Contradictory emission regulations across transport chains: challenges for international supply chains

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Abstract

Purpose – The greenhouse gas emissions of transport are currently addressed by a combination of global, regional and national regulatory initiatives, often designed without analyzing the possibly overlapping other regulations. For a transport chain, this might mean multiple conflicting requirements, increasing costs and adding administrative burden. This research attempts to build an overall picture of environmentally motivated regulations targeting the key stakeholders in a transport chain.

Design/methodology/approach – This research combines inputs from focus group interviews and workshops with literature-based estimates on the extent and impacts of environmentally motivated regulatory initiatives. These regulations were further evaluated to identify the ones with the strongest impact as well as the most exposed parts of the transport chain.

Findings – In the analysis, around 25 different regulations were identified, many of them targeting multiple phases in the transport chain. Many of these regulations included conflicting requirements with other regulations, making abiding by them a challenge for the companies.

Research limitations/implications – The focus group included all the phases of a transport chain, whereas regulators were not included. Therefore, the motives of regulators are not empirically analyzed.

Social implications – Regulation is often prepared from a narrow perspective, targeting a single goal without considering the combined impact with other overlapping regulations. Understanding the impacts of conflicting requirements is essential for policymakers.

Originality/value – Previous research has mainly approached emission regulation from the perspective of a single regulation and actor. This research is one of the first to provide a comprehensive view of GHG-related regulation on a transport chain level.

Keywords Transport chain, Emissions, Regulation, Policy

Paper type Research article

1. Introduction

In extant supply chain management literature, environmental performance, greenhouse gas (GHG) reduction and climate change mitigation have been longstanding areas of scholarly interest. However, much of the existing research continues to frame these issues from the perspective of a focal firm or within dyadic supplier–buyer relationships. For example, Ellram and Tate (2025) highlight the need to shift toward a systems-level perspective and argue that both the challenges and solutions related to climate change mitigation and GHG reduction must be addressed across the entire supply chain.

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De Stefano and Montes-Sancho (2023) call for analyses that move beyond the perspective of a focal firm, thus emphasizing the potential trade-offs between firm-level and supply chain–level sustainability objectives. In a similar vein, Dahlmann *et al.* (2023) describe a *performing–organizing paradox*, referring to tensions that arise while aligning diverse performance goals across supply chain partners. According to Björklund *et al*. (2024), these tensions include contradicting key performance indicators (KPIs) on cost and environment, as well as different stakeholders' competing interests. As Andersson *et al*. (2022) point out, some of the actions necessary for sustainability may not be profitable in the short run. In such cases, it may be difficult or even impossible to reach a win-win solution (Montabon *et al*., 2015), but instead firms try to secure their own short-term KPIs, and attempt to pass the possible additional cost to other members of the supply chain, depending on the bargaining power they possess (Björklund *et al*., 2024). In such cases, the outcome may deviate from optimum. According to Torriti (2007), similar tensions are present also in preparation of regulation, in which the stakeholders participating in the process may target their individual KPIs instead of the common goal. To mention one, stricter regulation in the form of fuel standards and blending mandates stabilizes the market from the perspective of fuel producers, whereas it reduce possibilities to adapt from the users of fuels (Ghoddusi, 2017).

As attention is increasingly shifting toward addressing Scope 3 emissions – that is, indirect GHG emissions occurring throughout a company's value chain, both upstream and downstream (Hertwich and Wood, 2018) – the need for a more holistic and systemic perspective has become apparent. Such a challenge can be emphasized via a practical example. Since 2024, the European Union has included shipping as part of the emission trading system (EU ETS). However, it covers only journeys either between the European Economic Area (EEA) or the first leg to and from EEA. Previous research (see, for example, Gu *et al*., 2019) has demonstrated that such a regional approach may result in increased emissions outside the regulated area, as firms and supply chains optimize primarily based on economic, rather than environmental goals.

Ellram and Tate (2025) raise critical questions regarding the role of government or multilateral policy in regulating and incentivizing GHG emission reductions at the supply chain level. Similarly, De Stefano and Montes-Sancho (2023) advocate for further research into the institutional and regulatory contexts that may impede the rapid and successful implementation of globally harmonized guidelines regarding GHG emissions. This study contributes to this emerging discourse by examining such regulatory contexts specifically through the lens of environmental regulation in the transport sector.

Economic theory establishes certain preconditions for the effective regulation of GHG emissions. To prevent allocative inefficiencies (Liebenstein, 1966) and address market failures, a common and coherent legal framework is required (DiMaggio and Powell, 1983). However, in practice, environmental regulations – particularly those that target GHG emissions – are often fragmented by the transport mode, geographical scope, and jurisdictional authority. This fragmentation undermines regulatory effectiveness, particularly in the context of interjurisdictional competition (Oates and Schwab, 1988), where inconsistencies across regions can create uneven playing fields and regulatory arbitrage.

One of the central challenges is the absence of a global governing body with the authority to enforce and coordinate GHG emission reductions across all modes of transport. While aviation and maritime transport are inherently international in nature and are, thus, regulated through global institutions – that is, the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) – road and rail transport remain largely governed by national or regional policies. These localized regulations often lack both the geographic scope and the level of ambition necessary to effectively address the climate impact of the sector on a global scale.

Further, much of the current emission-related regulation targets individual transport modes in isolation, without accounting for intermodal competition or potential rebound effects, such as those arising from shifts in the relative competitiveness of modes (see, e.g. Llorca and Jamsb, 2017). For cargo owners, this fragmentation complicates efforts to reduce emissions in a cost-effective manner and to decarbonize their transport chains, which are often inherently multimodal. The lack of integrated regulation across modes may lead to suboptimal environmental outcomes and hinder system-wide efficiency improvements.

The European Union (EU) has positioned itself as a global leader in climate policy, pursuing ambitious emission reduction targets through stringent, environmentally motivated regulations across various sectors (Oberthür and Dupont, 2021). In parallel, international efforts – particularly those led by the United Nations (UN) and its specialized agencies – have also moved toward promoting emission reductions and the decarbonization of key industries. For example, the IMO recently updated its long-term climate strategy, thus setting a new target of achieving net-zero emissions by 2050. Nevertheless, the climate policies currently articulated by these global institutions remain significantly less ambitious compared to those adopted by the EU.

In the context of international multimodal transport chains, recent developments imply that various segments and transport modes are becoming increasingly subject to a complex and continually evolving regulatory landscape. This study aims to qualitatively examine the challenges posed by GHG-related regulations on supply chains, to identify potential conflicts arising from regulatory requirements at regional and global levels, and to explore market implications stemming from differing levels of ambition across transport modes and geographical scopes. Against this backdrop, the following central research question is addressed: What are the key challenges posed by environmentally motivated regulatory frameworks within multimodal transport systems? By answering this question, this research attempts to enable policymakers to better identify these challenges and their impacts on transport chains and to better consider how to address them.

The remainder of this paper is organized in the following manner: Section 2 formulates environmental regulations relevant for this work within a broader theoretical framework. Section 3 outlines the qualitative research methodology employed. Section 4 presents the main empirical findings. Section 5 discusses the results and concludes the study.

2. Theoretical underpinnings

2.1 The motivation for emission reduction and regulation

In extant business and economic literature, emission reduction and (environmental) sustainability have been examined through a range of theoretical lenses. From the perspective of classical economic theory, emissions are viewed as a negative externality – a concept introduced by Pigou (1920) – which is defined as an indirect cost imposed on a third party not directly involved in the economic activity causing environmental harm. Externalities such as GHG emissions arise due to market failures, where the private costs and benefits of an action diverge from its social costs and benefits. In such cases, firms benefit from polluting activities without bearing the full societal and environmental costs, thus resulting in a lack of incentive to act sustainably.

Economists have proposed several mechanisms to internalize externalities. One influential proposition comes from Coase (1960), who argued that clearly defined property rights could lead to efficient outcomes through market-based bargaining. If the rights to clean air or water, for example, were clearly allocated, the affected parties could negotiate compensation, thereby enabling the market to determine the value of environmental harm and the appropriate remediation. However, many contemporary environmental problems relate to common-pool resources – such as the atmosphere, oceans or biodiversity – that lack ownership and, thus, are accessible to all without restriction.

This condition reflects a fundamental insight attributed to Aristotle: "That which is common to the greatest number gets the least amount of care. Men pay most attention to what is their own: they care less for what is common." Building on this idea, Hardin (1968) famously coined the concept of the *Tragedy of the Commons*, subsequently elaborated upon by Ostrom (1990) and others, arguing that when resources are commonly held, individually rational decisions can lead to collectively irrational outcomes – that is, the overuse and degradation of shared environmental assets. This concept remains central to understanding the systemic challenges of environmental governance and the regulatory responses needed to address climate-related externalities.

When considering the behavior of individual firms, the notion of rational economic decision-making becomes more nuanced than the simplistic idea of firms exploiting "the commons" without restraint. The concept of corporate social responsibility (CSR) recognizes that firms are increasingly expected to engage in activities that go beyond profit maximization and contribute positively to societal well-being (Moir, 2001). Importantly, CSR is not defined in isolation but is shaped through ongoing interaction with a firm's stakeholders (Lindgreen and Swaen, 2010).

This stakeholder-oriented perspective links CSR to the stakeholder theory, which categorizes stakeholders into primary stakeholders—such as customers, suppliers, employees, managers and shareholders – and secondary stakeholders, including governments, competitors, investors, nongovernmental organizations (NGOs) and the media. The stakeholder theory expands the view of corporate purpose beyond the neoclassical notion of maximizing shareholder value. Rather than considering social and economic goals as inherently conflicting, recent scholarship argues that these objectives are interrelated and primarily distinguished by temporal orientation.

For example, Valentinov (2023) suggests that the stakeholder theory views value creation not merely in terms of short-term financial returns but in terms of the firm's long-term flourishing, incorporating both economic and moral dimensions. Similarly, Bridoux and Stoelhorst (2016) emphasize that firms must account for diverse stakeholder interests, many of which carry ethical and noneconomic weight, particularly in sustainability-related decisions.

