FROM BARRIER TO ENABLER: THE ROLE OF LAW IN CLOSING THE MARITIME ENERGY EFFICIENCY GAP

Anna Kaparaki [1,2] , Christos A. Kontovas[1, *]

[1] Liverpool Logistics, Offshore and Marine Research Institute (LOOM) and School of Engineering and Build Environment

[2] Liverpool Business School

Liverpool John Moores University, Liverpool, United Kingdom

*c.kontovas@ljmu.ac.uk

Abstract

This paper revisits the energy efficiency gap in maritime shipping by foregrounding its legal and regulatory dimensions. While economic and technical barriers have been extensively studied, the analysis here emphasizes how law and regulation shape investment behaviour, risk allocation, and contractual relationships in the shipping industry. Drawing on Sorrell et al.'s taxonomy of barriers, each category is reinterpreted through a legal lens. The analysis shows that legal instruments are not merely compliance tools but can function as active enablers of decarbonisation. The paper concludes with a research agenda aimed at harmonising legal frameworks, standardising contractual practices, and fostering institutional coherence to accelerate the uptake of cost-effective abatement measures in global shipping.

Keywords

Decarbonisation, Energy efficiency gap, Barriers, Legal barriers

Accepted version (subject to final revisions)

Please cite as:
Kaparaki, A. and Kontovas, C. (2026). 'From Barrier to Enabler: The Role of Law in Closing the Maritime Energy Efficiency Gap'.
In: Proceedings of the International Association of Maritime Economists (IAME) 2026 Conference, Singapore, 20 June–3 July 2026.

1 Introduction

Maritime transport is the backbone of global trade, carrying approximately 80–90% of world goods by volume. Yet despite its relative energy efficiency and being the most energy efficient transport mode, the shipping sector is responsible for around 2–3% of global anthropogenic greenhouse gas (GHG) emissions (IMO, 2020) — a share that may grow without decisive action. In view of the accelerating climate crisis, the International Maritime Organization (IMO) has strengthened its regulatory ambition in its revised strategy, adopted in July 2023, to reduce GHG emissions from ships. This 2023 IMO GHG Strategy sets out urgent new targets: a carbon intensity reduction of at least 40% by 2030 (relative to 2008 levels), increasing uptake of zero or near-zero GHG fuels to at least 5%, striving for 10%, by 2030; and an overall aim of reaching net-zero GHG emissions from international shipping "close to 2050." The Strategy also introduces indicative check-points: aiming for at least a 20%–30% absolute reduction in GHG by 2030 and 70%–80% by 2040 (again, relative to 2008). These enhanced ambitions make clear that reduction measures are needed with urgency.

Over the past decade, the maritime sector has actively pursued strategies to reduce greenhouse gas (GHG) and air pollutant emissions, generally classified into operational, technological, and market-based measures (IMO, 2020; Psaraftis and Kontovas, 2013). Operational measures focus on improving vessel efficiency through management and operational practices such as slow steaming (Cariou, 2011; Psaraftis and Kontovas, 2013), weather routing, trim optimisation, hull and propeller maintenance, and just-in-time (JIT) or virtual arrival operations. These low-cost actions can yield immediate fuel and emission reductions. Technological measures involve design improvements or retrofits, including advanced hull coatings, waste-heat recovery systems, air lubrication, wind-assist technologies, and alternative fuels such as LNG, methanol, or ammonia (Bouman et al., 2017; Balcombe et al., 2019). Market-based measures (MBMs)—such as emission trading schemes and carbon levies—aim to internalize environmental costs and provide financial incentives for abatement. The IMO and regional regulators, notably the EU ETS – the trading system implemented by the EU which is now including shipping, are advancing such mechanisms.

Although regulatory mandates play an important role, many measures are inherently cost-effective given that fuel represents 40–60% of total operating costs (Stopford, 2009; Smith et al., 2015). Because CO_2 emissions are proportional to fuel consumption, improving energy efficiency should simultaneously reduce costs and emissions.

Nonetheless, the persistence of the **energy efficiency gap**—where profitable measures remain unimplemented—reveals the presence of significant economic, behavioral, and institutional barriers (Sorrell et al., 2004; Kontovas and Psaraftis, 2013; Rehmatulla and Smith, 2015). Numerous techno-economic and **marginal abatement cost curve (MACC)** studies show that many shipping abatement measures are cost-effective, with several offering *negative abatement costs* and payback periods under two years (Eide et al., 2011; Acciaro et al., 2013; Longva et al, 2024); many of these measures actually fall into the operational/logistics measures category as these do not require a large capital expenditure. Typical examples include improved hull coatings, regular hull cleaning, trim optimization, and slow steaming—the latter can actually achieve high emission reductions at practically no direct cost but with side-effects (Psaraftis and Kontovas, 2010) highlighting the paradox that economically viable options remain only partially adopted.

Indeed, a striking feature of this evidence is that these measures are not only environmentally beneficial but also economically attractive—they represent “win–win” solutions or what is also in the relevant literature referred to as “no-regret” options. In theory, such options should diffuse rapidly through the global fleet, driven by pure cost minimisation. Yet empirical data reveal that uptake remains slow and uneven across ship types and ownership structures. This persistent discrepancy between apparent economic rationality and observed behaviour lies at the heart of what scholars describe as the energy-efficiency gap: the enduring underinvestment in cost-effective energy-saving opportunities. Understanding the nature of this gap—and the barriers, incentive misalignments, and institutional frictions that sustain it—remains essential for designing effective regulatory, contractual, and financial mechanisms to accelerate shipping’s decarbonisation.

