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Research article

Flickering guiding light from the International Maritime Organisation's policy mix

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ABSTRACT

The maritime shipping sector is one of the hard-to-abate sectors in need of policy guidance for enabling sustainability transitions. Through the lens of policy mix characteristics, specifically consistency and comprehensiveness, we analyse the development of the global policy mix, implemented by the International Maritime Organisation, for reducing ship emissions, and its technology implications regarding ship-owners' choice of propulsion technology. We elaborate on conceptualisations of policy mix consistency and comprehensiveness, which allow for an improved understanding of the role of policy in transition processes. Our empirical analysis indicates that although the sector has one main regulator, the overall policy mix lacks consistency and comprehensiveness, as the implemented instruments are insufficient to achieve set emission reduction targets. Furthermore, the design of the regulatory framework creates a technological lock-in on fossil fuels and there are insufficient incentives for ship-owners to invest in sustainable technology.

1. Introduction

Sustainability transitions are complex processes in need of support for development of new, sustainable technologies as well as destruction of current, unsustainable systems (Turnheim and Geels, 2013). Policy has been pointed out as playing a key role in enabling such transitions, if providing a clear direction for the changes required to reach sustainability targets and compliance with the Paris Agreement (Markard, 2018; Weber and Rohracher, 2012). However, within the field of sustainability transitions there is a need for a better understanding of the impact of policies on the direction and speed of transitions (Markard et al., 2012). In order to fill this research gap, the concept of 'policy mixes' has been introduced in the sustainability transitions literature during the last decade (Flanagan et al., 2011; Kern et al., 2019; Kern and Howlett, 2009; Rogge et al., 2017). Policy mixes include three building blocks: policy elements (policy strategies and instruments), policy processes and policy mix characteristics (Rogge and Reichardt, 2016). However, previous empirical research on the role of policy mix characteristics is limited to a small handful of papers (Costantini et al., 2017; Reichardt and Rogge, 2016; Rogge and Schleich, 2018; Sanz-Hernández et al., 2020). Thus, while empirical policy mix analyses map e.g. the development of policy instruments over time, they rarely analyse the historical development of policy mix characteristics (Kivimaa and Kern, 2016). Responding to this gap, in this paper we focus on the role of policy mix consistency and comprehensiveness,

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building upon the conceptual framework for policy mix characteristics proposed by Rogge and Reichardt (2016). The analytical focus lies on the development of consistency (how well different parts of the policy mix fits together) and comprehensiveness (how extensive the policy mix is) of the global policy mix for air emissions from ships since the implementation of the first international regulations in 2005.

Certain sectors, such as aviation, the steel industry and the maritime shipping sector, are considered particularly difficult to decarbonise (Bauer et al., 2022; Davis et al., 2018). Although being promoted as the most eco-friendly form of transportation, the shipping sector currently accounts for around 3% of global greenhouse gas (GHG) emissions, however, with increasing global trade, emissions are expected to increase (IMO, 2020a). Even if energy efficiency gains have been accomplished (Bouman et al., 2017), the majority of the global fleet continue to run on fossil fuels (Endresen et al., 2007). Following the Paris Agreement and further COP climate negotiations, the latest IPCC report, and recently implemented international emission standards, the shipping industry is now under pressure to decarbonize (IMO, 2020a; UNFCCC, 2015). Up until recently, global emission regulations and standards for the shipping sector have been focused on air polluting substances (such as sulphur and nitrogen emissions), failing to regulate the increasing GHG emissions. With the introduction of the International Maritime Organisation's (IMO) Initial GHG Strategy (released in 2018), GHG emission reduction targets for the global shipping sector have been formulated for the first time and new regulations are coming into force, as the shipping industry is now under pressure to decarbonize. However, this process is complicated due to the complexity of IMO as a member state-led organisation, as all new environmental and climate regulation is negotiated by member states with different level of ambition (Baumler et al., 2021; Bows-Larkin, 2014).

Apart from the development of new sustainable propulsion technologies, there is a need for investigating societal challenges and opportunities for the implementation of such technologies. Earlier research on sustainability transitions within the shipping sector has for example focused on socio-technical scenarios for future fuels (Köhler, 2020), differences between shipping segments (Bergek et al., 2021; Mäkitie et al., 2022), national technological innovation systems for low- and zero carbon fuels for coastal shipping (Bach et al., 2020, 2021), and the role of ports in driving decarbonisation of the shipping sector (Bjerkan et al., 2021, 2021). However, global policy and its effects remains an understudied topic. Being an international sector, the shipping sector is regulated on several governance levels, from the subnational to global. The main regulatory framework for maritime transport is governed by the IMO, an UN agency, which has jurisdiction in all international waters, in contrast to national and regional regulations. Since the Kyoto Protocol from 1997 stated that IMO and the International Civil Aviation Organisation (ICAO) should be responsible for regulating GHG emissions from shipping and aviation respectively, the IMO has been repeatedly pointed out as the most suitable body to regulate GHG emissions from ships given the international character of the sector. A sector having one main regulator provides an interesting case for investigating policy mix characteristics, as it can be assumed that this setting provides favourable prerequisites for achieving an effective policy mix. Although the IMO has historically mainly implemented regulatory and standard setting policy instruments, introduction of other types of instruments are being negotiated as mid- and long-term measures to fulfil the emission reduction targets in the IMO GHG Strategy.

In this article, we focus specifically on policy mix comprehensiveness and consistency. Given the limited work on the topic, our aim is to elaborate on the conceptualisation and operationalisation of comprehensiveness and consistency at the levels of instrument mix, policy strategy, and the overall policy mix. We subsequently apply this framework to analyse the development of consistency and comprehensiveness of the global policy mix regulating ships' air emissions. This allows us to explore potential technology implications of the policy mix characteristics regarding implementation of propulsion technologies. Consequently, in addition to the aim of elaborating on the conceptualisation of comprehensiveness and consistency, we seek to answer the following two empirical questions where the latter is more exploratory given the lack of existing work on policy mix characteristics:

- How has the level of consistency and comprehensiveness of the IMO policy mix for shipping emissions developed since its initial implementation?
- What are the technology implications of the consistency and comprehensiveness of the policy mix for ship's propulsion technologies?

The paper is structured as follows: in the next section the conceptual framework is outlined, followed by the methodological approach in section three. Our findings and analysis are presented in section four, before summarising the main findings in a concluding discussion.

2. Conceptual framework

The concept of 'policy mixes' has gradually been introduced in the sustainability transitions literature during the last decade to better understand the impact of policies and policy processes on the direction and speed of transitions (Flanagan et al., 2011; Kern et al., 2019; Kern and Howlett, 2009; Rogge et al., 2017). Weber and Rohracher (2012) highlight the need for specific policy instruments addressing different types of failures that hinder sustainability transitions. In response to this, Rogge and Reichardt (2016, p. 1620) propose an "extended, interdisciplinary policy mix concept", as an analytical framework for sustainability transitions, based on three building blocks: policy elements, policy processes, and policy mix characteristics. These characteristics have a potential important impact on the success of a policy mix (Rogge, 2019; Rogge and Reichardt, 2016) and they thereby *"matter for sustainable innovation"* (Rogge, 2019, p. 175). In fact, it is central to the extended policy mix concept to not only map instruments, strategies and processes, but to also describe the attributes of the entire mix, for example to consider relations between instruments and strategies (Howlett and Rayner, 2007).

Despite the ascribed importance of policy mix characteristics, little empirical work is centred on understanding their implications for transition processes. The existing previous research suggest that a high degree of comprehensiveness (understood as the extensiveness of the policy mix) promotes policy mix effectiveness and efficiency, leading to increased levels of innovation (Costantini et al., 2017), while, conversely, less comprehensive policy mixes promote the status quo (Sanz-Hernández et al., 2020). In this way, lack of comprehensiveness reduces innovation, but Reichardt and Rogge (2016) find that these effects may be mediated by other policy mix characteristics such as credibility. In terms of policy mix consistency (understood as the degree of alignment of the policy elements), previous research assumed that a higher degree of consistency increases the efficiency of policy mixes (Howlett and Rayner, 2007). Supporting this, empirical studies indicate that consistency has positive effects on both investments in development and uptake of innovation (Reichardt and Rogge, 2016; Rogge and Schleich, 2018). Similarly, Uyarra et al. (2016) demonstrate how constant changes to a policy mix create inconsistencies that impede private sector investments in innovation.

Thus, while some empirical studies have considered policy mix characteristics, there is a disconnect between the importance ascribed to them in the literature and actual empirical research focusing on them. An explanation for this is *"challenges [in] the operationalization and measurement of such characteristics"* (Rogge, 2019, p. 178), which may hinder our ability to reach consolidated insights on the role of policy mix characteristics. Consequently, in this paper, we focus on two of the characteristics (consistency and comprehensiveness) with the aim of improving their conceptualisation and operationalisation. Below, we link consistency and comprehensiveness to the policy elements of policy strategy and instrument mix as well as the overall policy mix. Policy strategy consists of objectives, such as long-term emission targets, and principal plans (describing how to achieve the objectives). The instrument mix consists of individual instruments of different types (such as economic, regulatory and soft instruments) targeting creative and destructive processes interacting with each other. The combination of the policy strategy and the instrument mix is referred to as the overall policy mix.[1]

2.1. Policy mix comprehensiveness

Rogge and Reichardt (2016) suggest analysing the degree of policy mix comprehensiveness in order to explore how extensive and exhaustive the instrument mix is in addressing market, system and institutional failures, and whether policy strategies include objectives and principal plans linked to instruments.[2] They furthermore suggest to categorise instruments according to a typology including three primary instrument purposes (technology push, demand pull and systemic) and three primary instrument types (economic, regulatory and soft). However, previous operationalisations of comprehensiveness, especially for the policy strategy and overall policy mix, are scarce. Previous studies analysing instrument mix comprehensiveness follow Rogge and Reichardt's (2016) typology in its full extent (Costantini et al., 2017), or only apply the distinction between technology push, demand pull and systemic instruments (Reichardt and Rogge, 2016; Rogge and Dütschke, 2018; Rogge and Schleich, 2018). Although the concepts of technology push and demand pull are well established in the literature (Di Stefano et al., 2012), we found that the introduction of systemic concerns lacks operationalisation in the empirical studies referenced above. We agree that it is important to include systemic concerns in the assessment of comprehensiveness, however, given the lack of previous operationalisation of 'systemic instruments', we do not follow the suggested typology for primary instrument purposes of Rogge and Reichardt (2016). Rather, we apply Kivimaa and Kern's (2016) framework differentiating between creative and destructive processes and suitable instruments targeting these (see below).

