PLOS SUSTAINABILITY AND TRANSFORMATION

RESEARCH ARTICLE

# Towards a Mission-oriented Innovation Systems (MIS) approach, application for Dutch sustainable maritime shipping

**Joeri Wesseling**[1]*, **Nick Meijerhof**[2]

**1** Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, The Netherlands, **2** PNO Consultants, Utrecht, The Netherlands

* j.h.wesseling@uu.nl



OPEN ACCESS

**Citation:** Wesseling J, Meijerhof N (2023) Towards a Mission-oriented Innovation Systems (MIS) approach, application for Dutch sustainable maritime shipping. PLOS Sustain Transform 2(8): e0000075. https://doi.org/10.1371/journal.pstr.0000075

**Editor:** Ana Delicado, Universidade de Lisboa Instituto de Ciencias Sociais, PORTUGAL

**Received:** March 24, 2022

**Accepted:** July 5, 2023

**Published:** August 11, 2023



**Data Availability Statement:** Other than the publicly available data detailed in the paper's reference list, our minimal dataset includes interview data as well. In the 'interview consent document', we have promised interviewees not to publicly share their responses, after a first interviewee did not agree with publication of the transcripts due to the political sensitivity of the topic for their organization. To guarantee candid interviewee responses, we promised interviewees not to publicly share the transcripts. Deidentified transcripts can be shared upon request via the

## Abstract

This paper builds on the literature on mission-oriented innovation policy, governance, transition studies and innovation systems, and develops a structural-functional approach to formatively evaluate mission governance from a Mission-oriented Innovation Systems (MIS) perspective. Central to this MIS approach is the mission arena, a governance structure where actors formulate and govern the mission, by mobilizing and directing other, preexisting system components. Their goal is to meet the mission by developing and diffusing innovative mission solutions and destabilizing harmful practices. The MIS approach involves a problem-solutions diagnosis and an analysis of structural, functional, and systemic barriers. To provide formative mission governance recommendations, the systemic barriers are then contrasted with the mission arena's governance tasks. To illustrate the value of the MIS approach, we use a case study of the Dutch mission for sustainable maritime shipping. This case study illustrates a mission arena striving to increase coherence amongst different innovation system structures in semblance of a MIS. The mission arena configuration of actors shaped the mission formulation and negotiated governance actions. Dominant industry networks negotiated green growth as problem direction and non-committal governance actions, which are likely ineffective for inherently transformative sustainability missions. The paper concludes by identifying directions for further developing the MIS approach and the mission arena concept.

## Author summary

Missions like 'a net-zero greenhouse gas emissions economy by 2050' are used increasingly to tackle societal challenges like climate change. However, no analytical frameworks currently exist that can adequately evaluate the impacts of such challenge-led missions. We therefore introduce the Mission-oriented Innovation Systems (MIS) approach, which captures all social, technological, and other factors that affect the success of developing and spreading the use of mission solutions. Mission solutions include innovations, like electric drivetrains, but also changing or phasing-out harmful practices, like growing consumption. Central to our MIS approach is the mission arena, where different stakeholders

Ethics Review Board of the faculties of Science and Geosciences (ETC Bèta-Geo) at Utrecht University; interested researchers should contact ETC Bèta-Geo secretary H.H. Rump (h.h.rump@uu.nl).

**Funding:** The authors received no specific funding for this work.

**Competing interests:** The authors have declared that no competing interests exist.

negotiate the rate and direction of mission-oriented societal change and mobilize external stakeholder support. We study how the arena's actions impact systemic barriers to mission success. We apply our MIS approach to the Dutch mission for sustainable maritime shipping. We find that its mission arena targets many systemic barriers, like missing business models and lacking direction in selecting between mission solutions, but that complementary actions are necessary. Notably, mission arenas should watch out for capture by vested industry interests, that may lobby for a green growth paradigm and for non-committal mission-supportive actions, neither of which are likely to meet the inherently transformative, sustainability missions.

## 1. Introduction

Sustainability challenges are considered the most wicked of today's societal problems [1]. To deal with such wicked problems, a 'third generation' innovation policy has emerged [2], referred to as 'Transformative Innovation Policy' [3–5] or 'challenge-led, Mission-oriented Innovation Policy' [6–8]. Both these literatures converged around a notion of challenge-led policy that underlines (a) the wickedness of societal problems; (b) the directionality provided by governance constellations across sectors, disciplines and geographical levels, involving strategic stakeholder deliberation and balancing short and long term; (c) the multifaceted nature of innovation policy (mixes) as requiring new rationalities; and (d) the need for behavioral or social change in addition to technological fixes [2]. The difference is that Mission-oriented Innovation Policy provides directionality through ambitious, actionable, measurable, and time-bound goals, while Transformative Innovation Policy is more open-ended and bottom-up [2,4,9].

Mission-oriented Innovation Policy is slowly gaining traction [10–12] and can be defined as "*a directional policy that starts from the perspective of a societal problem, and focuses on the formulation and implementation of a goal-oriented strategy by acknowledging the degree of wickedness of the underlying challenge, and the active role of policy in ensuring coordinated action and legitimacy of both problems and innovative solutions across multiple actors*" [13, p.476]. To enable effective design of missions, such as the EU's mission of climate neutrality by 2050, and their underlying governance actions, further research into their potential leverage points and transformative societal impacts is needed [12,14]. Systems perspectives promise such valuable insights, but scholars agree that none of the current innovation systems and transition frameworks are sufficiently equipped to understand and systematically assess the impact of missions for formative evaluation [14–22]. Therefore Hekkert et al. [15] call for developing a new approach, the *Mission-oriented Innovation System (MIS) approach*.

Developing such a MIS approach faces various challenges, pertaining to (a) the *wickedness* of both a mission's problems and solutions, i.e. their contestedness, complexity, and uncertainty [9,23]; (b) the *temporality and embeddedness of missions* as missions have time-bound goals, typically medium- to long-term, meaning 10–30 years ahead [10,24] and build on preexisting innovation system structures; and (c) the directionality by which missions select between competing problems and solutions. These challenges imply that, on the one hand, a MIS approach should capture all relevant societal problems that 'compete' for legitimacy and prioritization in the mission formulation process [9,25]. On the other hand, a mission's solution scope includes both technologically and socially innovative solutions; as wicked societal problems like climate change cannot be resolved by technological fixes alone [1,26]. Here, social innovations are described as "novel combinations of ideas and distinct forms of collaboration

that transcend established institutional contexts" [27, p.1] like sustainable consumption [28]. Solutions include not only the development and implementation of the 'new', but also the replacement and phase out–or exnovation [29]–of the 'old' problematic practices and technologies [30–32]. While 'accelerator' missions focus on supporting technological innovation, 'transformer' missions require socio-technical transformation (i.e. the replacement of harmful goods and practices by innovative solutions) but with the 'radicality' of that transformation differing per mission [10,11,33]. Hence, transformer mission solutions include both diffusion of technological, organizational, behavioral, or institutional innovations and the phase-out of the old [30–32,34]. Finally, missions require development and diffusion of different sets of technologically and socially innovative solutions, that interact in various ways [35]. Hence, to capture the wickedness of missions, a MIS approach should embody (a) *coordination of interacting technological and social solutions–including phase-out;* (b) associated *contestation* processes; and (c) *reflexivity* to capture the uncertainty of how societal problems and solutions develop in relation to set goals [36,37].

Here, we refer to a MIS as "*a temporary semi-coherent configuration of different innovation system structures that interact and affect the development and diffusion of solutions to a mission that is defined and governed by a mission arena of different stakeholders"*. The *mission arena*, a concept developed in Section 2.1.2.1, refers to actors engaged in the highly political and often heavily contested process of mission governance. We describe this governance process as mobilizing, directing, and aligning existing innovation system structures into a semi-coherent ensemble that aims to pursue the mission. Since many more than governmental actors are involved in these governance processes [3,11,19], we refer to measures aiming to achieve a mission goal as '*mission governance actions*' rather than as Mission-oriented Innovation Policy.

This paper aims to develop for the first time a first MIS approach and illustrates its usefulness through application to the case of the Dutch Green Deal mission on sustainable maritime shipping. The Dutch Green Deal involves a goal-oriented collaboration process between a clearly defined set of actors that, despite contestation, try to develop different types of innovative mission solutions. Our approach first identifies the MIS barriers that inhibit development of a 'well-performing MIS', i.e. a MIS that develops and diffuses innovative solutions sufficiently rapidly to meet the mission's time-bound goals. The approach then assesses, ex ante, whether the mission arena's governance actions adequately target all MIS barriers to effectively support functional MIS development. In this formative assessment lies the value of the MIS approach, in that it allows us to provide recommendations for more effective governance of transformative missions, notably around sustainability. In the Discussion Section we reflect on the MIS approach and induce theory based off our empirical case study.

