

Circular intellectual capital and disclosure readiness in European port ecosystems

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Abstract

Purpose – This study examines how public sustainability disclosures in European port ecosystems reveal the maturity of governance and measurement structures supporting circular intellectual capital (CIC) and credible circular transition claims. Rather than assuming carbon-insetting as an empirically established practice, this study uses insetting-like value chain decarbonisation initiatives as an analytical benchmark. Double materiality is interpreted as a governance maturity benchmark, avoided emissions (Scope 4) as a measurement maturity benchmark and knowledge decoupling as a lens for assessing the credibility of disclosure.

Design/methodology/approach – This study applies qualitative content analysis to sustainability reports, integrated reports and selected website disclosures from leading European ports. Automated analysis using Leximancer is combined with manual coding to examine how decarbonisation initiatives are disclosed and whether they are supported by observable governance, boundary-setting, measurement and verification cues.

Findings – The results reveal that European ports widely disclose value chain decarbonisation initiatives connected to human, structural and relational capital; however, the disclosure of advanced accountability elements remains uneven. Double materiality is only partially integrated, while avoided emissions (Scope 4) are rarely supported by explicit methodologies. This suggests that port disclosures are more developed at the level of operational decarbonisation narratives than at the level of governance and measurement architectures required for credible accountability.

Originality/value – This study contributes to intellectual capital and sustainability disclosure research by repositioning CIC as a capability whose credibility depends on the governance and measurement structures through which it becomes publicly visible. It also advances a diagnostic approach to port disclosures by using double materiality and avoided emissions as maturity benchmarks and knowledge decoupling as a lens for distinguishing aspirational claims from more bounded, structured and credible forms of disclosure.

Keywords Circular intellectual capital, Disclosure readiness, Port ecosystems, Sustainability disclosure, Knowledge decoupling, Double materiality, Avoided emissions

Paper type Research article

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1. Introduction

Ports are critical nodes in international supply chains and operate as complex ecosystems in which infrastructure, stakeholder expectations, technological innovation, and environmental pressures intersect (Acciaro *et al.*, 2014; Del Giudice *et al.*, 2022). As critical centres in international supply chains, ports face growing pressure to support circular and regenerative transitions through sustainability-oriented practices, digital innovation, and collaborative forms of environmental governance (Battisti and Deakins, 2017; Raimo *et al.*, 2025). This transition requires a re-evaluation of how intangible assets and intellectual capital contribute to long-term sustainability, accountability, and value chain transformation; therefore, Green Intellectual Capital (GIC) supports organisations in improving their environmental sustainability by integrating environmental protection, pollution prevention, and green innovation into structural, relational, and human capital (Paoloni *et al.*, 2023). GIC can be understood as a set of environmental knowledge resources, skills, competencies, and relational capabilities that help organisations improve environmental performance and develop sustainability-oriented advantages (Abd *et al.*, 2023). However, the global emphasis on environmental considerations has prompted companies to further enhance their sustainable practices by integrating environmental aspects into their intangible resources (Benevene *et al.*, 2021). While GIC explains how organisations embed environmental concerns into human, structural, and relational capital, circular transitions require a broader perspective because they involve closed-loop thinking, resource regeneration, interorganisational coordination, and value chain accountability. Circular Intellectual Capital (CIC) is therefore used in this study as the primary conceptual backbone for interpreting how port ecosystems mobilise knowledge, routines, infrastructures, and relationships in support of credible circular transition claims. Even though the role of intellectual capital in facilitating environmental innovation and sustainability transitions has been investigated in prior studies (Inkinen, 2015; Dumay *et al.*, 2020; Di Vaio *et al.*, 2024), less is known about how CIC becomes publicly visible and credible in complex multi-actor systems such as ports (Raimo *et al.*, 2025). However, some studies suggest that broader configurations of intangible resources beyond organisational boundaries are required (Dumay *et al.*, 2020; Paoloni *et al.*, 2023). Meanwhile, increasing regulatory and scholarly attention has been directed towards disclosure mechanisms that can make sustainability claims more assessable. These include the principle of double materiality (EFRAG, 2023) and the idea of avoided emissions (Scope 4) as a possible measure of value chain decarbonisation (WRI, 2023). However, empirical research has not yet sufficiently explained how these emerging governance and measurement mechanisms interact with circular capability development and sustainability disclosure in port ecosystems. This limitation is particularly relevant because ports coordinate multiple actors, infrastructures, and knowledge flows; therefore, disclosure credibility depends not only on sustainability initiatives but also on the governance and measurement structures that support them. Unfortunately, the literature provides little insight into the process through which ports assemble and convey intangible assets to facilitate the development of regenerative values.

Among several emerging decarbonisation approaches, carbon-insetting initiatives have attracted growing attention as organisations are increasingly investing in emission reduction actions across their respective value chains as opposed to solely utilising external carbon offsetting mechanisms (BCI, 2023). Carbon-insetting refers to a combination of a novel approach of embedding sustainability in operations and stakeholder relationships (Abatable and International Platform for Insetting, 2016). Compared with traditional offsetting, which has often been criticised for being opaque or weakly connected to core business activities, carbon-insetting is generally associated with emission reduction actions embedded within an organisation's own value chain. However, in port ecosystems, the boundaries between strict carbon-insetting, collaborative decarbonisation, and broader value chain sustainability initiatives are not always clearly defined in public disclosures. For this reason, this study does not assume that the analysed disclosures provide direct evidence of fully developed carbon-insetting practices; rather, it examines insetting-like value chain decarbonisation

initiatives as an analytical benchmark. This more cautious formulation allows this study to assess whether port disclosures contain credibility cues that would be required to support stronger inseting or avoided-emissions claims, including defined boundaries, clear responsibilities, specific metrics, explicit methods, verification mechanisms, and stated limitations. At the same time, sustainability disclosure frameworks in Europe have attracted increasing scholarly attention. In particular, the European Sustainability Reporting Standards (ESRS) have introduced the concept of double materiality, requiring organisations to report both how sustainability matters affect enterprise value and how organisational activities impact people and the environment (EFRAG, 2023).

In this study, double materiality is not treated simply as a reporting item that may be present or absent; rather, it is interpreted as a governance maturity benchmark because it requires organisations to connect sustainability impacts, risks, and opportunities with governance, strategy, and reporting processes (EFRAG, 2023). Accordingly, this study views emerging disclosure mechanisms not as practices that organisations may adopt or reject but as indicators of governance and measurement maturity. Similarly, avoided emissions (Scope 4) are interpreted as a measurement maturity benchmark because they require explicit assumptions, boundaries, counterfactual reasoning, and credible methods for assessing value chain decarbonisation effects (WRI, 2023). Rather than assuming that these elements will be widely disclosed, this study examines what their presence or absence reveals about the readiness of port ecosystems to support credible circular and regenerative transition claims. Active stakeholder collaborations, sustainable technology investments, optimisation of the use of resources, promotion of sustainable practices, and reporting practices and transparency are the key measures for reducing Scope 4 emissions (Di Vaio *et al.*, 2025). Their limited or uneven visibility is therefore analytically meaningful, as it suggests whether current port disclosures provide the governance, boundary-setting, and measurement conditions required for credible accountability.

The research gap addressed by this study can therefore be specified more clearly. First, prior studies examined the role of intellectual capital in environmental innovation and sustainability transitions, but they paid less attention to how circular capabilities become publicly visible and credible in complex multi-actor ecosystems such as ports (Inkinen, 2015; Dumay *et al.*, 2020; Di Vaio *et al.*, 2024; Raimo *et al.*, 2025). Second, sustainability disclosure research has increasingly examined accountability, materiality, and greenwashing risks, but it has not yet sufficiently explained how emerging governance and measurement mechanisms, such as double materiality and avoided emissions, can be used diagnostically to assess disclosure readiness (EFRAG, 2023; WRI, 2023; Di Vaio *et al.*, 2025). Third, port sustainability research has documented digitalisation, environmental initiatives, and decarbonisation strategies, but it has rarely connected these practices to CIC and to the maturity of the disclosure structures through which circular transition claims are made credible (Acciaro *et al.*, 2014; Del Giudice *et al.*, 2022; Raimo *et al.*, 2025). This gap matters because the visibility of decarbonisation initiatives does not necessarily imply that the underlying governance and measurement architecture is mature enough to support credible circular or regenerative claims.

The current study adds to the theoretical knowledge on intellectual capital and sustainability disclosure literature by introducing CIC as a capability framework for understanding how organisations formulate the governance and measurement patterns that need to be credible for circular and decarbonisation transitions. More specifically, this study shifts the focus from asking whether ports disclose sustainability initiatives to asking whether their disclosures exhibit the minimum conditions for credible accountability. Public sustainability disclosures are therefore interpreted not simply as communication outputs but as observable signals of disclosure readiness. This study examines whether port disclosures contain governance, boundary-setting, measurement, and verification cues that indicate the maturity of the structures supporting CIC-related claims.

This study provides a diagnostic framework for assessing port ecosystems' readiness to support credible circular transition accounting based on the emerging mechanisms of

accountability double materiality and avoided emissions (Scope 4) found in public disclosures. Knowledge decoupling is used in this context as an interpretive credibility lens, and rather than treating it as a broad label for symbolic compliance, this study uses knowledge decoupling to distinguish between disclosures that remain aspirational and those that are more bounded, structured, and methodologically inspectable. Accordingly, this study is guided by the following research question (RQ): *To what extent do public sustainability disclosures in European port ecosystems reveal readiness to support credible circular and regenerative transition claims through governance, measurement, and accountability structures?* This overarching question is addressed through three sub-questions:

- (1) What governance, boundary-setting, measurement, and verification cues are observable in the sustainability disclosures of port organisations?
- (2) To what extent do current port disclosures provide the conditions required for credible reporting of advanced accountability mechanisms such as double materiality and avoided emissions?
- (3) What maturity gaps emerge from current disclosure practices, and what do these gaps reveal about the readiness of port ecosystems to support credible CIC-related circular transition claims?