Furthermore, Meissner and Kergroach (2019) point out that the framework introduced by Rogge and Reichardt (2016) distinguishes comprehensiveness as different than the completeness of the instrument mix, implying that the analytical focus should be on assessing the capacity of the policy mix to address the market, system and institutional failures it was designed to solve. However, this conceptualisation of comprehensiveness closely resembles an assessment of the overall fit of the policy mix, which arguably also depends on other policy mix characteristics. In our opinion, it is crucial that assessment of the overall policy mix comprehensiveness is not confused with evaluation of the overall policy mix performance.

Thus, we suggest a different approach to assessing policy mix comprehensiveness. We distinguish between comprehensiveness at three levels: policy strategy, instrument mix and overall policy mix (see Fig. 1). We suggest that *policy strategy comprehensiveness* depends on the breadth of policy topics covered and the policy objectives' level of concretisation. The breadth of policy topics depends on the extent to which the policy strategy addresses all relevant themes given the analytical focus. As the current paper focuses on air emissions, this implies that the policy strategy's comprehensiveness depends on how many air polluting substances and GHGs are addressed by the policy strategy, compared to the type of emissions identified by previous research as constituting all emissions from ships (see Section 3.3). Furthermore, we argue that assessing the degree of concretisation of policy objectives over time (Cashore and Howlett, 2007), such as gradual inclusion of more specific targets for GHG reduction, is a good indicator for evaluating the degree of comprehensiveness.

Instrument mix comprehensiveness is evaluated based on what types of policy instruments are included in the mix. This analysis includes the distinctions between instruments targeting creative and destructive processes, and between regulatory, economic and soft instruments. An ideal instrument mix for a sustainability transition should include elements of 'creative destruction', meaning instruments supporting the creation of new sustainable technologies, solutions and regimes, as well as instruments limiting the old, unsustainable systems (Kivimaa et al., 2017; Kivimaa and Kern, 2016; Rogge and Johnstone, 2017). This argument reflects that sustainability transitions also require destabilisation of existing socio-technical configurations (Turnheim and Geels, 2013), in

[1] In the definition of Rogge and Reichardt (2016), the overall policy mix also includes policy processes, which we, however, do not analyse in the current paper.

[2] Rogge and Reichardt (2016) also describe comprehensiveness of policy processes, which we, however, do not consider in this article.

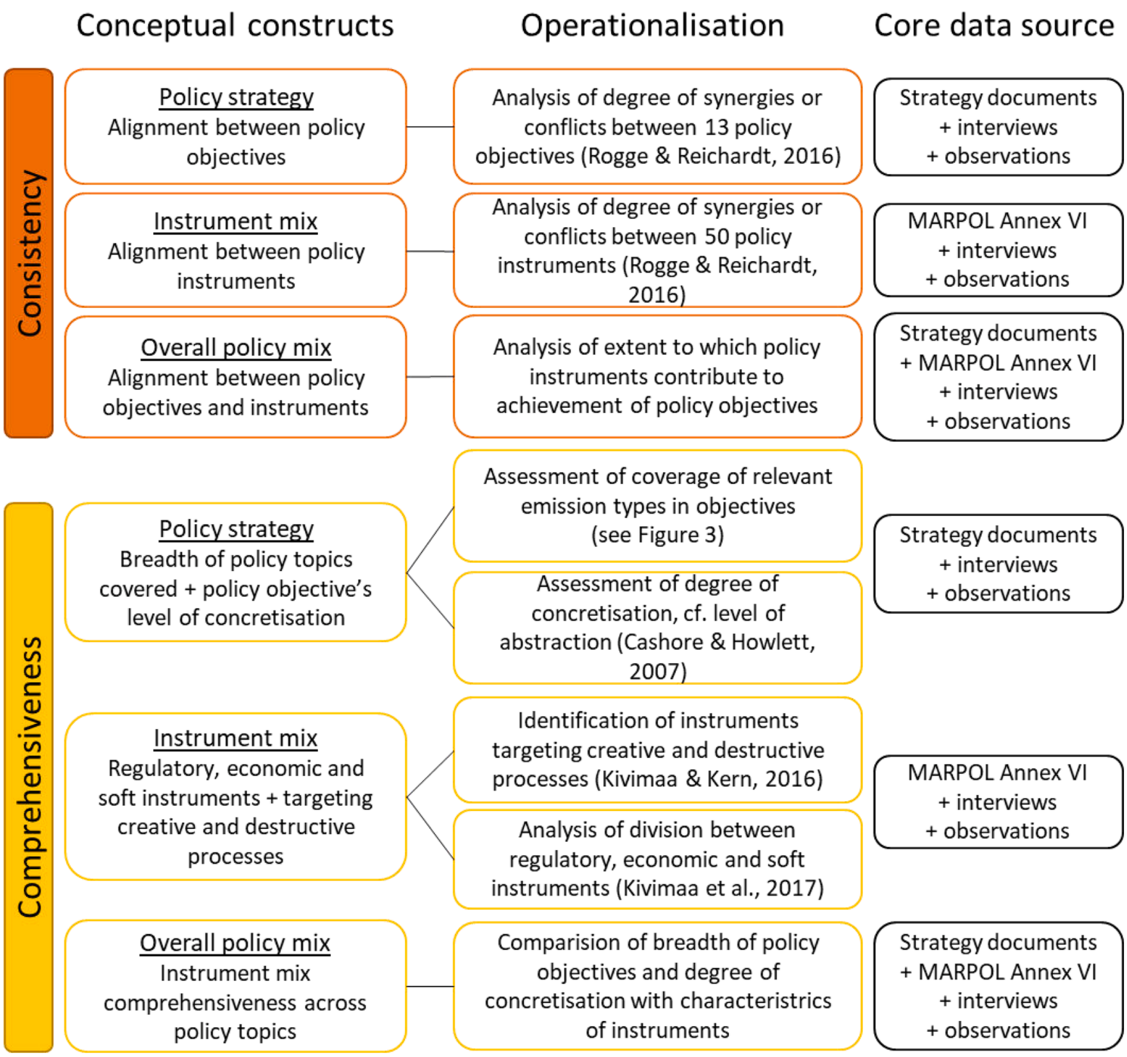

Fig. 1. Operationalisation of central conceptual constructs.

particular as transition processes progress from the emergence to the acceleration phase (Markard, 2018). We follow the framework Kivimaa and Kern (2016) introduced to suggest defining instruments targeting creative and destructive processes, see Table 1.

Furthermore, a balance between regulatory (based on laws and binding regulations), economic (provision of pecuniary incentives and disincentives) and soft (voluntary measures and information provision) instruments (see Table 2) increases the effectiveness of policy mix implementation (Borrás and Edquist, 2013; Rogge and Reichardt, 2016; Schmidt and Sewerin, 2019). As pointed out by Borrás and Edquist (2013), the complexity of innovation processes[3] implies that a portfolio of instruments are needed to address different challenges, and soft instruments may target issues that regulatory and economic instruments cannot attend to. Following this, the comprehensiveness of the instrument mix is assessed based on the distribution of instruments included in the mix, i.e. the use of regulatory, economic and soft instruments, as well as the use of instruments targeting creative and destructive processes and the categories of creative and destructive processes covered.

For example, an overall policy mix that include policy topics each operationalised by a single type of instrument and/or a single category of creative and destructive processes, would be assessed as intermediate comprehensive. Finally, *overall policy mix comprehensiveness* depends on the extent to which policy objectives are addressed by a broad portfolio of policy instruments, and the level of concretisation of policy objectives over time. The overall policy mix is evaluated as fully incomprehensive if policy topics in the policy strategy are not addressed by any instruments, and if objectives lack concretisation. A fully comprehensive overall policy mix should include several types of instruments (regulatory, economic and soft instruments) and instruments targeting creative and destructive processes. The policy instruments should operationalise each policy topic included in the policy strategy, as well as concrete objectives

[3] And, we would argue, to an even greater extent transition processes.

Table 1
Overview and examples of policy instruments included in the respective categories of instruments targeting creative and destructive processes. Partly adapted from Kivimaa and Kern (2016).

Focus of policy	*Examples of policy instruments*
Targeting creative processes	
C1 Knowledge creation, development and diffusion	Innovation platforms and other policies aimed at knowledge creation and diffusion through networks, educational policies, training schemes, reference guidelines for best available technology, progress and status reports (such as the IMO GHG studies)
C2 Establishing market niches/market formation	Market-based policy instruments such as certificate trading, feed-in tariffs, labelling
C3 Price-performance improvements	R&D support (cost reductions through learning)
C4 Entrepreneurial experimentation	Relaxed regulatory conditions for experimenting, goal-based regulations
C5 Resource mobilisation	Financial: R&D funding Human: educational policies, labour-market policies, secondment of expertise
C6 Support from powerful groups/ legitimation	Innovation platforms, foresight exercises, and labelling to create legitimacy for new technologies, practices and visions
C7 Influence on the direction of search	Goals set and framing in strategies, targeted R&D funding schemes, goal-based regulations, tax incentives, voluntary agreements, technical performance standards, fuel standards
Targeting destructive processes	
D1 Control policies	Regulation and taxes such as bans, carbon emission trading schemes, pollution taxes or a global CO_2 tax to put economic pressure on current regimes. Banning certain technologies is the strongest form of regulatory pressure (e.g. carrying non-compliant fuel onboard)
D2 Significant changes in regime rules	Policies constituting, for example, structural reforms in legislation or significant new overarching laws, such as the first regulations of GHG emissions through an energy efficiency index
D3 Reduced support for dominant regime technologies	Withdrawing support for selected technologies, e.g. removing requirements to only use fuels derived from petroleum refining
D4 Changes in social networks, replacement of key actors	Balancing involvement of incumbents for example in policy advisory councils with niche actors (such as giving more organisations working with sustainable shipping consultative status to the IMO), formation of new organisations or networks to take on tasks linked to system change

Table 2
Overview and examples of policy instruments included in the respective categories of regulatory, economic and soft instruments Partly adapted from Kivimaa et al. (2017) and Rogge and Reichardt (2016).

Regulatory Instruments	Ban, performance standard, mandatory certification and labelling
Economic Instruments	Tax incentives, subsidies, feed-in tariffs, trading systems, public procurement, R&D funding
Soft Instruments	Voluntary measures (such as certification and labelling), information and advice, education programs

for each policy topic. The spectrum between a fully comprehensive and fully incomprehensive overall policy mix holds several constellations of to what extent the instrument mix supports the policy strategy, as well as the degree of concretisation of policy objectives. These constellations are all categorised as intermediate comprehensiveness.

We argue that specifying the policy topics that the instrument mix should address provides an improved understanding of the comprehensiveness of a policy mix, compared to Rogge and Reichardt's (2016) suggested generic assessment based upon if each policy objective is operationalised by at least one policy instrument (of any type).