## 2. Methods

### 2.1 MIS approach: a structural-functional approach to evaluating missions

The MIS approach' foundation lies in the structural-functional approach normally applied to Technological Innovation Systems (TIS) [38,39], as it provides a clear operational systems approach that can serve for ex-ante, formative innovation policy assessment [20,21,40,41]. The structural-functional approach to studying TIS starts with the analysis of system's structural components (i.e. actors, networks, institutions and materiality). It then assesses 'key innovation activities', called 'system functions', to identify weaknesses in the system's performance and to uncover the systemic barriers that cause these weaknesses. These barriers serve as a starting point for an ex-ante policy assessment of the systemic policy instruments (or in our case mission governance actions) that should overcome barriers to improve system

**Table 1. Overview of the differences between TIS and MIS along various analytical dimensions.**

| Dimension | TIS | MIS |
|---|---|---|
| *'Wickedness'* | Involves uncertainty, complexity, and contestation within the scope of a single solution, involving competition between technological designs. Overlooks regime resistance. | Involves uncertainty, complexity and contestation in terms of (a) the problem definition and prioritization, and (b) the solution scope in which sets of different types of solutions interact. Contestation translates into the risk of capture by the regime. |
| *Temporality and embeddedness* | Technologies emerge, mature, and phase out, in one or more sectoral contexts. | MIS emerge with mission formulation and develop as mission problems and solutions increasingly institutionalize. They build on and realign existing innovation system structures. MIS decline as the societal problem is sufficiently overcome, or loses societal relevance. |
| *Directionality and transformation* | Encompasses the attention for the focal technology and competition between underlying designs. Overlooks phase-out and replacement effects. | Encompasses the attention for the mission formulation and underlying societal problem(s), as well as attention for the competing sets of innovative and 'phase-out' solutions. |

https://doi.org/10.1371/journal.pstr.0000075.t001

performance [40,41]. Similar to Wieczorek and Hekkert [42], we use 'diagnostic questions' to operationalize and guide our MIS approach.

The analytical focus of TIS is on a single technological solution. This differs from the focus of MIS on societal problems and the corresponding sets of interrelated solutions. Moreover, TIS and Regional Innovation System approaches focus on innovation ('the new') and overlook that which is being replaced ('the old') [22,30]. As a result, innovation systems approaches like TIS focus less on contested arena's that direct transformation processes. Consequently, these perspectives have different conceptions of (a) wickedness, (b) temporality and embeddedness, and (c) directionality and transformation (see Table 1 for an overview). This necessitates changes to the structural-function approach when analyzing missions from a systems perspective. For our MIS approach, we therefore add a first analytical step, the problem-solution diagnosis, and a final step that assesses mission arena tasks; see Table 2 for an overview of the MIS analytical steps.

Other adaptations of the structural-functional approach have been undertaken by Ghazinoory et al. [16], in their concept of a 'Problem-oriented Innovation System' (PIS), and by Haddad and Bergek [20], in their assessment of transformative innovation policy at the sectoral level. The main difference between the MIS and Ghazinoory et al.'s [16] PIS approach is that by focusing on a societal problem, the PIS delineation becomes more diffuse, while the MIS approach introduces the *mission arena* concept (see Section 4.2.1) as the central governance structure that mobilizes and redirects innovation system structures into a well-functioning MIS. This also allows the MIS approach to formatively evaluate the mission arena processes

**Table 2. Overview of the different MIS analytical steps.**

| Theme MIS approach: | Analytical steps: |
|---|---|
| *Scoping the MIS* | 1. *Problem-solution diagnosis*: Exploring the societal problems and corresponding solutions related to the mission goal; this helps in scoping the MIS breadth.<br>2. *Structural analysis*: Mapping out the (often semi-coherent ensemble of) MIS' structural components, starting with its core governance structure: the mission arena. |
| *Assessing the MIS* | 3. *System functions analysis*: Assessing the MIS' system functional performance using 'key transformation activities'.<br>4. *Systemic barriers analysis*: From the weak system functions, identifying their underlying structural causes, i.e. structural MIS components or interactions that are missing or unable to support system functions and thereby hamper overall MIS performance, and then identifying causal relations between these systemic barriers. |
| *Formative evaluation* | 5. *Formatively evaluating mission governance actions*: Contrasting interrelated MIS barriers with the mission arena's governance actions to evaluate if the actions target the most important barriers. |

https://doi.org/10.1371/journal.pstr.0000075.t002

and governance actions. Building on the structural-functional TIS approach, and bringing in transition, governance, and Mission-oriented Innovation Policy literature, we below outline our MIS approach, summarized in Table 2.

**2.1.1 Problem-solution diagnosis.** First, we contextualize the mission within a broader set of problems and solutions, that may underlie the mission goal. Although missions typically focus on a single societal problem [9,24], other societal problems tend to be involved via framework conditions that define what solutions are desirable. For example, the Dutch Delta Works mission for water safety required solutions to comply with framework conditions related to maritime transportation, ecology, and cultural heritage [43]. The way in which different societal problems are included and prioritized in mission formulation and supportive instruments, constitutes *'problem directionality'* and is assessed as part of the system functions analysis.

Problem directionality determines what solutions are relevant for the mission. *'Solution-directionality'* reflects how stakeholders search for and invest in solutions they deem promising. This is impacted by regulative, normative, and cultural-cognitive institutions [44], which the mission arena may attempt to influence. Inventorying solutions requires understanding how solutions interrelate [45]. Diagnostic questions relevant to problem-solution diagnosis include:

- How do different societal problems and 'wants' relate to the mission?
- What technological and social solutions are relevant to the mission?
- How radically innovative are these solutions, how well do they correspond with existing innovation system structures' resource endowments, and what is their state of development?
- How do solutions interact (symbiosis, neutralism, parasitism, commensalism, amensalism [45])?

**2.1.2 Structural analysis.** The second MIS analytical step is mapping the actors, institutions, networks, and materiality [46], in which we distinguish the *mission arena* from the *overall MIS*, i.e. the semi-coherent configuration of different innovation system structures that interact and affect the development and diffusion of solutions to a mission.

*2.1.2.1 Mission arena*. The *mission arena* concept builds on Loorbach's [47] notion of transition arenas and Jørgensen's concept of arenas of development [48] and refers to actors engaged in highly political and contested processes of mission governance. Mission governance involves mobilizing and aligning existing innovation system structures into a semi-coherent ensemble that aims to pursue the mission goal. The arena metaphor is taken from political and social theory to emphasize its temporary, actor-dependent, and contested nature [48,49], which reflects the struggles between proponents and opponents of swift transformative mission action [9]. Based on Mission-oriented Policy Observatory's (MIPO) ongoing work [12,50], we distinguish four mission arena tasks:

- setting up the mission arena,
- formulating the mission,
- mobilizing MIS components via mission governance actions, and
- continued, reflexive mission governance.

In *setting up the mission arena* actors decide a mission governance structure, including which actors are involved in what decision-making centers, how to deal with power

imbalances, how to mobilize resources, at what levels to coordinate policies and other actions, and whether to build on existing networks or develop new, dedicated, and cross-sectoral structures. Literature on governance arrangements, ranging from hierarchical to self-governance [51] and different governance theories, on multi-level (e.g. [52]), polycentric (e.g. [53,54]) and network (e.g. [55,56]) or collaborative (e.g. [57]) governance provide handholds for understanding the benefits and impact of different mission arena structures. Smith and Stirling [37] furthermore distinguish inside-political from outside-management transformative governance strategies and Larrue [11] empirically identifies bottom-up as well as top-down mission governance approaches. Different situations ask for different governance structures and strategies, perhaps even over time for the same mission. By placing the mission arena at the heart of the MIS approach, we may eventually induce theory on how mission arena's governance strategies impact MIS functioning. Although highly institutionalized arenas may have more stable boundaries and configurations, this likely does not hold for societal transformative visions reflected in transformative missions–particularly when it comes to sustainability [49,58].

*Formulating the mission* entails prioritizing societal problems and translating them into ambitious and actionable mission goals that guide to the overall MIS. Since societal-challenge-led missions typically require transformation of existing socio-technical systems [9,12,20], mission goals often oppose expectations and visions of regime actors, leading to conflict with powerful vested interests [47]. This inherent conflict, and struggle with inclusivity, social learning, and regime persistence needs to be considered in inclusive deliberation methods employed in the mission arena and might require excluding powerful vested interests, as fundamental conflict affects collective sense-making processes and mission formulation outcomes [47,49,58–60]. Larrue [11] finds that mission formulation processes ideally "unfolds as a succession of top-down and bottom-up phases, opening and reducing the space of potential options through a mix of concertation and selection stages" [11, p.54].

*Mobilizing MIS components via mission governance actions* requires an overall mission agenda or action plan that includes not only activities that existing innovation system structures need to pursue, but also governance actions that incentivize and enable these structures to undertake such activities. We refer to '*mission governance actions*' as all measures by which the mission arena aims to mobilize and align MIS components to improve MIS performance. They include Mission-oriented Innovation Policy instruments and other stakeholders' actions to mobilize innovation system components, such as networking organizations sharing knowledge; and educational organizations providing training and re-integration programs.

*Continued*, *reflexive mission governance* is required throughout the mission, including (a) *monitoring* and *evaluating* mission progress; (b) *reflecting* on coordination of solution pathways; (c) ensuring mission *reformulation* and MIS *redirection* when it loses societal relevance or legitimacy; (d) ensuring that *mission governance actions are adapted* or existing institutions changed when solution pathways are evaluated as inadequate to the mission goal; and (e) ensuring *restructuring the mission arena* itself, when certain parties inhibit mission progress. Hence, continued governance should consider changing stakeholder appraisals of societal problems and solution development trajectories [37,49,61]. This requires recurring broad and empowered deliberation [37,49,61] and the ability "to draw on a monitoring, anticipation, evaluation and impact assessment system ("strategic intelligence") that provides the analytical and forward-looking basis for reflexive discourses and adaptive policies" [36, p.1044,47,59,62].