To that extent, a growing body of research seeks to answer this question by examining the complex array of barriers to energy efficiency—including market failures, organisational constraints, information problems, and behavioural biases—that limit the uptake of efficient technologies and practices; see Section 3.1 for the review of the relevant. Within this context, the principal–agent (PA) problem has received particular attention in shipping because of the industry’s fragmented ownership and operational structures. The separation of incentives between shipowners, operators, charterers, and financiers often leads to misaligned decision-making, where those investing in energy-saving technologies are not necessarily those who reap the benefits from reduced fuel consumption.

This paper contributes to the literature by exploring how well-established taxonomies of barriers to energy efficiency (notably Sorrell et al., 2004) can be applied to shipping and by discussing potential pathways to bridge the efficiency gap focusing mainly on the underexplored legal/regulation aspect.

To that extent, the paper in Section 2 maps classical categories of barriers—such as risk, imperfect information, hidden costs, and split incentives—to concrete examples in maritime operations and ship management; in Section 3 synthesises theoretical insights into the energy efficiency gap as it manifests in shipping markets; and, finally, in Section 4 discusses potential policy, contractual, and organisational mechanisms that could help align incentives and accelerate the adoption of cost-effective emission-reduction measures. The conclusions and suggestions for future research are presented in Section 5.

2 The Energy Efficiency Gap: Theory Foundations

Sorrell et al. (2004) defines a barrier to energy efficiency as *"a postulated mechanism that inhibits a decision or behaviour that appears to be both energy efficient and economically efficient".* A substantial body of literature has examined the barriers to energy efficiency, drawing on diverse theoretical perspectives from neoclassical economics, institutional economics (including principal–agent theory and transaction cost economics), behavioral economics, sociology, and psychology (Howarth and Andersson, 1993; Jaffe and Stavins, 1994; Howarth and Sanstad, 1995; Brown, 2001; Sorrell et al., 2004; Schleich, 2009). These barriers are multifaceted and have been classified in various ways by different authors (Jaffe and Stavins, 1994; Brown, 2001; IEA, 2003; Sorrell et al., 2004, 2011). For an extensive review of this literature and an overview of the historical evolution of the debate, see Giraudet and Missemer (2023).

This body of research seeks to explain why firms and other organizations often fail to invest in energy-efficient technologies, even when such investments appear — or are perceived — to be economically profitable under existing market conditions. This apparent underinvestment is commonly referred to as the energy efficiency gap (Jaffe and Stavins, 1994). Jaffe and Stavins (1994) distinguish between market barriers and market failures: the former encompass any factors that inhibit the adoption of seemingly cost-effective technologies, while the latter refer specifically to those barriers that justify policy intervention to improve energy efficiency. Moreover, some market failures, such as environmental externalities not captured in energy prices, may warrant policy action even if they do not directly explain the energy efficiency gap (Sorrell, 2004).

The energy efficiency gap can also be understood as the delay between the availability of energy-efficient technologies and their widespread implementation. This has led to a long-standing debate over whether there exist substantial opportunities for low-cost or even no-cost reductions in fossil fuel use through improved energy efficiency.

Jaffe et al. (1999) further distinguish between two notions of economic potential and two corresponding social optima. The economists' economic potential refers to the level of energy efficiency attainable if only market failures (e.g., inadequate information provision) were eliminated. In contrast, the technologists' economic potential represents the efficiency level achievable if both market failures and non-failure-related market barriers (e.g., high discount rates arising from uncertainty) were addressed.

2.1 The Nature of Barriers - A Taxonomy Based on Sorrell et al. (2004;2011)

Barriers to energy efficiency are multifaceted and have been categorized in numerous ways across the literature. The question of whether particular barriers constitute genuine market failures remains the subject of considerable debate (Levine et al., 1994; Sutherland, 1996). Table 1 presents the taxonomy proposed by Sorrell et al. (2004, 2011) whose frameworks are among the most widely recognized in the field. It should be emphasized that many of these barriers are interrelated, and complex interactions often occur between them.

Table 1. A taxonomy of barriers to energy efficiency – Source: Sorrell et al. (2004)

BARRIER	CLAIM
RISK	The short paybacks required for energy efficiency investments may represent a rational response to risk. This could be because such investments represent a higher technical or financial risk than other types of investment, or that business and market uncertainty encourages short time horizons.
IMPERFECT INFORMATION	Lack of information on energy efficiency opportunities may lead to cost-effective opportunities being missed. In some cases, imperfect information may lead to inefficient products driving efficient products out of the market.
HIDDEN COSTS	Engineering-economic analyses may fail to account for either the reduction in utility associated with energy efficient technologies, or the additional costs associated with them. As a consequence, the studies may overestimate energy efficiency potential. Examples of hidden costs include overhead costs for management, disruptions to production, staff replacement and training, and the costs associated with gathering, analysing and applying information.
ACCESS TO CAPITAL	If an organisation has insufficient capital through internal funds, and has difficulty raising additional funds through borrowing or share issues, energy efficient investments may be prevented from going ahead. Investment could also be inhibited by internal capital budgeting procedures, investment appraisal rules and the short-term incentives of energy management staff.
SPLIT INCENTIVES	Energy efficiency opportunities are likely to be foregone if actors cannot appropriate the benefits of the investment. For example, if individual departments within an organisation are not accountable for their energy use they will have no incentive to improve energy efficiency.
BOUNDED RATIONALITY	Owing to constraints on time, attention, and the ability to process information, individuals do not make decisions in the manner assumed in economic models. As a consequence, they may neglect energy efficiency opportunities, even when given good information and appropriate incentives.