Stakeholder pressures influence firms through a variety of institutional mechanisms. In their theory of institutional isomorphism, DiMaggio and Powell (1983) identify three primary types of pressures that drive organizations toward conformity: mimetic, normative and coercive isomorphism. Mimetic isomorphism occurs when organizations imitate the practices, structures or policies of perceived successful or legitimate peers, particularly in situations of uncertainty or ambiguity regarding goals or appropriate responses. Such imitation serves to reduce risk and enhance legitimacy in the eyes of stakeholders. In contrast, normative isomorphism arises from professionalization processes, such as shared education, training and professional networks. It leads organizations within the same field to adopt similar values, norms, and practices that are considered appropriate or legitimate by the professional community. Coercive isomorphism refers to both formal and informal pressures exerted by entities upon which organizations are dependent – such as governments, regulators or key customers – as well as by prevailing societal expectations. One of the most prominent examples of coercive isomorphism is the imposition of a common legal or regulatory framework to which firms are required to adhere.

Together, these institutional pressures help explain why organizations converge around similar practices and why they often align with societal norms and regulatory requirements, even in the absence of immediate economic incentives.

At the same time, few studies have examined what occurs when the three forms of institutional pressure – coercive, normative and mimetic – come into conflict (Arranz *et al.*, 2022). This raises a critical question: Are stakeholders, such as firms, conforming to conflicting or misaligned pressures, thus potentially leading them to pursue suboptimal or even counterproductive goals? In the context of the regulatory focus of this research, the central issue becomes whether the regulatory framework is aligned to direct firms efficiently toward emission reductions.

2.2 The challenge of efficient regulation

2.2.1 The conflicting goals of regulation. In designing environmental regulation, policymakers must reconcile multiple and often conflicting, policy objectives (Haines and Gurney, 2003). Environmental goals represent only one dimension of a broader and more complex policy landscape in the transport sector. Policymakers and regulators must simultaneously consider a range of additional priorities, including but not limited to (1) transport safety; (2) security concerns; (3) the development and maintenance of transport infrastructure; (4) market access and competition issues and (5) the needs of other transport system users and providers, such as the general public and public transportation services.

Irrespective of the type or field of regulation, the key dimensions to consider are *administrative efficiency, informational efficiency, and allocational efficiency* (De Benedetto, 2018; Kolstad, 1987).

Administrative efficiency pertains to the regulatory burden imposed on both public authorities and regulated entities. This includes the costs associated with designing, implementing, and enforcing regulations, as well as the compliance costs borne by firms – such as establishing and maintaining monitoring, reporting and verification systems (De Benedetto, 2018).

Informational efficiency relates to the quality and flow of information within the regulatory system. It concerns the availability, accuracy, completeness and timeliness of data exchanged among stakeholders. For example, Schramm and Lehner (2024) highlight significant challenges in the transparency and reliability of emissions data reported by firms, which undermines the effectiveness of regulatory oversight and policy evaluation.

Allocational efficiency refers to whether the targeted outcomes – in this case, emissions reductions – are achieved in a manner that minimizes costs and maximizes overall benefits (Kolstad, 1987). Theoretically, this requires that regulators possess complete information regarding the marginal abatement costs and benefits across all stakeholders. With this information, regulations could be tailored – that is, differentiated – to ensure that emissions reductions are optimally distributed across actors (Fowlie and Muller, 2019). However, in practice, such perfect information is rarely available. Measurement difficulties, strategic behavior and reluctance to disclose cost structures often result in informational asymmetries.

Consequently, regulators are typically compelled to adopt second-best solutions, most commonly in the form of uniform regulation, where all stakeholders are subject to identical requirements regardless of their individual cost structures or mitigation potential (Kolstad, 1987). While even a single uniform regulation deviates from the optimal allocation of effort, the introduction of multiple, overlapping regulations – each targeting the same environmental issue – can compound allocative inefficiencies. These compounded effects may further undermine the cost-effectiveness and environmental effectiveness of the overall regulatory regime (Axsen *et al.*, 2020).

2.2.2 Regulatory instruments: CAC vs. incentive-based policies. Environmental regulation can broadly be categorized into two main approaches: command-and-control (CAC) policies and incentive-based instruments. Similar to coercive isomorphism, CAC policies impose mandatory requirements on producers and consumers, thereby compelling behavioral change through direct regulation (Santos *et al.*, 2010). In the context of transport, these policies may include emission limits, fuel quality standards or usage restrictions. The appeal of CAC instruments lies in their administrative and informational efficiency, as they apply uniform rules to all stakeholders. However, this uniformity tends to come at the expense of allocational efficiency, as such regulations do not account for differences in marginal abatement costs across actors (Aldy *et al.*, 2008).

In contrast, incentive-based policies seek to influence behavior by altering the economic costs and benefits of different choices. These instruments can involve repressive incentives (e.g. taxes or charges on emissions) or restitutive incentives (e.g. subsidies for low-emission vehicles or technologies) (Raoofi *et al.*, 2024). A prominent example is EU's Emissions Trading System (EU ETS) – which functions as a quantity-based, market-oriented policy instrument – that sets a cap on total emissions and permits trading of emission allowances to encourage cost-effective reductions.

Santos *et al.* (2010) argue that incentive-based policies are generally more effective than CAC ones, as they direct emission reductions toward stakeholders with the lowest marginal abatement costs, thereby achieving environmental goals in a more cost-effective manner. In addition, these market-based instruments reveal valuable information regarding the actual costs of reducing emissions, which can inform future policy design. However, from a regulatory perspective, incentive-based mechanisms often entail higher administrative and monitoring costs due to their complexity (Santos *et al*., 2010).

Further, there are notable differences in the design and effectiveness of various incentive-based systems. For example, carbon taxes impose a fixed cost per unit of emissions, thus providing a consistent price signal that encourages emission reductions. However, because they do not set a quantitative cap on emissions, their overall effectiveness in reducing total emissions remains uncertain (Di Filippo *et al*., 2019). In contrast, cap-and-trade systems – such as EU ETS – establish a fixed emissions ceiling and allow for the trading of allowances, which typically ensures more predictable environmental outcomes. While these systems are efficient in achieving emissions reductions (Di Filippo *et al*., 2019), they tend to produce volatile carbon prices, potentially creating uncertainty for investors and regulated firms. To address this, hybrid systems – such as the revised EU ETS II – incorporate price ceilings to limit volatility. However, such mechanisms may reduce cost-efficiency by restricting market-driven price signals (Haywood and Jakob, 2023).

It must be noted that CAC approaches may still be appropriate under certain conditions – particularly when there is little information asymmetry, when the regulator's credibility and commitment are strong, or when uniform emissions reductions are necessary across all actors (Aldy *et al*., 2008). In such contexts, CAC measures may provide greater regulatory certainty and enforceability despite their lower allocative efficiency.

An important consideration in the design and implementation of environmental regulation is the temporal dimension, as the responsiveness – or elasticity – of stakeholders often differs between the short and long terms (Haywood and Jakob, 2023). In the short term, firms may be constrained by existing investments, contractual obligations or operational structures that limit their flexibility to adapt. These lock-in effects reduce the range of feasible compliance options and may lead to suboptimal adjustments. However, over the long term, firms typically have greater capacity to reorient their strategies, adopt cleaner technologies and adjust business models.

Haywood and Jakob (2023) caution that poorly timed or (too) rigid regulation may compel firms to make short-term adjustments that result in irreversible behavioral or investment decisions, thereby locking them into pathways that are misaligned with optimal long-term outcomes. Such premature adjustments can hinder the overall efficiency and effectiveness of decarbonization strategies.

Conversely, regulatory uncertainty – a concept discussed by Rodriguez Lopez *et al*. (2017) – can have the opposite effect. When firms are uncertain regarding the scope, stringency or future trajectory of environmental regulation, they may delay or avoid making necessary investments in low-carbon solutions. This regulation-induced uncertainty can significantly weaken the intended incentives of policy measures, thereby undermining long-term climate objectives.

2.2.3 Modal and geographical fragmentation of regulation. In the transport sector, environmental regulations currently vary significantly across modes and jurisdictions (Dobson, 2020). A key distinction lies in the existence of global regulatory bodies for certain modes of transport. Specifically, IMO and ICAO serve as global authorities for shipping and aviation, respectively, thus reflecting the inherently international nature of these industries. To a certain extent, these institutions have succeeded in establishing globally applicable environmental standards, thereby contributing to a more level playing field across markets.

However, certain regions – most notably the EU – have adopted more ambitious emission reduction targets and, consequently, implemented stricter regional regulations for transport operations under their jurisdictions. Notable examples include the inclusion of maritime shipping in the EU ETS and the *FuelEU Maritime Regulation*, which mandates a progressively declining carbon intensity threshold for maritime fuels used within the European Economic Area.

While such regional initiatives aim to accelerate decarbonization, they may also introduce unintended consequences in global logistics systems. According to existing research, including Gu *et al.* (2019), these fragmented regulatory approaches can lead to suboptimal behavior in international transport chains. Firms may adjust their operations to minimize regulatory compliance costs within the more tightly regulated regions, while continuing to operate according to a global commercial logic elsewhere. This can result in distorted routing decisions, regulatory arbitrage or the concentration of high-emission activities in jurisdictions with more lax standards, thereby undermining the overall effectiveness of climate policy in the transport sector.

Even within the EU, different transport modes are subject to varying regulatory frameworks and emission requirements. For example, maritime shipping has been integrated into the EU ETS, while road transport is set to be included in a separate trading scheme – ETS II – alongside buildings and other sectors. Under the EU ETS, the carbon price has approached €100 per ton of CO_2, whereas the initial carbon price in ETS II is expected to be fixed at €45 per ton. In contrast, rail transport is not considered for such schemes in the EU. According to Pigouvian tax theory, the price of a tax or tariff on pollution should reflect the true societal cost of the externality (Pigou, 1920). However, in practice, these externalities are priced differently (if at all) across modes due to political considerations rather than economic efficiency (Haywood and Jakob, 2023).

Such regional and mode-specific disparities introduce allocative inefficiencies (Liebenstein, 1966) and result in market failure, as emissions are not reduced in accordance with their marginal abatement costs. Instead, reduction efforts are driven by political and regulatory factors. For global supply chains, this fragmentation creates a complex operational environment in which different segments of the chain are exposed to inconsistent regulatory pressures. This necessitates strategic optimization of supply chains with respect to both emissions and regulatory compliance.

