional pathway exists (Torrens and von Wirth, 2021). These insights motivate the present paper's focus on the mechanisms through which learning from port energy-transition LLs can enter contracts, procurement processes, operating procedures, organisational mandates, and other formal decision instruments.

1.2. Living Labs in port contexts

Ports increasingly serve as real-life settings for LL-type experimentation, particularly in sustainability, resilience, and digital and logistics innovation. Applications include climate resilience and disruption preparedness, where LLs convene stakeholders to co-create adaptation responses in operational environments (Polydoropoulou et al., 2025); sustainability transitions, including proposals for trans-local and multi-port LL configurations that support learning beyond individual sites (Gerlitz et al., 2024); and digital transformation and logistics innovation, where collaborative experimentation connects technical development with policy learning and stakeholder coordination (Catana et al., 2025).

Practice-led port LLs have also been established by port authorities, including initiatives in Singapore and Halifax, to support experimentation under real operating conditions (Maritime and Port Authority of Singapore, 2026; World Port Sustainability Program, 2023). These examples demonstrate growing practical interest in ports as experimental environments. However, they provide more limited analytical explanation of why some initiatives have clearer pathways into organisational decisions and operating practices than others.

Overall, the literature establishes ports as promising settings for collaborative experimentation but remains comparatively thin on an explicit, sector-grounded account of LL–governance fit in the context of energy transitions. In particular, it rarely examines how established port governance configurations and the allocation of assets and responsibilities shape (a) meaningful stakeholder participation, (b) the feasible scope of energy-system experimentation, and (c) the institutional embedding of evidence through instruments such as procurement specifications, operating procedures, organisational mandates, and concession or lease arrangements. Broader LL research demonstrates that institutional and organisational structures influence experimentation and its longer-term effects (Voorwinden et al., 2023; von Wirth et al., 2019; Sengers et al., 2021), but this relationship has not been systematically connected to the established governance configurations of ports or to their particular role in energy transitions. This paper addresses

Table 1
Ideal-type port governance configurations and illustrative examples reported in the literature.

Governance model	Basic infrastructure	Equipment and superstructure	Operations	Illustrative examples reported in the literature
Public service	Public	Public	Public	Mongla Port (Munim et al., 2019)
Tool	Public	Mainly public	Mainly private	Chittagong (Chattogram) Port (Munim et al., 2019)
Landlord	Public	Mainly private	Mainly private	Ports of Rotterdam, Antwerp, and Singapore (World Bank, 2025; Notteboom et al., 2021)
Private service	Private	Private	Private	Port of Southampton and other ports in the privatised UK port system (Dombois and Koutsoutos, 2007)

Note: The examples reproduce classifications reported in the cited literature at particular points in time. Governance arrangements may subsequently change and may differ across terminals, assets, or activities within the same port. Even in a Private Service port, public authorities normally retain statutory regulatory and safety responsibilities.

that gap by using port governance, asset and operational allocation, and decision authority as an explanatory lens for analyzing variation in the design and prospective institutional uptake of energy-transition LLs.

1.3. Port governance models and the research gap on LL–governance fit

Port governance refers to the institutional arrangements through which infrastructure ownership, operational responsibilities, and decision-making authority are allocated among public and private actors (World Bank, 2025). These arrangements determine who controls assets such as port land, berths, terminal equipment, energy infrastructure, digital platforms, and grid connections, and therefore influence investment priorities, stakeholder relationships, and the scope for coordinated innovation.

A widely used port-governance typology distinguishes four ideal-type configurations: Public Service, Tool, Landlord, and Private Service ports (World Bank, 2007, 2025; Notteboom et al., 2021). These models differ principally in the allocation of responsibility for basic infrastructure, equipment and superstructure, and port operations (see Table 1).

Table 1 summarises how responsibility for basic infrastructure, equipment and superstructure, and port operations is distributed between public authorities and private operators across the four ideal-type configurations. The Landlord configuration, in which the public authority retains land and basic infrastructure while private firms provide superstructure and terminal operations, is widely used among medium-sized and large commercial ports (World Bank, 2025; Notteboom et al., 2021).

These configurations should not be interpreted as mutually exclusive descriptions of individual ports. Port authorities operating under the same broad model may differ substantially in their legal status, autonomy, functions, and relationships with operators and public authorities (Ng and Pallis, 2010; Notteboom et al., 2021). Governance may also vary across assets and terminals within the same port. Corporatisation, concessions, public–private partnerships, and joint ventures may therefore create hybrid or overlapping arrangements. In this study, the typology is used to identify each case's *dominant configuration*, while recognising that both ports may also exhibit characteristics associated with other models.

For LLs addressing port energy transitions, these differences matter because they shape (i) who can authorise and finance experiments, (ii) which port, energy, regulatory, and infrastructure actors need to participate, (iii) what can realistically be tested across organisational and infrastructure boundaries, and (iv) which contractual, procedural, or organisational instruments are available for formalising learning. Port-governance research has extensively examined ownership reform, devolution, operational responsibilities, and port-authority functions (Brooks and Cullinane, 2007; Verhoeven, 2010; Ng and Pallis, 2010; Notteboom et al., 2021). However, it has paid less attention to how these established governance configurations condition the design of LLs for port energy transitions and the pathways through which experimental learning may enter routine decisions and organisational practices.