3 The Energy Efficiency Gap in Shipping

3.1 Literature Review

The exploration of the energy efficiency gap within the shipping industry is not new. A substantial body of research has investigated why many cost-effective abatement measures are not implemented, despite their apparent profitability under prevailing market conditions. Much of this work has been conducted in parallel with studies on *Marginal Abatement Cost Curves (MACCs)*, which identify and rank greenhouse gas (GHG) reduction measures by cost-effectiveness while highlighting the persistent gap between technical potential and actual uptake.

Early work in this area emerged in the late 2000s and early 2010s. The report by AEA (2008) provided one of the first comprehensive assessments of potential CO_2 abatement options in shipping. It examined both technical and operational measures and offered a systematic review of existing and potential barriers to their implementation. Among the key barriers identified were the *principal–agent problem*, *lack of information* about available measures, *hidden costs*, and *materiality*—the tendency to overlook incremental but collectively significant energy efficiency improvements. The Second IMO GHG Study (Buhaug et al., 2009), commissioned by the International Maritime Organization (IMO), further quantified shipping emissions and analyzed a wide range of abatement measures. Chapter 5 and Appendix 2 of this report outlined various technical and operational options for emission reduction and briefly discussed the associated implementation barriers, including financial, informational, and institutional challenges. Subsequent analyses, such as DNV (2010) and Eide et al. (2011), expanded on this work by evaluating 25 mitigation measures, including 12 new options not considered in earlier studies (e.g., the use of fuel cells as auxiliary generators). While Eide et al. (2010) explicitly referenced *split incentives* as a key barrier—highlighting the misalignment between ship owners and operators—they also noted a broader *"lack of responsiveness to economics"* within the industry, implying that behavioral and organizational factors play a significant role in hindering adoption.

Several submissions to the IMO -especially the Marine Environment Protection Committee (MEPC) have highlighted the issue. For example, the IMAREST (2011) study, submitted to the IMO as document MEPC 62/INF.7), introduced a standardized methodology for evaluating shipboard energy-efficiency measures and categorized barriers into *technological*, *financial*, and *institutional* types. This framework reflected growing recognition that the barriers to energy efficiency in shipping are multidimensional, extending beyond simple market imperfections.

Throughout the 2010s, an increasing number of empirical and conceptual studies sought to identify, classify, and explain these barriers in greater detail. Key contributions include those by Faber et al. (2009), Kontovas and Psaraftis (2013), Acciaro et al. (2013), Jafarzadeh and Utne (2014), Rehmatulla and Smith (2015), and Johnson and Andersson (2016). These works collectively emphasize that the adoption of green technologies in shipping is constrained by a complex interplay of technical, economic, organizational, and behavioral factors. Many of these studies adopt or adapt the general framework of energy efficiency barriers developed by Sorrell et al. (2004), as discussed in Section 2.1, applying it specifically to the maritime context.

More recently, Masodzadeh et al. (2022) provided the most comprehensive and integrative review of barriers to decarbonisation in the shipping sector. Their study offers not only a systematic repository of identified barriers and proposed solutions but also seeks to develop an optimal policy framework for combining these solutions effectively. Masodzadeh et al. (2022) distinguish between *economic* and *non-economic* barriers.

Economic barriers include both *non-market barriers* (such as risk, hidden costs, and limited access to capital) and *market failures* (including incomplete markets, imperfect competition, information asymmetries, and split incentives).

Non-economic barriers encompass *organizational and managerial*, *behavioral and human-element*, *policy and regulatory*, *technical*, and *safety and security* considerations.

The expanded taxonomy of barriers to energy efficiency reflects a growing recognition that closing the maritime energy efficiency gap requires addressing not only market imperfections, but also deeper structural, institutional, and behavioral impediments (Sorrell et al., 2004; Schleich, 2009; Masodzadeh et al., 2022). Consequently, the literature has gradually evolved from identifying isolated economic explanations toward more holistic and systems-based analyses of the barriers shaping maritime energy efficiency and decarbonisation.

Nevertheless, the majority of existing research continues to focus primarily on market-based explanations, with particular emphasis on the split incentives and principal–agent problems that characterize ship operation and chartering arrangements (OECD/IEA, 2007; Kontovas and Psaraftis, 2013; Rehmatulla and Smith, 2015). In such cases, the costs and benefits of energy-efficient investments are distributed among different parties—most commonly between shipowners and charterers—thereby diluting the incentive to invest in efficiency-enhancing technologies or operational measures.