Several studies have addressed this challenge. Pan *et al.* (2013) examine the emissions and costs of two multimodal supply chains and conclude that the strategic pooling of supply chains can reduce both costs and emissions. Hoen *et al.* (2014) introduce the concept of a portfolio effect, thus suggesting that emissions caps applied at the product portfolio level – rather than on individual products – enable more cost-effective allocation of emissions reductions. Similarly, He *et al.* (2019) find that cap-sharing schemes between transport modes permit more efficient emissions reductions by reallocating reduction efforts where they are most cost-effective.

From a broader supply chain perspective, Randrianarisoa and Gillen (2022) emphasize that efficiency improvements in specific segments, such as export formalities, can enable the transport function to operate in a more environmentally sustainable manner. However, achieving such system-wide efficiency is challenging due to conflicting priorities, performance targets and regulatory scopes among supply chain actors. Björklund *et al.* (2024) identified multiple tensions that inhibit the greening of transport, even in relatively simple buyer–supplier relationships. In more complex global supply chains, these tensions are likely to be amplified, further complicating coordinated efforts toward decarbonization.

2.2.4 Conflicting interests of stakeholders. Much of the existing research and many regulatory impact assessments focus on individual regulations, such as the EU ETS, often without addressing their interactions with other regulatory instruments or considering their broader systemic impacts (Wu *et al.*, 2024). Due to the methodological complexity of identifying and quantifying such regulatory interactions, analyses are frequently simplified to consider only isolated components of the regulatory framework (see, e.g. Goyal and Llop, 2024). Moreover, scholars have criticized the regulatory preparation process for its difficulties in balancing comprehensive stakeholder consultations with robust and transparent impact assessments (Torriti, 2007). A further limitation is that many impact assessments fail to fully quantify the associated costs and benefits, particularly for complex or cross-sectoral regulations (European Court of Auditors, 2020).

These challenges bring the discussion back to economic and regulatory theory. According to the public interest theory, regulation emerges primarily to promote collective welfare by addressing market failures. However, in practice, the notion of public interest is difficult to define, as stakeholder interests are often heterogeneous and conflicting (Bongo and Sy, 2024). In response to this limitation, Stigler (1971) introduced the theory of regulatory capture, which suggests that regulation tends to advance the interests of well-organized private actors rather than the general public. This occurs because political institutions provide incentives for policymakers to cater to actors with concentrated and significant stakes in the regulatory outcome – typically firms – while the dispersed and relatively minor impact on individual citizens renders them rationally ignorant (Downs, 1957). Consequently, those with the highest stakes also have the strongest incentives to lobby and shape the regulatory process in their favor.

Peltzman (2021) builds on and partially critiques this perspective. While acknowledging the influence of concentrated interests, he argues that empirical evidence does not always support the more deterministic versions of the capture theory. Rather than dominating the regulatory process, firms and other well-organized actors could benefit indirectly from regulation – particularly when it serves to raise barriers to entry, limit competition or legitimize existing business practices. According to this perspective, regulation is not simply a product of private interest dominance but also a reflection of institutional dynamics where regulatory outcomes emerge from the interplay between competing interests, policy constraints and governance structures.

3. Methodology

This research particularly focuses on the regulatory framework for different phases of a transport chain. As compared to a traditional supply chain that includes primary members of the supply chain with a role in the production of the product – such as the focal firm, suppliers, customers as well as secondary members (3PLs, financial providers and market research firms) that play a role in any of the supporting activities (Mentzer *et al.*, 2001) – the transportation chain particularly focuses on the physical movements of goods as part of the processes. In the ISO14083 standard, the transport chain is defined to encompass all the actions from the point at which the freight leaves its last point of production or transformation to the point where the freight reaches its first nontransport-related operation (ISO, 2023).

Song *et al.* (2016) conceptualize the transport chain as consisting of multiple sequential phases, including deep-sea shipping, port handling, feeder services, and inland transportation. More generally, a transport chain can be defined as a series of transport and terminal activities – whether unimodal or multimodal – occurring between the origin and final destination of a shipment. In contrast, an (ultimate) supply chain encompasses a broader scope – potentially including multiple transport chains – perhaps also including procurement, production, inventory management, and distribution processes. Conversely, a single transport chain may serve multiple supply chains. Figure 1 illustrates the conceptual distinction between a transport chain and an (ultimate) supply chain, thereby highlighting their respective components and interrelations.

This research adopts a holistic perspective on environmental regulation at the level of the transport chain, with a specific focus on regulatory instruments targeting GHG emissions. Other forms of environmentally motivated regulation – such as those addressing noise, air pollutants or biodiversity – are beyond the scope of this study.

Empirical data were collected using a range of qualitative methods, including focus group discussions and semi-structured interviews. The research team gained access to informants who represented all phases of international, multimodal transport chains, thereby enabling a global perspective. Consequently, it was possible to identify key pieces of GHG-related regulation that affect different stages of transport chains at the national, regional (within the EU), and global levels.

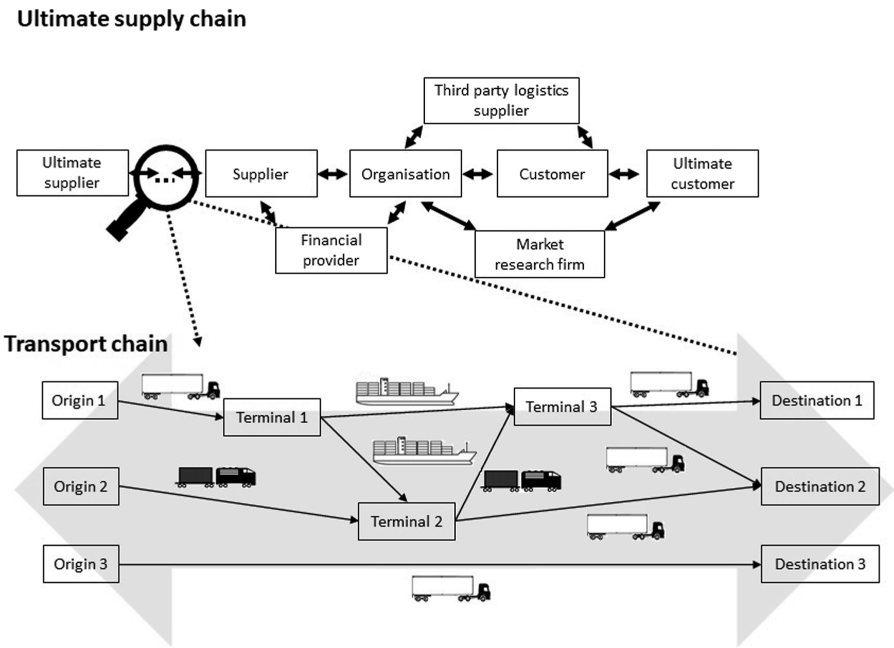

Figure 1. Transport chain and ultimate supply chain. Adapted from Mentzer *et al*. (2001), Bhattacharya *et al*. (2014)

The data collection was conducted as part of a broader research project aimed at assessing emission calculation methodologies and identifying emission-reduction opportunities in three international, multimodal transport chains. The informants – summarized in Table 1 – represented a diverse set of stakeholders across the transport system, including both shippers and transport service providers. Their insights provided a comprehensive view of the regulatory challenges and practical implications encountered at various stages of the transport chain, thereby enriching the analysis with perspectives from multiple operational and strategic levels.

The data for this study were collected through two focus group workshops, structured to include phases of individual work, small-group collaboration, and full-group discussion. Participants were grouped according to their roles within the transport chain, thus ensuring that insights were grounded in operational realities across different segments. In parallel with the workshops, participants also participated in individual, semi-structured theme interviews, which explored the impacts, requirements and challenges of environmental regulations from each informant's specific perspective.

Although all participants were involved in the same overarching research project – thus suggesting a degree of collaborative engagement – the initial data collection process was researcher-led, which aligned more closely with the contractual participation model described by Cornwall and Jewkes (1995).

In the first phase of the workshop, participants were divided into three working groups based on their professional background and role in the transport chain:

(1) cargo owners/shippers,

(2) road and land transport operators, and

(3) maritime transport and port operations.

Table 1. Informants of the focus groups

Job title	Company/industry	Market scope	Work experience
Strategy manager	Equipment manufacturer	Global	+30 years
HSEQ manager	Container shipping company	Global	+20 years
Senior project manager	Equipment manufacturer	Global	15–20 years
Director, Business development	Energy company	Nordic	20–25 years
R&D Project coordinator	Road transport	Europe	5–10 years
Operations and Environment Director	Bulk shipping company	Baltic Sea	10–15 years
Head of Logistics	Metals producer	Global	25–30 years
Director, global container shipping	Bio-based product conglomerate	Global	25–30 years
Senior manager, safety, security and sustainability	Bio-based product conglomerate	Global	15–20 years
Head of EHS	Metals producer	Global	15–20 years
Environment and sustainability specialist	Ro-Ro shipping company	Baltic Sea	10–15 years
VP, Business Development	Producer and distributor of H and synthetic fuels	Finland	10–15 years
Head of sustainable logistics solutions	Energy company	Nordic	20–25 years

Source(s): Authors' own work

Each participant was first asked to independently list all relevant GHG-related regulations and voluntary agreements, including those currently in force or under development, that apply to their respective part of the transport chain. Thereafter, they were prompted to reflect on and provide insights into the following four thematic areas for each regulation listed:

(1) Content and focus of the regulation

(2) Perceived impact

(3) Compliance requirements

(4) Specific challenges

Following the individual exercise, participants worked collaboratively in their assigned groups to consolidate and expand upon their findings. The shipping group included five members, while the cargo owner and road transport groups consisted of four members each. Each working group was supported by a researcher and/or research assistant who documented the discussion using a structured matrix format, thus capturing notes systematically across predefined thematic categories. Finally, all 13 participants were brought together for a plenary discussion, which enabled the synthesis of perspectives across the different transport segments and highlighted cross-cutting challenges and insights that emerged from the group work.

Following the first round of working group discussions, the materials produced during the sessions were compiled and analyzed by the research team. A summary of the preliminary findings was then shared with the participants, who were subsequently asked to individually evaluate each identified regulation using a five-point Likert scale (1 = very mild, 5 = very severe), based on their assessment of the regulation's current or anticipated impact on the transport chain.