This study incorporates these developing constructs into a conceptual framework that is coherent in terms of CIC. Within this framework, CIC is treated as the primary conceptual backbone for interpreting how port ecosystems mobilise human, structural, and relational capital in support of circular and regenerative transitions (Scarpellini *et al.*, 2019). In this context, shared value chain decarbonisation efforts are viewed as expressions of CIC mobilisation rather than as evidence of fully developed carbon-insetting practices. Carbon-insetting is used in this framework as a demanding value chain mitigation benchmark rather than as an empirically assumed category. Double materiality is interpreted as a governance maturity benchmark, while avoided emissions (Scope 4) are treated as a benchmark for measurement maturity. Knowledge decoupling is then used as an interpretive lens for assessing whether sustainability narratives are supported by sufficiently bounded and credible disclosure structures. This structure allows this study to treat double materiality and Scope 4 as diagnostic stress tests of disclosure maturity, rather than as simple variables that are either present or absent.

This study employs double-level content analysis – using Leximancer software (v5) and manual content analysis – of sustainability reporting and website pages published between 2020 and 2024 by ten leading European ports, all of which are core nodes in the Trans-European Transport Network (TEN-T) (European Commission, 2023), which is recognised for its advanced investments in digital and environmental innovation. Leximancer is used to identify dominant semantic patterns, while manual coding assesses whether decarbonisation disclosures are supported by observable maturity cues, including boundaries, responsibilities, metrics, methods, verification, and limitations. The analysis systematically codes how insetting practices are framed, disclosed, and legitimised, focussing on double materiality dimensions and avoided emissions claims.

The framework of this study is based on the CIC view that describes how organisations deploy human, structural, and relational capital to support circular and regenerative transitions. The conceptual framing is deliberately organised around CIC, which provides the main theoretical backbone because it explains how human, structural, and relational capital can support circular transition claims in port ecosystems. This ability-based point of view receives extra support from the natural resource-based view (NRBV), which highlights the role played by environmental capabilities and organisational resources in achieving ecological sustainability with the help of the creation of value (Hart, 1995). The NRBV is therefore used to explain why environmental capabilities may have strategic value. Stakeholder and legitimacy theories (Suchman, 1995) are used more narrowly to interpret sustainability

disclosure as a mechanism that helps ports to respond to external accountability pressures. Stakeholder and legitimacy perspectives are used more narrowly to explain why ports disclose sustainability claims to external audiences and why credibility matters. Finally, the dynamic capabilities framework (Teece, 2007) might be employed to comprehend how ports will be able to feel, grab, and reorganise their intangible assets to introduce new measures, such as avoided emissions (Scope 4), into reporting and decision-making. Dynamic capabilities are not treated as a separate framework but as a complementary way to understand how ports may adapt and reconfigure intangible resources in response to emerging accountability requirements. This structure avoids treating multiple theories as parallel frameworks and instead subordinates them to the central CIC argument.

This study contributes to the literature in three ways. First, it advances CIC research by showing that the credibility of CIC-related circular transition claims depends not only on the mobilisation of intangible resources but also on the governance and measurement structures through which such mobilisation becomes publicly visible. Second, it contributes to sustainability disclosure research by interpreting double materiality and avoided emissions as diagnostic benchmarks for assessing governance and measurement maturity, rather than as simple disclosure items that are either present or absent. Third, it develops knowledge decoupling as a credibility lens for distinguishing aspirational disclosure from that which is more bounded, structured, and verifiable. Hence, this study responds to the need for a clearer conceptual link between intellectual capital, sustainability disclosure, and accountability in complex infrastructure ecosystems.

This study is organised as follows. Section 2 reviews the relevant literature, and Section 3 describes the research methodology. The fourth section presents the results, while Section 5 discusses them and outlines this study's theoretical and practical contributions, as well as policy recommendations and limitations. Section 6 offers concluding remarks and directions for future research.

2. Theoretical background

2.1 From green intellectual capital to circular intellectual capital: extending the environmental intangibles paradigm

Intellectual capital has attracted growing attention in sustainability accounting research as a key driver of sustainable development (Di Vaio *et al.*, 2024). Organisations are therefore increasingly involved in green initiatives aimed at reducing waste and emissions and improving their environmental impact. Enhanced environmental performance can be achieved when organisations are actively engaged in green resources and green knowledge (Chuang and Huang, 2018). GIC captures this relationship by explaining how environmental knowledge, capabilities, and relationships help firms reduce environmental costs, strengthen employees' environmental awareness, and support green innovation. Therefore, GIC can be defined as "the total stock of all kinds of intangible assets, knowledge, capabilities, and relationships, etc. about environmental protection or green innovation of both the individual and organisation levels within a company" (Chang and Chen, 2012, p. 77). Accordingly, GIC prioritises the development of environmental expertise, organisational capabilities, and strategic collaborations to reduce environmental impact, advance green innovation, support regulatory compliance, and enhance environmental performance. However, CIC extends these environmental intangibles perspectives by linking environmental knowledge and capabilities to circular economy principles, including closed-loop systems, resource regeneration, and sustainable business models (Dumay *et al.*, 2020). While GIC has received attention for its role in linking environmental issues with intangible resources (Inkinen, 2015), it mainly explains how organisations integrate environmental concerns into human, structural, and relational capital. CIC goes further by examining how intangible resources are mobilised to enable circularity and regeneration across value chains (Zheng *et al.*, 2024; Raimo *et al.*, 2025). Empirical research on circular business models has expanded

in heavy industrial sectors, including manufacturing, mining, and cement industries, thereby extending the debate beyond logistics and ports. For instance, these studies illustrate the adoption of circular strategies such as waste valorisation, resource recovery, and closed-loop production systems in industrial value chains (Geissdoerfer *et al.*, 2017; Pieroni *et al.*, 2021). These findings suggest that circular transitions depend on the systematic mobilisation of organisational knowledge, technological capabilities, and inter-firm collaboration, all of which contribute to the development of CIC. However, limited attention has been paid to how ecosystem-scale organisations, such as ports, mobilise human, relational, and structural capital to support circular innovation, transparency, and credible disclosure. New metrics, including avoided emissions (Scope 4) (Young-Ferris *et al.*, 2025), together with new regulatory frameworks, including the principle of double materiality (European Commission, 2022), generate new opportunities to operationalise and disclose CIC. From this perspective, sustainability disclosure practices can be interpreted as observable manifestations of CIC, reflecting how human, structural, and relational knowledge resources are mobilised to support the governance, measurement, and accountability mechanisms required for credible circular transition strategies.

In this study, CIC is treated as the main conceptual framework for understanding how port ecosystems mobilise human, structural, and relational capital to support circular and regenerative transitions. Carbon-insetting is used as a demanding value chain mitigation benchmark rather than as an empirically assumed category. Double materiality is interpreted as a governance maturity benchmark, while avoided emissions (Scope 4) are treated as a benchmark for measurement maturity. Finally, knowledge decoupling is applied as an interpretive lens for assessing whether sustainability discourses are supported by sufficiently bounded, credible, and verifiable disclosure structures. In this combined view, CIC is not only a stock of environmental knowledge and capabilities but also a dynamic system through which organisations organise circular practices, sustainability governance, and disclosure processes.

2.2 Carbon-insetting and the natural resource-based view: embedding regenerative practices into intangible resources

Ports, as key participants in supply chains, operate through complex infrastructures and face increasing regulatory pressure to align environmental and social objectives with economic targets (European Parliament and Council of the European Union, 2023). Such integration can be supported by emissions reduction programmes that optimise the use of existing resources while incorporating circular economy principles (Tao *et al.*, 2019). Supporting this transition, carbon-insetting plays an important role within port value chains by directing investments towards emissions reduction projects linked to organisations' own activities and stakeholders. These initiatives might include digital monitoring systems, alternative fuels infrastructure, shipping electrification, renewable energy deployment, and credible monitoring, reporting, and verification (MRV), as well as coordinated multi-stakeholder cooperation (BCI, 2023). Additionally, carbon-insetting generally follows a process based on emissions mapping, intervention design, implementation, and MRV, thereby connecting value chain decarbonisation to more accountable forms of measurement and governance (van Anel, 2025).

Carbon-insetting initiatives can be linked with the NRBV because they rely on the mobilisation of environmental capabilities and CIC components to implement regenerative environmental practices. Hart (1995) introduced key strategies such as product stewardship, pollution prevention, and sustainable development to achieve competitive advantage. However, the NRBV is also useful for explaining environmental value creation because it emphasises the strategic use of environmental resources and capabilities (Asiaei *et al.*, 2023). In this study, however, the NRBV is used as a supporting capability logic rather than as a framework competing with CIC, which remains the main conceptual backbone because it explains how human, structural, and relational capital are mobilised to support circular and

regenerative transitions. Unlike typical decarbonisation measures, insetting mechanisms are embedded within a company's own value chain rather than relying on the purchase of carbon offsets from external markets. They also require the active involvement of multiple supply chain actors, since emissions reduction initiatives often depend on coordinated action across organisational boundaries. In addition, credible insetting depends on project-specific monitoring and measurement arrangements that make the intervention identifiable, traceable, and assessable (BCI, 2023). At the same time, carbon-insetting must be used cautiously in the context of public port disclosures, which may describe value chain decarbonisation, electrification, renewable energy, or circular infrastructure without providing enough information to verify whether these initiatives fully meet strict carbon-insetting criteria. For this reason, this study treats carbon-insetting as a demanding analytical benchmark rather than as an empirically assumed category. Empirically, this study therefore refers to insetting-like value chain decarbonisation initiatives or collaborative decarbonisation disclosures when the available evidence does not allow stronger claims.