Kontovas and Psaraftis (2013), building on the OECD/IEA (2007) framework, illustrated four distinct manifestations of the principal–agent problem in shipping, emphasizing how contractual and operational arrangements fragment decision-making authority and distort investment incentives. Subsequent studies, including most importantly Rehmatulla and Smith (2015), empirically examined these dynamics using a large-scale survey of over 1,200 industry respondents. Their analysis identified several key perceived barriers: the difficulty of implementing measures under certain charter types, limited access to reliable cost and performance information, lack of operational control, and restrictions embedded in charterparty clauses. Similarly, Dirzka and Acciaro (2019) applied panel data methods to the container shipping charter market, showing how information asymmetries between owners and charterers perpetuate inefficiencies in technology adoption.

3.2 The Legal and Regulatory Dimension: A Missing Link in Maritime Energy Efficiency

While the above studies make significant contributions, their focus remains largely economic, often treating legal and regulatory arrangements as static background conditions. Yet, we feel that many of the barriers identified—such as split incentives, informational asymmetries, and operational control limitations—are rooted in legal and institutional design.

From a law-and-economics perspective, many of the barriers and failures identified in the energy efficiency literature can be understood as manifestations of incomplete, ill-specified, or weakly enforced legal entitlements. Legal rules structure the incentives of shipowners, charterers, cargo interests, financiers, and classification societies by allocating rights to the cost savings and co-benefits of efficiency improvements, defining liability for non-compliance, and governing the allocation of retrofit and operational costs across complex contractual chains. By reducing uncertainty, standardizing expectations (for example through clauses in charterparties or uniform technical standards), and lowering transaction and enforcement costs, law can enable parties to contract around bounded rationality and information asymmetries that would otherwise inhibit cost-effective investments in energy-efficient technologies and practices (Coase, 1960; Calabresi and Melamed, 1972; Cooter and Ulen, 2016). In this sense, legal institutions do not merely correct market failures ex post; they co-create the very market conditions under which the "economic potential" can be realized in the shipping industry.

Public and private regulatory instruments in maritime transport illustrate this enabling role. Public regulation —such as international ship energy-efficiency standards (see for example the Energy Efficiency Design Index, EEDI, for newbuildings; the Energy Efficiency Existing Ship Index, EEXI, for existing ships; and the Carbon Intensity Indicator, CII, for operational performance), monitoring and reporting requirements (the European Union Monitoring, Reporting and Verification system, EU MRV, and the International Maritime Organization Data Collection System, IMO DCS), and port state control (i.e. the enforcement of these rules by coastal and port states)— can transform diffuse environmental externalities and informational problems into legally cognizable obligations, backed by credible enforcement, thereby making future energy-cost savings and compliance pathways more predictable for investors. At the same time, private ordering through contracts and industry standards (such as performance-based clauses in charterparties, energy-efficiency warranties in shipbuilding contracts, or "green" covenants in ship finance) relies on, and is facilitated by, the surrounding legal framework. These legal arrangements can realign incentives where the split between those who invest in efficiency (e.g. shipowners) and those who pay for fuel (e.g. charterers) would otherwise generate a principal–agent problem, and they can create new markets for efficiency services and technologies. Thus, law and regulation—still relatively understudied in the energy-efficiency-gap literature—function not only as constraints, but also as institutional enablers that reshape the opportunity set faced by maritime actors and help close the energy efficiency gap. In the two Sections below we outline how law acts as a causal mechanism but also, and most importantly, how it can help address the problem and bridge the energy efficiency gap.

3.3 Law as a Causal Mechanism in the Energy Efficiency Gap

In the context of the maritime energy efficiency gap, legal and regulatory factors can either amplify or mitigate existing economic and organizational barriers. Drawing on Sorrell et al.'s

(2004) taxonomy, it becomes apparent that legal structures are not merely peripheral influences but integral determinants of how such barriers manifest, interact, and persist. Law shapes the allocation of risk, defines informational obligations, conditions access to capital, and structures contractual relationships—each of which bears directly upon the adoption of energy-efficient technologies and operational practices in the shipping industry.

Risk and uncertainty are central to investment decisions in maritime decarbonisation. Legal ambiguity surrounding the certification, safety, and liability regimes applicable to emerging technologies—such as ammonia and hydrogen propulsion systems, wind-assist devices, and onboard carbon capture—significantly elevates the perceived risk of adoption (in line with Schleich, 2009; Rehmatulla and Smith, 2015). The absence of harmonized standards under the International Maritime Organization (IMO) generates uncertainty over compliance obligations and potential liabilities in the event of accidents or equipment failure. Insurers, for example, may be cautious in underwriting vessels powered by alternative fuels due to unresolved questions of causation, coverage, and limitation of liability under existing conventions (see current discussion at the IMO Legal Committee (LEG)). These legal uncertainties translate into higher discount rates and shorter payback expectations, discouraging investment in otherwise cost-effective efficiency measures. Recent contractual developments (*see the relevant BIMCO Clauses*) seek to mitigate such uncertainty by clarifying responsibility for compliance and the allocation of associated costs and liabilities between shipowners and charterers.