Subsequently, thematic analysis was performed on the collected data, thus applying the framework method as outlined by Gale *et al*. (2013). The main findings were synthesized into a framework matrix, primarily using inductive coding (Fereday and Muir-Cochrane, 2006). It must be noted that elements of deductive coding were also present, given that certain coding categories were embedded in the structure of the original theme interviews.

To ensure reliability and to deepen the analysis, a second focus group session was organized – as recommended by Braun and Clarke (2006) – following the same structure: individual reflection, group work based on the participant's role in the transport chain, and a final joint discussion that involved all participants. As in the first session, participants were again asked to individually rate the listed regulations using the same Likert scale. Thereafter, the outcomes were presented back to the group for final feedback and validation.

In line with methodological recommendations from Denzin (2012), the findings were triangulated through a review of official regulatory texts. This step was applied particularly to verify the content, focus and formal requirements of the identified regulations. Appendix provides the identifying information for each regulation, including IMO resolution numbers and CELEX numbers for relevant EU directives, as well as direct links to the regulatory documents. For regulations that involve reporting obligations, the verification process included reviewing the reporting extent (e.g. tank-to-wheel [TTW] vs. well-to-wheel [WTW]) and reporting scope (Scope 1, 2 or 3 emissions). Where applicable, the emission reduction targets and timelines were also cross-checked against the original regulatory sources.

4. Findings

4.1 Coverage of regulation by mode and geography

With the process described above, 25 pieces of regulation and voluntary initiatives or agreements that addressed the GHG emissions from the different phases of the transport chain were identified (Table 2). Of these, 5 are voluntary initiatives, whereas the vast majority (20) of them are regulatory. The ISO14083 standard was considered a regulation – even though it technically is not – as a few of the upcoming regulatory initiatives refer to it; therefore, it can be considered a part of the regulatory framework.

Of the regulatory initiatives, only 4 have a global coverage, whereas 16 are limited to the EU. In addition, in many cases, the EU sets the minimum criteria, whereas the member states have the option to enforce stricter regulations on a national level. This is the case, for example, regarding the regulation of renewable fuels, where a few member states, such as Finland, decided that a higher share than the EU criteria of renewable fuels in road transport is necessary. Of the individual regulations, 12 are currently in force to a certain extent, whereas 8 regulatory initiatives are still upcoming.

Figure 2 illustrates the scope of the different regulations and voluntary agreements based on which of various parts of the transport chain are covered by regulation. Four of the five voluntary agreements or initiatives – the Science Based Target initiative, the First Mover Coalition and Greenhouse Gas Protocol, and obviously customer requirements – consider all the parts of the transport chain.

Six distinct regulatory instruments were identified as collectively covering all segments of the transport chain. In addition to these chain-wide frameworks, several mode-specific or segment-specific regulations were found to apply only to specific phases of the transport process.

For example, cargo owners, are subject to the Carbon Border Adjustment Mechanism (CBAM), which aims to level the playing field by imposing GHG-related criteria on imported goods that are equivalent to the emissions standards applied to domestic production within the EU. Meanwhile, road, rail, maritime and air transport, as well as ports and other terminal facilities, fall under the scope of the EU *Renewable Energy Directive* (RED). This directive establishes minimum standards and requirements for the quantity and sustainability of renewable fuels used within the EU. In addition to these regulatory frameworks, all actors in the transport chain are also covered by the *Global Logistics Emissions Council* (GLEC) Framework, a voluntary, internationally recognized standard for harmonized emissions accounting and reporting across supply chains.

The individual transport modes are subject to a variety of mode-specific regulations. Road transport is subject to the EU ETS II emission trading mechanism, the Euro 7 emission criteria

Table 2. Identified regulatory initiatives (regulation, voluntary)

Regulation/voluntary framework	Valid from	Objective/key content	Mechanism	EU	Global	Voluntary/market based	Regulation
Customer requirements	N/A	Customers setting emission reduction/reporting targets to their suppliers			X	X	
Corporate Sustainability Reporting Directive (CSRD)	2024	Set requirements for non-financial issues including emissions in the supply chain	Set requirements for non-financial issues including emissions in the supply chain	X			X
ISO 14083 standard	2023	Standardize GHG emission reporting and measurement	Set criteria for emission calculation		X		(X)
Renewable Energy Directive	2009	Enable the development and uptake of renewables	Criteria for minimum usage as well as definitions of renewable energy sources	X			X
Science based targets initiative (scope 3)	2015	companies to set science-based net zero targets . . . adopt transition plans covering scope 1, 2 and 3 emissions	Short-term milestones, board-level governance and link executive compensation to the company's adopted milestones		X	X	
(WEF) First Mover coalition	2021	To take climate action by creating a market for the emerging technologies crucial to reach net zero by 2050	Members must make a demand commitment in at least one of FMC's target sectors (aluminum, aviation, cement and concrete, shipping, steel, trucking, carbon dioxide removal)		X	X	
Carbon Border Adjustment Mechanism	Reporting 2023, effective 2026	To prevent more polluting production from having competitive advantage	GHG-based charge for imports outside EU to prevent carbon leakage	X			X
Count emissions EU	Expected 2025	Standardize GHG emission reporting and measurement in EU	Set criteria for emission calculation	X			X
EU Energy Taxation Directive (ETD)	2003	Minimum tax levels for energy production		X			X

(*continued*)

Table 2. Continued

Regulation/voluntary framework	Valid from	Objective/key content	Mechanism	EU	Global	Voluntary/ market based	Regulation
EU Taxonomy for sustainable activities	2020	Classification system to clarify which economic activities are environmentally sustainable	Define activities that are sustainable	X			X
Greenhouse Gas Protocol	Estd. 1998, first standard 2001	The GHG Protocol Corporate Accounting and Reporting Standard provides	Requirements and guidelines for companies and other organizations preparing a GHG emissions inventory		X	X	
EU Alternative Fuels Infrastructure Requirement (AFIR)	2030 for ports	Enhance the creation of supporting infrastructure for alternative fuels	Mandatory national targets for the deployment of alternative fuels infrastructure in the EU	X			X
EU Corporate Sustainability Due Diligence Directive (CSDDD)	Agreed 2024, Expected 2025	To foster sustainable and responsible corporate behavior in companies' operations and across their global value chains	Companies are liable for sustainability issues in their supply chain	X			X
EU Emission Trading System (ETS)	2024 (shipping)	Pricing of GHG-related externalities	Pricing of GHG emissions via a cap and trade system	X			X
EU Emission Trading System II (ETS II)	2027	Pricing of GHG-related externalities	Pricing of GHG emissions via a cap and trade system	X			X
EU Renewable Energy Directive II/III	REDIII 2023	Increase the usage of alternative fuels in the EU	Overall target for EU (32%) and a separate target for transport (14%) of usage of alternative fuels by 2030	X			X
Euro 7	Expected 2028	To lower air pollutant emissions from exhaust fumes and brakes	Rules for the exhaust emissions of, tire abrasion and brake particle emissions of road vehicles	X			X
Fuel EU Maritime	2025	Increase the usage of alternative fuels in EU shipping	Declining maximum carbon intensity of marine fuels to incentivize the use of low-carbon and carbon-neutral fuels	X			X

(*continued*)

Table 2. Continued

Regulation/voluntary framework	Valid from	Objective/key content	Mechanism	EU	Global	Voluntary/ market based	Regulation
Global Logistics Emissions Council (GLEC) framework	2014	To accelerate companies' action to reduce greenhouse gas emissions and to collectively meet the Paris Climate Agreement	Harmonized and transparent way to calculate and report logistics emissions. Industry standard for usage of ISO14083		X	X	
Heavy Duty Vehicle (HDV) CO_2 standard	2030	To drive down emissions in the road transport sector and ensure the increasing supply of new zero-emission vehicles (ZEVs) to the market	CO_2 emission criteria for road transport vehicles	X			X
IMO Carbon Intensity Indicator (CII)	2023	To ensure continuous improvement of a ship's operational carbon intensity within a specific rating level	Annual reduction factor for ships' operational carbon intensity		X		X
IMO Data Collection System (DCS)	2019	Emission and energy consumption-related reporting requirement in the EU			X		X
IMO Energy Efficiency Design Index EEXI/EEDI	EEDI 2013, EEXI 2023	To increase energy efficiency of new-built and existing vessels	Annual required increase in energy efficiency against reference line		X		X
Monitoring, Reporting and Verification (MRV)	2018	Emission and energy consumption-related reporting requirement in the EU		X			X
National regulation on renewable fuels	2007	Reduce national transport emissions via increased usage of renewable fuels	Supplementary to RED II, national requirements for the usage of renewable energy sources in transport	X			X

Source(s): Authors' own work

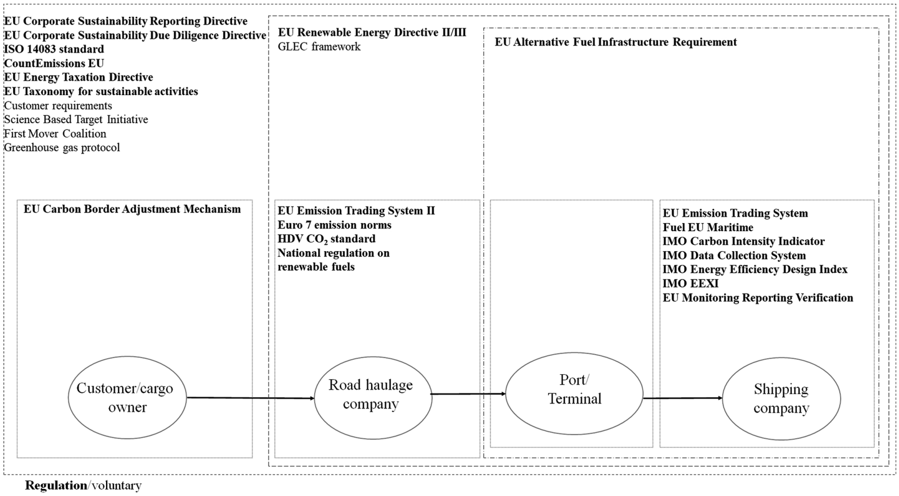

Figure 2. Environmentally motivated regulation and initiatives for different parts of transport chain (regulation, voluntary). Source: Authors' own work

and Heavy Duty Vehicle (HDV) CO_2 standard, as well as to national criteria of renewable fuels in transportation – either directly at the company level or indirectly via fuel distributors and equipment manufacturers. The EU *Alternative Fuels Infrastructure Requirement* (AFIR) determines requirements for road transport as well. However, the requirement particularly considers EU member states – not the members of the transport chain – to provide a minimum 160 kW charging station every 60 km along the TEN-T network. Therefore, the AFIR was not considered to directly impact the transport chain.