1.4. Research aims and scope

This study has both an analytical and an empirical aim. Analytically, it develops and operationalises a governance–LL fit framework that connects port governance, asset and operational responsibilities, and decision rights to four LL pillars—co-creation, real-life setting, iterative learning, and institutional embedding—in the context of port energy transitions. Empirically, it applies the framework to two contrasting port contexts to examine how governance conditions interact with the scope of the focal initiatives in shaping early-stage LL development and prospective pathways for institutional uptake.

The study addresses three research questions:

RQ1 (Conditions): How do the dominant governance arrangements in the two case study ports—including the allocation of assets, operational responsibilities, and decision authority—shape stakeholder dynamics, innovation scope, and potential pathways for embedding learning from port energy-transition LLs?

RQ2 (Mechanisms): Which contractual, procedural, and organisational mechanisms are identified as possible routes for translating learning from port energy-transition LLs into more durable organisational practice?

RQ3 (Design): How should LL design—including stakeholder participation, sequencing, and the artifacts produced—adapt to these governance conditions to strengthen the prospects for institutional embedding?

The empirical analysis focuses on PoA and PoT, which participated in POTENT-X, a collaborative European research project on ports as energy-transition hubs. Their participation in a common LL capacity-building process provides a shared basis for comparing early-stage development across contrasting governance settings. The broader four-model typology provides the theoretical background, but the study does not empirically test all four governance configurations. Nor does it evaluate completed pilots or long-term organisational outcomes. Instead, it examines early-stage institutionalisation dynamics: how asset control, operational responsibilities, and decision rights shape problem framing, stakeholder mobilisation, proposed energy-related experimentation, and the identification of routes through which emerging evidence could inform subsequent decisions.

2. Methods

2.1. Study design and case selection

The study uses a qualitative comparative case design to examine how port governance conditions shape the early development and prospective institutionalisation of LLs for energy transitions. PoA and PoT were selected from within POTENT-X because they participated in a common LL capacity-building process while differing in their dominant governance configurations. This shared project context supports comparability, while PoT's later withdrawal means that the common comparison rests on the initial capacity-building evidence; later

Table 2
Case characteristics and evidence available for comparison.

Feature	Port of Aalborg	Port of Trelleborg
Dominant governance configuration	Landlord-oriented	Tool/Public Service-oriented
Corporate ownership	Wholly owned by Aalborg Municipality.	Wholly owned by Trelleborg Municipality.
Asset and operational context	Owns and develops core infrastructure and works with firms and other actors through tenant, infrastructure, and partnership relationships.	Comparatively stronger direct responsibility for port infrastructure, operations, and investment within municipal owner directives.
Initiative scope and case anchor	Primarily intra-port/system-level: proposed energy community involving shared energy, data, regulatory, and stakeholder-coordination questions.	Inter-port/corridor-level: proposed Green Corridor involving ports, governments, and businesses along a maritime trade route to support zero-emission vessels and cleaner fuels.
Evidence available	Initial LL capacity-building and workshop evidence, supplemented by later stakeholder interviews and governance-development activities.	Initial LL capacity-building and workshop evidence; no equivalent later phase following PoT's withdrawal from POTENT-X.

Aalborg material is used only for supplementary interpretation. The implications of researcher involvement and unequal empirical depth are considered in Sections 2.5 and 4.4.

Both ports are wholly municipally owned limited companies—Port of Aalborg A/S by Aalborg Municipality and Trelleborgs Hamn AB by Trelleborg Municipality—so municipal corporate ownership is not a source of cross-case variation (Port of Aalborg, 2026; Trelleborgs Hamn AB, 2026). The contrast lies in asset and operational allocation, decision authority, contractual interfaces, and statutory setting. PoA is treated as Landlord-oriented: it owns and develops core infrastructure and works extensively through tenant, infrastructure, and partnership relationships. PoT is treated as Tool/Public Service-oriented, with comparatively stronger direct responsibility for port infrastructure, operations, and investment within municipal owner directives. Danish and Swedish municipal-port frameworks also differ in how the organisational form and municipal oversight are defined (Danish Ministry of Transport, 2024; Riksdag, 2017). These classifications describe the governance conditions relevant to the study rather than pure examples of the ideal types. The focal initiatives also differ in scope. PoA's energy community concerns several actors and infrastructures within the port ecosystem, whereas PoT's Green Corridor spans a maritime trade route and requires coordination among autonomous organisations and jurisdictions. Governance configuration and initiative scope therefore co-vary in the two cases. The comparison is not treated as a test of governance effects alone, but as an examination of how governance conditions interact with the organisational and geographical reach of the transition challenge (see Table 2).

2.2. Empirical material

The empirical material was generated through a sequence of capacity-building, co-creation, and governance-development activities conducted within POTENT-X (European Network of Living Labs, 2025; Madon et al., 2025). The evidence consists of workshop artifacts, digitised canvases, stakeholder maps, SWOT matrices, value-creation exercises, problem statements, facilitator reports, interview summaries, and project documentation. Table 3 summarises the empirical material and its role in the analysis.

Data collection was organised in two stages. First, both ports participated in a common Living Lab capacity-building process designed to establish a shared conceptual basis and generate comparable evidence on purpose, context, stakeholders, value creation, and transition priorities. Although the workshop formats were adapted to each port's organisational circumstances and available capacity, they produced a common set of artifacts that formed the primary basis for the cross-case analysis.

Second, the Aalborg case was examined in greater depth through stakeholder interviews and a subsequent governance-development workshop. These additional materials were used to triangulate and elaborate the initial Aalborg interpretation, particularly regarding stakeholder roles, barriers to collaboration, decision-making responsibilities, and possible institutional uptake pathways. Because equivalent follow-up material was not available for Trelleborg, these sources were excluded from the comparative scoring. Project documentation and facilitator reports supported traceability, contextual interpretation, and factual verification throughout the analysis.