Imperfect information similarly finds a legal expression in the fragmented and overlapping regulatory landscape governing maritime emissions. The coexistence of global, regional, and national reporting regimes—most notably the IMO's Data Collection System (DCS) and the EU's Monitoring, Reporting, and Verification (MRV) Regulation—creates duplication and inconsistency, raising transaction costs and compliance uncertainty (Jafarzadeh and Utne, 2014; IMO, 2020). Information asymmetries are exacerbated by contractual confidentiality clauses and the limited enforceability of data-sharing provisions between charterers and owners.

The barrier of **access to capital** is also conditioned by law. Financing institutions and insurers rely on clear legal signals to assess the risk and legitimacy of emerging technologies. Ambiguities regarding safety standards, flag-state recognition, and regulatory approval impede investment in energy-efficient retrofits or alternative-fuel vessels (Acciaro et al., 2013). The development of frameworks such as the *Poseidon Principles for Financial Institutions (2019)* and the *Poseidon Principles for Marine Insurance (2021)* has begun to align lending and underwriting practices with international climate goals by embedding legal obligations for disclosure and compliance with IMO decarbonisation trajectories.

Split incentives represent perhaps the most overtly legal barrier. In the charter market, energy costs are typically borne by the charterer, while investment decisions are made by the owner, creating a structural misalignment of incentives that is contractual in nature (Johnson and Andersson, 2016; Kontovas and Psaraftis, 2013). Traditional charterparty forms do not adequately address the allocation of costs and benefits associated with energy efficiency improvements, thereby perpetuating the principal–agent problem. Recent legal innovations, including the relevant BIMCO Clauses (see more below) and bespoke "Green Charter" frameworks promoted by leading shipping law firms and the Comité Maritime International (CMI) Decarbonisation Working Group (2023), aim to redistribute responsibility for fuel efficiency and emissions compliance more equitably between contractual parties. These developments illustrate how targeted contractual reform can act as a legal lever for overcoming structural market failures.

Despite their pervasive influence, such legal mechanisms are typically subsumed under the broad category of "institutional barriers" in the energy efficiency literature. This analytical omission obscures the causal chain through which legal design—ranging from international conventions and classification rules to private contracts and insurance frameworks—shapes economic outcomes and investment behavior. Recognizing law as a constitutive, rather than ancillary, component of the energy efficiency gap allows for a more complete understanding of the interplay between technology, economics, and governance in the decarbonisation of maritime transport.

4 Law as Enabler: Some Contractual and Regulatory Drivers of Energy Efficiency in Shipping

In the above, Sorrell et al.'s (2004) taxonomy was reinterpreted through a legal and regulatory lens, treating the legal environment as a key causal mechanism shaping whether barriers to energy efficiency arise, persist, or are overcome. In this subsection, we illustrate this argument with more concrete examples from recent contractual and regulatory practice in maritime transport, showing how law can operate as a "double-edged sword": it can create or amplify barriers, but it can also help re-align incentives and close the maritime energy efficiency gap.

4.1 Risk and regulatory uncertainty

In shipping, "risk" is not only technological or market-related (i.e. related to the cost-effectiveness and financial risk of operational and investment decisions) but heavily mediated by legal rules: contractual liability, regulatory compliance obligations, and exposure to enforcement and sanctions. Studies of barriers in shipping highlight that uncertainty over future regulation and its allocation between owners and charterers dampens incentives to invest in efficiency, even when measures appear cost-effective ex ante (Johnson and Andersson, 2016; Jafarzadeh and Utne, 2014).

The introduction of the IMO's Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) sharpened these risks: in many legacy time charterparties it was unclear which party had to ensure regulatory compliance, bear the cost of the relevant technological measures, or accept the commercial consequences of slower steaming.

To address these, the BIMCO's CII Clause for Voyage Charter Parties 2023 allows the owner/master *"to adjust course and/or to reduce speed or RPM (main engine Revolutions Per Minute)"* in order to reduce the carbon intensity of the vessel and achieve a specific CII rating. The clause protects owners against claims related to the obligation requiring the vessel to proceed by the usual/customary route and/or with utmost and/or due despatch. As the Explanatory Note makes clear, this does not provide owners with a "carte blanche" to operate their vessel at any (low) speed: to satisfy the interests of the charterer, a minimum speed is prescribed.

Similarly, the BIMCO CII Operations Clause for Time Charter Parties 2022 helps address CII compliance in the more complicated setting of a time charter. In this type of charter, the commercial activities and employment of the ship are determined by the charterers and, traditionally, lie outside the owners' control, yet they have a direct and significant impact on the ship's carbon intensity and performance. The clause gives the owner the right to control the operation and employment of the vessel (including the planning of voyages) and sailing directions, with speed reductions again playing a central role, while protecting them against claims related to vessel underperformance. It should be noted, however, that in practice the application of these clauses remains uncertain at present, as the CII regulation is not yet strictly enforced – i.e. vessels with a low CII rating are not fined or otherwise penalised under IMO regulations. These clauses nevertheless transform diffuse regulatory uncertainty into contractually allocated compliance obligations, thus making investment timing and cost exposure more predictable.