Further, maritime transport stands out as the mode with the largest number of newly introduced environmentally motivated regulations. This regulatory surge can be partially attributed to the historical context: for an extended period, both maritime transport and aviation operated with minimal oversight regarding their GHG emissions. Among recent developments, shipping companies and ports have been significantly affected by the AFIR. Under this regulation, ports are mandated to provide the necessary infrastructure to enable vessels to utilize alternative fuels, with a specific emphasis on onshore power supply (OPS). Simultaneously, certain vessel types – such as Ro-Ro and container ships – are obliged to use shore power during their port calls, thereby reducing emissions from auxiliary engines while at berth.

In addition to the AFIR, shipping firms are subject to a growing array of regulatory requirements, including inclusion in the EU ETS, as well as global and regional measures regarding carbon intensity standards, energy efficiency and mandatory reporting of GHG emissions. Together, these regulations mark a significant shift toward decarbonizing maritime transport, thereby aligning it more closely with broader climate policy objectives.

4.2 The administrative impact of regulation

The regulatory initiatives were categorized based on their primary requirements and intended impact. Specifically, each initiative was classified according to whether it

(1) constituted a reporting obligation,

(2) set a GHG emission reduction target, or

(3) imposed technical requirements – either on fuel standards or equipment specifications.

In assessing the cost implications of these regulations, the analysis focused exclusively on direct cost impacts. Although participants consistently noted during the workshops that all regulatory measures entail costs, many of these are indirect in nature and, therefore, more difficult to quantify. For example, reporting requirements, while not imposing direct emission-related costs, lead to increased administrative burden – including the need for additional personnel, data systems and compliance management – thereby generating significant indirect financial impacts.

As presented in Table 3, a significant number of the identified regulations impose reporting obligations. From the perspective of both the entire transport chain and individual firms, one of the key challenges highlighted by the focus group was the lack of harmonization across reporting requirements and criteria. For example, the IMO Data Collection System (DCS) and the EU Monitoring, Reporting and Verification (MRV) system currently operate with different reporting standards. At present, the EU MRV requires firms to report TTW CO_2 emissions, but it is transitioning toward requiring the reporting of all TTW emissions expressed as CO_2 equivalents (CO_2e). Simultaneously, under the *Corporate Sustainability Reporting Directive* (CSRD), companies are expected to report WTW emissions as CO_2e.

Consequently, firms subject to multiple frameworks are often obligated to provide similar data in varying formats, using different system boundaries, units, and metrics. This fragmentation leads to increased administrative burden, duplicated effort and greater complexity in compliance processes – particularly for companies that operate across multiple jurisdictions and transport modes.

In addition to the complexity of reporting, the informants also considered the behavioral effects of different types of reporting and measurement of emissions. As an example, some of the fuels have very different TTW and WTW emission factors and, therefore, they may be rather differently penalized or rewarded depending on how the emissions are measured. The informants considered this problematic from both the perspective of company-level decision-making, directing investments toward the wrong direction, as well as biasing competition in the wrong direction, as actors producing higher emissions are not appropriately penalized due to the wrong level of measurement. An example of this is evident in the treatment of liquefied natural gas (LNG). The TTW emissions of LNG are lower than of other conventional fuels due to the former's lower carbon content. On account of this, shipping firms have invested in LNG capacity as a solution to meet the emission-reduction target. However, the TTW approach neglects the methane slip in the production and use phases of LNG. In case these are included in the emission calculations, the LNG emissions would be higher than those of fossil fuels. Since TTW is still utilized, the end result is higher total emissions and misdirected investments.

Beyond the complexity of reporting requirements, informants also emphasized the behavioral implications of how emissions are measured and reported. Specifically, they highlighted that different measurement boundaries – such as TTW versus WTW – can significantly influence corporate decision-making and may unintentionally distort market dynamics.

Further, certain fuels exhibit substantial differences between their TTW and WTW emission factors, which implies that, depending on the measurement approach used, the same fuel may be either rewarded or penalized. Informants expressed concern that such discrepancies could lead to misaligned investment decisions, as companies may pursue compliance strategies that appear favorable under one reporting framework but do not actually reduce total emissions. Additionally, this inconsistency may bias competition, thereby allowing firms with higher actual (WTW) emissions to appear more sustainable under TTW-focused regulations.

A frequently cited example was LNG. While LNG has lower TTW CO_2 emissions than conventional marine fuels – due to its lower carbon content – TTW metrics exclude methane slip occurring during production, distribution and combustion. Consequently, shipping firms have made significant investments in LNG-fueled vessels, viewing LNG as a compliant solution under current TTW-based frameworks. However, when methane slip is accounted for

Table 3. GHG regulation of a transport chain by impact type

Regulation/voluntary framework	Customer/ cargo owner	Road transport	Sea transport	Port/ terminal	Reporting requirement	Emission reduction target	Technical requirement	Cost impact
Customer requirements	X	*X*	*X*	X	Customer specific	Company specific	Company specific	Energy efficiency and emission reduction costs
Corporate Sustainability Reporting Directive (CSRD)	X	X	X	X	Scope 1,2,3, energy consumption, emissions (CO2eq), turnover-based GHG-intensity			
ISO 14083 standard	X	X	X	X	Standard for calculating and reporting transport emissions			
Renewable Energy Directive	X	*X*	*X*				Technical criteria of alternative fuels	Renewable fuels more expensive than conventional
Science based targets (scope 3)	X	X	X	X		Net zero by 2050		
First Mover coalition	X	X	X	X		Net zero by 2050		
Carbon Border Adjustment Mechanism (CBAM)	X				Default values by the commission, Direct and indirect emissions			Increases the price of imports
Count emissions EU	X	X	X	X				
EU Energy Taxation Directive (ETD)	X	*X*	*X*	X			Technical criteria on definition of fuels	Energy taxes increase the price of energy
EU Taxonomy for sustainable activities	X	X	X		Shares of taxonomy-aligned and non-aligned activities			
Greenhouse Gas Protocol	X	X	X	X	Minimum scope 1 and 2 emissions, WTW	Company specific		

(*continued*)

Table 3. Continued

Regulation/voluntary framework	Customer/ cargo owner	Road transport	Sea transport	Port/ terminal	Reporting requirement	Emission reduction target	Technical requirement	Cost impact
EU Alternative Fuels Infrastructure Requirement (AFIR)			X	X			Requirement to have alternative fuel infrastructure in place and for usage, e.g. in ports	Investments to alternative fuel infrastructure and equipment
EU Corporate Sustainability Due Diligence Directive (CSDDD)	X	X	X	X	Plan for climate change mitigation, emission reduction targets (2030–2050) for scope 1,2,3 emissions			
EU Emission Trading System (ETS)			*X*		Default or actual emission factors, TTW	EU target −55% by 2030, carbon neutral by 2050		Fuel cost increased due to price of carbon
EU Emission Trading System (ETS) II		*X*			Default or actual emission factors, TTW	EU target −55% by 2030, carbon neutral by 2050		Fuel cost increased due to price of carbon
EU Renewable Energy Directive (RED) II/III		X	X	(X)			Technical criteria for production and content of renewable fuels	Renewable fuels more expensive than conventional fuels
Euro 7		X				NO_x (−62%), CH_4 (−13%)	Technical criteria for maximum level of emissions	
Fuel EU Maritime			*X*		WTW default emission factors or actual GHG emissions of fuel	carbon intensity −2% by 2025 - > −80% by 2050	Requirements on carbon intensity of fuels	Low-carbon fuels more expensive than conventional fuels

(*continued*)

Table 3. Continued

Regulation/voluntary framework	Customer/ cargo owner	Road transport	Sea transport	Port/ terminal	Reporting requirement	Emission reduction target	Technical requirement	Cost impact
Global Logistics Emissions Council (GLEC) framework		X	X	X	Industry standard of utilization of ISO14083			
HDV CO_2 standard		*X*				−45% (2030), −65% (2035), −90% (2040)	Technical criteria for maximum level of emissions	Emission reduction technology more expensive than old technology
IMO Carbon Intensity Indicator (CII)			*X*		According to IMO DCS	−40% (2030) −70% (2050)	Requirements on carbon intensity of transport work	Low-carbon fuels more expensive, investments on energy efficient technologies
IMO Data Collection System (DCS)			X		TTW default emission factors or actual CO_2 content of fuel			
IMO Energy Efficiency Design Index EEXI/EEDI			*X*		According to IMO DCS	−40% (2030) −70% (2050)	Requirements on energy efficiency	Investments on energy efficient technologies
Monitoring, Reporting and Verification (MRV)			X		TTW default emission factors or actual GHG content of fuel			
National regulation on renewable fuels		*X*			Share of renewables in fuel		Requirements on usage of renewable fuels	Renewable fuels more expensive than conventional fuels

Source(s): Authors' own work

in a WTW assessment, the overall GHG footprint of LNG may exceed that of traditional fossil fuels. Thus, the continued reliance on TTW metrics may not only result in higher total emissions but also misguide long-term investments, thereby undermining the goals of environmental regulation.

The issue of administrative burden was also perceived to disproportionately affect firms based on their size. Larger companies are generally better equipped – with the necessary personnel, expertise and technological infrastructure – to handle complex reporting requirements. In contrast, smaller firms often lack the internal capacity or resources to comply with such requirements, which creates significant challenges in meeting regulatory expectations.

While many reporting obligations – such as those under the CSRD – are formally imposed on large firms, smaller companies are indirectly affected. This is particularly evident in the reporting of Scope 3 emissions, where large firms must account for emissions throughout their value chain, including those associated with services provided by smaller suppliers. Consequently, small and medium-sized enterprises (SMEs) are increasingly required to generate emissions data to meet the compliance needs of their larger partners, despite not being the primary targets of the regulation.