*2.1.2.2 MIS scope*. A MIS, like any innovation system is defined by its structural components that affect the rate and direction of innovation and transformation [38,63–66]. Although these broader definitions do not exclude change-opposing forces, transition perspectives have often criticized innovation systems perspectives for under-conceptualizing forces of stability, i.e. the regime, that profoundly influence the rate and the direction of innovation [67,68]. We

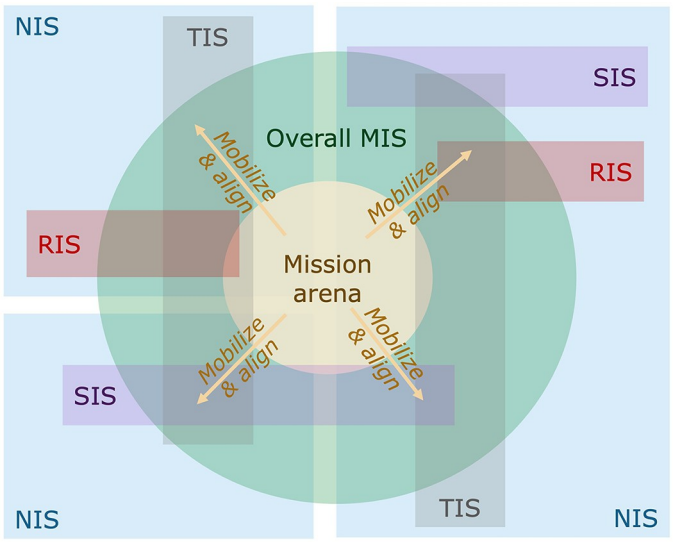


**Fig 1. A mission arena that aims to mobilize and align existing and overlapping National (NIS), Sectoral (SIS), Technological (TIS) and Regional (RIS) Innovation System components, structured in a semi-coherent MIS that supports the mission.**

https://doi.org/10.1371/journal.pstr.0000075.g001

therefore included in our MIS definition structural components that positively or negatively influence innovative mission solutions, either directly or indirectly, purposefully, or inadvertently, and for the sake of the mission's progress, for economic gains, or for other purposes. Existing regulations that inadvertently restrict adoption of innovative mission solutions (like double taxing of smart car charging) are thus part of the MIS lens, as are entrepreneurs developing innovative solutions for financial gain.

MIS emerge with mission formulation and develop as mission problems and solutions increasingly institutionalize. Over time, if the mission remains societally relevant and urgent, the MIS' societal problems and solutions will increasingly align, institutionalize, and materialize; and MIS' 'systemness' or MIS-defining structural characteristics (i.e. technologies, actors, institutions and networks), will become increasingly profound [16,17]. Although MIS coherence is an assumed precondition for effectively meeting transformative missions, the actual emergence of a coherent MIS is not assumed and should be empirically studied. In fact, it would be surprising if MIS structures that have developed in different TIS, Regional (RIS), National (NIS), Sectoral (SIS) Innovation System contexts, with different purposes (typically economic growth) would all easily realign around the same mission goal. As Fig 1 shows, the mission arena therefore attempts to align and mobilize (orange arrows) these structural components to improve MIS performance. For example, mission arena actors may lobby to remove restrictive regulations that served to preserve an established technology, or to redirect subsidy schemes, to benefit the performance of the MIS. The mission-oriented redirection of existing innovation system structures implies that certain existing innovation systems transform and prosper when aligned with the mission. For example, Bugge et al. [69] highlight the economic opportunities resulting from the mission-driven reorientation of the Western Norway regional innovation systems. At the same time, other pre-existing systems that conflict with the mission, may decline as the MIS develops; fossil fuel based TIS are likely to decline under a developing sustainability-oriented MIS that requires their phase out. At the same time, missions rarely emerge 'from scratch'; instead, problems and solutions have already started institutionalizing and developing in different stages in existing innovation system structures. The new

Horizon Europe missions, for example, did not originate in a vacuum, but built on previous problem and solution framings and pre-existing innovation system structures [9]. Because MIS performance depends on pre-existing innovation system structures, our MIS approach maps out and studies the impact of these embedded structures and how the mission's governance (i.e. the mission arena) aims to mobilize and redirect them, using the following diagnostic questions:

- What actors are part of the mission arena and contribute to (a) mission formulation; (b) mobilizing other MIS components; and (c) continued mission governance?
- What governance structure supports the mission arena?
- What actors, networks, institutions, and materiality support the development and diffusion of the mission's solution, including the phasing out of harmful goods and practices?
- How does the mission arena align with existing institutional structures related to the mission?

**2.1.3 System functions.** The system functions developed to study TIS [38,39] comprise a set of 'key innovation activities' that result from the structural system components identified in Step 2. The system functions are generic enough to apply to innovation systems characterized by a sector [70], by a societal problem [16], and by sustainability transition pathways [20]. We show that when sufficiently adapted, the system functions can reflect transformative MIS performance, i.e. the development and diffusion of innovative mission solutions and phase-out or destabilization of practices harmful to the mission. Table 3 lists MIS functions and associated diagnostic questions to assess them.

First, since 'mission solutions' involve both innovations and phasing out of old, harmful practices and technologies, MIS functions should reflect both key innovation activities that capture 'the new' and *transformation activities* capturing destabilization or phase-out of the 'the old'. In Table 3 we posit that all such destabilizing activities can be traced back to the counterpart of existing system functions oriented towards supporting 'the new'. A policy mandating phase-out of an existing technology or levying additional taxes may be interpreted as *market destabilization*, the counterpart of market formation. Capturing both sides results in MIS function 5 'market formation and destabilization' that reflects a key transformation activity instead of only an innovation activity. Similarly, the TIS function 'creation of legitimacy' has been extended to the transformative System Function (SF) 7 'creation and *withdrawal of legitimacy*' [71–73]; 'resource mobilization' is reinterpreted as SF6 'resource reallocation', to also capture withdrawal of resources, including supportive physical infrastructures, from harmful practices; SF2 'knowledge development and unlearning' now captures *unlearning* processes that refer to abandoning obsolete or ineffective practices and habits [74–76]; SF3 'Knowledge diffusion' has become 'knowledge diffusion and network breakdown' [74].

Second, the mission arena concept foregrounds governance structures and highlights its different tasks and system functions impacts. This moves beyond innovation systems' conceptualizations of network as only diffusing knowledge (see e.g. [38]).

Third, the mission arena aims to influence *directionality* or 'guidance of the search' (SF4) in the MIS. Directionality can range from open problem framings to specific mission formulations that exclude societal problems or many solutions. Azar and Sandén [45] argue *any* goal framing favors some solutions over others, because they can or cannot meet certain targets, synergize, or compete with a set of solutions, or are at a certain level of development. Consequently, missions may purposefully but also involuntarily shape what clusters of technological

**Table 3. Description of MIS functions and corresponding diagnostic questions.** Source: builds on TIS function works such as [38,39,42,81].

| System function | MIS interpretation | Examples of diagnostic questions |
|---|---|---|
| *SF1*: *Entrepreneurial activities* | *Innovation side*: Experiments with solutions (or clusters of solutions) to enable learning; entering markets for new solutions; engaging in business model innovation to foster the diffusion of solutions.<br>*Destabilization side*: experiment with destabilization of actors, institutions, networks, and technology that support harmful practices. | • Are technical, business model and other experiments with innovative and destabilizing solutions conducted fast enough to complete the mission? |
| *SF2*: *Knowledge development and unlearning* | *Innovation side*: Learning by searching and by 'doing', resulting in development and better understanding of new technical and social knowledge on innovative solutions, through R&D, social research, and behavioral science research.<br>*Destabilization side*: Similar but for knowledge on societal problems caused by harmful practices; unlearning harmful practices. | • Is knowledge to develop existing and new solutions created fast enough to complete the mission?• Is sufficient knowledge developed to understand the societal problem and the harmful effects of innovative goods and practices?<br>• Is knowledge created to help actors to *unlearn* practices harmful to the mission sufficiently rapidly? |
| *SF3*: *Knowledge diffusion and network breakdown* | *Innovation side*: Stakeholder meetings, conferences, governance structures, public consultations, mission progress reports and other forms of disseminating technical and social knowledge for innovative solutions.<br>*Destabilization side*: Similar but for dissemination of destabilization solutions and societal problem awareness, including breaking down knowledge-sharing networks on harmful practices. | • Is knowledge to develop and use solutions diffused amongst all stakeholders sufficiently rapidly to complete the mission?<br>• Is knowledge about the societal problem diffused sufficiently to formulate a broadly supported, clear, time-bound, and ambitious mission?<br>• Are networks supporting harmful practices broken down? |
| *SF4*: *Providing directionality (inherently transformative in nature)* | Besides pre-existing directional institutional structures, the mission arena is central to providing *transformative* direction and mobilizing support from the existing innovation system structures that comprise the overall MIS. | • Have effective governance structures been set up to establish an influential and well-embedded mission arena, that reflects different stakeholder interests?<br>• What are its top-down and bottom-up governance elements?<br>• Is an inside/political or outside/managerial governance approach taken? |
| *SF4a*: *Problem directionality* | The direction provided to stakeholders' societal problem conceptions and the level of priority they give it. | • Do stakeholders prioritize the mission's societal problems and framework conditions in relation to other societal problems and wants?<br>• Do stakeholders align the mission's societal problem with vested interests to justify growth-oriented innovation direction? (Indicative of *innovation MIS orientation*)<br>• Do stakeholders prioritize the societal problem over vested interests and societal wants? (Indicative of *destabilizing orientation*) |
| *SF4b*: *Solution-directionality* | The direction given, both by existing system structures and the mission arena, to the search for new and further development of *innovative* and *destabilizing* technological and social solutions, as well as the coordination efforts needed to identify, select, and exploit synergetic sets of solutions to the mission. | • Do stakeholders know what solutions are necessary to complete the mission (both innovative solutions and phasing-out of old practices and technologies)?<br>• Do stakeholders agree on what the necessary solutions are, or do they agree that they do not know all necessary solutions yet?<br>• What solution directions are currently being prioritized over others, and by what system structures or system contextual factors?<br>• Is a dominant set of solutions emerging?<br>• Do stakeholders sufficiently recognize and exploit the interdependencies between different solutions? |
| *SF4c*: *Reflexive governance* | Reflexive deliberation, monitoring, anticipation, evaluation, and impact assessment procedures; these provide the analytical and forward-looking basis for redirecting the system's problem framing and search for solutions based on lessons learned and changing contexts. Reflexive governance can be seen as second-order directionality, can be initiated by the mission arena or by critical outsiders, and is inherently *transformative*. | • Is the mission's progress monitored transparently (e.g., by a dedicated taskforce) and is the MIS on track to meet the mission?<br>• Does multi-stakeholder deliberation take place to assess whether the mission still adequately captures a pressing societal problem?<br>• Is the impact and relevance of mission governance actions regularly evaluated and, if necessary, are they adequately redesigned?<br>• Is the mission and its supporting measures redesigned when necessary? |