2.3. Governance–LL fit framework

The analytical framework was developed deductively by translating the four LL pillars introduced in Section 1.1 into four governance–LL fit dimensions relevant to port energy transitions. These dimensions specify what should be examined when LL activities are situated within different asset, operational, and decision structures. Table 4 summarises their relationship to the LL pillars and principal indicators. Fig. 1 presents the overall logic. Analytically, governance conditions shape governance–LL fit and its implications for LL design. Practically, the framework can also be applied in reverse by identifying the likely pathway for institutional uptake before specifying the experiment.

The four dimensions are defined as follows:

1. **Stakeholder dynamics** concerns which actors are identified and involved, the continuity and intensity of their participation, the clarity of their roles, and the existence of mechanisms for communication and conflict resolution. It operationalises the LL pillar of *co-creation*.
2. **Decision authority and embedding pathways** concerns where formal decision and budget authority reside, how decisions are sequenced, whether relevant decision windows can be identified, and whether LL learning has a plausible route into an authorised organisational process. It operationalises *institutional embedding*. In this paper, an *institutional landing zone* means a formal organisational process or instrument through which learning could influence a subsequent decision, such as a concession or lease provision, procurement process, standard operating procedure, organisational mandate, or municipal planning process.
3. **Innovation scope** concerns what can realistically be explored or tested under the prevailing governance arrangements. Indicators include whether activities are limited to a single port unit or tenant, whether several tenants or infrastructures need to be coordinated, the degree of energy–digital integration, operational scale, and connections to utilities, system operators, or municipal energy planning. It operationalises the LL pillar of experimentation in a *real-life setting*.
4. **Institutional uptake mechanisms** concerns how learning is revisited, adapted, and made more durable through organisational instruments. Indicators include evidence of repeated reflection or adjustment across LL activities; feedback, monitoring, and review arrangements; and the availability, specificity, and enforceability of contracts, concession or lease provisions, procurement specifications, standard operating procedures (SOPs), memoranda of understanding (MOUs), data-sharing requirements, and coordinator mandates. It operationalises *iterative learning* and its conversion into organisational practice.

Table 3
Data sources and their role in the analysis.

Activity	Date and format	Participation	Principal materials	Analytical role
Living Lab Basics webinar	11 March 2025; online; 120 min	17 participants, including two ENoLL facilitators	Slides, session notes, interactive responses on expectations, conceptual uncertainties, and support needs	Shared conceptual and project context
PoA Living Lab workshop and continuation	6 May 2025; full-day, in person; 30 May 2025, online	Three PoA representatives, five consortium participants, and two ENoLL facilitators in the in-person session	Purpose, host context, mission and scope, contextual mapping, SWOT, stakeholder map, value mapping, and problem statements	Common comparative corpus and PoA case evidence
PoT Living Lab workshop	12 June 2025; online; three hours	Seven participants reported; PoT and wider consortium participation, with ENoLL facilitation	Transition purpose and timeline, stakeholder prioritisation, value matrix, and SWOT	Common comparative corpus and PoT case evidence
PoA stakeholder interviews	September 2025; online; 45–60 min each	Five interviews: two academic, one public-sector, one private-sector, and one civil-society participant	Interview summaries organised around roles, collaboration, barriers, enabling conditions, and future engagement	Supplementary triangulation of Aalborg findings
PoA governance workshop and continuation	17 October 2025; online; three hours; continuation on 4 November 2025	Four PoA participants, with ENoLL facilitation	Governance canvas, stakeholder-role mapping, decision-level reflections, accountability and sustainability notes	Supplementary triangulation and illustration of governance-development processes
Project documentation	March–November 2025	ENoLL and POTENT-X management	Facilitator reports, digitised boards, workshop summaries, interview guide, governance templates, and follow-up documentation	Traceability, contextual interpretation, and factual verification

Table 4
Operationalisation of the governance–LL fit framework.

Governance–LL fit dimension	Linked LL pillar	Principal indicators
Stakeholder dynamics	Co-creation	Representation across relevant stakeholder groups; engagement continuity; role clarity; communication; conflict-resolution arrangements
Decision authority and embedding pathways	Institutional embedding	Decision and budget authority; authorised processes; timing and decision windows; identifiable routes through which evidence could inform decisions
Innovation scope	Real-life setting	Tenant- versus system-level focus; number of organisations and infrastructures involved; energy–digital coupling; operational scale; external energy-system and municipal linkages
Institutional uptake mechanisms	Iterative learning	Repeated reflection or adaptation across LL activities; feedback and review cycles; availability and quality of contracts, concessions, leases, procurement provisions, SOPs, MOUs, coordinator mandates, monitoring arrangements, and reusable templates