2.2. Policy mix consistency

In previous literature, consistency is described as the degree of alignment between the policy mix elements, *"thereby contributing to the achievement of policy objectives"* (Rogge and Reichardt, 2016, p. 1626). The consistency of policy mixes is divided into three levels (see Fig. 1): consistency of the instrument mix, consistency of the policy strategy, and overall policy mix consistency (Rogge, 2019; Rogge and Reichardt, 2016).

The first level of consistency, *consistency of the instrument mix* as presented in the extended framework refers to the interaction between the individual policy instruments. A consistent instrument mix, theoretically speaking, consists of instruments that complement each other in the effects they create, thereby reinforcing each other by creating synergies (Kern and Howlett, 2009; Rogge and Reichardt, 2016). Conversely, an inconsistent instrument mix implies that certain instruments within the mix are undermining each other. Weak consistency, in contrast, refers to the absence of contradictions between policy instruments, in this case, meaning instruments that relate to different objectives, which can be achieved simultaneously (Rogge and Reichardt, 2016).

The same principles for inconsistency, weak or strong consistency, apply to the second level of consistency – *consistency of the policy strategy*, which refers to the possibility of reaching several policy objectives at the same time (Kern and Howlett, 2009). Identification of significant negative trade-offs between policy objectives implies that the policy strategy is inconsistent. During assessment it is also important to acknowledge potential trade-offs between policy targets (Rogge and Schleich, 2018), implying that strong consistency occurs when there are existing synergies between policy objectives, which do not cause significant trade-offs. If there are trade-offs resulting in the undermining of certain policy objectives the policy strategy should be categorised as inconsistent. Weak consistency of the policy strategy, in contrast, indicates that there are no contradictions between policy objectives (Rogge and Reichardt, 2016).

The third level of consistency, *overall policy mix consistency*, is determined by the degree of alignment between the instrument mix and the policy strategy. Strong consistency of the overall policy mix is described as the policy instruments and policy strategy working together, in the same direction, enabling the achievement of the policy objectives (Howlett and Rayner, 2013).

3. Methodological approach

3.1. Introducing the case

Research on policy mix characteristics, like the majority of sustainability transitions research, has been empirically focused on national or regional case studies and national policy mixes. International shipping provides an interesting case for policy mix characteristics research as it is regulated by one international body, the International Maritime Organisation (IMO), through member state negotiations. Since ships (with some exceptions[4]) have to comply with the rules decided upon by the IMO at all times, the international regulatory framework provides the main regulatory setting for the shipping sector, similar to ICAO for the aviation industry. In theory, this implies that given the sole regulatory body, a consistent and comprehensive policy mix for the shipping sector should be possible, and perhaps more likely than for an industry regulated by multiple actors. Furthermore, IMO regulation of air polluting substances has proven to be very effective, as for example the implementation of a limit for sulphur content in ship fuel has resulted in a 77% reduction of sulphur oxides emissions (Offshore Energy, 2022), indicating the potential of effective regulation also of GHG emissions.

In general, policy mixes for sustainability transitions interact with several policy domains, such as industrial, innovation and environmental policy. Consequently, different rationales, targets and policy styles may result in inconsistency within the policy mix (Jochim and May, 2010; Nykamp, 2020). As the focus of this article is on the characteristics of the international policy mix, only policy implemented by the IMO is included. The IMO is an UN agency with 175 member states, and consists of the Assembly, the IMO Council, and five main technical committees with related sub-committees (see Fig. 2). Although regulations from several IMO committees potentially have an impact on the emissions to air from ships,[5] the main regulatory framework regarding air emissions is administered by IMO's Marine Environment Protection Committee (MEPC) through the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, which will be the focus for this study. Historically, the instruments implemented through MARPOL Annex VI have mainly been regulatory and standard setting policy instruments, however, there is no hinder for the IMO to implement other types of policy instruments. For example, introduction of market-based measures, i.e. economic instruments, are currently being negotiated in relation to the IMO GHG Strategy.

Decisions around implementation of new policy are made in the respective committees, and are preceded by legislative proposals submitted by member states and/or organisations with consultative status (such as the International Chamber of Shipping, BIMCO, and WWF - in total 81 organisations). Proposals are discussed during committee meetings (in the case of the MEPC, held around every six months) until the member states reach consensus (based on agreement between at least 50% of the member states) or decide to abandon the proposal. If voting is necessary, each member state has one vote. Agreed upon measures are implemented in the MARPOL convention, and come into force in all nations which have ratified the convention after the set implementation date. Compliance with the regulation is controlled by the member states through random checks by so-called port state controls. If the port state control reveals non-compliance, the ship is detained and cannot leave port until the issue has been fixed, resulting in increased costs and delays. However, this system is dependant on all nations ratifying IMO conventions and updates to them, as well as conducting proper port state controls, implying that the monitoring and enforcement powers of the IMO are limited as this responsibility is delegated to individual states and there is currently no monitoring of compliance in international waters.

The process for implementing regulations of emissions to air through MARPOL Annex VI was initiated in parallel with the Kyoto Protocol negotiations in 1997, and the first policy instruments were implemented in 2005 after lengthy discussions within the MEPC regarding the type and level of regulation. Although the Kyoto Protocol points out that the shipping industry is accountable for decreasing the sector's GHG emissions, none of the climate agreements over the years have provided binding reduction targets. Following this, the majority of GHG emissions from the shipping sector is not directly included in the Paris Agreement, as it is based on 'Nationally Determined Contributions' excluding international shipping and aviation. However, the Paris Agreement, the Sustainable Development Goals and generally increasing societal attention to climate change mitigation still put pressure on the shipping sector to decarbonise.

3.2. Methods and material

In order to analyse the level of comprehensiveness and consistency for the global policy mix regarding air emissions from ships, we have collected data in two stages through document analysis, observations and semi-structured interviews. Thereby, we combine the

[4] Smaller ships (below 500 gross tonnes) and military ships are excluded from international regulation. Although 38 % the global fleet in 2020 consisted of small ships, these only represented 1 % of the global cargo capacity, and the majority of small ships are only operating nationally (Equasis, 2022). National policy may include regulation also for smaller ships, as for example in Norway where public procurement contracts for car- and passenger ferries include emission requirements (Bach et al., 2020), however, these regulations only have jurisdiction within national waters and do not apply to international shipping.

[5] For example, safety standards and extensive knowledge about the impact on the ocean environment of a fuel leakage involving an alternative type of fuel (such as hydrogen or ammonia) are currently lacking, which is a barrier for the implementation of new types of marine fuels.

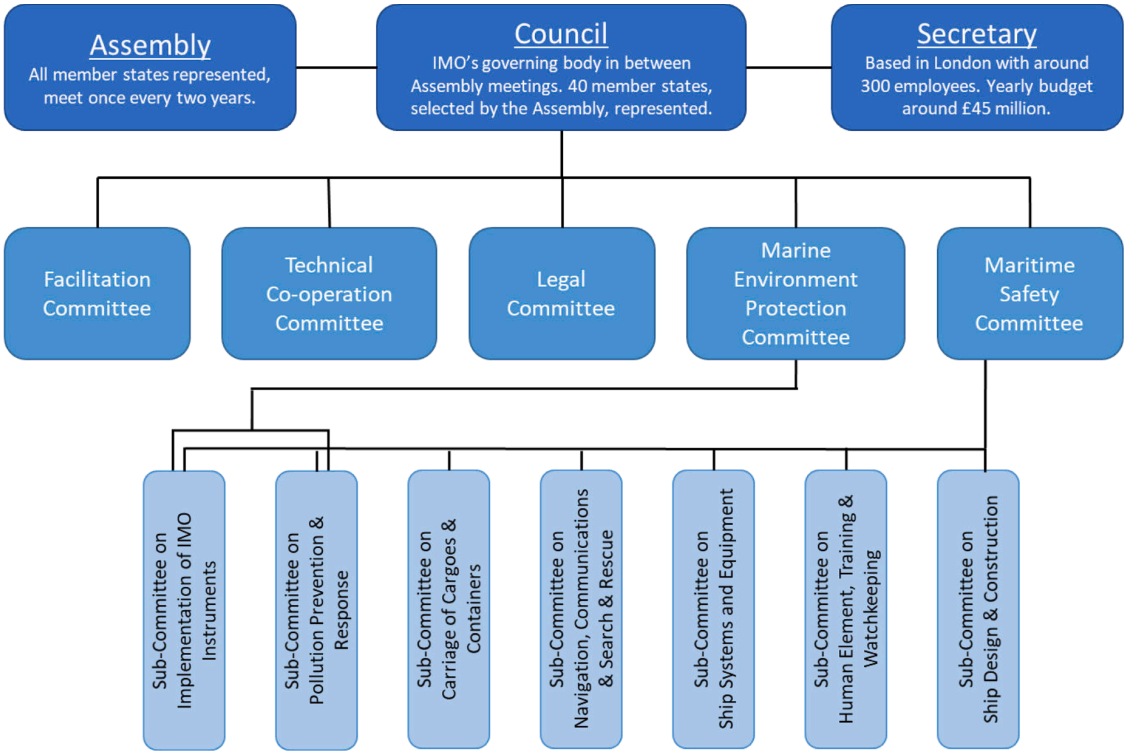

Fig. 2. Overview of IMO's organisational structure (IMO, 2022a, 2022b; Psaraftis and Kontovas, 2020).

two methodological approaches for operationalising policy mix characteristics suggested by Rogge and Reichardt (2016), to either derive such characteristics by analysing policy mix elements, or through collecting stakeholders perceptions about the specific characteristics. First, we conducted a document analysis to map the policy mix elements and outline timelines of the development of the instrument mix as well as the policy strategy. Mapping of individual policy instruments (in total 50) were done by going through the legislative text for MARPOL Annex VI, as well as resolutions and amendments indicating updates to the regulatory framework. The four IMO GHG Studies were also included as policy instruments although these studies are not measures included in MARPOL Annex VI, however, they function as a knowledge base for the work on developing specific instruments within the IMO MEPC (IMO, 2020b). All individual instruments were coded in NVivo (see Appendix A for the full codebook) with the type of air emission they are regulating (policy topic, broadly categorised as climate change and air pollution), and type of the policy instrument (targeting creative or destructive processes; regulatory, economic or soft instrument), to enable assessment of the comprehensiveness of the instrument mix. As basis for the assessment of instrument mix consistency, each instrument was coded for existing synergies or conflicts with other instruments at the time of its implementation (see Table 3 for examples). The policy instruments were also coded for implementation year, if they are a replacement or addition to an earlier instrument, and extracted to create a timeline of the development of the instrument mix.

The identified policy instruments were triangulated by comparing our database with flag state summaries of new regulation (aimed at informing ship-owners) published through the entire time period, and observational data from 24 webinars provided by for example the classification society DNV (see Appendix B for a complete list). In addition we asked our interviewees to review an overview of identified instruments (see Appendix C).