Risk is equally pronounced in the transition to alternative fuels. The CMI International Working Group's Green Fuels discussion paper (Kruit et al., 2024) demonstrates that there is currently no dedicated international civil liability regime for incidents involving alternative fuels used as bunkers (e.g. ammonia, methanol, hydrogen), in contrast to the well-developed system for oil pollution (see the International Convention on Civil Liability for Oil Pollution Damage and the International Fund for Compensation for Oil Pollution Damage). This liability gap generates uncertainty for shipowners, charterers and insurers regarding the magnitude and allocation of potential claims in the event of an accident, thereby discouraging early investment in near-zero-carbon propulsion. The paper explicitly frames the absence of a robust compensation regime as a barrier to uptake and calls for an IMO-level solution with strict liability, compulsory insurance and direct action, mirroring the oil pollution framework (Kruit et al., 2024). This is currently under discussion at the IMO LEG Committee.

Marine insurance practice is beginning to respond to these new risks. P&I clubs and hull insurers have issued decarbonisation briefings and guidance on alternative fuels, exploring how existing pollution and liability covers apply to ammonia and methanol incidents and highlighting the need for regulatory reform (e.g. Gard, 2024; Global Maritime Forum, 2024). Parallel initiatives such as the Poseidon Principles for Marine Insurance and for Financial Institutions embed climate-alignment metrics into underwriting and lending decisions, thereby pricing regulatory and technological risk in a more transparent way and rewarding early movers that invest in compliant tonnage. The leading classification society DNV (Det Norske Veritas) reported that in 2023 alone, it served 12 ship financing banks and 2 maritime insurance providers in their Poseidon Principles reporting. In all these cases, legal instruments reconfigure risk rather than merely reflecting it, influencing both the perceived and actual risk–return profile of efficiency investments.

4.2 Imperfect information and legal asymmetry

Empirical work on the shipping energy efficiency gap repeatedly emphasises information problems: incomplete knowledge about the performance of energy-saving technologies, poor feedback on day-to-day fuel consumption, and asymmetric information between technical and commercial departments or between owners and charterers (Johnson and Andersson, 2016; Johnson et al., 2014; Bonello and Smith, 2019). In traditional time charterparties, owners have no general duty to share granular performance or sensor data, and charterers lack legally enforceable rights to real-time operational information. This contractual silence exacerbates informational barriers and weakens incentives for performance-based cooperation, such as slow steaming or weather routing. One can argue that there was traditionally a commercial rationale for owners not being very transparent with data related to, for example, fuel consumption, as this would be considered confidential and key to increasing owners' profits.

Recent clause drafting starts to correct this "legal asymmetry". BIMCO's Energy Efficiency Data Sharing Clause for Time Charter Parties (2025) grants charterers rights to use existing on-board sensors and, subject to owners' consent, to install additional sensors, while requiring both parties to share specified data on fuel consumption, speed, draught and environmental conditions, subject to confidentiality and cybersecurity safeguards. The clause was expressly designed to harness high-frequency vessel data to support operational optimisation and regulatory reporting (e.g. under IMO's Data Collection System and the EU MRV regime), thereby reducing informational opacity around energy performance.

At a more systemic level, the CMI Gothenburg discussion papers and related work on "green contracts" call for standardised digital reporting and for integrating "greenworthiness" into core charterparty doctrines such as seaworthiness and speed and consumption warranties (Diaz Cameselle, 2025). By embedding data-sharing obligations and performance metrics directly into contracts, these initiatives convert information from a discretionary managerial tool into a legally enforceable asset, lowering transaction costs for energy-efficiency services and enabling more sophisticated monitoring, benchmarking and enforcement.

4.3 Hidden costs and legal externalities

Techno-economic studies often classify certification fees, off-hire during retrofits, crew training (costs and time), or compliance documentation as "hidden costs" that reduce the apparent profitability of energy-saving measures (Jafarzadeh and Utne, 2014). In practice, many of these costs are legal in nature: survey fees, contractual disputes over off-hire entitlements, or liability exposure if modifications compromise safety or lead to off-spec performance.

Most of the relevant clauses actually help not only identify and clarify these hidden costs but also reduce legal uncertainty by clearly allocating risks. In fact, any techno-economic study (or cost-effectiveness assessment) of a decarbonisation measure should clearly incorporate what is referred to as TCO – total cost of ownership – including all these non-obvious costs, for example by monetising lost time, reputational damage, or the handling of environmental externalities, which we discuss below.

The Green Fuels discussion paper goes further by highlighting a category of “legal externalities”: social costs associated with accidents involving alternative fuels that are not internalised because current liability regimes do not fully cover personal injury and property damage risks linked to such fuels. The absence of a dedicated regime for alternative fuels means that victims may face under-compensation, and shipowners may confront unpredictable liability exposure. This misalignment between social and private costs is itself a barrier to investment in alternative-fuel technologies and, indeed, in many energy-efficiency measures. Proposals to extend or complement existing regimes to cover alternative fuels, or to put a “cost” on heavily polluting fuels (see, for example, the discussion around the EU ETS or the IMO net-zero framework), are therefore not only about environmental justice but also about correcting a hidden-cost distortion that hampers the decarbonisation of the industry.

4.4 Access to capital and the legal structuring of finance

Access to capital is a well-documented barrier to energy efficiency improvements in shipping, especially for smaller owners and for higher-CAPEX technologies (Rehmatulla and Smith, 2015; Longarela-Ares et al., 2020). In the last decade, however, the barrier has increasingly been shaped by legal instruments that tie finance to environmental performance. The Poseidon Principles for Financial Institutions (2019) commit signatory banks to measure and disclose the climate alignment of their shipping portfolios relative to IMO decarbonisation trajectories, and to integrate this information into credit decisions. In effect, they create a soft-law standard under which inefficient vessels risk facing higher margins, tighter covenants, or even capital rationing.