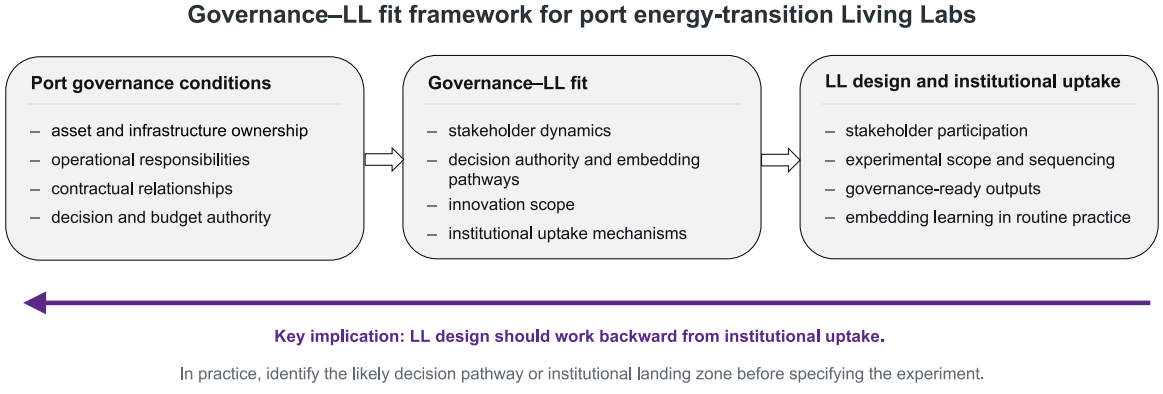

Fig. 1. Conceptual governance–LL fit framework. The forward arrows represent the analytical relationship from governance conditions to LL design and institutional uptake; the reverse arrow represents the practical logic of designing backward from the intended uptake pathway.

The distinction between the second and fourth dimensions is important. Decision authority and embedding pathways concern *where* authority sits and through which decision process learning could travel. Institutional uptake mechanisms concern *how* learning is revisited and adapted and *what specific instrument* could codify, monitor, or sustain it.

2.4. Coding, scoring, and cross-case comparison

The analysis followed a qualitative, theory-informed sequence. Fig. 2 presents the research and analytical sequence. First, the common comparative material was organised by case, activity, and date. Second, evidence from the workshop artifacts and facilitator reports

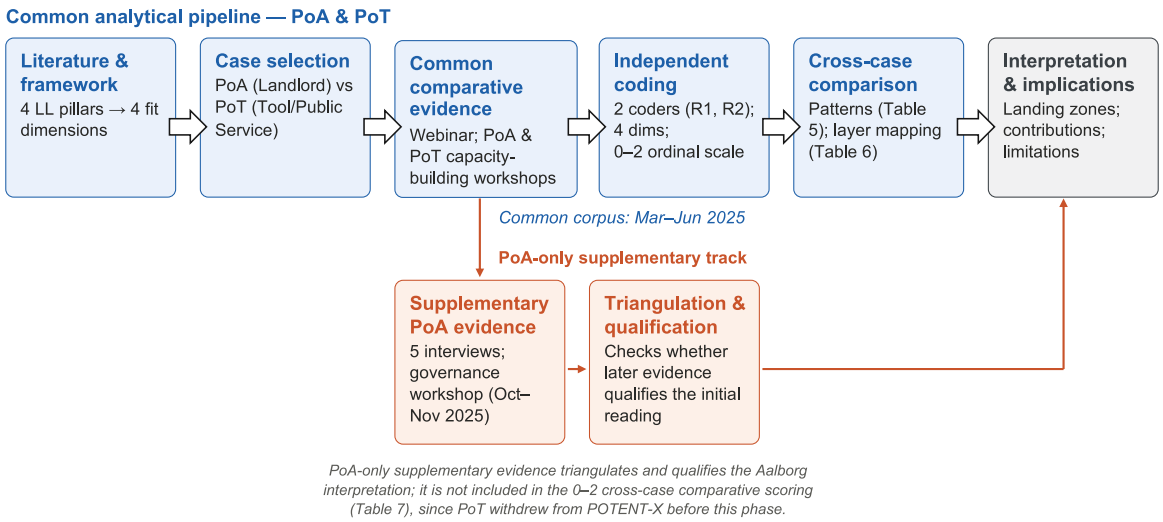

Fig. 2. Research design and analytical sequence. The Aalborg-only branch represents supplementary evidence used for triangulation and illustration rather than comparative scoring.

was coded against the four governance–LL fit dimensions. Third, the coded material was compared across the two ports to identify similarities, contrasts, and case-specific pathways from experimentation to institutional uptake. The two case anchors were used to ground the interpretation in the energy-transition priorities identified by each port. The supplementary Aalborg interviews and governance workshop were qualitatively analyzed against the same four dimensions. They were used to support, qualify, or illustrate the initial Aalborg interpretation but were not included in the comparative scoring because no equivalent later material was available for Trelleborg.

Each dimension was assessed using a three-point ordinal scale:

- 0 = limited or absent evidence;
- 1 = mixed, partial, or developing evidence;
- 2 = comparatively strong and clearly documented evidence.

The scale supports broad qualitative distinctions rather than precise quantitative measurement. Appendix 5 provides the complete indicator definitions and scoring rubrics.

Two researchers independently coded the common PoA and PoT material using a structured template. Researcher 1 participated in the capacity-building activities, while Researcher 2 coded the digitised artifacts, facilitator reports, and associated documentation without participating in the live workshops. The two scores are reported separately in Appendix 6, together with brief evidence anchors.

The four dimensions are interpreted separately and are not aggregated into an overall index. The scores are used to support transparency in the qualitative comparison rather than to rank the ports or measure LL effectiveness.

2.5. Traceability, researcher position, and ethics

Several procedures were used to strengthen transparency and traceability. Workshop outputs were digitised and archived together with dated facilitation reports and follow-up documentation. Coding notes linked each assessment to specific artifacts or documented statements. A pre-review draft of the manuscript was circulated to ENoLL trainers and port representatives to verify the accuracy of descriptions of organisational roles, processes, and constraints. These checks concerned factual accuracy rather than asking participants to approve the authors' analytical interpretation.