The empirical data for the document analysis of the policy strategy included strategy documents published by the IMO, see Appendix B, from which 13 policy objectives were identified. To enable assessment of the policy strategy's level of consistency, each policy objective was coded to identify synergies or conflicts with other policy objectives at the time of its implementation. In addition, policy objectives were coded according to policy topic(s) covered, and for degree of concretisation to enable assessment of the comprehensiveness of the policy strategy (see examples in Table 4). The coding of policy instruments and policy objectives also provided the basis for assessment of overall policy mix consistency and comprehensiveness according to the operationalisation scheme in Fig. 1.

Second, the main purpose of the observations and semi-structured interviews were to gain insights regarding the technology implications of the development of the policy mix characteristics. In total, eight persons were interviewed, right after the MEPC's 76th meeting in June 2021, where the first short term measures for GHG reduction were adopted. The interview persons include representatives from ship-owners, ship-owner associations, a national maritime authority, a classification society, as well as IMO. On average, the interviews lasted 60 minutes, and followed a semi-structured interview guide based on the conceptual framework as well as the result of the document analysis (see Appendix C for the full interview guide and a list of interview persons). The interviews were

Table 3
Examples of coding of policy instruments. Regarding synergies, the other instruments (for example 10.17) can be found in Appendix D.

Policy Instrument	Global Sulphur Cap: sets the limit for maximum sulphur content in ship fuel and prohibits use of fuel with higher sulphur content	International Energy Efficiency Certificate: mandatory certificate for ships over 400 gross tonnes validating the ship's Energy Efficiency Design Index
Implementation year	2005 (stringency increase in 2012 & 2020)	2013
Policy Topic	Air pollution; Sulphur Oxides (SO_x)	Climate change; Energy Efficiency
Target of policy instrument: creative and/or destructive processes	Destructive; D1	Creative; C7
Type of policy instrument: regulatory/economic/soft instrument	Regulatory; ban	Regulatory; mandatory certification
Conflicts	No	No
Synergies	Yes; 10.17; 10.22; 10.23; 10.24; 19.42; 20.46 (see Appendix D)	Yes; 13.30; 13.31; 13.32 (see Appendix D)

Table 4
Examples of coding of policy objectives. Regarding synergies, the other policy objectives (for example PO4) can be found in Appendix D.

Policy Objective	Contributing to international efforts to reduce atmospheric pollution and address climate change, by contributing to the achievement of the Millenium Development Goals and relevant outcomes of UNCSD 2012, including through the development of major projects targeting emerging issues	To reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008 levels
Implementation year	2012 (repeated in 2014 & 2016)	2018
Policy Topic	Air pollution Climate change	Climate change: CO_2
Conflicts	No	No
Synergies	No	Yes; PO4; PO7; PO8; PO9, PO10; PO11; PO13 (see Appendix D)
Degree of concretisation	Low	High

transcribed and coded in NVivo following the conceptual framework as well as identified additional themes. Included direct quotes have been accepted by the interviewees.

3.3. Boundaries and limitations

As indicated in the conceptual framework (see Section 2.1.1), the assessment of the breadth of policy topics regarding the policy strategy comprehensiveness is based on the types of emissions from ships that have been identified by previous research including air polluting substances as well as GHG emissions (see Fig. 3) .[6] If policy objectives did not specifically address air pollution or GHG emissions, but rather more general themes connected to air emissions from ships, these were categorised as "Sustainability and environmental protection".

4. Findings

Our empirical analysis reveals two major turning points for the IMO's air emissions policy mix since the implementation of MARPOL Annex VI in 2005. First, the introduction of the initial energy efficiency regulations in 2012 was an early attempt to regulate GHG emissions from ships. Second, the adoption of the Initial IMO GHG Strategy in 2018 (scheduled to be updated in 2023) marks a substantial shift in policy focus from air pollution to climate change. These serve as a basis for categorisation of three time periods (2004–2011, 2012–2017, and 2018–2023) for which we have analysed and compared the development of consistency and comprehensiveness of the policy strategy, instrument mix and the overall policy mix. This comparison, as well as technology implications following the policy mix characteristics in each period, is presented in the following sections.

4.1. Consistency and comprehensiveness in period 1 (2004–2011)

4.1.1. Policy strategy

The three identified policy objectives for the first period are generally formulated, focusing on environmental protection and sustainability, indicating a low level of concretisation (see Fig. 4). For example, the following objective was present in all High Level Action Plans in period 1: "IMO will focus on reducing and eliminating any adverse impact by shipping on the environment by: develop

[6] Following a mission from the IMO, the IMO GHG Studies are performed by a team of researchers from various universities and research institutes. These studies are the most comprehensive evaluations of emissions from ships to date.

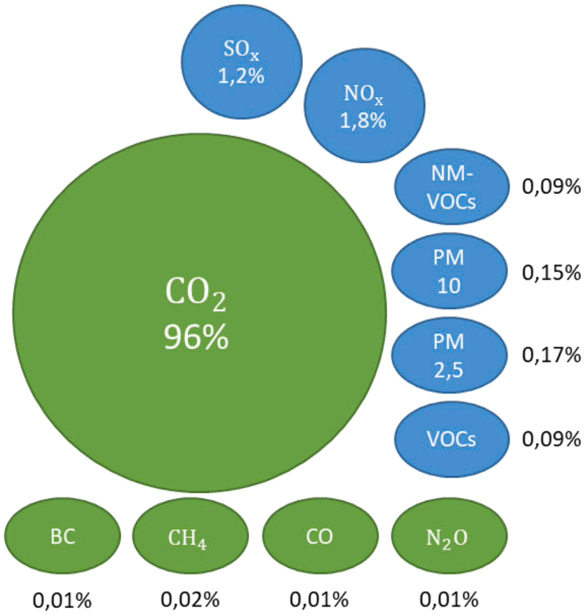

Fig. 3. Overview of type and share of emissions to air from ships in accordance with the emissions inventory in the Fourth IMO GHG Study (IMO, 2020a). Blue = air polluting substance, green = GHG, CO_2 = carbon dioxide, SO_x = sulphur oxides, NO_x = nitrogen oxides, NMVOCs = non-methane volatile organic compounds, PM = particle matter, VOCs = volatile organic compounds, BC= black carbon, CH_4 = methane, CO = carbon oxide, N_2O = nitrous oxide.

effective responses to shipping incidents in order to mitigate their impact on the environment". Although no specific policy objectives were identified as devoted to climate change and reduction of GHG, a resolution adopted in 2003, A.963(23) on "IMO policies and practices related to the reduction of GHG emissions from ships", indicates the formal starting point of the process to regulate GHG emissions. This resolution urges the Marine Environment Protection Committee (MEPC) to start developing regulation of GHG emissions.

Given that there are no contradictions between the general policy objectives, and no indication of existing synergies, the policy strategy is assessed to have *weak consistency*. Since the policy objectives are formulated in a generic way, and given the lack of specific objectives concerning air pollution or GHG during the majority of the time period, the policy strategy at this time is seen as *incomprehensive*.

Placing the focus on environment during period 1 in a larger context, several respondents connected the societal debate on environmental problems to work within the IMO: *"If you think about it, where was the debate as a society on decarbonisation in the early 2000′s? It was about air quality, it is just a reflection of where society was at. The priorities then was cleaning up air pollution. It is only in the last few years that we have started focusing on removing carbon."* explained a representative from the International Chamber of Shipping. However, already the Kyoto protocol from 1997 points out that shipping needs to take responsibility for its GHG emissions, which is not reflected in the policy strategy for period 1. The same is the case for the Copenhagen Accord agreed upon in 2009, which states the long-term goal to limit global warming to maximum 2°C compared to pre-industrial levels.

4.1.2. Instrument mix

Differing from the policy strategy, the instrument mix during period 1 had a clear focus on air polluting substances. Initially, the main focus of the instrument mix was to regulate sulphur emissions. A global sulphur cap of 4.5% mass by mass (m/m) was introduced 2005, and the implementation of the first two Sulphur Emission Control Areas (SECAs) in the Baltic and North Sea (requiring max 1.5% m/m sulphur content in ship fuel) followed in 2006 and 2007. Furthermore, there was an initial focus on ozone depleting substances (ODS) and to a certain extent NO_x within the instrument mix. The second IMO GHG Study was published in 2009, presenting updated statistics for air emissions from ships. Amendments of MARPOL Annex VI came into force July 1st 2010 (for further details see Appendix D), implementing additional instruments and stricter requirements for SO_x, ODS, NO_x and VOCs, thereby reinforcing earlier instruments. For example, instruments reinforcing the Global Sulphur Cap implemented in 2005, are rules appointing the responsibility for the sulphur content of the fuel to the fuel producer, and that each nation should support fuel producers in making compliant fuel available. In addition, the sulphur limit within SECAs was lowered 0.5 percentage-points in 2010, and in 2011, the North American SECA was implemented, regulating emissions of SO_x as well as PM, which further sharpened regulation of sulphur. Furthermore, requirements for NO_x emissions were sharpened for new engines, and engines manufactured before 2000 were included in the requirement levels implemented in 2005. Given the main focus on regulating air polluters, and especially SO_x, as well as how instruments reinforce each other, the instrument mix during this time period is assessed to have *strong consistency*.

A majority of the instruments implemented during this first period, except for the GHG studies, are *Control policies* (D1) and

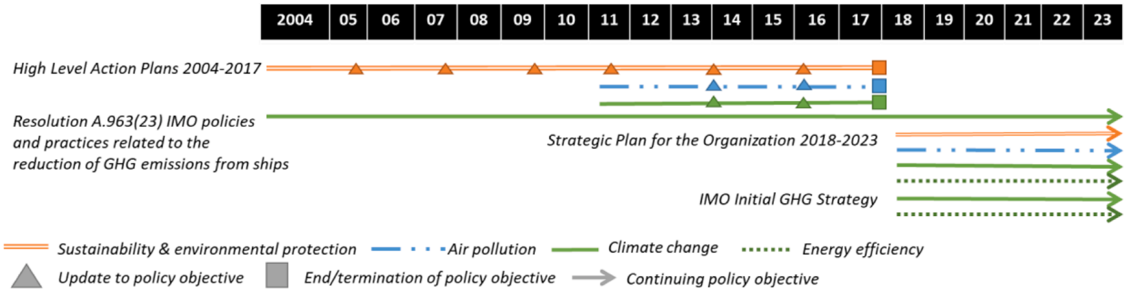

Fig. 4. Overview of policy topics included in the policy strategy.

categorised as regulatory instruments (including bans, performance standards, mandatory certificates and other regulations, see Appendix D for details). The second largest categorgy is *Influence on the direction of search* (C7), including regulatory (such as requirements for the fuel supplier to document the sulphur content) and soft instruments (for example instructions to member states to promote the availability of compliant fuel). Some instruments, such as the SECAs, are categorised as both control policies (D1) and influence on the direction of search (C7) as the instrument both includes a ban for using non-compliant fuel, as well as indicates that decreasing sulphur emissions close to the coast is of great importance to reduce local air pollution. Although a majority of the instruments target destructive processes, only control policies are used (see Fig. 5). To guarantee effectiveness of control policies they would need to be complimented with other instruments targeting destructive processes (D2, D3 and/or D4) to create an effective policy mix (Kivimaa et al., 2017). Also given the limited variety of instruments targeting creative processes, the lack of economic instruments, and that there is only one soft instrument (the GHG studies, C1) addressing climate change, the instrument mix during period 1 is therefore assessed as *incomprehensive*.