The integration of environmental resources usage in carbon-insetting projects can be successfully supported by CIC components. Human capital is relevant because organisations need technical expertise, environmental knowledge, and operational skills to identify and implement value chain mitigation initiatives. Structural capital becomes important when insetting-like initiatives are embedded consistently in organisational routines, data systems, MRV procedures, and governance arrangements (Di Vaio *et al.*, 2024). Relational capital supports cooperation with stakeholders and enables firms to identify projects that can generate environmental and social benefits simultaneously (BCI, 2023). As ports have complex ecosystems in their supply chain activities, NRBV-based regenerative capabilities can help them adopt technological advancements, reduce environmental impacts, improve waste management, and strengthen circular economy practices (George *et al.*, 2018).

Current studies have not sufficiently explored the linkage between organisational intangible resources and resilient value creation in port ecosystems, especially when value chain decarbonisation initiatives require coordination across multiple actors. This gap helps us to structure this study by focussing on knowledge capabilities, stakeholder collaboration, and organisational learning while using carbon-insetting as a benchmark for assessing the maturity and credibility of disclosed circular transition practices.

2.3 Double materiality and avoided emissions: new governance mechanisms for circular intellectual capital

The rapidly increasing importance of sustainability reporting has led to the introduction of the ESRS and to the growing relevance of the principle of double materiality (European Commission, 2023b). This legislative act represents an important step towards embedding environmental sustainability into corporate value chains and requires organisations to examine whether existing reporting practices are aligned with evolving regulatory demands. In this regard, the concept of double materiality helps define the reporting boundaries of sustainability-related intangible resources, including environmental knowledge, people, intellectual rights, organisational structures, and sustainability practices (Pizzi *et al.*, 2024). Sometimes, firms may engage in greenwashing by emphasising positive environmental actions while under-reporting negative impacts, methodological assumptions, or unresolved trade-offs; however, the quantification and measurement of avoided emissions (Scope 4) enable both organisations and stakeholders to obtain a clearer view of how firms' activities contribute to reducing emissions (Di Vaio *et al.*, 2025).

Applying CIC as the conceptual pillar, double materiality can be interpreted as a governance maturity benchmark, whereas avoided emissions (Scope 4) can be treated as a benchmark of measurement maturity. These two mechanisms influence both the mobilisation of intangible resources and the way in which organisations communicate them through sustainability disclosure. Specifically, double materiality encourages firms to integrate

environmental and social dimensions into decision-making, thereby shaping the orientation of human expertise, organisational practices, and stakeholder relationships towards sustainability goals. Simultaneously, Scope 4 emissions can provide an additional measurement lens for capturing the broader decarbonisation effects of the collaborative value chain programme. These new disclosure practices, when viewed through the prism of CIC, indicate the maturity of governance systems and the extent to which organisations translate circular knowledge and competencies into measurable sustainability outcomes (Paoloni *et al.*, 2023). Although integrating CIC with double materiality can support the governance of sustainable business models and strengthen the measurement of avoided emissions, De and Gulluscio (2023) note that there is still only a limited amount of empirical research focused on its practical implementation and disclosure. This gap highlights an area in the literature where the intricate nature of double materiality has not been sufficiently examined (Dragomir *et al.*, 2024). Similarly, Nielsen (2023) underscores the importance of further investigation into double materiality reporting practices, particularly regarding the variability observed in preliminary evaluations. Advancing research into the adoption of double materiality will facilitate a deeper understanding of its operational practices (De and Gulluscio, 2023).

2.4 Port ecosystems as cognitive and multi-actor innovation spaces

Port ecosystems can be understood as Triple Helix environments because they involve interconnected collaborations among port authorities, research institutions, governments, private companies, and regulatory bodies. These actors contribute to technological advancement, regulatory coordination, and the provision of financial and institutional support; however, the collaboration is not limited to them but covers a wider range of players such as shipping companies, logistics providers, financial institutions, technological vendors, and local communities (Vitellaro, 2021). Within such environments, sustainability transitions entail coordinated activities across organisational boundaries. The decarbonisation efforts of a single organisation are usually insufficient to address the larger environmental effects of maritime transport and logistics operations; rather, joint governance systems and common tools are needed to make a systemic sustainability transition possible (Di Vaio *et al.*, 2025).

Hence, ports can be considered cognitive and multi-actor innovation spaces because they combine diversity, adaptability, complex knowledge-sharing platforms, interconnectedness, and data-driven decision-making. In this setting, multiple stakeholders play different roles in fostering innovation in port ecosystems, including technology firms that develop and implement advanced technologies, shipping companies that influence maritime operations, government agencies that provide regulatory guidance, research institutions that support research and development, port authorities that coordinate and govern the ecosystem, and logistics providers that connect ports with wider supply chain activities (Falayi *et al.*, 2020; Piantoni *et al.*, 2023). Specifically, under the European Green Deal, European ports are key to the advancement of circular economy principles, yet they face obstacles such as technological adoption, financial impediments, and legislative misalignments. Therefore, multi-stakeholder collaboration facilitates technological adoption and cohesive governance, helping ports align with social and environmental goals (Andriamanantena *et al.*, 2025).

Although research has progressed regarding the impact of digitalisation and sustainability in port operations, much of the existing literature focuses primarily on the adoption of technology, green initiatives, or external compensation models. The concept of carbon-insetting as an innovative approach to reconfiguring port ecosystems towards circularity and regenerative outcomes has received comparatively little scholarly attention. Moreover, the role of knowledge capabilities and digitalisation in mobilising circular knowledge, improving transparency, strengthening stakeholder engagement, developing organisational structures, and supporting collaborative learning around insetting-like initiatives is still not well understood.

In this context, digital relational capital plays an important role because the success of circular and decarbonisation initiatives in port ecosystems increasingly depends on digitally mediated relationships and shared knowledge infrastructures. Recent studies on intellectual capital highlight that, in ecosystem environments, digital and artificial intelligence (AI)-driven data models can become part of structural capital, while also shaping human capital and strengthening relational capital through knowledge exchange, stakeholder learning, and collaborative decision-making (Baiooco *et al.*, 2026). This issue is particularly relevant in maritime ecosystems, where digital transformation, environmental, social and governance (ESG) concerns, and human capital are increasingly connected with data governance, cyber-resilience, and interoperable reporting systems. Digital tools such as shared data platforms, blockchain-based traceability systems, digital twins, and port community systems can foster trust, facilitate data sharing, and enhance traceability among port stakeholders, thereby reinforcing the relational foundations required for effective sustainability governance (Arslan and Akturan, 2026). Thus, digital relational capital can be understood as the network of digitally mediated relationships, data-sharing practices, interoperable platforms, and trust-based information exchanges that enable multiple actors to coordinate sustainability efforts across organisational boundaries. This is particularly relevant for value chain decarbonisation initiatives, Scope 4 avoided emissions, and carbon-insetting claims, as these efforts require the integration of data from multiple actors, clear boundary definitions, counterfactual assumptions, and monitoring and verification routines. Consequently, digital relational capital complements CIC by illustrating how relational capital is increasingly enacted through digital infrastructures, thereby making circular transition claims more traceable, coordinated, and auditable.

Therefore, this study addresses the lack of integrative research connecting port ecosystems, CIC, insetting-like value chain decarbonisation initiatives, and disclosure credibility.

2.5 Knowledge decoupling: a new mechanism for preventing symbolic compliance

Although sustainability reporting has grown tremendously in the last 20 years, researchers have expressed concerns about the possible discrepancy between sustainability narratives and actual organisational practices. This has been frequently referred to as “knowledge decoupling”, where organisations symbolically adopt sustainability commitments without introducing the underlying organisational changes needed to support them (Bromley and Powell, 2012; Crilly *et al.*, 2012; Cho *et al.*, 2015). In port ecosystems, knowledge decoupling becomes particularly relevant because sustainability claims are often produced across multiple actors, infrastructures, projects, and reporting channels. In this context, disclosure is more credible when it is bounded and verifiable through clear value chain and accounting boundaries, explicit assumptions, MRV arrangements, and auditable routines. Talk–action gaps, including symbolic compliance, can emerge when disclosure is aspirational and loosely bound, especially in complex regulatory and technological settings (Tang *et al.*, 2023).

Within the framework adopted in this study, knowledge decoupling offers an interpretive lens for assessing the plausibility of sustainability disclosures related to circular initiatives. Although carbon-insetting initiatives can indicate the practical implementation of CIC, the presentation of these initiatives through governance mechanisms, such as double materiality, and measurement indicators, such as avoided emissions, helps distinguish between general commitments and more structured capability formation. Sustainability narratives can develop faster than the knowledge systems and organisational structures needed to sustain them in complex multi-actor systems like port ecosystems. Knowledge decoupling can thus be used to understand the disparities in disclosure practice that signal different degrees of alignment between reported sustainability commitments and the mobilisation of the CIC components that should support them.

As previous research indicates, the symbolic adoption of environmental or social standards entails significant risks, particularly in the sustainability context (Giuliani *et al.*, 2017;

[Park and Cha, 2019](#)). Knowledge sharing can be seen in this context as an ecosystem-wide response, which reduces the room for symbolic claims by prioritising bounded, technically specified, and verifiable knowledge, while limiting unsupported or weakly substantiated claims. These interpretations are in line with previous research suggesting that accountability and reliability might be increased through the purposeful creation of measures that support concrete action and knowledge exchange, rather than merely signalling compliance ([Lee, 2017](#)).