Among the more complex elements of the CSRD, shipping companies specifically highlighted the challenges of turnover-based carbon intensity metrics. The directive requires firms to report emissions relative to turnover, a measure that does not account for the highly cyclical nature of the maritime transport market, where freight rates can significantly fluctuate over short periods. Consequently, a firm may demonstrate genuine reductions in GHG emissions, but still appear to perform poorly under the CSRD metric due to falling turnover, thus leading to misleading signals regarding its environmental performance.

Further complications arise from inconsistencies in calculation parameters and methodological criteria across regulations. A notable example is the IMO's CII, which requires shipping companies to report carbon intensity as a ratio of CO_2 emissions per unit of potential cargo carrying capacity, rather than the actual transported volumes. During the workshops, this was criticized as potentially distortive and open to manipulation. For example, an empty ship sailing could artificially improve its CII score, since the denominator (capacity) increases without a proportional rise in the numerator (emissions), despite no actual gain in transport efficiency or emissions reduction.

Efforts such as *ISO 14083* and the forthcoming *CountEmissionsEU* initiative represent important steps toward standardizing the calculation and reporting of emissions in the transport sector. However, even these frameworks permit variation in emission factors and methodological choices, which continues to hinder comparability and consistency across firms and regulatory regimes. This issue was also identified in the context of technical requirements, where differences in definitions, parameters and thresholds further complicate compliance and benchmarking.

Despite these challenges, the informants acknowledged positive aspects of stricter reporting requirements. Enhanced transparency was viewed as a catalyst for elevating sustainability to a competitive differentiator. Several interviewees – particularly those who self-identified as industry forerunners – perceived stricter reporting obligations as an opportunity to distinguish themselves from competitors that engaged only in minimal compliance. For these frontrunners, even more stringent and harmonized criteria were considered desirable, as they would help to level the playing field and reward genuine efforts toward decarbonization.

One participant noted that the current regulatory environment often "rewards averages," which can disincentivize ambition by penalizing proactive firms and enabling less committed actors to appear compliant. From this perspective, regulatory convergence and more rigorous requirements are not only concerned with environmental integrity but also with fair market dynamics and reputational differentiation.

4.3 The technical requirements of regulation

Technical requirements form a core component of many environmental regulatory initiatives. In the EU, such requirements are embedded in the regulation – for example, in the RED, which establishes criteria for low-carbon and carbon-neutral fuels, including thresholds for sustainability and lifecycle emissions. However, the *FuelEU Maritime* regulation – while referencing the RED – applies stricter sustainability criteria in certain areas, such as by limiting the use of specific raw materials for biofuels.

This divergence has led to a regulatory inconsistency, where certain fuels may be classified as sustainable under one regulation but not so under another. This issue was particularly emphasized by shipping firms, given their need to operate across both EU and non-EU jurisdictions. Each fuel batch may have varying WTT emissions, depending on its production process and may comply with one regulation while simultaneously violating another. Consequently, firms face significant complexity in reporting and verifying emissions, which undermines the predictability and efficiency of decarbonization strategies. Moreover, these inconsistencies complicate operational decisions, particularly with respect to bunkering, as the pool of compliant fuel options is constrained by regulatory fragmentation.

Further, transport companies also expressed concern that regulations that impose strict usage criteria – such as mandates for low-carbon fuels – reconfigure power dynamics within the supply chain. These policies were considered to shift market power toward fuel and technology providers, who – given the captive demand created by regulatory requirements – may be incentivized to limit supply and maintain high prices. In contrast, energy sector representatives in the focus group held opposing views and advocated for a more rapid transition and stricter obligations regarding the use of low-emission fuels, thus viewing these policies as necessary for driving innovation and market growth in clean energy technologies.

4.4 The cost impact of regulation

Excluding customer-driven requirements, ten regulatory initiatives were identified as having a direct cost impact – either through carbon pricing mechanisms or through mandates to adopt alternative, often more expensive, energy sources. An additional two regulations were perceived to have indirect cost implications, primarily due to the investment requirements in new technologies necessary for compliance. Moreover, of the twelve initiatives with either direct or indirect cost effects, five were associated with road transport and six with maritime transport. The RED already applies to both road and maritime sectors, and the EU *Energy Taxation Directive* (ETD) is expected to extend its scope to include shipping and marine fuels, pending successful renewal and agreement on its revised terms.

Among the ten initiatives with direct cost implications, eight were regional in nature – either introduced by the EU or implemented at the national level. Despite a consensus across stakeholder groups that these regulations will likely lead to increased transport costs, there were divergent views on the magnitude of these increases and disagreement regarding who will ultimately bear the financial burden. Further, energy firms predominantly argued that end customers would absorb most of the cost increases, viewing price transmission through the supply chain as likely and feasible. In contrast, transport providers expressed skepticism, thereby suggesting that while customers increasingly demand emission reductions, they are often unwilling to accept or acknowledge the associated costs and, in many cases, are able to resist cost pass-through due to their strong bargaining position. Cargo owners, for their part, adopted a more collaborative tone, thereby emphasizing ongoing efforts to work jointly with logistics providers in identifying cost-effective pathways to meet sustainability goals. However, they did not explicitly comment on the potential power asymmetries in the buyer–supplier relationship.

The participants of the focus groups were asked twice to provide their individual estimates on how severe the impact of the identified regulatory initiatives is or would become for the transport chain. Table 4 presents the descriptive results. When the informants were requested

Table 4. Estimates on how severe the impact of GHG-motivated regulatory initiatives will likely be for the transport chain (1 = very mild, 5 = very severe)

Regulation	Mean	Stdev	Min	Max
Customer requirements	4.5	0.71	3	5
Fuel EU Maritime	4.0	0.94	2	5
EU ETS II	3.8	0.63	3	5
EU ETS	3.6	0.97	2	5
EU RED II/III	3.6	1.07	2	5
Renewable Energy Directive	3.3	1.34	1	5
National regulation on renewable fuels	3.1	0.74	2	4
ISO 14083 standard	3.0	1.05	1	4
CountEmissionsEU	3.0	0.94	1	4
EU Alternative Fuels Infrastructure Requirement (AFIR)	3.0	1.05	2	5
EU Energy Taxation Directive (ETD)	2.8	1.23	1	5
IMO EEXI/EEDI	2.7	0.67	2	4
Corporate Sustainability Reporting Directive (CSRD)	2.6	0.52	2	3
HDV CO_2 standard	2.6	1.17	1	5
Global Logistics Emissions Council (GLEC) framework	2.6	0.73	2	4
Science based targets (scope 3)	2.5	0.97	1	4
EU Corporate Sustainability Due Diligence Directive	2.5	0.85	1	4
IMO Carbon Intensity Indicator	2.5	0.85	1	4
IMO Data Collection System	2.5	0.85	1	4
First Mover coalition	2.4	0.97	1	4
Monitoring, Reporting and Verification (MRV)	2.4	1.07	1	4
First mover coalition	2.4	1.06	1	4
Carbon Border Adjustment Mechanism	2.3	0.67	1	3
EU Taxonomy for sustainable activities	2.3	0.82	1	3
Greenhouse Gas Protocol	2.3	0.67	1	3
Euro 7	2.2	0.63	1	3

Source(s): Authors' own work

to present their estimate, "severity" was not defined in advance, but they made the evaluation based on their own perspective of the definition.

When the results regarding severity were presented to the focus group, they presented and discussed the differences among their perspectives. Naturally, many of the informants understood severity to mean direct and indirect cost impacts, but other definitions were also presented. A few of the informants emphasized the conflicts or joint impacts with other regulations, either via additional administrative burden, or difficulty of complying; a few also emphasized the impact on the market.

This is particularly applicable to *FuelEU Maritime*, which was considered to have the most severe impact of regulations (customer requirements were estimated to be more severe, but are not technically regulations). The comments regarding *FuelEU Maritime* can be applied to many of the other regulations with high perceived severity. *FuelEU Maritime* is a CAC-type or regulation, which requires shipping firms to gradually reduce the carbon intensity of fuels they use – in reality, forcing them to purchase alternative fuels, regardless of their price. The severity of this regulation was explained not merely by the fact that the alternative fuels are currently more expensive than fossil fuels but by the difficulty in forecasting how the market elements of the fuels will develop in the future, thus making the investment decisions regarding fuels and power systems insecure. Generally, it would appear that the wider and uncertain the impacts of regulation, the higher the perceived severity.

Participants in the focus groups were asked on two separate occasions to individually assess the severity of the identified regulatory initiatives in terms of their impact on the transport chain. The results are summarized in Table 4. Importantly, the concept of severity was intentionally left undefined, thus enabling participants to base their evaluations on their own interpretations, shaped by their respective roles and perspectives within the transport system.

Upon presenting the aggregated results to the entire focus group, participants were invited to discuss differences in scoring and interpretation. While many informants understood severity primarily in terms of direct and indirect cost impacts, others highlighted regulatory overlaps, administrative burdens, or compliance complexity. A number of participants also indicated market-level impacts, including competitive distortions and strategic uncertainty.

One regulation that generated particular concern was *FuelEU Maritime*, which was rated as having the highest perceived severity among regulatory initiatives (although customer requirements were ranked even higher, they fall beyond the scope of formal regulation). *FuelEU Maritime* is a CAC regulation that mandates a gradual reduction in the carbon intensity of maritime fuels, effectively forcing shipping companies to adopt alternative fuels, regardless of their cost. The perceived severity of this regulation was not only attributed to the high cost differential between conventional and alternative fuels but also to the uncertainty surrounding future fuel market dynamics, which complicates long-term investment decisions in both fuel sourcing and propulsion technologies.

More broadly, the results reveal a pattern: the more uncertain and wide-ranging the implications of a regulation, the higher its perceived severity. This highlights a key challenge for regulators – balancing ambition and enforceability with predictability and investment stability in a highly interconnected, capital-intensive industry.

Among the other regulations estimated to have the most severe impact, most were related to emission trading (EU ETS and ETS II), technical requirements, or taxing of fuels (RED, REDII/III, national regulations on renewable fuels, EU AFIR, EU ETD). Moreover, among the reporting requirements, *CountEmissionsEU* and *ISO 14083* were also among the top ten with the most severe anticipated impact. An analysis of the perceived severity of impact reveals that most of the regulations graded highest were the ones that have a direct cost impact.