4.1.3. Overall policy mix

Given that the policy strategy and the instrument mix have such different focus, with the policy strategy focusing on environmental protection and sustainability in general while the instrument mix has a strong focus on regulating air pollution, the overall policy mix is assessed to be *inconsistent*. Furthermore, implemented instruments are not sufficient to reach the policy objectives, which further adds to decreasing the consistency. The lack of policy objectives specifically addressing air pollution, represents a mismatch between the large number of instruments regulating air polluters and the policy objectives. Following this, the overall policy mix is evaluated as *incomprehensive*.

4.1.4. Technology implications

Following the incomprehensiveness and weak consistency of the policy strategy in the first period, there is a lack of clear long term

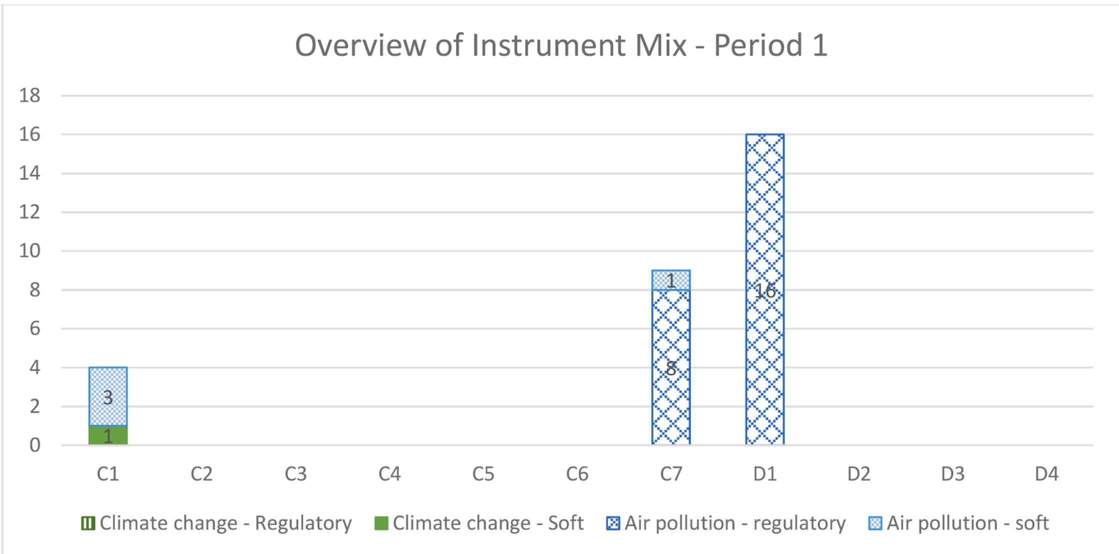

Fig. 5. Overview of the instrument mix by instrument type and instruments targeting creative and destructive processes, for air polluting substances and GHG emissions respectively. Note that some instruments target both creative and destructive processes, so the total number of instruments is lower than represented in the figure.

visions for decreasing emissions. Instead, it is the characteristics of the instrument mix, especially the strong consistency following the focus on regulation of air pollution, which steer technology developments towards decreasing SO_x and NO_x emissions. For example, the formulation of the global and regional sulphur caps opened up for installation of scrubbers[7] as a way of complying with sulphur limits while continuing to use fuel with a high sulphur content. This has contributed to increased GHG emissions (as the operation of the scrubber increases the fuel consumption) (Zis and Psaraftis, 2019). In addition, allowing the use of scrubbers to comply with sulphur regulation further reinforce the technological lock-in regarding conventional fossil fuels, and has potentially slowed down the transition to low-sulphur fuels.

Regarding regional effects, stricter SECA regulations had a positive impact on the emission patterns within these areas, as well as the development of low-sulphur fuel markets. These measures also had a large impact on the industry. A representative from the ship-owner Stena Line expressed "*The SECA regulation in 2015 had a much bigger impact on Stena Line than the global limit on 0.5%. The uncertainty of fuel availability and the cost increase of switching to 0.1% had a bigger impact on the business than the global switch to 0.5%.*". Furthermore, according to our respondents, the strong focus on air polluting substances, and specifically SO_x and NO_x, initiated work within the shipping industry to investigate liquefied natural gas (LNG) as a ship fuel. *"It was tough when the sulphur rules came here in Northern Europe, and it led to that there were several ship-owners who started to think not just about sulphur emissions but also about other coming regulation, mainly NO_x, which led to large investments in LNG by many ship-owners."* said a representative from the Swedish ship-owners association Sweship. Although LNG contributes to less CO_2 emissions, it is still a fossil fuel, and this further indicates a technological lock-in on fossil fuels within the shipping sector.

4.2. Consistency and comprehensiveness in period 2 (2012–2017)

4.2.1. Policy strategy

The single policy objective identified for period 2 remains unspecific, however, it includes clear connections to air pollution as well as climate change: "Contributing to international efforts to reduce atmospheric pollution and address climate change". As stated in the High Level Action Plans, this should be done through "contributing to the achievement of the MDGs[8] and relevant outcomes of UNCSD 2012, including through the development of major projects targeting emerging issues." (IMO, 2011, p. 5) Although there are no contradictions within this policy objective, the general formulation and lack of indications for existing synergies points to the policy strategy still having *weak consistency*. Regarding the level of comprehensiveness, it slightly increases as climate change and air pollution as policy topics are addressed in the policy strategy for the first time. However, since the policy objective have a very low level of concretisation it is still rather *incomprehensive.*

The formulation of the policy objective in period 2 relates to the general debate and UN negotiations around reduction of air pollution and GHG emissions more clearly than in period 1, given the specific reference to achieving the Millennium Development Goals.[9] However, especially in relation to the Copenhagen Accords and later the Paris Agreement from 2015, the continued lack of quantified targets for the shipping sector in period 2 shows a discrepancy in terms of ambition, which is mirrored in the continuously increasing GHG emissions from the shipping sector.

4.2.2. Instrument mix

With the introduction of the Energy Efficiency Design Index (EEDI), the International Energy Efficiency Certificate (IEEC) and the Ship Energy Efficiency management Plan (SEEMP) in 2013, IMO made its first attempt at regulating GHG emissions from ships. The implementation of the EEDI regulation (categorised as performance standards and thereby regulatory instruments) represents the introduction of instruments targeting destructive processes concerning climate change, in the form of a *significant change in regime rules* (D2) as this is the first measure targeting the operation of a ship with regard to energy efficiency. However, there were no actual EEDI requirements in force until 2015, and these requirements only applied to newly constructed ships of certain sizes within specific segments.[10] In addition, the IEEC and SEEMP are the first (and still only) instruments aimed at *influence on the direction of search* (C7) with regard to climate change mitigation. However, although the IEEC is a mandatory certificate, it does not (as other certificates aimed at reducing air pollution do[11]) require yearly surveys to ensure compliance, implying that this is a less stringent instrument than corresponding instruments targeting air polluting substances. Our respondents shared stories about how negotiations around implementing more stringent GHG emission reduction measures (for example market based measures) stranded in 2009–2010, and how discussions became focused on energy efficiency instead: *"For GHG it was hampered by the politics, it was made into an energy efficiency index in the first run – because that was less controversial than a* CO_2 *index, politically it was more acceptable.*" explained an official from the classification society DNV.

Furthermore, the global sulphur cap decreased from 4.5% to 3.5% m/m from 2012, and the sulphur limit within SECAs was

[7] Installation for after treatment of exhaust gas to remove sulphur emissions.

[8] Millennium Development Goals

[9] In later versions of the High Level Action Plans, this formulation is changed to "achieve the Sustainable Development Goals"

[10] EEDI rules only apply to bulk carriers, gas carriers, tankers, container ships and refrigerated cargo carriers above 5 000 GT.

[11] The shipping sector is regulated by several mandatory certificates. The standard design of these certificates (such as the International Air Pollution Prevention Certificate) includes yearly surveys of equipment or performance standards, resulting in a prohibition to leave the current port if the survey reveals non-compliance. As seen in Appendix D, other certificates following the standards design has been categorised as control policies (D1) and regulatory instruments.

lowered to 0.10% m/m in 2015 – a year after the introduction of a fourth SECA located in the US Caribbean Sea. As of 2016, compliance with NO_x Tier III is required within the North American and US Caribbean Sea ECAs, making them SECAs as well as NECAs. During this period, instruments aimed at LNG ships were implemented, dual-fuel engines were included in the NO_x Technical Code in 2015 and the International Air Pollution Prevention (IAPP) certificate became mandatory for gas-fuelled ships in 2016. There are synergies between instruments addressing air pollution, for example, the stricter sulphur limits within ECAs and inclusion of dual-fuel engines and gas fuelled ships in certifications. We found no indication of synergies between instruments addressing climate change and air pollution respectively. As the implementation of the new instruments introduced during this period does not counter-act instruments within the previous instrument mix, the level of consistency remains the same – *strong consistency*. Similarly to the first period, regulatory instruments targeting destructive processes is still the dominant category. Although the number of instruments targeting creative processes slightly increases and the instrument mix now includes instruments aimed at *influence on the direction of search* (C7) for climate change, and a supplementary category (D2) of instruments targeting destructive processes are implemented (see Fig. 6), there is still a lack of economic instruments as well as other instruments targeting creative and destructive processes apart from C1, C7, D1 and D2. Therefore, the instrument mix for period 2 is assessed to have intermediate comprehensiveness.

4.2.3. Overall policy mix

The level of comprehensiveness for the overall policy mix increased slightly during period 2, following the introduction of a policy objective addressing air pollution as well as climate change accompanied by an increased number of types of policy instruments. This represents a more extensive instrument mix, now also including climate change as a policy topic. However, as the majority of policy instruments are still regulatory, and still mainly targeting destructive processes, the overall policy mix for period 2 is assessed as *incomprehensive.*

The instrument mix is aligned with the policy objective since it includes instruments addressing both air pollution and climate change. Although it is difficult to assess to which extent the instrument mix enables achievement of the policy strategy due to vague formulation of the policy objective, it can be assumed that the instruments contribute to such international efforts to reduce emissions. Therefore, the overall policy mix *consistency is assessed to be strong.*

4.2.4. Technology implications

Similarly to the first period, there is a lack of clear future visions for reduction of all types of emissions to air from ships within the policy strategy. Thus it is still the characteristics of the instrument mix (strong consistency but incomprehensive) that steers technology implementation, resulting in a continued narrow focus on efforts for reducing SO_x and NO_x emissions. For example, the inclusion of LNG in the technical regulation contributed to standardisation and uptake of LNG as a ship fuel. An official from IMO explained the process: *"Basically the regulation was drafted at a time when LNG was extremely secondary and was not widely used at all. […] There was a number of concerns regarding safety, explosive risk, etc., but it was done, and it really helped also the uptake of the technology in the past few years."*. This implies further aspects of the technological lock-in on fossil fuels within the maritime sector.