(*Continued*)

**Table 3.** (Continued)

| System function | MIS interpretation | Examples of diagnostic questions |
|---|---|---|
| *SF5*: *Market formation and destabilization* | *Innovation side*: Creating a niche market and upscaling support for technical and social solutions.<br>*Destabilization side*: Phasing out or destabilizing markets for practices and technologies harmful to the mission. | • Do formal or informal institutions support sufficiently rapid diffusion of innovative solutions and phase out of harmful practices?<br>• Do stakeholders adopt innovative solutions sufficiently rapidly?<br>• Do stakeholders abandon harmful practices sufficiently rapidly? |
| *SF6*: *Resources reallocation* | *Innovation side*: Mobilization of human, financial and material resources to enable all other system functions<br>*Destabilization side*: Withdrawal of resources and supportive physical infrastructure from harmful practices. | • Have sufficient human, financial and material resources been mobilized to fulfil other system functions?<br>• Have sufficient resources been withdrawn from harmful practices to stop their continuation? |
| *SF7*: *Creation and withdrawal of legitimacy* | *Innovation side*: Creating legitimacy for development and diffusion of innovative solutions.<br>*Destabilization side*: Creating legitimacy for prioritizing the societal problem over vested interests; withdrawing legitimacy from harmful practices; lobbying against institutions supporting harmful practices and in favor of destabilizing institutions; mitigate power and access of established incumbents' lobby. | • Do actors vocally support the mission's societal problem and solutions?<br>• Do they lobby for broader stakeholder support?<br>• Do they lobby for institutions that destabilize the regime for harmful practices?<br>• Is the stabilizing power of this regime mitigated? |

https://doi.org/10.1371/journal.pstr.0000075.t003

and social solutions, or solution pathways, which is overlooked in existing innovation systems approaches [22]. Many practitioners face the challenge of providing directionality that balances different stakeholder interests while meeting a mission goal [10,11]. Achieving such directional mission governance requires inclusive multi-stakeholder processes, well-informed reflexivity, and coordination to prevent unintended exclusion of potential solutions [24,36,37,60]. Hence, MIS functions should capture both problem directionality (SF4a) and solution directionality (SF4b). Additionally, since the mission arena's continued, reflexive governance processes are central to monitor mission progress and to readjusting problem and solution-directionality and mission arena tasks [24,77], we include this as a third directionality dimension (SF4c). Finally, mission goals provide a clear reference point to assess system function performance, allowing for diagnostic questions like "Are system functions developed 'sufficiently rapidly to complete the mission'?".

Fourth, solution-directionality (SF4b) is affected specifically by the increased scope and complexity of MIS, because of including sets of interacting technological and social solutions. This affects the granularity of the MIS analysis; should MIS functions be assessed per individual mission solution, per set of solutions or mission-generically? We take the latter approach to manage complexity–assessing MIS functions for mission solutions in general while critically reflecting on solution-type-specific exceptions. The broader MIS scope also raises the question if MIS functions can sufficiently capture social innovation processes. Ghazinoory et al. [16] and Haddad and Bergek [20] tentatively showed that adapted system functions can do so. Interrelatedness of solutions requires mission arena processes of solution pathway coordination that TIS and Regional Innovation System analyses overlook [20,22,46].

Similar to the TIS functions approach by Suurs and Hekkert [78], it is possible to distinguish between positive system function fulfillment (i.e., transformation processes that contribute to meeting the mission goal, like more support for innovative solutions or phase-out of harmful practices) and negative fulfilment (i.e. a decrease in innovation activities or increase in harmful practices).

**2.1.4 Systemic barriers analysis.** Systemic barriers (also known as systemic problems or blocking mechanisms) are structural components or interactions that are missing or unable to support system functions, thereby hampering the overall system functioning [79]. Often, the origin of systemic barriers can be traced to the regime as vested interests may result in different barriers to radical innovation, like standardization committees or other gatekeeper positions

dominated by regime players [70]. Different, interrelated systemic barriers may result in systemic lock-in [70].

**2.1.5 Formative evaluation.** The innovation systems literature refers to systemic instruments as policy or governance actions that address systemic barriers [80]. Effective systemic instruments or governance actions should be targeted at the root causes of barriers that prevent innovation system development [70]. In the context of MIS, we understand systemic instruments as the *mission governance actions* that mission arena participants committed to, in support of the mission.

We use the rationale of systemic instruments that tackle barriers to improve MIS performance, to enable ex-ante, formative evaluation of mission governance actions. Prospective, formative evaluation is most desirable, as policy makers are currently still planning or struggling with the implementation of mission policies and look for ways of improving this process 'on the go', and insufficient time has passed for retrospective, summative evaluation [12]. Hence, instead of assessing ex ante the likely impact of a mix of governance actions based on the mix' design criteria, such as consistency and coherence [82,83], our MIS approach starts from an additionality perspective, stressing that existing MIS components are already engaging in various innovation activities and that the mix of actions should focus on resolving remaining MIS barriers to boost MIS performance effectively and efficiently. To assess if all MIS barriers are adequately targeted, we compare them with the mission governance actions. Formative recommendations follow from untargeted MIS barriers or that may be unintentionally reinforced by mission governance actions. Building on this overarching systemic evaluation rationale, more generic formative governance recommendations may follow from our approach when stakeholders have not yet defined mission governance actions.

## 2.2 Case study description

We take a single case study approach, as this is the preferred research strategy for exploring the usefulness of our MIS approach while enabling theory generation, in a contemporary context that is outside the researcher's control [84,85]. We focus on the case of the Dutch (not European) 'Maritime and Inland Shipping and Ports' Green Deal. Specifically, we focus on the mission to achieve a 20% reduction in $CO_2$ emissions per maritime short sea shipping operation by 2024 [86] and a 70% reduction in absolute $CO_2$ emissions in the sector by 2050 [87]. The mission arena in this case comprises a governance structure in which different types of public and private actors negotiated and signed the 'Green Deal' document that specified the mission goal and signees' commitments to taking mission governance actions to increase MIS performance [87]. One of these actions is the initiation of a taskforce that represents the signees, and that coordinates, monitors and evaluates the implementation of the Green Deal. Other planned actions involve the implementation of various innovation policy instruments by public organizations, and the mobilization of members of industry networks to contribute to innovative mission solutions [87], see Section 3.5 for an overview and evaluation of these actions. We tentatively evaluate ex ante (data collection started eight months after the Green Deal's signing) whether the Green Deal's mission governance tasks and actions effectively target MIS barriers.

Maritime transport is efficient in terms of emissions per unit of cargo carried but is responsible for 2% of global emissions and uses some of the most polluting fuels available [88]. The past decade has seen a reduction in the carbon intensity of shipping activities by around 20% [89], achieved by incremental innovation, but a greenhouse gas emission increase by 9.6% due to increasing demand [90]. Dutch shipping shows a similar trend [91]. The shipping sector is essential for societal functioning, as it transports over 90% of total world commerce [92]. In

the Netherlands, the sector accounts for 3.2% of Dutch GDP totaling 79.4 billion euros in turnover [93]. While the sector has distinguishable market segments [94], the global maritime sector has become highly consolidated, with oversupply of capacity. This has caused strong horizontal and vertical integration, leading the four largest carriers to control more than half of global capacity [89]. Inland shipping is however dominated by smaller, family-owned businesses [95]. The Dutch rank 15$^{th}$ in terms of ownership of the world fleet (totaling 23.9 billion USD) and is the sixth most connected maritime economy worldwide [89].