The involvement of Researcher 1 in the workshops provided contextual knowledge of the discussions and how the artifacts were produced, but it also created a risk of interpreting the materials through prior involvement in the project. Independent documentary coding by Researcher 2 provided a partial counterbalance. Reporting both sets of scores and their evidence anchors makes interpretive differences visible rather than concealing them through an aggregate result.

Participation in the workshops and interviews was voluntary. Interview participants received information about the purpose of the activity, the intended use of their contributions, and data handling, and provided consent before participation. The stakeholder interviews followed applicable General Data Protection Regulation principles. No sensitive operational information is reported, and identifiable statements are anonymised unless explicit permission has been granted.

3. Results

The results are organised by case and synthesised across the four governance–LL fit dimensions introduced in Section 2.3. The comparison draws primarily on the common capacity-building evidence from PoA and PoT. The later Aalborg interviews and governance-development activities are used to support or qualify the interpretation of that case. The independent coder scores and detailed evidence anchors are reported in Appendix 6.

3.1. Port of Aalborg: Landlord-oriented governance

3.1.1. Stakeholder dynamics

The initial Aalborg workshop identified a broad stakeholder ecosystem spanning municipal and other public bodies, port-based companies and tenants, infrastructure and energy actors, academia, and civil society. The workshop sequence also allowed the port team to revisit its mission, stakeholder map, value propositions, and initial problem statements over more than one session, providing direct evidence of iterative refinement within the common comparative phase. This provided a comparatively strong basis for co-creation and explains the higher Aalborg scores for stakeholder dynamics in Appendix 6.

At the same time, the evidence shows that stakeholder identification was more advanced than the formalisation of stakeholder roles. Many of the contributions assigned to external actors remained expectations formulated by the PoA team rather than confirmed commitments. The

later stakeholder interviews reinforced the importance of trust, responsiveness, shared objectives, and clear benefits for participation. They also identified practical barriers, including limited access to operational and financial data, regulatory restrictions, technical requirements, and misaligned financial incentives. Aalborg therefore had a broad collaboration base, but sustained participation still depended on clearer roles and value propositions.

3.1.2. Decision authority and embedding pathways

PoA's Landlord-oriented configuration creates several organisational interfaces through which learning from an LL could influence subsequent decisions. These include port procurement, strategic planning, tenant and partnership arrangements, and, where relevant, lease or concession provisions. Such interfaces provide potential institutional landing zones beyond the internal procedures of the port authority itself.

The later governance workshop added greater detail to these pathways. Participants distinguished strategic, operational, project, and evaluation levels and considered how responsibilities might be distributed across the port and external partners. The exercise also revealed uncertainty about whether particular LL functions should remain within PoA or be assigned to participating organisations. The prospective pathways were therefore identifiable, but responsibility, accountability, resources, and decision timing still required further specification.

3.1.3. Innovation scope and the energy community case

The proposed energy community project illustrates the system-level scope that is possible in the Aalborg setting. The project would involve several organisations and infrastructures and raise questions concerning energy sharing, metering, data access, regulation, investment, and the allocation of benefits and responsibilities. It therefore extends beyond a technical demonstration undertaken by a single tenant or port department.

The Landlord configuration creates potential routes for connecting such experimentation to organisational practice. For example, evidence concerning metering, data-sharing, or energy-performance requirements could inform future procurement specifications or agreements with participating firms. The stakeholder interviews also identified possible links to flexibility markets, shared renewable-energy procurement, surplus-heat utilisation, and local energy-community development. These were identified as collaboration opportunities rather than adopted arrangements.

The case also demonstrates the importance of sequencing. Technical and economic experimentation would need to be coordinated with regulatory assessment, stakeholder agreements, and relevant procurement or contract windows. Aalborg's governance model provides several possible routes for institutional uptake, but the existence of these routes does not by itself ensure that learning will be adopted.

3.2. Port of Trelleborg: Tool/public service-oriented governance

3.2.1. Stakeholder dynamics

The Trelleborg workshop used a more focused process to define the purpose of the LL, identify and prioritise stakeholders, examine reciprocal value, and assess contextual strengths and constraints. Five priority stakeholder groups were identified. The resulting engagement structure was more targeted than in Aalborg and closely connected to the proposed Green Corridor project.

The common Trelleborg evidence captures a single, focused workshop. It documented relevant actors and possible forms of collaboration, but provides limited evidence of how engagement, role allocation, or iterative refinement would have developed over successive LL cycles. The Green Corridor focus also implies that several important actors—including other ports, shipping companies, fuel and infrastructure providers, and public authorities—would operate beyond PoT's direct organisational authority.

3.2.2. Decision authority and embedding pathways

PoT's Tool/Public Service-oriented configuration gives the port comparatively direct authority over infrastructure and activities within its operational remit. This can support clear internal decisions and provides potential pathways through procurement requirements, standard operating procedures, investment planning, and coordination with the municipality.

The Green Corridor case, however, extends beyond the boundaries of the port. Decisions concerning vessels, clean fuels, infrastructure compatibility, data exchange, and route-level commitments would be distributed among organisations in different locations and jurisdictions. PoT could formalise port-controlled elements through its own procurement and internal procedures, while corridor-wide learning would require inter-port arrangements, joint workplans, memoranda of understanding, or other agreements among the participating organisations. The workshop evidence identified the need for such coordination but did not document adopted instruments.

PoT later withdrew from POTENT-X after senior management changed strategic focus. At that point, the project material did not document a procurement provision, investment commitment, SOP, municipal decision, or corridor agreement that anchored the Green Corridor work. The withdrawal is therefore informative about the distinction between decision authority and institutional anchoring, without implying that the absence of such an instrument caused the strategic change.