The nature of CIC diversity and acceleration has further aggravated the issue of the misalignment between substantive practices and symbolic representations, especially since sustainability information is mediated increasingly by digital structures ([Bresciani et al., 2022](#)). This issue is particularly relevant in port ecosystems, where sustainability narratives and performance claims are created, aggregated, and circulated across multiple actors, projects, and interoperable data systems. Viewing ports as digital knowledge infrastructures emphasises the idea that circular transitions are shaped not merely by investments and partnerships but by how data and digital knowledge flows are designed, governed, and politicised. Hence, digital relational capital may reduce knowledge decoupling by transforming dispersed stakeholder relationships into digitally supported accountability routines, where sustainability claims can be connected to shared data, interoperable systems, and verifiable evidence. The same trend has been noticed in other transport infrastructures, especially airports, where sustainability reporting practices may not always be in line with their regular operating behaviours. Research on sustainability reporting at airports demonstrates that there is a wide range of differences in the reporting of environmental indicators and highlights inconsistencies between the declared sustainability goals and the existence of standardised measurement frameworks ([Dimitriou and Karagkouni, 2022](#); [Raimundo et al., 2023](#)). This set of observations implies that the credibility issues of sustainability narratives are not specific to port ecosystems but may be a broader feature of complex transport hubs, thereby justifying the generalisability of the CIC framework presented in this study.

Knowledge decoupling, therefore, is viewed as a group of credibility-bounding routines that limit the scope of sustainability narratives by anchoring them to verifiable indicators, defined organisational boundaries, and identifiable governance responsibilities. These routines can be disclosed when organisations include measurement methods, operational boundaries, decision responsibilities, verification mechanisms, or explicit limitations that support sustainability claims. When these elements are absent, disclosure narratives remain more aspirational and loosely connected to measurable organisational practices ([Brem and Radziwon, 2017](#); [Mannak et al., 2019](#)).

Regenerative value produced in the ecosystem while using the circular model not only improves the environmental performance of a port but also brings various socio-economic benefits to nearby communities, such as environmental quality, green jobs, and regional economic resilience. Thanks to the mobilisation of CIC across multi-actor networks, port ecosystems deliver not only emissions reductions but also a better quality of life and balanced economic development in the regions where they operate ([Acciaro et al., 2014](#)). However, these claims require credible disclosure structures, as without boundaries, metrics, responsibilities, and verification, regenerative value risks remaining an aspirational narrative rather than a defensible disclosure outcome.

Knowledge decoupling has been positioned as a complementary process to CIC in this study and has been facilitated and moulded by digital infrastructure. While CIC focuses on how human, structural, and relational capital enable circular and regenerative practices, knowledge decoupling explains how these intangible resources become credible and defensible in disclosure and governance. It does so by showing how ecosystems privilege disciplined, verifiable knowledge – for example through bounded accounting logics and verification routines – and separate it from claims that may otherwise reinforce greenwashing risks or symbolic compliance ([Giuliani et al., 2017](#); [Park and Cha, 2019](#)).

This conceptualisation supports the overall framework of this study, where carbon-insetting is used as a value chain mitigation benchmark connected to CIC capability building, while double materiality and avoided emissions operate as governance and measurement stress tests that reveal whether disclosure is supported by sufficiently bounded and verifiable knowledge. The conceptual foundation of this study is illustrated in Figure 1.

3. Methodology

3.1 Research design: qualitative content analysis for emerging practices

This study employs qualitative content analysis (QCA) in analysing how public sustainability disclosures in port ecosystems reveal the maturity of governance and measurement structures supporting CIC and credible circular transition claims. Existing literature recognises QCA as an established method in the study of sustainability reporting, as well as for the analysis of emerging, weakly codified practices, e.g. carbon-insetting, double materiality, avoided emissions, and CIC (Krippendorff, 2018). Since consolidated disclosure patterns and standardised quantitative indicators remain underdeveloped for these practices, QCA provides a systematic and interpretive framework for analysing textual documents. In fact, QCA does not only focus on the frequency or volume of disclosure as it also supports researchers in examining how specific practices are described and made visible in organisational reporting (Unerman, 2000; Steenkamp and Northcott, 2007; Torelli *et al.*, 2020).

Existing literature recognises the efficacy of QCA in identifying both manifest and latent information in analysed documents, while strengthening the rigour and effectiveness of theory-grounded studies (Hsieh and Shannon, 2005; Mayring, 2014). Thus, QCA is used to code sustainability reporting in a transparent and replicable way to identify insetting-like value

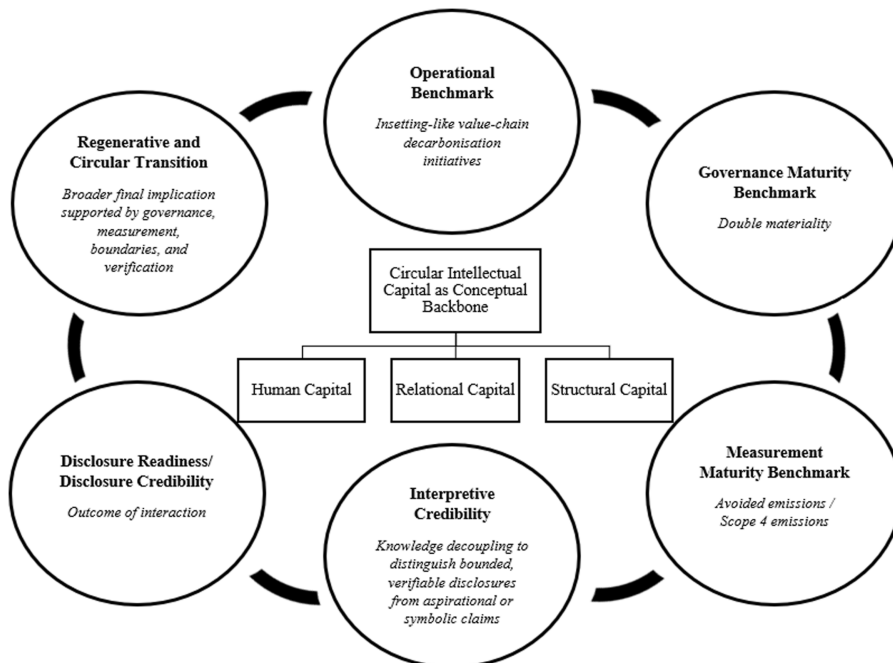


Figure 1. Conceptual framework of CIC as a backbone for operational, interpretive, governance and measurement benchmarks achieving credibility, disclosure readiness and regenerative transition. **Source:** Authors' own creation

chain decarbonisation initiatives, double materiality, avoided emissions, CIC dimensions, and knowledge decoupling cues. The aim is to deepen the understanding of how ports define the objectives, scope, and governance of insetting-like value chain decarbonisation initiatives, while assessing whether these disclosures contain the credibility cues required to support circular transition claims. Therefore, QCA is in line with the conceptual and exploratory nature of this study since it supports the construction of theory in emerging fields. Thus, this study conducts a two-level content analysis focussing on how value chain decarbonisation initiatives are disclosed and whether they are supported by observable governance, boundary-setting, measurement, and verification cues. This design is consistent with the diagnostic aim of this study, as it does not assume that ports already disclose mature carbon-insetting, double materiality, or Scope 4 practices, but assesses whether current disclosures exhibit readiness to support such claims credibly.

3.2 Sampling strategy and case selection

The sample is composed of sustainability reporting and website disclosures by ten leading European ports, analysed with a view to understanding how public disclosures represent insetting-like value chain decarbonisation initiatives and the governance and measurement structures supporting CIC-related circular transition claims.

These ports were identified from their formal designation as core nodes in the Trans-European Transport Network (TEN-T) (European Commission, 2023a), which reflects both their role in major freight and transit flows and their access to European Union (EU) funding instruments that support investments in infrastructure, digitalisation, and knowledge-based assets (L’Abate et al., 2025). As shown in Table 1, the ports included in the sample represent strategically significant nodes in European supply chains, providing a relevant empirical setting for analysing how insetting-like value chain decarbonisation initiatives are connected to human, structural, and relational capital and articulated through sustainability disclosure.

The sample was further refined based on the evidence of investments in digital innovation and knowledge-based infrastructures, both of which are considered indicators of potential developments of intellectual capital, and on the availability of recent, publicly accessible sustainability disclosures sufficiently detailed to allow qualitative interpretation. Ports were excluded when disclosure was fragmented, outdated, or purely promotional. The focus on European ports is justified by the strong regulatory pressure exerted by the European Commission, through different regulatory instruments including the EU Taxonomy, the Corporate Sustainability Reporting Directive (CSRD), and the Omnibus Package, by their

Table 1. Selected European ports’ sustainability reports and website pages

Port	Country	TEN-T status	Sustainability disclosures		Years
			Sustainability reports	Website pages	
Rotterdam	Netherlands	Core	6	10	2020–2024
Antwerp-Bruges	Belgium	Core	2	5	2020–2024
Hamburg	Germany	Core	3	16	2020–2024
Valencia	Spain	Core	4	5	2020–2024
Barcelona	Spain	Core	5	13	2020–2024
Marseille Fos	France	Core	1	5	2020–2024
Ports of Genoa	Italy	Core	2	12	2020–2024
Trieste	Italy	Core	1	8	2020–2024
Piraeus	Greece	Core	5	4	2020–2024
Gdańsk	Poland	Core	5	5	2020–2024

Source(s): Authors’ own data collection of selected European ports’ sustainability reports and website pages (2020–2024)

central role in global supply chains, and by their position as early adopters of circular and regenerative infrastructure initiatives.

Table 1 summarises the ports included in the sample, the type of report analysed, and the corresponding reporting years.