Notably, there was considerable variation among respondents' evaluations of different regulations. The largest standard deviations – indicating divergence in perceived severity – were observed for the RED (SD = 1.34), the ETD (SD = 1.23), and the *Heavy-Duty Vehicle CO_2 Standards* (SD = 1.17). These regulations also exhibited the widest gaps between minimum and maximum scores, further emphasizing the heterogeneity of stakeholder perspectives. This variation is likely attributable to differences in the degree of familiarity with the respective regulations as well as their varying relevance depending on the transport mode and the respondent's role within the supply chain.

5. Discussion and conclusion

The purpose of this research was to identify the challenges of the introduced GHG-motivated regulations for the transport chain. For this, qualitative data was collected through focus group workshops and interviews, with participants who are experts from different phases of a multimodal transport chain, the cargo owner, road transport, cargo handling, and ports and sea transport. The experts were requested to list regulatory initiatives with either global, regional (EU), or national coverage that target GHG emissions. In addition, they listed voluntary agreements with a GHG emission reduction target. This information was supplemented by reviewing the current and proposed EU regulations as well as global regulatory initiatives, such as those introduced by the IMO. The experts were further requested to provide their views on whether the identified regulations had a reporting requirement, a specified emission reduction target or a technical requirement associated with fuels or equipment; finally, they were also asked to specify whether the regulations had direct cost implications. Further, the experts were asked to estimate the severity of the impact of individual regulations for the transport chain on a five-point scale. The experts were also individually interviewed to deepen the understanding of their perspectives on the topic.

Approximately 20 distinct regulatory initiatives addressing GHG emissions across transport chains were identified. Of these, four operate at the global level, while the remainder are primarily EU-wide or national in scope. This distribution reflects the EU's long-standing ambition to act as a global leader in climate policy, as emphasized by Oberthür and Dupont (2021). However, from the standpoint of international transport chains and globally operating firms, this fragmented regulatory landscape poses potential competitive disadvantages. Specifically, firms based outside the EU – or those able to shift operations to pollution havens – may benefit from more lenient environmental standards. While the EU often invokes the *Porter Hypothesis* (Porter and van der Linde, 1995) – which suggests that stringent environmental regulations can spur innovation and enhance productivity – the short-to medium-term risk of carbon leakage and competitive imbalances remains a key concern.

To address this, the EU has introduced mechanisms such as the Carbon Border Adjustment Mechanism, aimed at leveling the playing field by imposing carbon-related costs on certain imports. However, it is important to note that CBAM addresses production-related competitiveness within the EU versus imports and does not mitigate broader competitiveness concerns in non-EU markets, where EU-based firms still face potentially higher compliance costs than international competitors.

Among the transport modes, maritime transport is subject to the highest number of upcoming regulatory initiatives, which is partially a consequence of the historic absence of binding GHG regulations in this sector – both at the regional and global levels. Although considerable scholarly attention has been paid to the cost implications of maritime emission regulations (e.g. Sys *et al*., 2016; Schwartz *et al*., 2020), most of this research has focused on individual regulatory instruments, with limited consideration of their cumulative and overlapping effects across jurisdictions.

Further, the lack of coordination between regional and global regulations, and among different actors within the transport chain, introduces inefficiencies that may undermine the effectiveness of climate policy. Currently, the level of ambition in terms of GHG reduction as well as the implied cost of emissions varies across industries, modes of transport and regulatory regimes. This inconsistency, or as De Stefano and Montez-Sancho (2023) call it, vertical and spatial complexity, risks triggering market distortions, where emission reductions are achieved in suboptimal segments of the chain, without regard for economic efficiency or marginal abatement costs.

In addition, such asymmetries raise important questions regarding regulatory design and governance. Specifically, there is a risk of regulatory capture (Peltzman, 2021), wherein policies may be shaped more by organized private interests than by the broader public good. For example, the automotive industry – a key employer in many EU member states – holds considerable influence in the design of emissions and efficiency standards for road transport. Similarly, energy producers – particularly those in the fossil fuel sector – stand to benefit financially from regulations that mandate the adoption of renewable fuel (Ghoddusi, 2017). These dynamics emphasize the importance of transparency, stakeholder balance, and economic rationale in the development of future regulatory frameworks, as previously suggested by, for example, Bongo and Sy (2024). From the perspective of a multimodal transport chain, this may lead to suboptimal behavior regarding emissions in cases where the commercial logic is in conflict with the goals of the regulation (Gu *et al*., 2019).

5.1 Regulatory implications

The key finding of this research is that the regulatory initiatives are in conflict with each other. Obviously, there is a great likelihood for conflict among national, regional and global regulations, as the governing organizations are different; however, this was also found to be the case among the different regulatory initiatives of the EU. To a certain extent, this applies to reporting as well as to technical standards among the regulations. For an individual company, this implies additional administrative burden, as the same data has to be processed multiple times with different criteria for different authorities, depending on the regulation. At the EU level, there is an attempt to standardize the emission calculations with the *CountEmissionsEU* initiative, but the challenges go beyond that, as a few of the regulations require WTW-emission calculations, whereas a few others settle for TTW emissions.

The administrative burden and technical competencies required to comply with environmental and sustainability regulations are often more manageable for large firms due to their greater resources, infrastructure, and internal expertise. This reality has been partially acknowledged in recent policymaking. For example, regulations such as the *EU Corporate Sustainability Reporting Directive* (CSRD) and the recently adopted *Corporate Sustainability Due Diligence Directive* (CSDDD) explicitly target large firms. However, due to their integration into broader supply chains, SMEs are also indirectly affected. Even if not directly subject to the same legal requirements, SMEs are increasingly expected to provide comparable data and transparency to their larger partners, despite possessing more limited capacities and technical expertise.

This situation is related to broader academic debates within the economic theory of regulation. While many regulatory instruments formally aim to address large actors, the practical implications often extend downstream, inadvertently disadvantaging smaller firms. Consequently, regulation may further consolidate the market power of large firms, which are better positioned to absorb compliance costs, develop technical reporting capacities and navigate regulatory complexity. This creates competitive distortions that may reinforce existing inequalities in market structure.

Even more acute challenges arise when it comes to technical compliance, particularly in the case of environmental standards. In certain instances, a fuel or practice deemed sustainable under one regulation may simultaneously be classified as unsustainable under another. Such regulatory contradictions create serious operational challenges for firms, particularly in sectors such as shipping. For example, maritime operators may face restrictions in bunkering options, as certain fuels meet the sustainability criteria under one regulatory framework but not under another. These inconsistencies complicate fleet management and route planning, thereby reducing the flexibility of firms to make economically or environmentally optimal decisions.

5.2 Theoretical implications

These findings contribute to the ongoing debate regarding the efficiency of regulation. As noted by Santos *et al*. (2010), regulators often prefer policy instruments that are administratively simple and require lower enforcement effort. However, in line with De Sefano and Montez-Sancho (2023), our findings suggest that from the perspective of regulated entities – particularly those that operate across multiple jurisdictions and supply chains – the cumulative effect of overlapping reporting obligations across different regulatory layers constitutes a significant administrative burden. This highlights a growing tension between the regulators and the regulated, where efforts to streamline enforcement on the institutional side may lead to disproportionate complexity and compliance costs for firms, particularly smaller ones.

As the stakeholder theory (Bridoux and Stoelhorst, 2016) suggests, the actions and choices of the firms are directed by the pressures coming from their various stakeholders. With the environmental questions, the focus of the regulation – and perhaps of the overall discussion – has been on setting targets for emission reductions, likely neglecting the other, possibly conflicting, goals of the stakeholders. As Arranz *et al*. (2022) suggest, these goals and, thus, the pressures from the stakeholders may be conflicting; therefore, the end result may deviate from the desired result. This research provides empirical evidence of this phenomenon in the emission regulation of transport chains.

Further, it also appears that there are challenges regarding information efficiency (Aldy *et al*., 2008). Both the CAC as well as incentive-based regulations are dependent on the scope and precision of the emission and cost data. As Schramm and Lehner (2024) have previously argued, many of the emission measurement and calculation tools do not provide sufficiently detailed data for precise calculations. The same problem is also applicable for regulations, as many of them are focused on a narrower scope (TTW) or enable the usage of average load and emission factors. Our results indicate that on account of this, emissions are not priced according to their true value, rewarding slow movers and reducing incentives for efficient emission reduction. Even as administrative efficiency might be challenged, from the perspective of the end result, regulations and the associated sanctions require a certain level of accuracy.

Efficient allocation (Liebenstein, 1966) assumes that the emissions are optimally reduced, with the lowest cost and lowest loss of utility. In case the regulatory framework directs emission reductions away from this "optimal allocation," the result is a welfare loss to society as a whole. The results of this study indicate that the complexity of the current regulatory framework might do just that through various mechanisms. Even if CAC-type mechanisms (Santos *et al.*, 2010) are easier for the regulators, they treat all those regulated in a similar manner, without considering their different marginal costs and benefits, thereby allocating suboptimal reductions. As suggested by Aldy *et al.* (2008), this effect is amplified even more when multiple regulations that target the same goal are introduced.

The results of this study also contribute to the discussion on the intertemporal efficiency of regulation. As previously presented by Haywood and Jakob (2023), especially in capital-heavy businesses with a long investment cycle, it might be that if the regulation is wrongly planned, firms are forced to make certain decisions in the short term that limit them from making optimal decisions in the long term. In these cases, the long-term emission reduction pathway may once again suffer from inefficiency and lead to a welfare loss.

5.3 Managerial implications

In line with Björklund *et al.* (2024), our results also reveal tensions among the members of the transport chain. As many of the technical and emission reduction requirements are directed at transport firms, it changes the balance of power between them and their customers and suppliers. Instead of aiming for win-win solutions as suggested by Montabon *et al.* (2015), cargo owners push the cost of emission reduction to transport companies. In line with previous findings of Ghoddusi (2017), fuel producers are more than happy to benefit from the higher prices caused by the imbalance between regulated demand and supply. From the perspective of allocative efficiency, this can clearly be seen as a problem. The different incentives for the members of the chain – created by the regulatory framework's push toward suboptimization from the perspective of the focal firm, in this case, thus increasing complexity and hindering the possibility of attaining a joint goal, as previously presented by De Stefano and Montes-Sancho (2023).