3.2.3. Innovation scope and the Green Corridor case

The proposed Green Corridor project gives the Trelleborg case a potentially broad geographical and organisational scope. Rather than focusing on a single installation, it concerns the alignment of ports, shipping services, clean-fuel supply, infrastructure, public policy, and business decisions along a maritime trade route.

The workshop identified several conditions that could support this work, including PoT's digital infrastructure, geographical position in the Baltic Sea region, and existing capacity related to green energy. It also identified constraints associated with high investment needs, environmental permitting, regulatory uncertainty, and limited space for expansion because of the port's proximity to the city.

These conditions produce a different governance challenge from Aalborg's energy community. PoT has relatively strong authority over some port-side decisions, but the Green Corridor depends more heavily on coordination between legally and organisationally separate partners. Its prospective institutionalisation pathways therefore combine internal procedures and procurement with bespoke external agreements.

3.3. Cross-case comparison

The comparison indicates that the same LL methods can operate differently across the two case settings. Both ports used workshops, stakeholder mapping, value exercises, and contextual analysis to define their transition priorities. Their differences emerged more clearly in the actors who needed to participate, the location of decision authority, and the instruments through which learning could subsequently be formalised. Because the cases differ in both governance configuration and initiative scope, these patterns are interpreted as interactions between the two rather than as effects of governance alone. Table 5 summarises the principal cross-case patterns.

Three common findings are also evident. First, identifying stakeholders did not automatically establish their roles or commitment. Both cases would require continuing engagement as projects move from broad transition ambitions towards concrete experimentation. Second, institutional uptake depends on aligning evidence with an authorised decision process and an appropriate timing window. Third, civil-society and user participation was less developed than participation by port, public-sector, industry, and research actors and would therefore require more deliberate outreach.

Table 5
Cross-case patterns by governance–LL fit dimension.

Dimension	Port of Aalborg: Landlord-oriented	Port of Trelleborg: Tool/Public Service-oriented
Stakeholder dynamics	Broad stakeholder ecosystem with repeated opportunities to refine the LL scope and stakeholder relationships. External roles and commitments remained partly under development.	Targeted stakeholder identification and prioritisation centered on the Green Corridor. Continuing participation and formal role allocation were less developed in the available evidence.
Decision authority and embedding pathways	Several prospective interfaces through procurement, strategic planning, tenant and partnership relationships, and potentially lease or concession arrangements. Decision responsibilities and timing still required clarification.	Comparatively direct authority over port-controlled infrastructure and operations. Corridor-wide decisions require coordination and agreement with actors outside the port's authority.
Innovation scope	System-level energy community involving firms, energy infrastructure, data, regulatory conditions, and potential energy-market participation.	Route-level Green Corridor involving ports, shipping actors, clean-fuel and infrastructure providers, governments, and businesses.
Institutional uptake mechanisms	Repeated refinement across the workshop sequence; potential uptake through procurement specifications, port strategy, tenant or partnership agreements, and relevant contractual provisions.	Potential uptake through internal procedures, procurement specifications, municipal coordination, and inter-port or corridor agreements; no subsequent LL iteration was documented before withdrawal.

The two case anchors also clarify the relationship between the three LL layers introduced in Section 1.1. The energy community and Green Corridor represent project-level, or meso-level, entry points. The workshops and stakeholder exercises operate at the micro level, while the wider allocation of roles, authority, and institutional uptake mechanisms forms part of the macro-level LL constellation.

Overall, Aalborg's intra-port initiative had access to several contractual and organisational interfaces within the port ecosystem, whereas Trelleborg's corridor-level initiative depended more heavily on agreement among autonomous organisations. The comparison therefore highlights how the location of authority and the organisational reach of an initiative jointly shape the pathways through which LL learning might enter routine practice.

4. Discussion

Taken together, the cases show that governance–LL fit is relational: institutionalisation depends on how governance conditions align with the organisational and geographical scope of the transition challenge. Because the cases vary on both dimensions, the comparison is not a clean test of governance effects. Instead, it shows how the location of assets and authority interacts with the reach of an initiative to determine who must participate, which boundaries must be crossed, and which instruments may carry learning into practice. Neither configuration is inherently superior.

4.1. Governance conditions, institutionalisation mechanisms, and LL design

Regarding RQ1, the findings indicate that asset allocation, operational responsibilities, and decision authority condition all four dimensions of governance–LL fit, but their practical implications depend on initiative scope. Aalborg's intra-port energy community could draw on tenant, procurement, and partnership interfaces within the port ecosystem, whereas Trelleborg's Green Corridor extended across autonomous organisations and jurisdictions. The stakeholder and coordination requirements observed in the cases therefore reflect the fit between where authority sits and how far the initiative extends, rather than governance configuration alone.

Regarding RQ2, the cases identify different combinations of contractual, procedural, and organisational mechanisms. In Aalborg, prospective routes include procurement specifications, strategic planning, tenant and partnership agreements, and, where relevant, lease or concession provisions. In Trelleborg, port-controlled learning could enter standard operating procedures, procurement, investment planning, and municipal coordination, while route-level learning would require inter-port or corridor agreements. These mechanisms are institutional landing zones: they connect experimental evidence to an authorised process through which organisational practice could change.