Empirical evidence suggests that these legal innovations are beginning to bite, albeit unevenly. Using a dataset of shipping loans, Fricaudet et al. (2024) show that banks—especially Poseidon Principles signatories—have started to reward borrowers with better corporate climate scores with lower loan margins after the Paris Agreement, with an estimated 4 per cent lower margin for the best performers compared with the worst. However, they find no systematic margin differentiation at the level of individual ships' carbon intensity, underscoring that current legal frameworks still operate largely at the portfolio or company level rather than directly privileging highly efficient assets. Soner (2025), using a fuzzy-cognitive-mapping approach to the Poseidon Principles, similarly concludes that voluntary disclosure frameworks can steer portfolios over time but may be insufficient, without supporting regulation, to generate the strong price signals needed for large-scale investment in zero-carbon vessels.

Similarly, the Sea Cargo Charter extends this logic to chartering decisions by requiring signatories to assess and disclose the climate alignment of their chartering portfolios. Together, these frameworks blur the traditional distinction between "green" public law and "neutral" private finance: contractual covenants and disclosure duties now function as quasi-regulatory levers that channel capital towards more efficient ships. In this way, future access to capital becomes contingent on legal classification of projects as sustainable, not solely on their discounted cash flows.

4.5 Split incentives and contractual-law solutions

The split-incentive problem—where the party enjoying the benefits is not the same as the party investing in efficiency—is perhaps the most prominent barrier in the shipping literature and has been widely studied (Kontovas and Psaraftis, 2013; Rehmatulla and Smith, 2015; Jafarzadeh and Utne, 2014). This is clearly manifested in time charterparties: owners bear capital expenditure for retrofits and newbuilds, while charterers control operations and fuel bills. Traditional charterparties internalise neither the climate externality nor the fuel-efficiency benefit, instead incentivising "sail fast, then wait" operational patterns through laytime and demurrage rules.

As discussed in more detail under the risk category, recent contractual innovations directly attack this misalignment. BIMCO has published several clauses to be added to charterparties to clearly allocate the risks and benefits; see, for example, the CII Clause for Voyage Charter Parties 2023, the CII Operations Clause for Time Charter Parties 2022, the Virtual Arrival Clause for Voyage Charter Parties 2013, and the Just in Time Arrival Clause for Voyage Charter Parties 2021.

A growing body of literature further suggests standardised clauses that build in cost-sharing for retrofits, performance-based hire adjustments, and "eco-speed" provisions that hard-wire slow steaming and just-in-time arrival into charterparty obligations (IMarEST, 2011; CMI Green Contracts papers; Diaz Cameselle, 2025). The interested reader is referred to Rebelo (2024) and the CMI "Green Contracts" discussion paper on the role of private contract law in addressing split incentives.

4.6 Bounded rationality and institutional complexity

Sorrell's category of bounded rationality is highly salient in shipping, where decision-makers must navigate a dense web of international, regional and private standards: IMO instruments (MARPOL, EEDI/EEXI, CII), EU measures (ETS, FuelEU Maritime), flag-state implementing legislation, and a rapidly evolving ecosystem of voluntary initiatives and contractual clauses. The cognitive and organisational burden of tracking, interpreting and reconciling these overlapping regimes can itself deter investment, especially when future stringency and interaction effects (e.g. between EU ETS and IMO measures) remain uncertain (Flodén, 2024; HFW, 2023).

Finally, Table 2 illustrates these legal manifestations, their sources, and associated legal remedies, and in doing so illustrates that bridging the maritime energy efficiency gap is as much a matter of legal design and institutional coordination as it is of technology and economics.

Table 2. Barriers, Legal source and potential solution approach.