The introduction of the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) as part of the first GHG regulations marks a turning point in regulation of ship emissions. However, the immediate effects of these regulations were quite limited during period 2, indicating that although there is a combination of instruments targeting creative and destructive

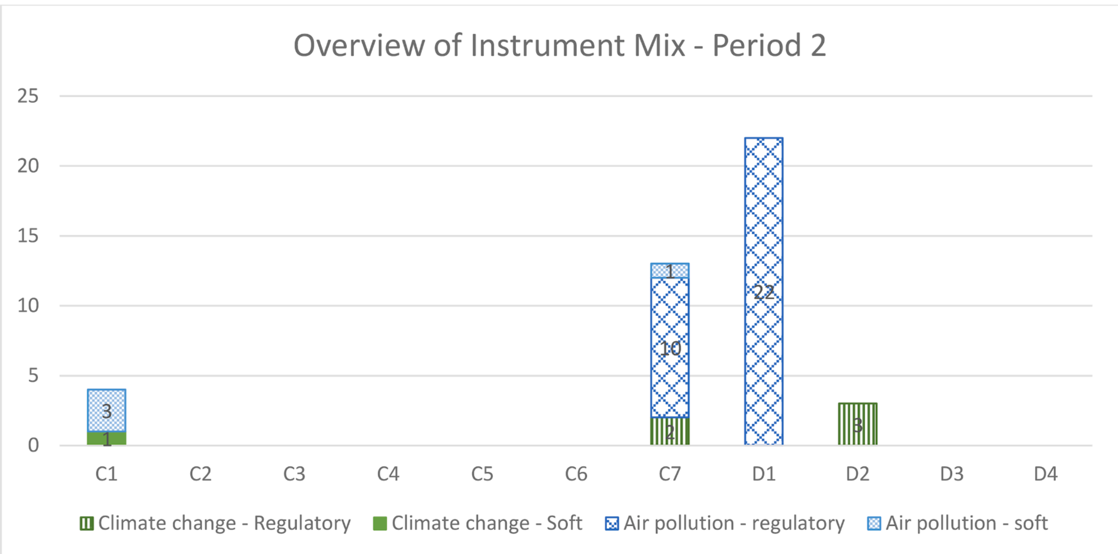

Fig. 6. Overview of the instrument mix by instrument type and instruments targeting creative and destructive processes, for air polluting substances and GHG emissions respectively. Note that some instruments target both creative and destructive processes, so the total number of instruments is lower than represented in the figure.

processes, as well as regulatory and soft instruments, the increased comprehensiveness is not enough to ensure an effective policy mix. Given that the regulation only applied to newbuilt ships of certain sizes within certain segments, a relative small number of ships were affected during the first years of EEDI regulation. Nevertheless, an uneven level of difficulty to comply has emerged between segments. According to several of our respondents, for example designing RoRo ships according to EEDI rules has been very challenging, while containerships have been favoured by the rules as even empty containers are counted as cargo when calculating the energy efficiency per transport work: *"You can calculate an empty container as two tonnes of cargo. It's empty, but it's two tonnes of cargo on the paper."* – said a representative from Sweship.

4.3. Consistency and comprehensiveness in period 3 (2018–2023)

4.3.1. Policy strategy

Period 3 includes nine policy objectives focused on different aspects of climate change – in contrast to only one objective concerning air pollution. Policy objectives regarding sustainability and environmental protection have been updated for this period, to mirror developments within other UN climate and environmental policies, such as inclusion of Agenda 2030 etc. (see Fig. 4). The Initial IMO GHG Strategy published in 2018 was pointed out as an important driver for GHG emission reduction efforts within the IMO by several of our respondents: "*The pressure from the institution itself means a lot, that they feel that they need to prove what the IMO can do. So I think that was one of the important points from adopting the initial strategy, that there was also pressure internally from the IMO organisation, that they wanted to progress on that.*" said a representative from Maersk, the world's second largest ship-owner within container shipping. With the GHG strategy, more concrete policy objectives including specific emission reduction targets and increased energy efficiency for 2030 and 2050 are introduced for the first time, which are complementing the more generally formulated overarching policy objectives aiming to for example "respond to climate change". Given these synergies between policy objectives and the absence of contradictions, the consistency for the policy strategy in period 3 is assessed as *strong*.

Even though the comprehensiveness of the policy strategy has increased since 2004, especially since 2018, the majority of current policy objectives still have very general, unspecific formulations targeting climate change and GHG in general rather than specific substances or gases. This makes it difficult to assess the degree of comprehensiveness, as a very general policy objective could be considered to cover all the related sub-categories (in this case the specific greenhouse gases included in the general climate change category, and vice versa for the air pollution category). However, following the criteria that the policy strategy should be assessed as comprehensive if it addresses all relevant policy themes identified according to the case limitations, the global policy strategy for the shipping sector is assessed as *incomprehensive*. This since it does not cover all the specific substances and gases included in the determined relevant policy themes (see Section 3.3), but only the two general themes of air pollution and climate change.

The quite drastic shift in focus from general formulations in period 2, to quantified emission reduction targets in period 3 following the implementation of the Initial IMO GHG Strategy appears to have clear connections to the Paris Agreement. Another representative from Maersk expressed: *"Honestly, I'm not sure the IMO GHG strategy would have been adopted without the Paris Agreement, it really was a driver for the IMO as well, so this was the overarching framework which gave us the direction and the principals which the IMO strategy is now based on."* However, the ambition level of IMO's targets (40% reduction of CO_2 emissions/transport work by 2030, and 70% reduction by 2050, as well as a reduction of total GHG emissions by at least 50% by 2050) is insufficient to support the Paris Agreement's 1.5 °C

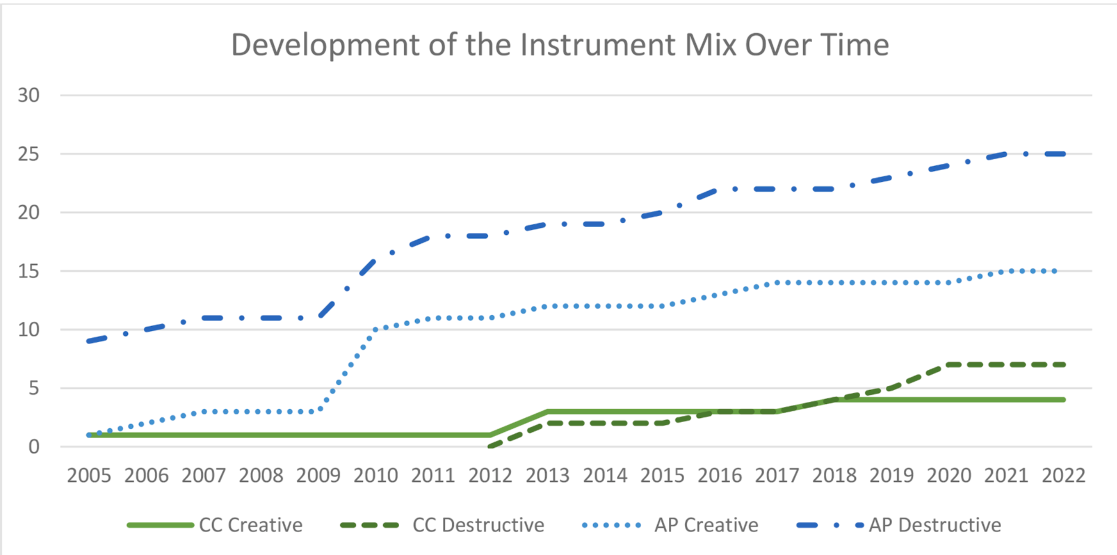

Fig. 7. Overview of the number of instruments targeting creative and destructive processes over all three time periods. CC = climate change, AP = air pollution.

target (Bullock et al., 2020). The discrepancy in level of ambition between the shipping sector and the general debate on climate change mitigation therefore remains.

4.3.2. Instrument mix

Period 3 includes a number of new and updated instruments aiming at regulation of GHG emissions from ships, implemented in two waves (see Figs. 7 and 8), as well as enforcement of a number of stricter regulations regarding air pollution. As a step towards further instruments regulating GHG emissions from ships, it became mandatory for vessels >5 000 GT to report their fuel oil consumption to an IMO database in 2018. Although not a significant measure at the time, the fuel consumption database is currently being used for calculating carbon intensity baselines for the Carbon Intensity Indicator (requiring yearly operational improvements) being implemented from 2023, which indicates reinforcement within the instrument mix as the requirements of the carbon index will be based on an already established policy instrument. This also represents a shift from a responsive form of regulation, which traditionally has been IMO's approach, to a pro-active regulatory form trying to regulate future consequences of anthropocentric climate change – rather than reacting after the damage (of an oil spill, safety accident etc.) has occurred. Furthermore, RoRo[12] ships were included in the EEDI requirements 2019, and the EEDI requirements were sharpened in 2020 when moving into EEDI Phase 2. From January 1, 2023 the energy efficiency regulations will also include existing ships.

The instrument that received the most attention during this period is the drastic tightening of the Global Sulphur Cap from 3.5% m/m allowed sulphur content in ship fuel to 0.5% m/m from 1 January 2020. In connection to the new global sulphur cap it also became prohibited to carry noncompliant fuel oil for combustion purposes on board a ship, as well as mandatory to save bunker delivery notes guaranteeing compliant sulphur levels in the delivered fuel, further indicating synergies between instruments. Furthermore, this indicates synergies between regulation of air pollution and climate change: *"Obviously this regulation aim at different goals, but to a large extent they support each other. For example, the sulphur regulation effectively increased the cost of fuel, so it is an important incentive to actually reduce ships' fuel consumption, and therefore to a certain extent worked as a market-based measure."* explained an official from IMO. These developments further strengthens the already *strong consistency* of the instrument mix.