## 2.3 Data collection and analysis

To analyze this mission, our case study approach is structured by the research steps summarized in Table 2. These five analytical steps have three overarching themes: mapping the MIS, assessing the MIS and formative evaluation. Since systems are dynamic and mission governance and MIS barriers change over time, another cycle of analytical steps may commence several years after the formative evaluation, see Fig 2.

The concepts relevant to these research steps were operationalized via the diagnostic questions listed in Section 2.1. We developed a database to apply these diagnostic questions to, consisting of 27 interview transcripts totaling 168 pages and, to enable triangulation, a complementary set of scientific publications, newspaper articles, trade magazine articles, websites, company and technology reports, and Dutch policy documents on sustainable maritime transportation (obtained using LexisNexis, Google, and Google Scholar, and via our networks).

The sample of our interviewees is representative of the Dutch maritime and inland shipping sector (see Table 4) and include both stakeholders actively involved in and affected by the mission arena. To ensure candid responses, interviews were anonymized. To further prevent interest-based biases, we did not rely on interviewees' direct normative assessments of events, but on their cause-and-effect explanations of events, which we triangulated with document data and other interviewed actor types, to then form our own assessment. Interview data provided the backbone in all research steps, with the exception of the 'solution diagnosis', for which a complementary literature review using sector reports and academic literature on sustainable maritime transportation solutions was conducted. Semi-structured interviews proved particularly useful for identifying interrelated MIS barriers, as they allow for building on the diagnostic questions with 'Why?'-type questions.

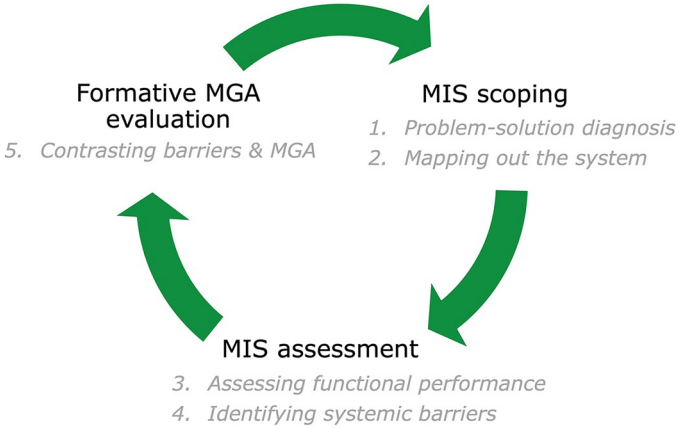


**Fig 2. Overview of the different analytical steps.**

https://doi.org/10.1371/journal.pstr.0000075.g002

**Table 4. Overview of interviewees.**

| Main actor group: | Organization: | Position in organization: | Number of interviewees: |
|---|---|---|---|
| Private sector | Industry association | Senior manager, senior advisor | 2 |
| | Technology supplier | Director, sales director (3), owner, R&D manager | 6 |
| | Shipping company | Director (2), fleet manager (2), environmental coordinator | 5 |
| | Freight forwarder | General manager, logistics manager | 2 |
| | Financial organization | Director, business developer | 2 |
| | Shipyard | Lead architect | 1 |
| | Naval architect | Engineering director | 1 |
| | Business developer | Business developer | 1 |
| Government | Government | (Senior) policy advisor (3) | 3 |
| | Port | Project leader | 1 |
| Research | Knowledge institute | Research coordinator, PhD researcher, assistant professor | 3 |

https://doi.org/10.1371/journal.pstr.0000075.t004

Our data analysis approach employs a four-stage blended coding approach [96], making use of NVivo. As an initial step, we engaged in open coding of textual fragments [97]. These coded fragments were then grouped into categories following focused coding [98]. These categories were then allocated to the respective MIS analytical steps and system functions and used to inductively construct MIS barriers. This step allowed us to identify themes that would not fit the predefined set of MIS functions, or re(de)fine the functions if necessary. Finally, axial coding was done to identify causal linkages between MIS functions and barriers. Axial coding largely built on interviewees' explanations of causalities. This allowed us to create a flowchart that captures MIS inhibitive dynamics [99]. This coding process resulted in a total of 1,403 coded textual fragments. A reliability check was applied by two other researchers, resulting in a Krippendorff's Alpha of 0.88, which is considered reliable [100].

## 3. Results

### 3.1 Problem-solution diagnosis

The Green Deal was initiated by policymakers in 2018 because the maritime sector was omitted from most environmental policies and agreements, including the Paris climate agreement [87]. Although the problem of sustainability acknowledged by all Green Deal stakeholders and goals were not contested, international economic competitiveness inhibited swift transformative action. Reduced mobility is another trade-off for more radical alternative energy carriers such as battery and hydrogen-electric ships, while the better local air quality these ships bring is a large benefit.

S1 Table lists the technological and social mission solutions. The main technological solutions to be implemented to the ship include exhaust gas treatment systems (scrubbers), electric propulsion systems, electrical sensor systems, and efficiency gains within established technologies. Alternative energy carriers such as hydrogen and LNG were also identified. We found two major social innovations, including efficient shipping routes, speeds and fleet use, and a smarter global production and transportation system. As S1 Table (Supplementary Information) shows, most of these solutions have already been proven in an operational shipping environment. Some incremental solutions, such as scrubbers and LNG ships, are starting to take off on the global market [101,102] whereas other, more radically innovative solutions, such as hydrogen fuel cell ships, need more development and policy support to become competitive [103,104]. From these solutions, different solution-pathways can be identified.

## 3.2 Structural analysis

While Dutch Green Deals are normally initiated by industry pioneers, the focal *mission arena* was initiated by the Dutch government, as it was required by the Dutch Coalition Agreement [95]. The arena initially consisted of 42 parties (including 11 industry and trade associations, 8 governmental organizations, 5 port representatives, 2 shippers, 1 chemicals company, 1 energy company, 1 freight forwarder, 1 consultancy, 4 financial organizations, 3 knowledge institutes, 1 knowledge platform, 1 education organization, 2 foundations). These parties negotiated in a top-down process and signed the Green Deal, committing to numerous mission governance actions over the period 2019–2024 (see Section 3.5) [87]. In 2024, an updated Green Deal will be negotiated. In 2021, the North-Holland and South-Holland provinces also committed to and signed the agreement. Interviewees agree that the negotiations for the Green Deal were dominated by government and industry associations, with a marginalized role for companies; in the end, only four companies signed the Green Deal [87]. This top-down approach of company representation via industry associations caused limited mission awareness and commitment by companies, despite their central role in solution development, production, and use. To safeguard the industry's economic competitiveness, the industry associations negotiated some public funds be mobilized to compensate for private investments, but also vaguer and noncommittal mission governance actions from the industry side.

The actors in the *overall MIS* are much more numerous. As indicated by the inventory of clean shipping solutions, knowledge institutes and technology suppliers had already developed various technological solutions independently of the mission. Shipping companies adopted more incremental solutions [105,106], and various ports researched and developed supportive infrastructure [107]. Most of these innovation activities received government support. The Green Deal strives to bundle, guide, and increase the innovation processes by these MIS components.

The Green Deal is embedded in a multi-level institutional context that supports sustainable short sea shipping. Interviewees point to the International Maritime Organization's (IMO) worldwide regulations, European and national regulations, and local regulations in the form of 'Emission Controlled Areas'. The IMO formally aims to halve global shipping emissions by 2050 [108], for which the International Chamber of Shipping proposed a 5bn USD fund to design zero-emissions vessels, fed by a 2 USD levy on every tonne of fuel [109]. Progress is slow, however, causing the EU to formulate its own emission-reduction strategy including market-based measures [110]. The Dutch mission was at the time of negotiation more ambitious than these IMO and EU targets, but, interviewees agree, likely less impactful due to its national scope.

## 3.3 Functional analysis

The mission benefitted from quite some *entrepreneurial activities (SF1)* and many experimental projects have moved incremental and radical innovations to TRL9 (see S1 Table). Thanks to supportive measures, such as accelerator PortXL, some startups–mostly smart technology providers as such firms need lower capital investments–are entering the market with clean innovations [111]. Business model innovation is however insufficient to overcome the cost of most clean shipping solutions.

Most interviewees (19/27) stated that knowledge institutes and technology suppliers have *developed* much *knowledge (SF2)* [112] and pushed clean innovations to high TRLs. Most interviewees (24/27) indicated *knowledge diffusion (SF3)* to be high, because of strong formal and informal networks and collaborations along the supply chain that serves the relatively

small market of short sea shipping. There was no indication of unlearning (SF2) or network breakdown (SF3).

With its ambitious $CO_2$ emission reduction goal, the Green Deal contributes to *problem-directionality (SF4a)*. Increasing economic competitiveness is however listed as the first consideration in the Green Deal [87]. Nine interviewees indicated the Green Deal's "green growth" trajectory already existed, implying the mission's impact on problem-directionality was limited. The three interviewees from knowledge institutes deem the goal inadequate to meeting the Dutch Climate Agreement.