3.3 Data sources and materials

The data collection comprises 117 documents, including 34 sustainability reports (e.g. sustainability reporting, integrated reporting, corporate social responsibility (CSR) reporting, and ESG reporting) and 83 website pages, published between 2020 and 2024 and downloaded from port authorities' official websites (Table 1). The selected period is particularly relevant for European ports due to the significant increase in decarbonisation and digitalisation efforts in the sector, influenced by ambitious environmental goals and policy initiatives such as the European Commission's Sustainable and Smart Mobility Strategy (2020).

Existing literature recognises sustainability reporting as a crucial tool for the legitimacy of an organisation since it can respond to double materiality requirements while providing significant information on the sustainability efforts and emissions reduction strategies adopted by the organisation (Landrum and Ohsowski, 2018; Torelli *et al.*, 2020). Sustainability reporting also represents a fundamental source of information on how intellectual capital (IC) is described, disclosed, and made visible to stakeholders. In this study, these reports are particularly relevant because they enable the analysis of whether port disclosures contain observable cues of governance, boundary-setting, measurement, and verification.

Reports were collected through a systematic review of official port authority websites, which represent the primary channels for formal sustainability disclosure. Where available, carbon emissions reports and strategic climate action plans were also included to ensure a comprehensive analysis of the available sustainability disclosure.

Website pages were identified through a combination of internal website searches and Google searches using a predefined keyword protocol (for example: decarbonisation, shore power, electrification, hydrogen, renewable energy, circular infrastructure, sustainability strategy, materiality, ESRS, CSRD, Scope 3, Scope 4, avoided emissions, MRV, International Organization for Standardization (ISO) 14,001, and ISO 50001). The authors selected exclusively website pages that featured specific initiatives, processes, partnerships, and reporting information to ensure in-depth interpretation of relevant and verifiable contents. Afterwards, the URLs of the selected pages were collected and stored in a dedicated file to ensure data traceability and transparency. This procedure helped distinguish between general promotional content and disclosures containing sufficiently specific information for assessing disclosure maturity and credibility.

3.4 Coding framework development

To strengthen coding rigour, the five co-authors adopted a structured cross-checking procedure. The first subgroup conducted the primary coding of the data collection, while the second subgroup independently recoded a predefined subsample of the material. Approximately 20% of the data set was independently recoded before consensus was reached with a second subgroup of authors. Inter-coder reliability was then assessed using Cohen's kappa for the main coding dimensions to account for chance agreement (Cohen, 1960; McHugh, 2012). Where disagreements emerged, category definitions were revisited and discrepancies were resolved through discussion. All coding decisions, refinements, and examples of borderline cases were collected in a codebook and logged to maintain an audit trail supporting traceability and replication.

The coding scheme was developed using a combined approach. First, the authors developed a coding scheme starting from existing literature and the theories that guide this study. Specifically, the CIC literature provided the primary basis for conceptualising and distinguishing among human, structural, and relational capital components. The NRBV was

used as a supporting capability logic to identify environmental capabilities related to insetting-like value chain decarbonisation initiatives, while dynamic capabilities theory supported the interpretation of how ports describe the adaptation and reconfiguration of intangible resources in response to emerging accountability requirements. Stakeholder and legitimacy perspectives were used more narrowly to interpret sustainability reporting as a response to external accountability pressures and credibility expectations. Scope 4 literature supported the coding of avoided emissions, including definitions, assumptions, boundaries, counterfactual logic, and methodological choices. Finally, the decoupling literature helped identify the distinction between aspirational claims and disclosures supported by observable credibility cues. This perspective builds on institutional accounts of decoupling between formal structures and actual practices (Bromley and Powell, 2012), and on studies showing how organisations respond selectively to stakeholder pressures through differentiated disclosure strategies (Crilly *et al.*, 2012).

The authors identified paragraphs and text blocks as the units of analysis, focussing on initiatives, emissions-accounting approaches, measurement arrangements, governance references, verification mechanisms, and stakeholder engagement processes relevant to CIC and insetting-like value chain decarbonisation initiatives. These units were tracked longitudinally with a view to understanding the evolution of disclosure practices over time. Second, the authors refined the coding scheme by adding relevant themes that emerged from a further and deeper reading of the selected sustainability reporting.

The final coding scheme comprised five dimensions: one concerning the operationalisation of insetting-like value chain decarbonisation initiatives; one on double materiality integration; one on avoided emissions (Scope 4); one on CIC components; and one on knowledge decoupling mechanisms. In addition to these dimensions, the codebook included explicit decision rules for assessing disclosure maturity. A disclosure was considered more mature when it included a higher number of observable credibility cues. These cues were clearly defined boundaries, e.g. inclusion or exclusion of activities or value chain scope; explicit responsibilities, including actors or governance structures that were clearly accountable; metrics or quantified targets; methods or standards such as reporting frameworks or accounting approaches; verification mechanisms, e.g. assurance, certification, or MRV systems; and limitations or uncertainty, such as assumptions or data gaps. These rules were systematically applied and documented in the codebook to distinguish between aspirational narratives and disclosures supported by more structured governance and measurement routines.

To make the coding logic auditable, the authors treated broad statements of commitment, strategy, or ambition as low-maturity disclosures when they were not connected to boundaries, responsibilities, metrics, methods, verification, or limitations. By contrast, disclosures were coded as more mature when they connected sustainability claims to identifiable actors, operational perimeters, quantified indicators, recognised standards, monitoring arrangements, or explicit methodological assumptions. This distinction was important for carbon-insetting, double materiality, and avoided emissions, because this study does not assume that these practices are fully implemented; rather, it assesses whether public disclosures contain the minimum number of credibility cues needed to support such claims.

This systematic coding process reinforced the credibility and reliability of the analysis, while the use of different document types and theoretical perspectives strengthened the validity of the results. The existing knowledge about IC and the sustainability reporting of the authors was seen as a potential bias that could affect the analysis and the interpretation of results. To avoid this risk and strengthen the validity of the findings, the authors followed a clear coding process with specific definitions and controls between the automated and manual coding results. In this way, the coding framework supported the diagnostic purpose of this study by linking disclosure text to observable indicators of governance, measurement, boundary-setting, verification, and credibility.

3.5 Data analysis procedures

A two-level content analysis was conducted on the selected documents: first, an automated content analysis using Leximancer software (v.5); and second, a manual content analysis. The authors conducted an initial screening of the documents to become familiar with their structure, focus, and themes and to better prepare for the data collection. The automated content analysis was conducted through Leximancer software (v.5), which is recognised by existing literature as an effective research tool for identifying word clusters and semantic codes (Smith and Humphreys, 2006; Crofts and Bisman, 2010). Prior studies also highlight its capacity to process large data sets and multiple documents, in contrast to other alternative software like NVivo (Sotiriadou *et al.*, 2014). Before the analysis, the documents were divided into folders, first according to port and then per type of disclosure (sustainability reporting or website pages), and uploaded to the software. Then, the authors manually modified the concept seeds to remove generic terms and common function words (e.g. “year”, “for”), and to merge singular and plural forms of the same words (e.g. “port/ports”). This process is crucial to avoid analysing words with the same semantic value. After these steps, the software generated a set of outputs, illustrated on a thematic map that highlighted the main themes that emerged from the analysis (Figure 2). These outputs supported the identification of recurring patterns across ports, differences in thematic emphasis, and emerging associations among key concepts. The Leximancer analysis was not treated as a substitute for interpretation; rather, it provided a first-stage semantic map that helped in identifying the dominant themes and concept associations in the corpus. These automated outputs were then used to guide the second-stage manual analysis, where the authors examined whether the identified themes were supported by observable disclosure cues, including boundaries, responsibilities, metrics, methods,

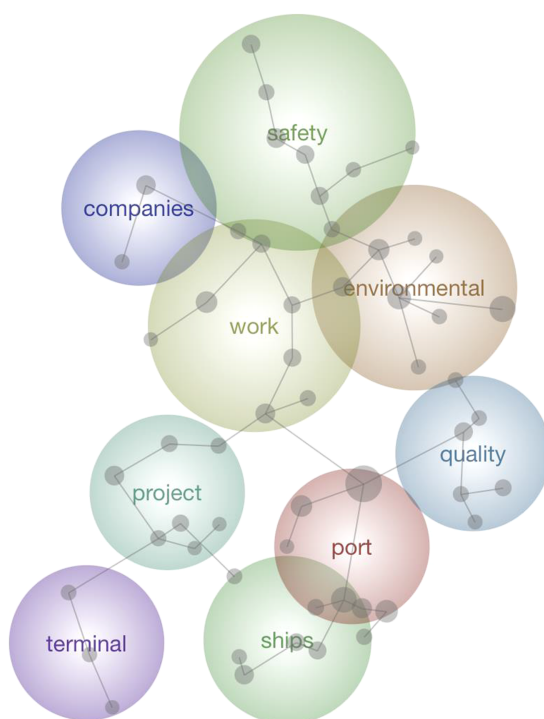


Figure 2. Thematic map of the selected European ports' sustainability reporting and website pages published from 2020 to 2024. **Source:** Authors' own creation from Leximancer (V.5)

verification arrangements, and limitations. This sequence allowed this study to move from broad semantic mapping to a more focused diagnostic assessment of disclosure maturity and credibility.

The second phase consisted of a manual content analysis based on the refined coding scheme. Disclosure maturity was assessed through observable credibility cues rather than narrative intensity. Specifically, a disclosure was considered more mature when it included a combination of the following elements: clearly defined boundaries, assigned responsibilities, metrics or quantified targets, methods or standards, and some form of verification or explicit limitation. This rule was applied consistently across all coded text units to distinguish between aspirational statements and disclosures supported by more developed governance and measurement structures.