However, even though the sulphur regulations have increased fuel costs, the current instrument mix developed during period 3 still lacks pure economic instruments. Implementation of marked based measures is currently being negotiated in relation to the IMO GHG Strategy. The official from the IMO headquarters saw no jurisdictional hinders for implementation of such instruments, he rather highlighted the lack of political consensus as the main hinder: "*The changes that are needed to support the IMO's level of ambition are such that we should not exclude any option. Carbon pricing could take different forms, the most evident one is the form of a carbon levy, there are different types of taxes, cap and trade systems. But as soon as you're talking about money it becomes extremely difficult and extremely controversial."*

Since the current instrument mix still does not include any economic instruments and remains primarily constituted by instruments targeting destructive processes (see Fig. 9), the instrument mix does not reach comprehensiveness. However, during period 3 implementation of a few specific instruments contribute to further increased comprehensiveness compared to period 1 and 2. For example, regarding climate change, the mandatory reporting of fuel oil consumption implemented in 2018 is one of the two[13] first control policies (D1) introduced for climate change, as well as the first instrument specifically targeting reduction of GHG, rather than increased energy efficiency. Although the instrument itself falls within the "regulatory" category, as the ships are required to report their fuel consumption, there is also an underlying purpose of the implementation of this policy instrument in contributing to fuel consumption statistics, thereby also contributing to *Knowledge creation, development and diffusion* (C1). However, the implementation of these additional instruments are not sufficient to reach a comprehensive instrument mix as economic instruments as well as a broader variety of instruments targeting creative and destructive processes are still missing. Therefore, the instrument mix for period 3 is assessed to have *intermediate comprehensiveness*.

4.3.3. Overall policy mix

The increased diversity in policy topics within the policy strategy are all addressed by newly implemented as well as existing instruments, indicating a more major increase in the level of comprehensiveness between period 2 and 3, than between period 1 and 2. However, there is an imbalance in the large number of instruments addressing the single policy objective concerning air pollution, and the few instruments connected with the policy objectives for climate change, GHG and energy efficiency. This indicates a shift in policy focus towards climate change, which was also confirmed by our interview data. For example, a representative from the Swedish Transport Agency expressed: *"At the beginning, the focus was on air pollution, now it's more focused on climate change. When the IMO Initial GHG Strategy was accepted, we also got an agenda item on greenhouse gases for the MEPC meetings, and now everyone is talking about greenhouse gases and climate change"*. In addition, the majority of the instruments remain to be regulatory and targeting destructive processes. There is still a lack of soft and economic instruments as well as a broader representation of instruments supporting mainly creative but also destructive processes. The overall policy mix for period 3 is therefore assessed to have *intermediate comprehensiveness.*

The more specific and ambitious policy objectives regarding reduction of GHG implemented during period 3 is to some extent supported by policy instruments, however, the current design of the instrument mix has a limited impact on the achievement of the policy objectives, especially regarding the reduction targets in the IMO GHG Strategy. There are no obvious contradictions between the instrument mix and the policy strategy, however, given the limited capacity of the current instrument mix to enable achievement of the

[12] RoRo = Roll-on, roll-off - indicating a ship type typically transporting trucks or individual trailers
[13] The other being a ban for installations containing hydro-chlorofluorocarbons.

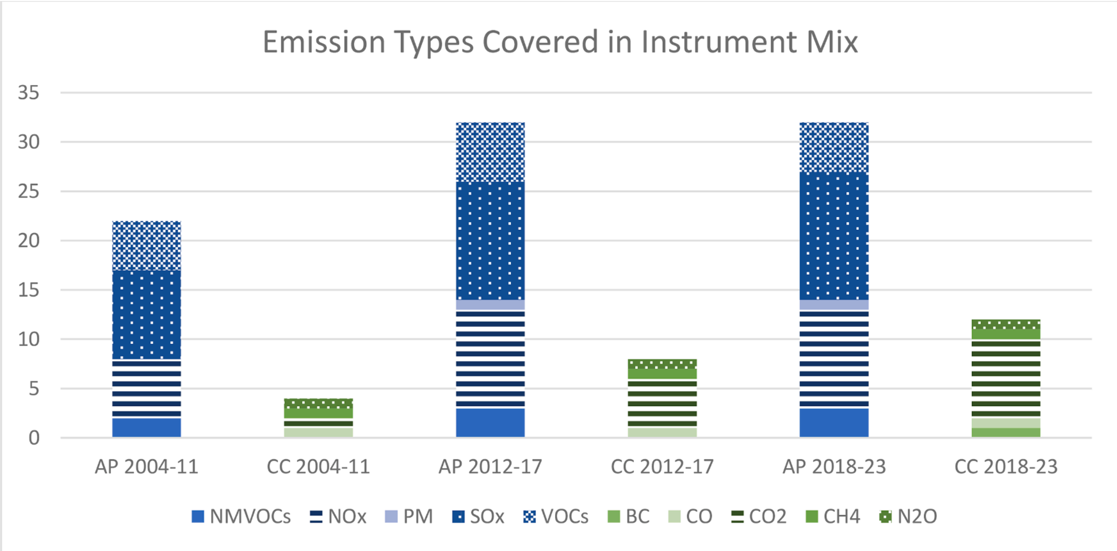

Fig. 8. Number of instruments addressing each type of emission for the respective time periods. AP = air pollution (blue colours), CC = climate change (green colours).

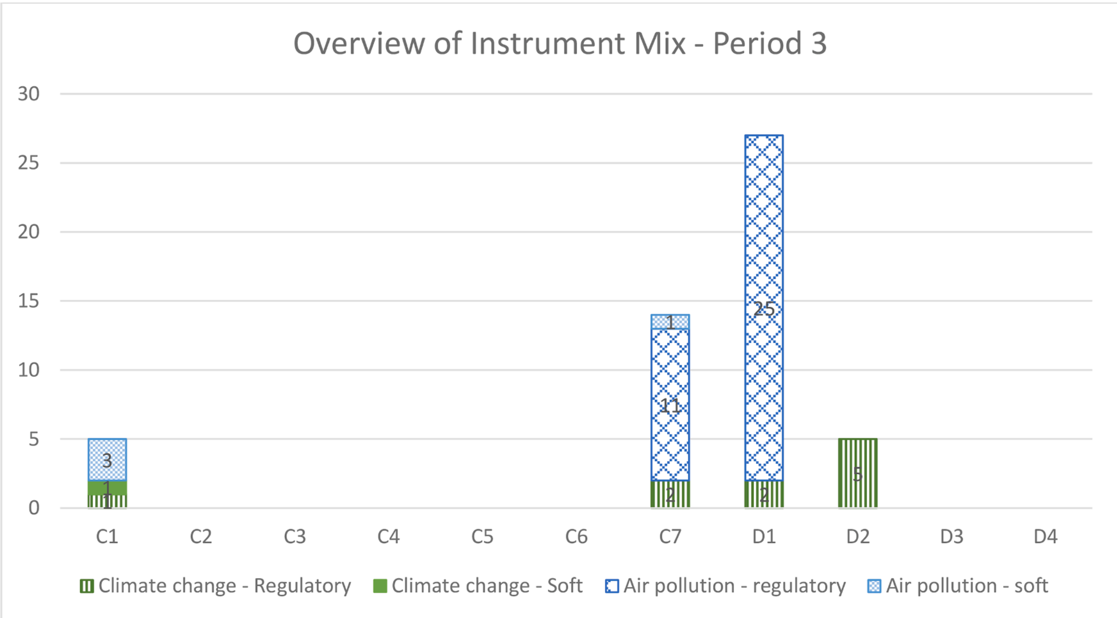

Fig. 9. Overview of the instrument mix by instrument type and instruments targeting creative and destructive processes, for air polluting substances and GHG emissions respectively. Note that some instruments target both creative and destructive processes, so the total number of instruments is lower than represented in the figure.

newly introduced, more stringent policy objectives the overall policy mix consistency decreased during the last years and is assessed to be *weak* during period 3 (see Fig. 10).

4.3.4. Technology implications

Given the limited capacity of the instrument mix to support the more diverse and concrete policy objectives in the policy strategy, the strong consistency of the instrument mix remains the strongest influence on technology choices, and the main technology implications in period 3 are similar to previous periods (see Table 5). Furthermore, the limited comprehensiveness of the instrument mix following the lack of instruments targeting creative processes and regulation of methane emissions hinders implementation of alternative technologies. For example, IMO regulation is supposedly technology neutral, however, the practical implications of the

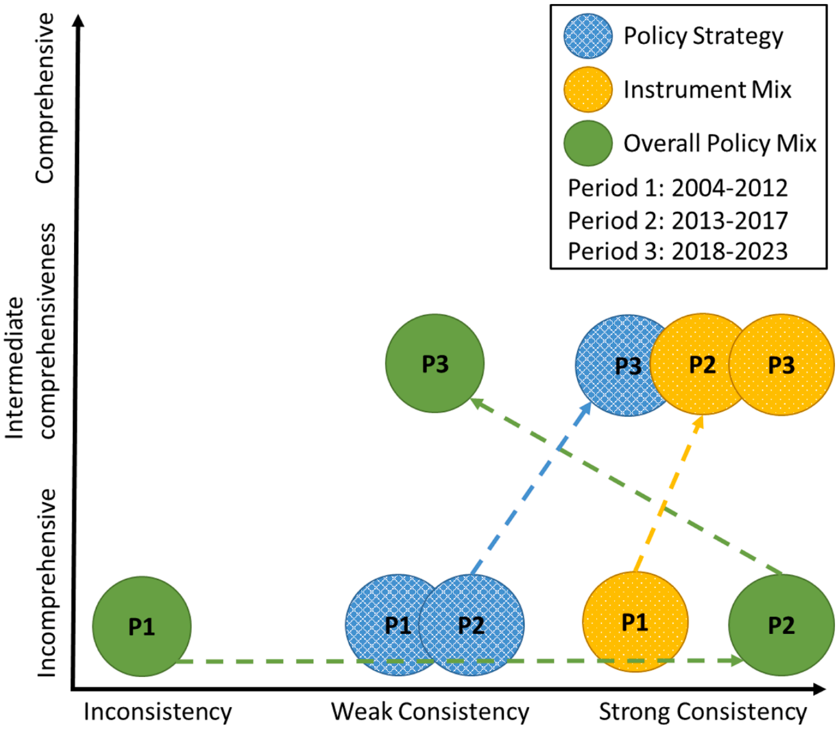

Fig. 10. Development of consistency and comprehensiveness over time.

current instrument mix in period 3 suggests otherwise. While some of our interviewees thought the regulations are still technology neutral, others expressed favouring of fossil fuels. This is partly due to the continued allowance for using scrubbers (see Technology Implications for Period 1), but also the lack of technological standards for other types of propulsion systems (such as fuel cells or electric engines) than conventional two- and four-stroke combustion, or gas, engines. This in combination with the complete lack of regulation for methane emissions while air pollution regulation has become increasingly stringent has created favourable conditions for implementation of LNG-fuelled ships. In 2021, more LNG-fuelled ships were ordered than in the previous four years combined, resulting in a total of 403 ordered ships in addition to the 251 vessels already in operation (DNV, 2022). The most recent IMO GHG Study (IMO, 2020a) found an 151–155% increase of methane emissions from ships between 2012 and 2018, adding up to 148 kt/year (IMO, 2020a). Given the exploding uptake, methane emissions will continue to increase, which is contradictory to the GHG emission reduction targets in the IMO Initial GHG strategy.