Although interviewees agree that a range of solutions is necessary to meet the mission, *solution-directionality* (SF4b) remains weak. Various radically innovative solutions have reached the market introduction stage but require substantial further development to become competitive. This range of uncompetitive alternative solutions means that shippers and ports are waiting for a dominant design to emerge. However, little selection is taking place. Additionally, the previous push in the Netherlands and Europe for LNG has led to high sunk development costs by engine manufacturers, making them reluctant to again switch technology [113]. Finally, two shipping companies indicated many shippers do not know the best solution for their type of ship and can be dependent on novel, uninstalled infrastructure. A port representative indicated this infrastructure is missing, due to lacking demand by shippers (a chicken-or-egg problem). Although the mission goal signals that a cluster of radical technological and social solutions needs to be widely diffused by 2050, ten interviewees indicated the mission arena might contribute more to solution-directionality if it provided information on and assessments of the different solutions stakeholders need. This is something that the mission arena failed to do adequately, but for which public funding was secured due to the lobby by knowledge institute mission arena members. Four interviewed companies (not involved in the mission arena) confirmed that the vague formulation of mission actions contributed little to solution-directionality.

*Reflexive governance* (SF4c) was low, as greenhouse gas emissions were not consistently monitored. Industry associations will 'stimulate' their members to report shipping emissions. More importantly, a taskforce will monitor and evaluate mission progress and effectiveness of mission governance actions. Their insights will inform negotiations for the updated 2024 Green Deal. Although all interviewees praised such a taskforce, half of them stressed the taskforce should have been installed immediately and should operate transparently, to better maintain stakeholder commitment throughout the mission.

In terms of *market formation and destabilization (SF5)*, the diffusion of clean shipping innovations is largely limited to incremental and add-on solutions. This includes ships equipped with exhaust gas treatment systems (scrubbers), alternative fuels (e.g. biofuels or LNG), efficiency gains within established technologies, electrical sensor systems, and more effective shipping routes, speeds, and fleet use [114]. Some solutions are tentatively being diffused on the global market, like scrubbers (2,947 ships by 2019 [102]), LNG (541 by 2019 [101]) and sensory systems, which have become mainstream in new ships [115]. Most solutions have been diffused in response to market-destabilizing regulations, such as emission-control areas and compulsory fuel consumption monitoring, that favor incremental and add-on innovation adoption [116,117]. Phase-out of existing technology is limited to replacement of conventional, oil-based marine fuels by LNG and biofuels. An important driver for sustainable shipping is the procurement of the government's shipping fleet. By 2018, 12 seafaring ships of the Dutch government were powered by 30% biodiesel and from 2019 onwards the government started the procurement of 15 hybrid-electric ships. These ships were equipped with electrical sensor and software systems to enable efficient shipping, shipping routes, and speeds; with enhanced hydrodynamics; heat recirculation systems; and solar panels [118].

Nevertheless, all interviewed stakeholders agreed that market formation for sustainable-shipping innovations is weak, particularly for radical innovations, for several reasons. First, other than the pre-existing regulations, eleven interviewees indicated that market-forming policies and destabilizing regulations are insufficient to kick-start the adoption of uncompetitive innovations. Second, both interviewed freight forwarders were unwilling to pay a sustainability premium to shippers because they cannot transfer it to their customers. Consequently, shippers are unwilling to pay for the implementation of radical sustainable innovations. A third reason is the aforementioned uncertainty regarding the dominant energy carrier and its dependence on infrastructure, resulting in a wait-and-see attitude in shippers [109]. Finally, two interviewed shipping companies and a technology supplier explained that energy-efficiency solutions, including the social solutions of optimal shipping speeds and routes, are impaired by organizational barriers. This is largely because the charterer prioritizes speed and timing over efficiency and pays the fuel, removing the incentive for shippers to innovate. Business model innovation can overcome this barrier. Niche markets in which some sustainability premium can be transferred to the end consumer tend to be more high-value, particularly high-tech industries in direct contact with the end consumer (confronting them with visible air pollution), such as the cruising industry [119].

Most interviewees found no clear barriers in the *(re)allocation of financial*, *human*, *or material resources* (SF6). The presence of public R&D support but the lack of business models, causes investments to focus on R&D instead of adoption, even though interviewed financial organizations are willing to finance. This imbalance is one reason for the many market-ready but uncompetitive innovations that are not being selected in for wider diffusion. The mission arena mobilized 5 million EUR public funding, which all interviewees consider unimpactful, compared to the billions of EUR necessary to finance the sector's sustainability transition.

Interviewees agreed that *problem-legitimacy* (SF7) was high politically, as the government's coalition agreement required the Green Deal [120]. The public, however, put little pressure on the sector as it (and its emissions) are mostly invisible to them. Hence the industry experienced little urgency looking instead to government to initiate and direct change. *Solution legitimacy* (SF7) has been lobbied for by various solution-specific and generic lobby groups, such as the emission-free shipping association that lobbied for a $CO_2$ tax to finance sustainable innovation [121]. Industry associations opposed these types of more transformative instruments in favour of vaguer and non-committal mission governance actions.

## 3.4 Systemic barriers analysis

The main, mutually reinforcing barriers in the overall MIS relate to the system functions 'market formation and destabilization', 'entrepreneurial activities', and 'solution-directionality' (see green area, Fig 3). The central barrier constitutes the missing business model among shippers to adopt, particularly more radical, sustainable innovations. This is caused (a) by too little market-oriented policy support (-*SF5*); (b) freight forwarders and end users unwilling to pay a premium for sustainable transportation (-*SF5*); (c) shippers waiting for an alternative energy carrier to become dominant and for infrastructure to emerge (-*SF4b*); and (d) charterer paying the shippers' fuel, taking away shippers' incentive to adopt fuel-saving solutions (-*SF5*). This lack of a business model impairs the investments of technology suppliers in developing technological solutions to commercially- competitive levels (-*SF1; 2*). In combination with the abundant early-stage R&D funding, this resulted in many uncompetitive radical solutions that require substantial physical infrastructure development. This systemic barrier reflects low solution-directionality and results in shippers adopting a wait-and-see approach (-*SF4b*), closing a vicious cycle of systemic barriers in which a lack of demand maintains a lack of supply and vice versa.

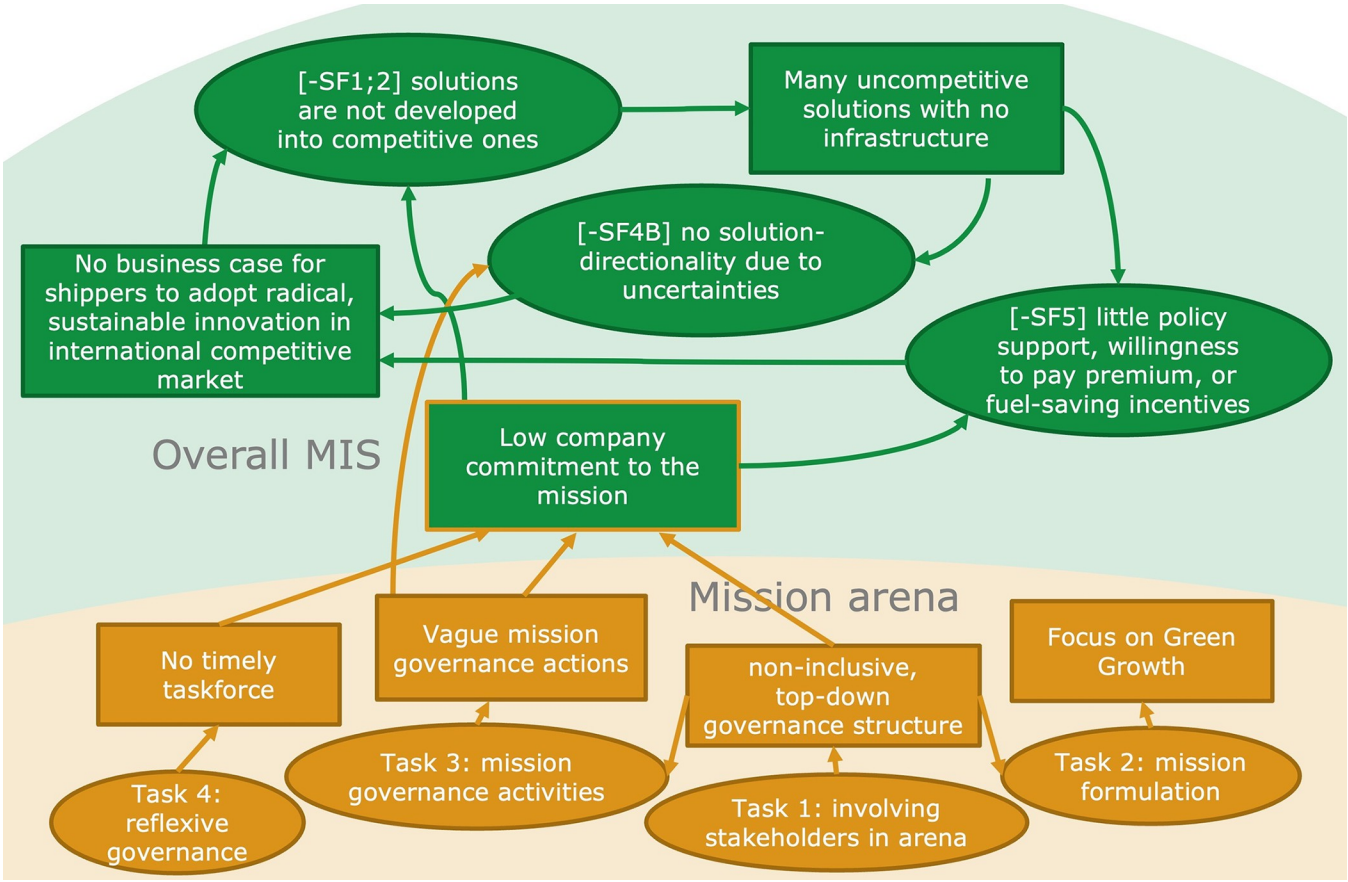


**Fig 3. General view of weak MIS functions (ovals) and interrelated main MIS barriers (rectangles) in the mission arena (orange) and overall MIS (green).**

https://doi.org/10.1371/journal.pstr.0000075.g003

### 3.5 Contrasting mission arena tasks and MIS barriers

We now assess the four mission arena tasks. The task to *involve stakeholders in the arena* held more potential, as companies were not adequately involved in the arena, relying instead on industry associations which are more conservative than their members (see orange area, Fig 3). This resulted in low company support to the mission.