The distinction between decision authority and uptake mechanisms is useful here. An organisation may possess formal authority without having a suitable instrument ready to incorporate learning, or it may identify an instrument but lack control over all actors required to use it. PoT illustrates the distinction: despite comparatively direct authority over port-controlled activities, the Green Corridor had not reached a documented procurement, investment, SOP, municipal, or corridor agreement before strategic priorities changed and the port withdrew. This does not imply that the absence of such an instrument caused the withdrawal; it shows only that authority had not yet translated into an institutional anchor. Conversely, PoA has several contractual interfaces with external actors, but using them may require negotiation and alignment with procurement, budgeting, or contract-renewal windows.

Regarding RQ3, LL design should begin with governance mapping rather than treating institutionalisation as a final stage after experimentation. This entails identifying relevant assets, decision and budget authority, contractual relationships, regulatory responsibilities, and timing windows before defining the experimental process. Stakeholder participation can then be organised around the actors whose decisions, resources, or assets are needed, rather than around breadth of participation alone.

Iteration should also be designed into the LL process, with opportunities to revisit assumptions, stakeholder roles, requirements, and proposed outputs as evidence develops. The artifacts produced by an LL should reflect the intended pathway for institutional uptake. Depending on the setting, useful outputs may include draft procurement requirements, data-sharing provisions, performance indicators, operating procedures, partnership agreements, decision briefs, or corridor-level workplans. Producing such artifacts does not guarantee adoption, but it reduces the gap between collaborative learning and the formal processes through which ports and their partners act. For port energy transitions, this is particularly important because experimentation often crosses organisational boundaries and interacts with regulated energy systems, long-lived infrastructure, and substantial investment decisions.

4.2. Positioning within and against the literature

The findings extend established port-governance research in a specific direction. Port-governance typologies explain how responsibility for infrastructure, equipment, and operations is divided between public and private actors, while research on port-authority functions shows that port authorities may act not only as landlords, regulators, or operators but also as community managers, facilitators, and entrepreneurs (Verhoeven, 2010; Ng and Pallis, 2010; Notteboom et al., 2021). Research on Port Community Systems similarly highlights the coordinating role of port authorities in innovations that depend on data exchange and collaboration among several organisations (Tijan et al., 2021). The paper's main analytical contribution is the governance–LL

fit framework, which extends this literature from the allocation of port functions to the conditions under which collaborative experimentation can be designed and embedded. It shows how the allocation of authority and organisational roles influences where LL learning can enter contracts, procedures, strategies, and inter-organisational agreements.

This finding also qualifies interpretations of port-governance models that imply a generally superior configuration. The relative advantage of a governance model depends on the problem being addressed and the organisational reach of the initiative. A Landlord arrangement can provide contractual interfaces for influencing tenants and partners, but authority may be dispersed and implementation can depend on voluntary or negotiated cooperation. A Tool/Public Service arrangement can enable decisive action within the port authority's own remit, but initiatives involving shipping routes, energy markets, utilities, or other ports require additional governance arrangements. This is consistent with research emphasising that port-governance reforms and institutional arrangements are context-dependent and that no single model is universally preferable (Ng and Pallis, 2010; Tijan et al., 2021; Notteboom et al., 2021).

The findings further support a growing body of LL research that treats institutional context as constitutive of experimentation rather than as external background. Legal form, organisational location, established decision structures, and access to resources affect how LLs are governed and whether their activities persist (Voorwinden et al., 2023). Studies of public-sector LLs show that they can create spaces for collaborative learning and reframe innovation processes, but that their influence depends on how learning connects to public organisations and democratic decision processes (Fuglsang and Hansen, 2022). Evidence from university LLs likewise shows that institutional structures, cultures, resourcing, and support from organisational leadership can enable or constrain the scope and longevity of sustainability experimentation (Hadfield et al., 2025).

The port cases contribute a sector-specific account of these institutional conditions. Ports combine public responsibilities, commercial relationships, regulated infrastructure, and networks of legally independent actors. Institutional embedding may therefore require several forms of coordination simultaneously: internal authorisation, contractual alignment with firms, engagement with municipalities and energy-system actors, and, in the Green Corridor case, agreement across ports and shipping organisations. The governance–LL fit framework makes these dependencies visible without assuming that the LL itself has authority over all participating actors.

The results are also consistent with sustainability-transition research distinguishing experimentation from its wider effects. Experimental learning can contribute to institutional change through embedding, translation, and scaling, but these processes require actors to adapt and anchor learning in existing or emerging institutional structures (von Wirth et al., 2019; Sengers et al., 2021). Project-based organisation can instead result in discontinuity, weak follow-up, and limited organisational learning when temporary activities are not connected to enduring mandates or resources (Torrens and von Wirth, 2021). The institutional landing zones identified here provide a more operational interpretation of embedding in port settings: learning must connect to a process or instrument through which an authorised actor can act.

The findings therefore challenge any assumption that applying a common set of LL methods will produce equivalent institutional effects across settings. Workshops, stakeholder maps, SWOT analyses, and value exercises can support problem framing and co-creation, but they do not by themselves determine who can approve an investment, amend a contract, establish a data-sharing obligation, or commit organisations along a shipping corridor. Methodological consistency can support learning across cases, but institutional uptake requires adaptation to both governance context and initiative scope.

4.3. Implications for port managers and policymakers

For port managers, the first implication is that an LL should be connected to the port's decision architecture from the outset. Before launching an experiment, the organisers should identify which organisation controls the relevant assets, who holds decision and budget authority, which external approvals are required, and when relevant procurement, investment, contract, or planning decisions will occur. This helps avoid producing evidence after the appropriate decision window has passed.