In manual coding, knowledge decoupling was treated as identifiable only when a sustainability claim was explicitly constrained or substantiated by at least one credibility cue. These elements included clearly stated boundaries (what is included in, or excluded from, the value chain or the accounting perimeter), assigned responsibilities (i.e. identifiable actors or governance structures), metrics or quantified indicators, explicit methodological assumptions or counterfactual logic, MRV arrangements, references to certified management systems or assurance, and explicit statements regarding limitations or uncertainty. Broad commitments, general strategy statements, or aspirational language not linked to boundaries, responsibilities, metrics, methods, verification, or limitations were not classified as knowledge decoupling. Manual content analysis is essential for interpreting contextual meaning and identifying nuances, assessing differences in disclosure maturity, and examining how practices, including inseting-like value chain decarbonisation initiatives, avoided emissions, and CIC, were articulated (Engstrom *et al.*, 2022; Nicolò *et al.*, 2023).

The last phase of the analysis consisted in interpreting and comparing ports to identify potential conceptual relationships. This analysis comprised a two-level triangulation aimed at strengthening the validity and interpretation of the findings: first, through the theoretical hierarchy adopted in this study, with CIC as the main conceptual backbone and the NRBV, dynamic capabilities, and stakeholder and legitimacy perspectives used as supporting lenses; and second, through the comparison of different code families, including CIC components, governance cues, measurement cues, knowledge decoupling cues, and inseting-like value chain decarbonisation initiatives.

3.6 The methodological choice

The authors selected this methodology due to its alignment with the research questions and the theoretical framework. Specifically, for RQ1, qualitative content analysis supports the identification of governance, boundary-setting, measurement, and verification cues in port sustainability disclosures. This is consistent with the diagnostic aim of this study, which examines whether public disclosures provide observable evidence of the structures needed to support credible CIC-related circular transition claims. For RQ2, this methodology allows an in-depth analysis of whether current port disclosures provide the conditions required for credible reporting of advanced accountability mechanisms, such as double materiality and avoided emissions. In this sense, double materiality is treated as a governance maturity benchmark, while avoided emissions are treated as a benchmark of measurement maturity. For RQ3, qualitative content analysis supports the comparison of disclosure maturity gaps across ports and helps in interpreting what these gaps reveal about the readiness of port ecosystems to support credible circular and regenerative transition claims.

Furthermore, this methodology is not only descriptive but also interpretive and theory building, thus supporting the development of conceptual insights. It allows this study to move beyond the identification of disclosed initiatives and towards a diagnostic assessment of disclosure credibility. CIC remains the main conceptual backbone, while the NRBV, dynamic capabilities, stakeholder and legitimacy perspectives, and knowledge decoupling are used as

4. Results

4.1 Automated content analysis: Leximancer (v.5)

The automated content analysis conducted through Leximancer software (v.5) identified the nine main themes and 53 key concepts characterising how European ports frame insetting-like value chain decarbonisation initiatives, sustainability transition, and the mobilisation of CIC. In line with the exploratory approach, all themes and concepts generated by the software were maintained in the analysis, including those apparently not directly related to the focus of said analysis. This approach was chosen to ensure a comprehensive and unbiased representation of the results.

As can be seen in Table 2, the key themes are *port*, *environmental*, *work*, *safety*, *ships*, *project*, *quality*, *companies*, and *terminal*. These themes present the highest score for frequency and connectivity, determining their relevance in the analysed sustainability reporting.

Port is the main theme of the analysis and is closely associated with concepts such as *energy*, *emissions*, *system*, *consumption*, and *network*. This suggests that ports identify decarbonisation as a system-level challenge, relying on sustainable infrastructure, operational flows, and networked value chains. Ports appear as complex ecosystems where insetting-like value chain decarbonisation initiatives are framed as operational and infrastructural actions rather than as isolated technical measures. The environmental theme also plays a central role in the analysed reports, being linked to *management*, *sustainability*, *strategy*, and *climate* concepts, suggesting that environmental performance is presented as a strategic and governance-related priority. *Work* and *safety* are also central themes and highlight the relevance of workforce capabilities for ports, as confirmed by their correlation with the emerged concepts of *employees*, *training*, *health*, and *policy*. This highlights the key role of human capital in contributing to the transition of the sector. The theme of double materiality and avoided emissions does not emerge as a dominant trend in the analysis, suggesting a weak or absent representation in the analysed disclosures. Rather than indicating non-engagement, the limited visibility of double materiality and avoided emissions suggests uneven development in the governance and measurement routines underlying port disclosures. In this sense, the empirical pattern is not simply one of absence but one of disclosure readiness gaps across port ecosystems.

Table 2. Themes and related concepts in sustainability reports and website pages

Leximancer settings: Concepts 100%; theme size 35%			
Theme	Hits	Connectivity	Concepts
Port	8,805	52,260.00	port, energy, emissions, system, consumption, network
Environmental	6,823	43,381.00	environmental, management, sustainability, sustainable, business, strategy, climate, protection, corporate
Work	5,994	33,553.00	work, services, development, value, economic, measures, operations, future
Safety	3,941	26,529.00	safety, employees, health, social, training, risk, policy
Ships	3,353	25,838.00	ships, electricity, power, production, gas, traffic, vehicles
Project	3,991	22,256.00	project, transport, infrastructure, construction, public, building, equipment
Quality	2,842	18,865.00	quality, waste, air, control, monitoring, noise
Companies	2,368	7,963.00	companies, support
Terminal	1,500	6,637.00	terminal, container, storage

Source(s): Authors’ own processing of selected European ports’ sustainability reports and website pages (2020–2024) using Leximancer v.5

This motivates the second-stage manual analysis, which traces how ports describe insetting-like value chain decarbonisation initiatives and whether these are connected to CIC dimensions and to emerging governance and measurement devices such as double materiality and Scope 4 (Figure 3).

Port, environmental, energy, management, and sustainability emerge as key concepts, suggesting the centrality of decarbonisation-related themes in the analysis. Concepts like *training, employees, companies, and value* are also relevant, suggesting that ports consistently link decarbonisation to human and relational capital dimensions (Table 3).

Specifically, the concept of *training* is directly linked to *employees* (25%), *health* (23%), and *safety* (18%), followed by other concepts (e.g. *development, social, risk, and policy*). These associations suggest that training is framed as a tool for strengthening workforce capabilities in safety and risk management, which are fundamental aspects of port ecosystems. On the other hand, the link to *management, sustainability, monitoring, and measure* suggests that training also supports decarbonisation and insetting-like value chain decarbonisation initiatives. The concept is also linked to *emissions, energy, infrastructure, and operations*, indicating that training also supports decarbonisation and carbon-insetting initiatives. However, this link appears less frequently than the others, suggesting that training in these fields may not be fully described within the analysed reports. Hence, these results represent a first-stage map of semantic concentration that informed the second-stage interpretive coding. In particular, the prominence of themes such as environmental management, training,

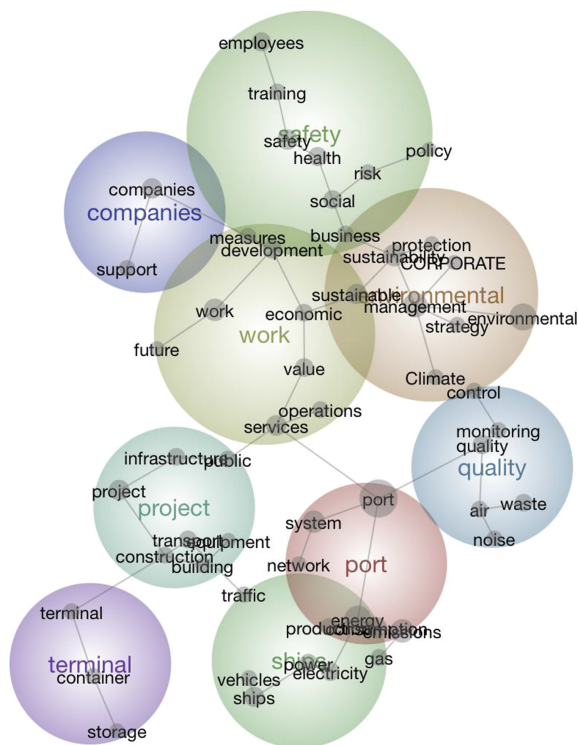


Figure 3. Concept map of the selected European sustainability reporting and website pages published from 2020 to 2024. **Source:** Authors' own creation from Leximancer (V.5)

Table 3. Most frequent concepts

Leximancer settings: Concepts 100%; theme size 35%		
Concept	Count	Relevance (%)
Port	6,111	100
Environmental	2,976	49
Energy	2,195	36
Management	2006	33
Companies	1818	30
Work	1808	30
Sustainability	1713	28
Emissions	1,631	27
Project	1,555	25
System	1,458	24
Employees	1,441	24
Safety	1,283	21
Services	1,259	21
Ships	1,251	20
Sustainable	1,236	20
Development	1,067	17
Consumption	1,059	17
Quality	1,047	17
Value	1,007	16
Waste	948	16
Social	928	15
Health	898	15
Transport	873	14
Infrastructure	836	14
Measures	762	12
Economic	756	12
Business	747	12
Operations	707	12
Electricity	702	11
Training	695	11

Source(s): Authors' own processing of selected European ports' sustainability reports and website pages (2020–2024) using Leximancer v.5

infrastructure, and monitoring guided the closer examination of how ports translated these themes into bounded disclosure practices.