This non-inclusive, top-down governance structure impacted the mission arena task of *formulating the mission*. Although the mission goal was largely uncontested due to its embedding in the Dutch Coalition Agreement, dominant industry associations succeeded in making Dutch economic competitiveness a first consideration in the Green Deal. The result has been a focus on 'green growth'.

The green growth orientation defined the task *'mission governance actions to mobilize the overall MIS'*, as the mission arena's strategy revolved around supporting sustainable shipping innovations, while leaving regime-destabilizing solutions up to transnational governance, as it would damage attractiveness of Dutch industry. In total 64 mission governance actions were defined [87], many of which target MIS barriers (see Table 5). Particularly the missing business model barrier is addressed by many governance actions, both from a market-forming and a solution-directing perspective. These actions should aspire not only to increase the attractiveness of clean shipping solutions (SF5), but also to provide clarity on preferential solutions (SF4b). If effective, these actions will also impact the 'many uncompetitive solutions with no infrastructure' barrier, as an improved business model directly translates into more

**Table 5. MIS barriers and corresponding mission governance actions to which actors in the mission arena are committed.**

| MIS barriers | Mission arena's supportive mission governance actions [87] |
|---|---|
| Missing business model, due to lack of market formation | *Governmental action*:<br>- Plan fiscal incentives and tax relief for electric shipping<br>- Triple Helix develops a profitable business model for zero emission shipping, supported by research projects and subsidies<br>- Public procurement criteria will better incorporate sustainability<br>- Development of a 'sustainable shipping' marketing strategy, including a sticker to enable transferring its surcharge to the end consumer<br>- Public procurement of three hybrid-electric, biofueled ships<br>- Operate public fleets on a 30% biofuels blend<br>- Explore other financial support schemes (e.g., guarantees and fiscal schemes)<br>- Lobby for transnational sustainable shipping regulations, such as a $CO_2$ tax and European low emission zones, to maintain a level economic playing field*Non-governmental action*:<br>- Urge members along the value chain to adopt sustainability as a purchasing criterium<br>- Lobby for a global fuel levy<br>- Push for prestigious awards to include sustainability as a criterion |
| Missing business model, due to lack of solution-directionality | *Governmental action*:<br>- Provide a regularly updated overview and independent assessment of available sustainable shipping solutions to enable informed decision making by shippers and financers<br>*Non-governmental action*:<br>- Urge members to share information on innovative solutions |
| Low company commitment | *Governmental action*:<br>- Allocate €5 million of public funding to the Dutch Green Deal<br>- Explore further R&D subsidy schemes<br>- Taskforce to coordinate and implement the Green Deal within 4 months [delayed], and to evaluate its effect 2.5 years after signing |

https://doi.org/10.1371/journal.pstr.0000075.t005

competitive solutions, particularly after learning processes and scale economies kick in. This triggers a process of demand-driven selection (SF4b) and infrastructure investments (SF6), which public mission governance actions will also support (SF5). Despite the funds allocated to assessing solution to market segment fit, most interviewees believe the mission arena could have provided clearer solution directions, e.g. via better coordination between actor types (e.g. ports, shippers and technology suppliers) and better information dissemination to shippers. While government committed to many innovation-support instruments, industry associations limited their actions to 'requesting', 'stimulating' and 'urging' their members to engage in various sustainable shipping activities. Government and industry associations committed to lobbying for regime-destabilizing measures at respectively, the European and global level [87].

Regarding the arena task to *engage in reflexive governance*, interviewees agreed that a quick follow-up to the mission agreement via the promised monitoring and evaluation taskforce would have benefited stakeholder commitment.

## 4. Discussion

### 4.1 Contribution to sustainable maritime literature

This paper provides a holistic view on the mission-oriented governance of the maritime sustainability transition. This expands previous maritime studies that focused only on parts of the transition, such as understanding the role of a specific actor type [90], of its segmented market [94], of pilot projects and public procurement [122], or of transnational governance via the

IMO [123]. Others have studied individual solutions from a TIS perspective [124] or combined TIS studies to understand the interplay between solutions and regime practices [125].

Our contribution lies in our comprehensive, goal-oriented transitions perspective, allowing us to understand contestation dynamics within mission governance arenas and how this may impact governing the rate and direction of the maritime sustainability transition. The MIS approach also allowed us to identify systemic barriers to social solutions that would have been overlooked by other (TIS) studies, such as charterers paying shippers' fuel costs and prioritizing timing and speed, which disincentivizes optimal shipping routes and speeds.

## 4.2 Reflection on MIS approach

From the conceptual and empirical work done in this study, we elucidate six characteristics that set the MIS approach apart from other innovation systems approaches. These characteristics structure our reflection on the strengths and weaknesses of the MIS approach in Table 6. Overall, we consider the approach' analytical steps useful for evaluating mission governance from a systems perspective, but further case studies are needed to confirm this. Systematic case study comparisons may enable theory induction on (a) typical dynamics and barriers in innovation system structures affecting missions, and on (b) the impact of different mission governance approaches. Comparison across the following dimensions would be quite valuable:

**Table 6. Overview of strength and weaknesses of the MIS approach.**

| Characteristics MIS approach | Strengths MIS | Weaknesses MIS |
|---|---|---|
| Mission arena and system embeddedness | The mission arena conceptualizes the central mission governance structure that aims to mobilize, direct, and align existing innovation system structures into an increasingly coherent ensemble that helps complete the mission (overall MIS). As such it helps understand the emerging and layered 'systemness' or coherence of MIS. | The 'systemness' of a MIS increases over time; initially it may be a semi-coherent ensemble of different (national, regional, technological, sectoral) innovation system structures. As the societal problem and solutions institutionalize and networks stabilize, we may speak of a more stable and coherent system (like TIS' stages of development). MIS' systemness should thus not be assumed, but empirically studied over time. |
| Problem-solution diagnosis | This helps to contextualize the focal mission in a field of societal problems and respective solutions, and to adjust the granularity of the MIS approach, trading off analytical breadth and depth, accordingly. This context helped assess the mission arena's narrow solution directionality. | Some TIS studies take an analytical approach to system delineation, following the actors' interactions to draw TIS boundaries [129], resulting in a more coherent system that does not need to deal with the wickedness of societal problems and ensuing fussy system boundaries. |
| Broad solution scope | The MIS approach takes a transitions perspective, including social and technical innovation and phase-out, and their interactions. It enables identifying solution-interaction barriers (e.g. wait-and-see dynamics) and recommendations in terms of coordination and business model innovation that other system views overlook. | The high complexity of increased system scope (compared to TIS' single solutions) poses feasibility and granularity (bundling mission solutions vs. analyzing them individually) problems for a comprehensive MIS analysis. |
| Focus on contestation of directionality | The mission arena focuses on contestation between stakeholders aiming to steer the rate and direction of societal transformation, allowing critical observation of negative mission impacts by vested interests. | More theory development on the impact of different mission arena stakeholder compositions–particularly the involvement of vested interests–on mission governance outcomes is necessary. Interest-based interviewee bias is likely on politically sensitive mission arenas, requiring critical triangulation across data sources. |
| Temporality, legitimacy, and reflexivity | As opposed to other innovation system views, the MIS approach explicates temporality and the need for continued legitimacy and reflexivity. Many TIS studies ignore that technologies are also temporary [34]. | Long term (20+ year) missions require sustained legitimacy for societal problems and solutions, to safeguard multiple rounds of future stakeholder commitments. Institutionalization resistant to political fads is necessary, as popularity of missions is subject to the policy delivering in the future [12,21]. Continued reflexivity on mission scope and actions by a dedicated taskforce is necessary. |
| Evaluation from a MIS perspective | The MIS approach proved useful to ex-ante, formatively evaluate the systemic impacts of implemented mission arena tasks, allowing for recommendations to increase the effectiveness of the mission arena in meeting its challenge-led mission. | Further application of the MIS approach is necessary to assess its applicability and usefulness in other settings. The approach only explores if barriers are targeted, not the impact of measures on these barriers. Development of a summative approach will eventually be necessary to assess the impact of mission policy. |

https://doi.org/10.1371/journal.pstr.0000075.t006

- level of 'wickedness', as degrees of complexity, uncertainty and contestation differ [9,23];
- type of required solutions, i.e. predominantly technological or social [126];
- accelerator missions or transformer missions [10,11,33];
- relatedly, 'big science' missions of old or today's challenge-led missions [8,127];
- number of possible 'solution-pathways' and ensuing complexities, within the mission scope;
- geographical scope and multi-scalarity, and ensuing coordination problems [22,128];
- bottom-up or top-down, and dedicated or business-as-usual governance structures [11];
- outside-managerial or inside-political governance strategies [37].