In addition, the calculations of the EEDI and the coming EEXI and CII includes an emission factor for CO_2 emissions, but such factors have not yet been developed for alternative fossil free fuels. *"When you calculate the carbon in the CII, it's just carbon, you don't look at where it comes from. And the methanol we plan to use, we want to use carbon from renewable sources but we won't get the reward for that."* said a representative from Maersk. IMO are currently working on life-cycle assessments of alternative fuels to develop emission factors, but it is unclear if this work will be finished before the EEXI and CII enters into force in 2023. The effects on technology implementation from these new regulations are yet to be seen, but insights from our interview data suggests that initially they will have a limited impact restricted to individual ships, which further indicates the negative effect of the instrument mix not being fully comprehensive. The CII includes stricter enforcement over time which could potentially be an important driver for implementation of sustainable propulsion technologies, however, reduction rates after 2026 are still not decided.

5. Concluding discussion

Policy mix characteristics such as consistency and comprehensiveness can potentially have substantial impact on a policy mix's influence on transitions to more sustainable socio-technical configurations (Rogge, 2019; Rogge and Reichardt, 2016). In this paper, we developed conceptualisations of the consistency and comprehensiveness of the policy strategy, instrument mix as well as overall policy mix, and empirically analysed IMO's policy mix regulating ships' air emissions. The shipping sector, having one main regulator, provides an interesting case for policy mix characteristics research as a consistent and comprehensive policy mix should, at least in theory, be achievable. Further, global regulation through the IMO has previously demonstrated great impact on emission reduction, as evident in the case with the strict global sulphur cap implemented in 2020, which has reduced SO_x emissions with 77% (Offshore Energy, 2022). In this concluding discussion, we present the paper's main findings, highlight policy implications, and point to future research avenues.

Table 5
Overview of the development of comprehensiveness and consistency as well as technology implications for the three time periods.

	Period 1	Period 2	Period 3
Policy Strategy	Incomprehensive Weak consistency	Incomprehensive Weak consistency	Intermediate comprehensiveness Strong consistency
Instrument Mix	Incomprehensive Strong Consistency	Intermediate comprehensiveness Strong Consistency	Intermediate comprehensiveness Strong consistency
Overall Policy Mix	Incomprehensive Inconsistent	Incomprehensive Strong consistency	Intermediate comprehensiveness Weak consistency
Technology Implications	The instrument mix's strong consistency and incomprehensiveness is the main influence on technology implications, which in combination with the regulatory focus on air pollution results in a continued lock-in on fossil fuels	The instrument mix's strong consistency and incomprehensiveness is continuously the main influence on technology implications, which in combination with the remaining regulatory focus on air pollution, as well as the lack of effect from GHG instruments results in a continued lock-in on fossil fuels	The instrument mix maintains strong consistency, but due to its incomprehensiveness it is insufficient to achieve policy strategy. Characteristics of instrument mix remain the main influence on technology implications, resulting in continued lock-in on fossil fuels and no incentives for investments in sustainable propulsion technologies

5.1. Main findings

Our conceptualisation of *comprehensiveness* highlights the importance of determining factors for the degree of comprehensiveness for all policy elements. The assessment of the level of comprehensiveness for the policy strategy includes level of concretisation of policy objectives as well as the breadth of policy topics. For the instrument mix, the assessment is based on the types of policy instruments (economic, regulatory or soft instrument) targeting creative and/or destructive processes in force. The level of comprehensiveness for the overall policy mix is determined by combining the level of concretisation of policy objectives with the extent that policy objectives are addressed by a broad range of policy instrument types targeting creative and/or destructive processes. We suggest that including level of concretisation as well as breadth of policy topics in the assessment of comprehensiveness contributes to a better understanding of the effectiveness of the policy mix.

Regarding *consistency*, we highlight the complexity in the relation between the different levels of consistency. Our findings question the suggestion that "a higher degree of first- [policy strategy] and second-level [instrument mix] consistency positively influences the degree of third-level consistency" (Rogge and Reichardt, 2016, p. 1626). Rather, the fit between the instrument mix and policy strategy determines if improved policy strategy consistency and instrument mix consistency lead to overall policy mix consistency. This further indicates the importance of analysing characteristics of all policy elements, rather than a narrow focus on policy instruments.

When analysing policy mix characteristics, it is important to not only investigate success cases, rather, it is essential to also analyse the influence of level of consistency and comprehensiveness in cases where the policy mix is not developed in the most optimal way. Our empirical analysis of the IMO's policy mix regulating ships' air emissions demonstrates that it has not managed to implement a comprehensive and consistent policy mix for regulation of GHG emissions, following a historic regulatory focus on air pollution and lack of political consensus around implementation of stricter policy instruments. Analysing the development over time, the level of *consistency* of the overall policy mix jumps from inconsistent to strong consistency between period 1 (2004–2012) and 2 (2013–2017), but then decreases to weak consistency for period 3 (2018–2023). Our analysis of the breadth of policy topics included in the policy strategy reveals a shift in policy focus from air pollution to climate change, however this shift has not (yet) trickled down to the instrument mix. Thus, while the consistency of the current instrument mix itself is strong, the instrument mix fails to support the specific emission reduction targets (resulting in decreasing consistency of the overall policy mix). In terms of *comprehensiveness*, specific attention to the inclusion of type of policy instruments in the assessment of instrument mix comprehensiveness highlights the lack of a diverse instrument mix for our case. The instrument mix mainly consists of regulatory instruments targeting destructive processes (almost exclusively *control policies*, D1), complemented by regulatory and a few soft instruments targeting creative processes (mainly C7 – *influence on the direction of search*, and a few C1 – *knowledge creation, development and diffusion*).

The policy mix' lack of consistency and comprehensiveness signifies that measures for driving implementation of alternative propulsion solutions are missing. The main technology implication is a continued lock-in on fossil fuels, partly through continued use of conventional fossil fuels, but also following the increasing use of low-sulphur fuel and LNG. Since it is possible to comply with current GHG regulation without implementing alternative propulsion technologies, there are insufficient incentives for ship-owners to invest in such technologies.

5.2. Policy implications

By applying the conceptual lens of policy mix characteristics on the global policy mix implemented by the IMO, we are able to highlight the shortcomings of global governance bodies such as the IMO, as well as changes needed to ensure necessary reductions of GHG emissions. Continuously relying primarily on regulatory instruments will not be sufficient to support decarbonisation of industries like the shipping sector. Given the discrepancy between the policy strategy and the instrument mix, and the lack of a comprehensive instrument mix, shipping is not yet on route to achieve the emission reductions outlined in the IMO GHG strategy. Further, these emission reduction targets are insufficient to live up to the sector's contribution to reach the 1.5 °C target of the Paris Agreement. Consequently, there is a need for both more ambitious policy objectives as well as a more effective instrument mix. Here we outline the main policy implications.

First, the on-going revision of the IMO GHG Strategy (due in 2023) provides a possibility for IMO to implement a policy strategy striving for emission reductions in line with the Paris Agreement. Given the urgent need for a decarbonisation of the shipping sector, this is an opportunity we strongly recommend IMO member states to act upon.

Second, the instrument mix needs to be updated and developed to include additional instrument types targeting creative and/or destructive processes as well as more stringent instruments to ensure a consistent and comprehensive policy mix able to achieve a more ambitious policy strategy. We suggest three core elements to this:

A *A need for introduction of economic instruments.* To ensure an effective policy mix, a balance between regulatory, economic and soft instruments is desirable (Borrás and Edquist, 2013; Rogge and Reichardt, 2016; Schmidt and Sewerin, 2019). Following this, there is a need for economic instruments such as a global carbon tax, emission trading scheme or R&D funding for alternative, sustainable fuels. We therefore urge delegates for the Marine Environment Protection Committee meetings to, in conjunction with the update of the GHG strategy, also further develop the instrument mix with sufficient short- and long-term measures (including implementation of market-based measures (Psaraftis et al., 2021)), to ensure a reduction of GHG emissions in line with the Paris Agreement.

B *A broadening of instruments targeting both creative and destructive processes.* Given that a focus on few categories of creative and destructive processes is insufficient to achieve an effective instrument mix (Kivimaa et al., 2017; Kivimaa and Kern, 2016), a broadening beyond policies influencing the direction of search (C7) and controlling the use of existing technologies (D1) is needed.

More disruptive instruments aimed at limiting the use of fossil fuels could include more stringent performance standards constituting *significant changes in regime rules* (D2). To support uptake of alternative, more sustainable propulsion technologies, there is also a need for further instruments targeting creative processes. This could include R&D funding, emission trading schemes and feed-in tariffs to contribute to *market formation* (C2), *price-performance improvements* (C3) and *resource mobilisation* (C5) promoting alternative solutions.

C *Updating existing instruments.* Existing instruments, such as the energy efficiency regulations, should be sufficiently stringent to actually contribute to decreasing GHG emissions and match with the ambition level of the policy strategy. Ideally, this would also include revising the enforcement mechanisms to ensure closer monitoring of compliance with the implemented regulations. Furthermore, given that methane emissions are rapidly increasing following the uptake of LNG as ship fuel, policy targets and instruments addressing methane emissions are urgently needed.

5.3. Future research

In a wider perspective, our findings highlight that even in a sector with one main regulator, achieving a consistent and comprehensive policy mix that drives innovation and implementation of more sustainable technologies is not an easy task. Previous research has identified lack of transparency of IMO negotiations (Psaraftis and Kontovas, 2020), limited organisational and financial capacity at the IMO to administer instruments such as a R&D fund, and lack of political consensus (Bach and Hansen, 2023) as factors limiting the ability of IMO to develop and implement other types of regulation. Future research could therefore devote more attention to compare advantages of different ways of organising regulation. We also see a need for further analysis of relationships between policy mix characteristics and their determinants, as well as welcome further operationalisations of the assessment of policy mix consistency and comprehensiveness. In particular, to further advance our understanding of comprehensiveness for the instrument mix as well as the overall policy mix, we see a need to consider the stringency (i.e. the level of ambition) of the policy instruments in addition to the extensiveness of instrument types (regulatory, economic and soft instruments), and instruments targeting creative and destructive processes. Furthermore, future research could explore and compare with policy mixes for other sectors with similar regulatory structures, such as aviation. Specifically for the shipping sector, there is a need for analysis of policy mixes at other spatial scales (such as national or EU) as well as multi-scalar analysis to gain a more complete picture of the policy context for international shipping.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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Supplementary materials

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