4.2 Manual content analysis: insetting-like initiatives and the mobilisation of CIC

Building on these patterns, the manual content analysis allows a more detailed assessment of how ports operationalise decarbonisation practices and whether these are supported by sufficiently developed governance and measurement structures. It does not assume that advanced disclosure practices, including double materiality and Scope 4 emissions, should already be widely adopted. Instead, these elements are treated as demanding benchmarks through which the maturity and credibility of current disclosure practices can be assessed. Specifically, the manual content analysis of the selected sustainability reporting provides insight into how insetting-like value chain decarbonisation initiatives are disclosed within port ecosystems and how they relate to CIC development. In this study, carbon-insetting is not treated as a directly verified empirical category; rather, it is used as an ideal type against which public disclosures can be interpreted. Empirically, we analyse initiatives that are “insetting-like”, in the sense that they are embedded within port ecosystem relationships but do not always disclose the full governance and measurement architecture required for strict insetting claims.

[Table 4](#) can be interpreted not only as a descriptive mapping of practices but also as evidence of varying levels of disclosure maturity across ports. Specifically, the authors conceptualise these cues as observable disclosure patterns (e.g. MRV protocols, specific indicators of boundary-setting or credibility reinforcement) that support ports in reducing the risk of symbolic compliance by describing verifiable practices ([Boiral, 2013](#); [Cho et al., 2015](#); [Michelon et al., 2015](#)). While all ports report value chain decarbonisation initiatives that can be interpreted as “insetting-like”, only a subset provides disclosures supported by clearly defined boundaries, methodological specifications, and verification mechanisms. This suggests that similar practices are underpinned by different levels of governance and measurement development.

The results suggest that port disclosures are more developed at the level of operational decarbonisation narratives than at the level of governance and measurement architectures. This distinction is analytically important because it reveals that the visibility of sustainability initiatives does not necessarily imply disclosure readiness or accountability maturity. Investments in digital and infrastructural assets are a central focus of the majority of analysed reports, often complemented by partnership-based arrangements with terminal operators, energy providers, and public actors. Ports explicitly link decarbonisation practices to the development of physical infrastructures. The [Hamburg Port Authority \(2022\)](#), for example, reports the use of building information modelling (BIM) and digital planning tools for assessing its environmental impact.

The ports analysed described the implementation of MRV agreements, certified management systems, and structured emissions inventories as support for the reporting of decarbonisation initiatives. For instance, in the reporting by the Port of Piraeus, decarbonisation statements are complemented by certified energy and environmental management systems, thereby reinforcing the credibility of the information disclosed ([Piraeus Port Authority, 2024](#)). In the [Hamburg Port Authority \(2022\)](#) disclosure, environmental performance claims are supported through method-specified routines such as BIM-based project management and life cycle assessment approaches. This makes the basis of the claim inspectable and therefore aligns with our definition of knowledge decoupling.

Human capital appears to be mainly connected with training, safety, and competence development, as also highlighted by Leximancer results. Training activities are often mentioned alongside the introduction of new technologies, energy systems, or sustainability procedures, as in the case of the ports of Gdansk and Piraeus ([Baltic Hub, 2024](#); [Piraeus Port Authority, 2024](#)); however, it is worth noting that the level of detail differs, and the reports rarely specify how skills evolve or how training outcomes are measured. The manual content analysis also highlights different stakeholder engagement strategies. The ports of Rotterdam and Antwerp-Bruges describe coordinated initiatives involving multiple stakeholders for the development of energy and low-emission infrastructure ([Port of Antwerp-Bruges, 2023](#); [Port of Rotterdam, 2024](#)).

A comparison across cases highlights a distinction between more mature and more aspirational disclosure patterns. In some ports, value chain decarbonisation initiatives are described in considerable detail, yet the disclosures remain weakly bounded in terms of responsibilities, metrics, and verification. In others, the disclosure architecture is more structured, suggesting a more advanced alignment between circular capability development and accountability routines. Ports such as Rotterdam, Hamburg, and Piraeus provide more structured disclosures, where decarbonisation claims are supported by methodological detail, digital monitoring systems, and references to certified standards. In contrast, other ports tend to describe similar initiatives in more general terms, without specifying boundaries, metrics, or verification mechanisms. This difference underlines the fact that while engagement in decarbonisation is widespread, the underlying capability to support credible and accountable disclosure remains uneven. It also suggests that disclosure maturity depends less on the number or visibility of initiatives reported than on whether these initiatives are supported by methodologically inspectable governance and measurement structures. Furthermore, double

Table 4. Port-level cross-case disclosure summary

Port	Insetting-like initiative types disclosed	CIC dimension(s) evidenced	Double materiality	Scope 4 (avoided emissions)	Knowledge decoupling cues
Rotterdam	Shore power, hydrogen infrastructure, CCS, electrification, industrial symbiosis	Structural, Relational, Human	Yes, double materiality assessment presented	No explicit Scope 4 methodology; avoided emissions discussed qualitatively	ISO/MRV stated; explicit project boundaries; limitations disclosed
Antwerp–Bruges	Alternative fuels, electrification, energy transition projects, modal shift	Structural, Relational	Partly, materiality referenced at strategic level, limited methodological detail	No, avoided emissions not disclosed	Standards-based reporting; platform-level boundaries
Hamburg	Shore power, renewable energy hubs, digital infrastructure, rail connectivity	Structural, Relational, Human	Implicit, materiality embedded in strategy, not formalised as double materiality	No, avoided emissions not disclosed	Certified systems; infrastructure-bound scope
Valencia	Shore power (OPS), renewable energy, energy efficiency, rail infrastructure	Structural	No, materiality not framed as double materiality	No, avoided emissions not disclosed	EMAS/ISO verification; explicit system limits
Barcelona	Electrification, alternative fuels, mobility transition, circular initiatives	Structural, Relational, Human	Implicit, sustainability strategy and stakeholder engagement, not formalised as double materiality	No, avoided emissions not disclosed	Initiative-focused; limited methodological disclosure
Marseille Fos	Shore power, LNG, hydrogen, modal shift, circular economy projects	Structural, Relational	No, materiality framed narratively	No, avoided emissions not disclosed	Project-level boundaries; no counterfactual framing
Ports of Genoa	Electrification, rail connectivity, energy transition projects	Structural, Relational	Implicit, materiality discussed but not formalised	No, avoided emissions not disclosed	Organisational boundaries; limits disclosed
Trieste	Rail-based modal shift, energy efficiency, digitalisation	Structural, Relational	Implicit, materiality discussed descriptively	No, avoided emissions not disclosed	System-level boundaries; strategy and measurement separation
Piraeus	Electrification, infrastructure upgrades, energy efficiency, EU-funded projects	Structural, Relational, Human	Yes, formal double materiality assessment	No, avoided emissions not disclosed	ESRS-aligned assumptions; risk boundaries; data gaps stated

(continued)

Table 4. Continued

Port	Insetting-like initiative types disclosed	CIC dimension(s) evidenced	Double materiality	Scope 4 (avoided emissions)	Knowledge decoupling cues
Gdańsk	Electrification, renewable electricity, low-emission construction	Structural, Human	No, materiality not framed as double materiality	No, avoided emissions not disclosed	Scope 1–2 boundaries; no avoided emissions logic

Source(s): Authors’ own processing of selected European ports’ sustainability reports (2020–2024)

materiality is explicitly referenced in some reports. In the Port of Piraeus report, for example, it is used to connect materiality results with sustainability priorities and risk management (Piraeus Port Authority, 2024). On the other hand, the other ports of the sample do not explicitly mention double materiality. In some cases, it is implemented indirectly, in others, it is completely absent. Similarly, avoided emissions (Scope 4) are rarely disclosed through explicit methodologies. The limited and uneven disclosure of double materiality and avoided emissions further reinforces this interpretation. These elements, which represent more advanced governance and measurement mechanisms, are either absent or only partially addressed in most cases, suggesting that while ports are actively engaging in decarbonisation practices, the governance structures and accounting capabilities required to support more advanced forms of sustainability disclosure are still in an early stage of development.

5. Discussion

These results reveal a structural asymmetry between the visibility of decarbonisation practices and the articulation of accountability architectures, suggesting that disclosure requires embedded governance and measurement systems if it is to support credible accountability. This creates a tension with parts of the sustainability disclosure literature, which often assumes that more disclosure corresponds to better accountability. Furthermore, this study functions as a diagnostic assessment of disclosure readiness, evaluating whether current practices meet the minimum governance and measurement conditions required for credible accountability. Rather than indicating a lack of engagement, the uneven visibility of double materiality and the absence of Scope 4 disclosures point to an imbalance in the development of governance and measurement routines within port ecosystems. While ports widely disclose decarbonisation initiatives embedded in structural, relational, and human capital, these practices are not yet matched by equally developed accountability architectures. These initiatives can be interpreted as insetting-like practices, although they rarely meet the full definitional requirements of carbon-insetting in terms of explicit boundaries, counterfactual accounting, and verifiable impact measurement. These results extend prior studies on intellectual capital and sustainability by demonstrating that circular capability development cannot be inferred solely from the visibility of decarbonisation initiatives; rather, the credibility of CIC-related claims depends on whether such initiatives are embedded in sufficiently articulated governance, boundary-setting, and measurement routines.

As can be seen from the results, double materiality and Scope 4 emissions are not yet institutionalised across ports. This pattern indicates a structural measurement gap: operational decarbonisation and credibility-oriented disclosure can advance faster than the development and institutionalisation of counterfactual quantification and value chain impact accounting. This is significant because it reframes absence not as a simple reporting omission but as evidence of an accountability infrastructure that remains under development. In relation to the first sub-question, for complex ecosystems like ports, intangible resources are not only

mobilised to reduce environmental impact, but they also support circular and regenerative value creation across value chains (Pache and Santos, 2013; Dumay *et al.*, 2020; Secundo *et al.*, 2020). The transition from isolated initiatives to integrated climate portfolios suggests that ports are progressively institutionalising integrated decarbonisation practices in response to stakeholder expectations and legitimacy pressures. This extends the NRBV by showing that environmental capabilities in complex ecosystems are not only enacted through operational practices but also depend on the development of governance and measurement infrastructures that enable credible disclosure. This practice positions ports as strategic nodes in circular and regenerative transitions moving beyond symbolic disclosure (Hart and Dowell, 2011; Barney *et al.*, 2021). In line with the dynamic capabilities perspective (Teece *et al.*, 1997), CIC operates within ports as an evolving capability, constantly adapting ports according to sustainability demands. In this sense, CIC emerges not only as a resource configuration but as a capability that links operational action with accountability structures.