Second, stakeholder selection should follow the governance and coordination requirements of the transition challenge. Broad participation can improve legitimacy and problem framing, but the LL must also involve actors able to commit the assets, data, expertise, finance, or regulatory authority required for implementation. For an energy community, this may include tenants, utilities, system operators, municipalities, technology providers, and organisations able to clarify regulatory and market conditions. For a Green Corridor, it requires counterpart ports, shipping companies, fuel suppliers, infrastructure providers, governments, and relevant regulatory bodies.

Third, LL activities should produce governance-ready outputs alongside technical findings. Examples include draft procurement language, data-access and data-sharing terms, proposed performance indicators, allocation of responsibilities, monitoring procedures, and templates for partnership or inter-port agreements. These artifacts can be refined through experimentation and provide a clearer bridge to organisational uptake than general recommendations alone.

Fourth, responsibility for maintaining the LL process should be specified beyond the initial project period. Stakeholder engagement, documentation, coordination, and learning require organisational capacity and resources. Reliance on individual champions or temporary external funding creates a risk that collaboration ends before evidence can reach a relevant decision process.

For policymakers and research funders, the results suggest that requirements for replication and scaling should recognise differences in governance context and initiative scope. Asking all ports to reproduce the same organisational model or project output may be less useful than requiring each LL to identify its decision authority, institutional landing zones, stakeholder commitments, and route to longer-term resourcing. Public authorities can also support uptake by clarifying regulatory conditions, facilitating coordination across jurisdictions, and developing reusable templates for data sharing, procurement, energy collaboration, and Green Corridor agreements.

4.4. Limitations and future research

The study's scope places several limits on the interpretation and generalisability of the findings, while also pointing to priorities for future research. First, the empirical material captures early-stage capacity building, organisational reflection, and the identification of prospective institutionalisation pathways. It does not evaluate completed pilots, measure long-term organisational change, or establish causal effects on port or energy-system performance. References to institutional uptake therefore concern identified possibilities rather than demonstrated outcomes.

Second, the two cases represent only two dominant governance configurations and are not statistically representative of Public Service, Tool, Landlord, or Private Service ports more generally. The configurations are ideal types, while actual ports may combine arrangements across assets and activities. The cases also differ in initiative scope: Aalborg combines a Landlord-oriented configuration with an intra-port energy community, whereas Trelleborg combines a Tool/Public Service-oriented configuration with an inter-port Green Corridor. Because the other two combinations are not observed, differences in prospective uptake mechanisms cannot be attributed uniquely to governance rather than initiative scope. Both cases were also embedded

in POTENT-X and participated in a common capacity-building process, which strengthened comparability but may limit transferability to independently initiated LLs or those developed under different institutional conditions.

Third, empirical depth is asymmetric. Both ports completed the initial capacity-building phase, but only Aalborg continued to stakeholder interviews and governance-development activities. Aalborg can therefore be examined with greater granularity, whereas the Trelleborg interpretation rests on earlier-stage workshop evidence. Some apparent differences may consequently reflect data availability as well as the underlying case conditions. The later Aalborg evidence was excluded from comparative scoring and used only to support or qualify that case. PoT's withdrawal is analytically informative, but it does not substitute for the missing follow-up evidence or support causal inference.

Fourth, the workshops involved relatively small and partly project-based groups. Some stakeholder roles and expected contributions were articulated by the port teams rather than confirmed directly by every organisation concerned. Facilitators and one of the researchers were also involved in producing the materials, creating a risk of positive or theory-informed interpretation. Independent documentary coding by a second researcher, separate reporting of the coder scores, and factual review by ENoLL trainers and port representatives improved traceability but do not remove these limitations.

Finally, the 0–2 scale is an ordinal coding aid rather than a validated measure of LL quality or port performance. The four dimensions were not aggregated, and differences between coder scores indicate areas where the evidence supported more than one interpretation. The scoring framework makes the qualitative judgments visible but should not be used to rank ports.

Future research should follow the cases longitudinally to examine whether the identified procurement provisions, agreements, procedures, and organisational responsibilities are adopted and sustained. Comparative studies could also fill the two unobserved combinations in the present design by examining the same initiative type across governance settings and different initiative scopes within the same governance setting—for example, Landlord-oriented ports pursuing corridor-level initiatives and Tool/Public Service-oriented ports pursuing intra-port energy initiatives. Research across a larger set of Public Service, Tool, Landlord, Private Service, and hybrid configurations would help test the framework's boundary conditions. Additional interviews with tenants, shipping companies, municipalities, utilities, regulators, civil-society organisations, and other corridor partners would allow the analysis to move beyond port-defined expectations towards negotiated stakeholder commitments.

A particularly useful next step would be to examine the full pathway from experimentation to organisational change: how evidence is produced, translated into a governance-ready artifact, negotiated within an authorised decision process, and subsequently monitored. This would allow future studies to assess not only whether an institutional landing zone exists, but whether and under what conditions LL learning successfully enters it.

CRediT authorship contribution statement

Sonia Yeh: Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Christopher Dirzka:** Writing – original draft, Methodology, Investigation, Funding acquisition, Conceptualization. **Aleksandr Kondratenko:** Writing – original draft, Methodology, Formal analysis. **Frans Libertson:** Writing – review & editing. **Benedicte Madon:** Writing – original draft, Writing – review & editing. **Veronika Slakaityte:** Writing – review & editing.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work, the authors used ChatGPT to improve the clarity and readability of the manuscript, including language editing and phrasing, and Claude to improve figure composition. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.tranpol.2026.104456.

Data availability

The data that has been used is confidential.

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