Barrier (Sorrell et al., 2004)	Examples of Legal Source or Manifestation	Examples from Maritime Practice	Emerging Legal / Contractual Solutions
Risk	Legal uncertainty over allocation of compliance responsibility and liability for non-performance under new IMO and EU decarbonisation regimes.	Ambiguity in responsibility for compliance with EEXI and CII standards; risk of non-performance disputes between owners and charterers.	**BIMCO EEXI Transition Clause (2021)** and **CII Operations Clause (2022)** define cooperation and risk allocation; **Poseidon Principles for Marine Insurance (2021)** and Lloyd's (2023) "green underwriting" guidelines integrate regulatory risk into insurance pricing.
Imperfect Information	Asymmetric information and lack of contractual data-sharing obligations between shipowners and charterers; insufficient transparency in emissions reporting.	Charterparties often omit requirements for sharing fuel-consumption data or voyage performance; discrepancies between IMO DCS and EU MRV systems.	**BIMCO Energy Efficiency Data Sharing Clause (2025)** mandates reciprocal disclosure; **CMI Gothenburg Papers (2023)** propose global standards for digital emissions data reporting; MRV–DCS harmonization initiatives under IMO/European Commission.
Hidden Costs	Legal transaction costs, compliance downtime, and liability exposure associated with retrofits and new technology certification.	Costs of off-hire periods during retrofits; class re-certification after EEXI modification; uncertainty in coverage for alternative fuel risks.	**BIMCO EEXI Transition Clause** provides cost-sharing framework for retrofits; **Gard (2024)** and **Swedish Club (2023)** insurance endorsements clarify liability for ammonia/methanol propulsion; legal recognition of retrofit downtime as "agreed off-hire."
Access to Capital	Legal eligibility and regulatory recognition of green investments under financial law and ESG frameworks.	Exclusion of inefficient vessels from "green portfolios"; uncertainty regarding sustainability classification of maritime loans.	**Poseidon Principles (2019)** and **Sea Cargo Charter (2020)** integrate IMO-aligned efficiency metrics into loan covenants;; ship finance contracts include sustainability-linked covenants.
Split Incentives	Contractual separation of investment cost (shipowner) and operational benefit (charterer); legal barriers to cost recovery.	Owners bear cost of efficiency retrofits, while charterers capture fuel savings; restrictive charterparty terms prevent operational cooperation.	**BIMCO CII Operations Clause (Time Charters) or CII Clause for Voyage Charters** allocates operational duties; **EEXI Clause** defines cost-sharing for modifications; **CMI (2023)** advocate standard clauses integrating fuel efficiency targets and cost recovery; contractual templates embed energy performance terms.
Bounded Rationality	Legal and institutional complexity across multiple regulatory regimes leading to uncertainty and delayed decision-making.	Overlapping IMO, EU, and flag-state requirements; inconsistent enforcement; difficulty assessing long-term legal implications of technology choices.	**CMI Decarbonisation Working Group (2023)** developing uniform interpretation principles for IMO measures; regulatory harmonization reduces decision complexity; legal clarity as a remedy to institutional bounded rationality.

5 Conclusions and Future Research

This paper revisits the maritime energy efficiency gap by placing law and regulation at the centre of the analysis, rather than treating them as a neutral backdrop to economic and technological forces. Building on Sorrell et al.'s (2004) taxonomy of barriers, it argues that familiar obstacles such as risk and uncertainty, imperfect information, hidden costs, access to capital, split incentives and bounded rationality all have distinct legal manifestations. Legal rules and institutions do not simply "sit behind" markets; they structure incentives, define information rights and obligations, allocate risks and rewards, and thereby shape whether cost-effective abatement measures are implemented in practice.

The analysis shows that law operates as a "double-edged sword". On the constraining side, legal ambiguity over future standards, liability regimes for alternative fuels and the allocation of regulatory compliance between owners and charterers inflates perceived risk and discourages long-term investment. Fragmented reporting regimes and weak data-sharing duties exacerbate information asymmetries and reduce the scope for performance-based cooperation. Existing liability conventions, designed around conventional oil-based bunkers, leave gaps for incidents involving alternative fuels, creating legal externalities: social costs are not fully internalised, yet potential private liability is unpredictable. Access to capital is also filtered through legal frameworks such as sustainable finance taxonomies and disclosure rules, which determine which projects qualify as "sustainable" and on what terms they can be financed.

At the same time, the paper highlights numerous ways in which law already functions as an enabler of energy efficiency and decarbonisation. Recent BIMCO clauses on EEXI, CII, data sharing, virtual arrival and just-in-time arrival demonstrate how standard-form contracts can be used to allocate compliance obligations, share retrofit costs, embed data flows and partially resolve owner–charterer split incentives. Initiatives such as the Poseidon Principles and the Sea Cargo Charter show how voluntary but legally operationalised frameworks connect access to debt and charter opportunities to climate-alignment metrics. Emerging concepts such as "greenworthiness" and zero-fuel-readiness frameworks suggest that core notions of private maritime law (e.g. seaworthiness, due dispatch, fitness for purpose) may evolve to incorporate environmental performance and decarbonisation norms. These developments underscore that narrowing the energy efficiency gap is as much a question of legal design and institutional coordination as of technology and economics.

The paper draws several implications for policy and practice. Public regulators at IMO, EU and national level should explicitly consider the contractual transmission channels of new decarbonisation measures and, where appropriate, support them with soft-law model clauses and interpretative guidance. For banks and insurers, the findings suggest the need to move from portfolio-level climate alignment to more granular, asset-level incentives that better reward highly efficient and transition-ready vessels. For market participants and their advisors, the message is that contract drafting is itself a decarbonisation strategy: reliance on unmodified legacy forms likely perpetuates barriers, while "green" clauses can help manage transition risk, capture fuel savings and improve access to capital.

Finally, the paper outlines a research agenda that treats law as a constitutive part of the energy efficiency problem rather than a residual "institutional" factor. Priorities include: empirical evaluation of how specific clauses and finance frameworks affect behaviour and investment; doctrinal work on the evolution of private-law concepts under decarbonisation pressures, including liability regimes for alternative fuels; integrated modelling that incorporates legal variables into techno-economic analyses; comparative and multi-level studies of regulatory coherence across jurisdictions; and interdisciplinary research on how firms' internal governance and cognitive frames mediate the impact of legal change. Overall, the paper argues that meaningful progress on maritime decarbonisation requires not only better technology and stronger price signals, but also deliberate legal engineering.

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