Specifically, the integration of MRV systems, as well as the use of certified management standards and digital planning tools, reflects seizing and reconfiguration processes through which ports stabilise decarbonisation pathways. On the other hand, training activities are mainly linked to new technologies and decarbonisation practices, suggesting that training is complementary to decarbonisation strategies rather than an independent strategic domain. Taken together, these outputs indicate that CIC is not a static stock of resources but rather a dynamic capability that evolves together with decarbonisation pathways (Secundo *et al.*, 2020; Caputo *et al.*, 2021). However, the results also indicate that these dynamic capabilities are unevenly developed, thereby limiting the full expression of CIC as a governance capability.

With reference to the second sub-question, the absence of explicit Scope 4 methodologies should not be interpreted merely as a reporting gap but rather as an indication of limited measurement capability at the value chain level. This finding challenges assumptions in the sustainability accounting literature that expanding disclosure automatically reflects more advanced accountability practices. Similarly, the uneven adoption of double materiality suggests that regulatory frameworks are being selectively integrated into disclosure practices. This reinforces the interpretation of double materiality as a “governance stress test”, revealing the extent to which organisations can translate sustainability commitments into structured decision-making and reporting systems.

With reference to the third sub-question, the identified gaps reflect differences in disclosure readiness rather than differences in engagement with sustainability practices. While ports actively invest in decarbonisation and circular initiatives, these are not consistently supported by structured governance and measurement systems. Ports strengthen their credibility by prioritising information and knowledge about tangible infrastructures, certified systems, and verifiable data (Delmas and Burbano, 2011). This reveals that the transition towards credible and accountable sustainability disclosure is still at an early and uneven stage across port ecosystems. This approach reinforces the legitimacy of CIC as a foundation for regenerative transitions; indeed, Lisi (2015) recognised reporting and MRV systems as organisational learning mechanisms and structural capital that could strengthen the legitimacy of the information disclosed. This finding contributes to the literature on knowledge decoupling by showing that credibility is not achieved through the volume of disclosure but through the presence of bounded, verifiable, and methodologically specified information. In this sense, knowledge decoupling operates as a selective mechanism that distinguishes between symbolic and substantive disclosure practices.

5.1 Theoretical implications

This study makes three main theoretical contributions. First, this study repositions CIC as a capability whose credibility depends not only on the mobilisation of intangible resources but also on the quality of the governance and measurement structures through which such mobilisation is disclosed. This extends intellectual capital research by showing that CIC can be

assessed not only through the presence of human, structural, and relational capital but also through the disclosure structures that make these forms of capital visible and credible. Second, it interprets double materiality and avoided emissions (Scope 4) not merely as reporting elements but as analytical benchmarks for assessing governance and measurement maturity in sustainability disclosure. This contributes to sustainability disclosure research by treating these mechanisms as diagnostic stress tests rather than as simple variables that are either present or absent. Third, it uses knowledge decoupling as a diagnostic lens to distinguish between disclosures that are more aspirational and those that are more bounded, structured, and therefore more credible. This study refines the role of knowledge decoupling by linking it to observable disclosure cues, such as boundaries, responsibilities, metrics, methods, verification, and limitations.

5.2 Managerial implications

This study provides a set of managerial implications for port managers: first, ports should strengthen the governance and measurement structures of value chain decarbonisation initiatives to approach more robust and verifiable inseting configurations; second, ports should invest in digital systems and MRV tools and certification to strengthen the transparency and credibility of data; third, lifelong training in emerging technologies is essential to strengthen the role of human capital within inseting-driven capability building; and fourth, double materiality and Scope 4 emissions should be conceived as essential tools to prioritise sustainability practices and strengthen stakeholder trust. In addition to governance and reporting implications, these strategies may also impact local port communities through improved air quality, reduced exposure to emissions-intensive operations, and the creation of new jobs linked to electrification, renewable infrastructure, digital monitoring, and circular service ecosystems. This highlights the need for port managers to integrate decarbonisation strategies with local employment, reskilling initiatives, and the development of circular service networks involving local suppliers. Port managers should therefore avoid treating disclosure maturity as a purely reporting issue; rather, it should be managed as part of the broader organisational infrastructure through which ports demonstrate accountability to regulators, investors, supply chain partners, and surrounding communities.

5.3 Policy recommendations

This study offers a set of recommendations to policymakers. First, EU and national funding frameworks (e.g. Connecting Europe Facility, Horizon Europe, TEN-T) should explicitly support digital infrastructures, MRV systems, and data platforms that enable ports to develop CIC through inseting practices. Second, policymakers should promote methodological clarity for Scope 4 emissions through guidelines and piloting activities to support companies in the accounting process. Third, policy frameworks should encourage ecosystem governance and data-sharing mechanisms to strengthen coordination among port authorities, operators, and public actors, thereby supporting regenerative outcomes and reducing greenwashing risks. In addition, policy frameworks should explicitly consider the local socio-economic implications of port decarbonisation, supporting job creation, reskilling programmes, and the inclusion of local suppliers in emerging circular service ecosystems. Thus, the credibility of port sustainability transitions also depends on whether such transitions generate visible benefits for the territories in which ports operate.

5.4 Limitations of the study

This study has several limitations that delimit the scope of its results. First, the analysis relies on public documents, which may be affected by narrative bias or uneven levels of detail across topics. This approach captures how carbon-insetting practices are communicated and disclosed, but not their actual implementation. Furthermore, the analysis focuses on what is

visible in port disclosures as well as what remains absent or weakly specified; however, it does not explain the internal organisational reasons underlying these absences. Second, since carbon-insetting is an emerging and non-standardised concept, the interpretation of decarbonisation practices may vary across the selected ports. For this reason, this study adopts the more cautious expression “insetting-like value chain decarbonization initiatives” when public disclosures do not provide sufficient evidence to support strict carbon-insetting claims. Third, the geographic focus on European hubs limits the transferability of the results to ports operating outside the EU. Fourth, this study applies systematic coding and triangulation across document types to strengthen its analytical robustness. However, the results could still be interpreted as identifying emerging patterns and tendencies rather than establishing causal relationships. Thus, future research across different institutional and geographical contexts is needed to validate and extend these results. Future studies could also combine disclosure analysis with interviews, internal documents, or longitudinal case studies to explain the organisational reasons behind weakly specified governance and measurement structures.

6. Conclusion

This study explores how insetting-like value chain decarbonisation initiatives are disclosed in European port ecosystems and what these disclosures reveal about the maturity of governance and measurement structures supporting CIC and credible circular transition claims. Beyond its empirical results, this study clarifies that the key challenge in port ecosystems does not lie only in the implementation of decarbonisation initiatives but in the ability to support these initiatives through sufficiently developed governance and measurement systems. In this sense, this study indicates that disclosure maturity, rather than disclosure volume, represents a critical condition for credible sustainability transitions. Rather than assessing the mere presence of specific practices, this study evaluates the readiness of port ecosystems to support credible and verifiable disclosure. Based on the results attained, this study proposes an analytical framework that captures how the adoption of insetting-like value chain decarbonisation initiatives can progressively strengthen CIC in port ecosystems by integrating elements usually addressed separately. At the core of the framework is the mobilisation of CIC components through insetting-like practices within the port value chain. The integration of such practices supports ports in mobilising intangible resources through concrete decarbonisation practices in the value chain. Furthermore, these strategies have a direct impact on local port communities: from the improvement of the air quality to the reduction of environmental exposure and the development of new employment opportunities in the area. Double materiality supports the alignment of intangible assets with financial, environmental, and social priorities and links sustainability practices to risk management and governance processes. Measuring Scope 4 emissions is crucial for developing more transparent and informed emissions reduction strategies. Finally, knowledge decoupling serves as a stabilising mechanism: on the one hand, it filters out unverified claims in favour of information validated by rigorous data, international standards, and verification systems; on the other hand, it helps distinguish between disclosures that remain aspirational and those that are supported by bounded, structured, and verifiable knowledge. These elements taken together support a more integrated and operational configuration of CIC, in which intangible resources are aligned with decarbonisation practices, governance requirements, and legitimacy expectations. This study sets the basis for future research on IC. First, the analysis could be extended to other infrastructure-intensive ecosystems (airports, logistics hubs, and energy networks) to test the transferability of the CIC framework. Second, longitudinal and mixed-method studies could capture how insetting practices, avoided emissions, and knowledge decoupling evolve over time through interviews and case-based approaches. Finally, future work could explore how Scope 4 accounting could enhance the legitimacy of sustainability reporting, as well as how double materiality could support managerial decision-making across different regulatory contexts. By integrating carbon-insetting, double materiality, Scope 4 emissions, and

knowledge decoupling within a unified framework, this study provides a novel lens for interpreting how circular and regenerative value creation is governed, measured, and communicated. More specifically, it highlights that CIC becomes credible not simply when ports report sustainability initiatives, but when those initiatives are supported by governance, boundary-setting, measurement, and verification structures. This perspective opens new avenues for research on the role of intellectual capital in sustainability transitions, particularly in complex and infrastructure-intensive ecosystems.

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