For businesses, this study provides a summary of GHG-motivated regulations on the transport chain, with a perspective on their anticipated impacts and requirements. It improves understanding of both the economic and administrative burdens for the different actors in the transport chain. At the same time, it deepens the understanding of individual firms regarding how the regulatory framework will impact the upstream and downstream of the transport chain.

5.4 Policy implications

This research identifies several aspects of the regulatory conflict between individual legislative instruments and emphasizes the critical need for coordination across the various levels of policymaking – regional, national and international. In order to improve coherence and effectiveness, policymakers must remain focused on the primary objective of emission regulation: the absolute reduction of total GHG emissions, regardless of their source or location. Regulatory frameworks that attempt to micromanage emission reductions at the level of specific sources or modes risk increasing administrative complexity, inefficiency and overall cost.

Extant research (e.g. Santos *et al*., 2010; Di Filippo *et al*., 2019) has consistently revealed that market-based instruments remain the most efficient mechanisms for achieving emissions reductions, provided they are well-designed and supported by adequate governance. Therefore, policymakers should be cautious regarding overregulating markets or introducing fragmented measures that distort competition or undermine cost-efficiency. Instead, the focus should be on designing incentive-compatible mechanisms that enable market actors to identify and implement the most cost-effective mitigation strategies.

In this context, the debate returns to the foundational theories of environmental economics – notably Pigou's (1920) concept of taxing externalities and Coase's (1960) argument for defining property rights to enable market transactions to correct market failures. Cap-and-trade systems, such as the EU ETS, embody these principles by capping total emissions and allowing the market to allocate reductions where they are most economically viable. Such systems provide clarity on environmental ambition (via the cap), while preserving flexibility and efficiency in implementation.

However, recent developments – such as the separation of road transport into a distinct emissions trading system (ETS II) – run contrary to this logic. Segmenting sectors into different schemes may distort market signals, particularly when competing transport modes are treated asymmetrically. In the worst case, this can result in undesirable modal shifts – not based on environmental efficiency but rather on regulatory arbitrage.

Ideally, all relevant transport modes and sectors should be covered by a single, unified emissions trading mechanism, thereby enabling emissions to be reduced in the most cost-effective manner across the entire system. As a solution to this, Aldy *et al*. (2008) suggested upstream programs. In these, the sanctions would apply to the raw materials of emission sources, and therefore would be directed equally toward all uses. Nevertheless, the feasibility of modal substitution varies by context. For example, in maritime transport – particularly for bulk or high-volume container cargo – shipping remains the only viable transportation mode due to capacity and cost considerations. As such, the potential for a modal shift is mainly restricted to certain Ro-Ro and short-sea container transport segments. Even in these cases, the cost differentials between transport modes are often too significant to permit meaningful shifts based solely on changes in regulatory burden.

However, the misalignment of regulatory incentives may nevertheless result in suboptimal allocation of emission reductions, with resources being diverted toward less efficient or more expensive solutions. Avoiding such inefficiencies requires improved policy alignment, comprehensive impact assessments, and a more holistic view of the transport system and supply chains.

Although previous research has consistently found CAC policies to be less efficient than market-based instruments (e.g. Santos *et al*., 2010; Aldy *et al*., 2008), they continue to be widely employed in environmental regulation. A recent example is the decision by the IMO Marine Environment Protection Committee in April 2025 to introduce the IMO *Net-Zero Framework*. This framework requires ships to reduce the carbon intensity of the energy they use, thus effectively mirroring the approach adopted by the *FuelEU Maritime Regulation*. Interestingly, while the framework is structurally a CAC-type policy – imposing direct performance standards – it also incorporates a market-based component, thereby enabling the trading of surplus credits and the purchase of remedial units. This hybrid approach reflects an evolving trend in environmental governance: integrating flexibility mechanisms into CAC instruments to improve cost-effectiveness and accommodate diverse capabilities within the industry.

5.5 Limitations and future research

For regulation to function effectively – achieving its intended objectives while minimizing unintended consequences – it is essential to consider its interactions with other existing or planned regulations during the impact assessment phase. Although such analysis can be complex, resource-intensive and time-consuming, it is a critical component of comprehensive policy evaluation and should be more thoroughly addressed in academic research.

Rather than performing narrowly focused assessments that isolate the effects of individual regulatory instruments, future research should strive to adopt a more holistic, systems-level perspective. In case costs are in focus, research should also consider other regulations and estimate the overall cost impact of all of them, rather than focusing on the impact of an individual regulation. As it comes to technical standards, possible conflicts beyond the reach of the respective regulation should be thoroughly analyzed. This need is particularly pronounced in the context of international multimodal transport and global supply chains, which are subject to a diverse array of regulations that vary in geographic scope, modal application and sectoral focus. Overlapping or misaligned regulatory frameworks can result in inefficiencies, compliance burdens and unintended behavioral responses.

This study identified several instances of regulatory conflict and misalignment, thus highlighting the practical challenges firms face when navigating multiple and, occasionally, contradictory requirements. These findings provide a foundation for more detailed analysis, both qualitative and quantitative, aimed at assessing the magnitude and implications of such conflicts and, ultimately, at supporting more coherent and efficient policy design. For long, supply chain management research has emphasized the need to take a wider perspective and to expand the analysis beyond the narrow scope of the focal firm and its first-tier suppliers and customers toward the ultimate supply chain. A similar approach would also be needed when it comes to regulation. Instead of limiting the analysis to direct impacts on the regulated, also the spillover effects upstream and downstream the supply chain should be included. In this, especially the supply chain management research would provide valuable input.

Although many of the firms included in this study operate on a global scale, their operations – and, thus, their regulatory perspectives – are strongly rooted in the European context. Consequently, the discussion of regional and national regulations in this study primarily focuses on the EU.

However, it is important to note that the objective of this research was not to provide a comprehensive global review of all transport-related environmental regulations. Rather, the study aimed to highlight the challenges arising from regulatory fragmentation, particularly in cases where regulatory scopes, mechanisms and geographical coverages are misaligned or overlapping. Thus, while the findings are grounded in the EU context, the core insights and recommendations are broadly applicable beyond Europe. The observed tensions among different layers of regulation – whether national, regional or global – are relevant to any jurisdiction seeking to decarbonize its transport systems through a mix of environmental policy instruments. Even if the existence of horizontal, vertical and spatial complexity of regulation is acknowledged, future research should be able to make these phenomena more tangible, so that they would be properly understood in the preparation of regulation.

Another limitation of the study concerns the absence of regulators or policymakers in the data collection process. Consequently, it was not possible to assess whether public authorities would share the same perceptions of regulatory conflicts and impacts as regulated firms. Future research should address this limitation by surveying the perceptions of different stakeholders, including regulators and policymakers, to see whether the perceptions and goals are aligned, or whether possible misalignment might complicate the regulatory process and anticipated outcomes.

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Appendix

Table A1. Identification information of regulations (IMO resolution numbers and CELEX-number of the EU directives) and links to the documents

Identification information of identified regulations		
Regulation/voluntary framework	ID/CELEX-number	URL
Customer requirements		
Corporate Sustainability Reporting Directive (CSRD)	32022L2464	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022L2464
ISO 14083 standard		https://www.iso.org/standard/78864.html
Renewable Energy Directive	32023L2413	https://eur-lex.europa.eu/eli/dir/2023/2413/oj/eng
Science-based targets initiative (scope 3)		https://sciencebasedtargets.org/
(WEF) First Mover coalition		https://initiatives.weforum.org/first-movers-coalition/home
Carbon Border Adjustment Mechanism	32023R0956	https://eur-lex.europa.eu/eli/reg_impl/2025/486/oj/eng
Count emissions EU	52023PC0441	https://eur-lex.europa.eu/legal-content/EN/PIN/?uri=CELEX:52023PC0441
EU Energy Taxation Directive (ETD)	32003L0096	https://eur-lex.europa.eu/eli/dir/2003/96/oj/eng
EU Taxonomy for sustainable activities	32020R0852	https://eur-lex.europa.eu/eli/reg/2020/852/oj/eng
Greenhouse Gas Protocol		https://ghgprotocol.org/
EU Alternative Fuels Infrastructure Requirement (AFIR)	32023R1804	https://eur-lex.europa.eu/eli/reg/2023/1804/oj/eng
EU Corporate Sustainability Due Diligence Directive (CSDDD)	32024L1760	https://eur-lex.europa.eu/eli/dir/2024/1760/oj/eng
EU Emission Trading System (ETS)	32023L0959	https://eur-lex.europa.eu/eli/dir/2023/959/oj/eng
EU Emission Trading System II (ETS II)	32023L0959	https://eur-lex.europa.eu/eli/dir/2023/959/oj/eng
EU Renewable Energy Directive II/III	32023L2413	https://eur-lex.europa.eu/eli/dir/2023/2413/oj/eng
Euro 7	32024R1257	https://eur-lex.europa.eu/eli/reg/2024/1257/oj/eng
Fuel EU Maritime	32023R1805	https://eur-lex.europa.eu/eli/reg/2023/1805/oj/eng
Global Logistics Emissions Council (GLEC) framework		https://www.smartfreightcentre.org/en/our-programs/emissions-accounting/global-logistics-emissions-council/
Heavy Duty Vehicle (HDV) CO_2 standard	32024R1610	https://eur-lex.europa.eu/eli/reg/2024/1610/oj/eng
IMO Carbon Intensity Indicator (CII)	MEPC. 328(76)	https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.328(76).pdf
IMO Data Collection System (DCS)	MEPC.278(70)	https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/278%2870%29.pdf
IMO Energy Efficiency Design Index EEXI/EEDI	MEPC. 328(76)/ MEPC.203(62)	https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.328(76).pdf https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Technical%20and%20Operational%20Measures/Resolution%20MEPC.203%2862%29.pdf

(*continued*)

Table A1. Continued

Identification information of identified regulations		
Regulation/voluntary framework	ID/CELEX-number	URL
Monitoring, Reporting and Verification (MRV)	02015R0757-20240101	https://eur-lex.europa.eu/eli/reg/2015/757/2024-01-01/eng
National regulation on renewable fuels	32023L2413	https://eur-lex.europa.eu/eli/dir/2023/2413/oj/eng

Source(s): Authors' own work

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