Central to our MIS approach is the mission arena concept, which merits further reflection. This case study showed that the mission arena took an outside, managerial type of mission governance approach [37] relying on existing, national, and sector-specific industry networks whose principal interest was to maintain the Dutch maritime sector's competitiveness. So, although the governance structure included many different actor types, individual companies were marginalized in its deliberation processes. In this light, our empirics suggest the following relations between mission arena composition and negotiated mission governance actions, that merit further study to build theory on mission arenas.

First, a non-inclusive, top-down mission arena approach undermines stakeholder support. This is reflected in the Mission-oriented Innovation Policy literature, which underlines the importance of bottom-up deliberation processes, such as participatory foresight methods, for tapping into stakeholders' creativity and support [11,130]. Further research should inventory best practices balancing top-down and bottom-up mission governance processes, and especially of effectively engaging individual companies in mission arenas.

Second, vested interests striving for economic competitiveness of sectors affected by the mission favor a 'mission accelerator approach' that focuses on technological development supported by public policy support [10,11,33] and neglects destabilizing and social solutions necessary for missions that are inherently transformative, like most sustainability missions. Bugge et al. [69] find that accelerator mission approaches may be adequately governed by existing innovation system networks. However, in our case, actors justified the accelerator approach to a transformative sustainability mission under the misleading (in terms of absolute, global decoupling) 'green growth' paradigm [131,132]. Hence, powerful vested interests can inhibit the achievement of a more impactful 'transformer mission approach'. Building on transition arenas and arenas of development literature [47,49,58,59], further research should study how to move away from pre-existing innovation systems' governance structures where vested interests like industry associations have positions of power. Instead, research should explore how to create dedicated, multi-stakeholder mission governance structures that do not build on, but exclude established networks that prioritize economic interest in established technologies. This is because such networks will negatively impact collective sense-making processes in terms of transformative mission goals, problem and solution directionality, and mission governance commitments. Finally, longitudinal research may study how mission arena configurations and boundaries shift over time, as stakeholder power and interests shift.

Third, although the focal national mission was created in a transnational (EU) and global (IMO) institutional context of developing similar mission targets, it lacked sufficient transnational commitment. The case study here suggests that in inherently transnationally oriented sectors, such lack of transnational institutional context may (a) undermine the national

mission's impact and (b) narrow its solution orientation to solutions less dependent on transnational cooperation. Limited transnational commitments are not uncommon in sustainability contexts, as even the United Nation's Sustainable Development Goals seems to have marginal transformative impact on national mission policies, due to the limited commitments and non-binding agreements [133]. Perhaps the EU mission areas and EU Green Deals can secure such commitments [134]. It may be necessary to further study how to align mission solution orientations and create cohesion of mission governance actions across multi-level governance structures [135], i.e. mission arenas interconnected across geographical scales as suggested by the concept of Challenge-oriented Regional Innovation Systems [22].

## 5. Conclusions

This paper introduces for the first time a MIS approach, which is a structural-functional approach to study missions from a systems perspective. Furthermore, the paper illustrates its applicability with a case study of the Dutch Green Deal mission for sustainable short sea shipping. We identified the most important barriers in the system structures affecting the mission, which inhibit the development and diffusion of innovative and destabilizing mission solutions. To formatively evaluate the mission-supporting tasks of the mission arena, we assessed if arena tasks targeted these MIS barriers.

The main MIS barriers revolved around the missing business model of shippers to adopt sustainable innovations. THis is caused by little market-oriented policy support, unwillingness to pay sustainability premiums, wait-and-see dynamics due to missing solution directionality, and inadequate incentive structures. These barriers and low company commitment to the mission illustrate the semi-coherence of existing system structures influencing the mission, indicating that a coherent MIS still needs to emerge. Assessing the first arena task in relation to the MIS barriers, we find individual firms were not adequately involved in forming the mission arena, which was dominated instead by industry associations that negotiated a mission formulation around green growth (second arena task) and vague and non-committal governance actions, although these actions did target MIS barriers (third task). This, combined with the delayed installment of a taskforce (fourth task), failed to overcome the barrier of limited company support to the mission. There also was more potential to provide the much-needed solution-directionality in a MIS characterized by a wide range of still uncompetitive but infrastructure-dependent technological solutions that require coordinated selection by different actors to becomes successful. Finally, better attempts could be made to overcome problematic incentive structures in support of social innovation.

Building on the assumption that a coherent MIS is necessary to effectively meet mission goals, we conclude that the value of the MIS approach lies in its ability to explore emerging mission governance dynamics in relation to the broader innovation system structures that the mission arena aims to impact. The MIS approach acknowledges the political nature of missions, their overarching societal problems, and underlying innovative and transformative solutions. Instead of building on prescriptive principles, the MIS approach provides a heuristic tool to systematically identify MIS barriers, which forms as basis to formatively assess mission governance actions.

## Supporting information

**S1 Table. Overview of solutions, their TRL, innovation type, involvement of interviewees, advantages, and disadvantages.**
(DOCX)

## Acknowledgments

The authors want to thank the interviewees for their candid responses; the three anonymous referees and the section editor for their comprehensive feedback that enabled us to improve this paper; our colleagues at the MIPO (Mission-oriented Innovation Policy Observatory) for the discussions that helped shape this paper; Matthijs Janssen for his comprehensive comments on the draft paper; a maritime transport expert working at RVO that factually checked the draft; in particular Koen Frenken for his continued support throughout the publication process.

## Author Contributions

**Conceptualization:** Joeri Wesseling.

**Data curation:** Nick Meijerhof.

**Formal analysis:** Joeri Wesseling, Nick Meijerhof.

**Investigation:** Joeri Wesseling, Nick Meijerhof.

**Supervision:** Joeri Wesseling.

**Writing – original draft:** Joeri Wesseling.

**Writing – review & editing:** Joeri Wesseling.

## References

1. Levin K, Cashore B, Bernstein S, Auld G. Overcoming the tragedy of super wicked problems: Constraining our future selves to ameliorate global climate change. Policy Sci. 2012; 45: 123–152. https://doi.org/10.1007/s11077-012-9151-0
2. Haddad CR, Nakić V, Bergek A, Hellsmark H. Transformative innovation policy: A systematic review. Environ Innov Soc Transit. 2022; 43: 14–40. https://doi.org/10.1016/j.eist.2022.03.002
3. Diercks G, Larsen H, Steward F. Transformative innovation policy: Addressing variety in an emerging policy paradigm. Res Policy. 2019; 48: 880–894. https://doi.org/10.1016/j.respol.2018.10.028
4. Schot J, Steinmueller WE. Three frames for innovation policy: R & D, systems of innovation and transformative change. Res Policy. 2018; 47: 1554–1567. https://doi.org/10.1016/j.respol.2018.08.011
5. Grillitsch M, Hansen T, Coenen L, Miörner J, Moodysson J. Innovation policy for system-wide transformation: The case of strategic innovation programmes (SIPs) in Sweden. Res Policy. 2019; 48: 1048–1061. https://doi.org/10.1016/j.respol.2018.10.004
6. Kattel R, Mazzucato M. Mission-oriented innovation policy and dynamic capabilities in the public sector. 2018; 27: 787–801. https://doi.org/10.1093/icc/dty032
7. Foray D, Mowery DC, Nelson RR. Public R&D and social challenges: What lessons from mission R&D programs? Res Policy. 2012; 41: 1697–1702. https://doi.org/10.1016/j.respol.2012.07.011
8. Robinson DKR, Mazzucato M. The evolution of mission-oriented policies: Exploring changing market creating policies in the US and European space sector. Res Policy. 2019; 48: 936–948. https://doi.org/10.1016/j.respol.2018.10.005
9. Wanzenböck I, Wesseling JH, Frenken K, Hekkert MP, Weber KM. A framework for mission-oriented innovation policy: Alternative pathways through the problem–solution space. Sci Public Policy. 2020; 1–16. https://doi.org/10.1093/scipol/scaa027
10. JIIP Joanneum Research, Tecnalia TNO, VTT Danish Technological Institute. Mission-oriented research and innovation: inventory and characterisation of initiatives: final report. 2018.
11. Larrue P. The design and implementation of mission-oriented innovation policies: A new systemic policy approach to address societal challenges. Brussels; 2021.
12. Janssen MJ, Torrens J, Wesseling JH, Wanzenböck I. The promises and premises of mission-oriented innovation policy—A reflection and ways forward. Sci Public Policy. 2021; 48: 438–444. https://doi.org/10.1093/scipol/scaa072

13. Wanzenböck I, Wesseling JH, Frenken K, Hekkert MP, Weber KM. A framework for mission-oriented innovation policy: Alternative pathways through the problem-solution space. Sci Public Policy. 2020; 47: 474–489. https://doi.org/10.1093/scipol/scaa027
14. Rohracher H, Coenen L, Kordas O. Mission incomplete: Layered practices of monitoring and evaluation in Swedish transformative innovation policy. Sci Public Policy. 2022; 00: 1–14. https://doi.org/10.1093/scipol/scac071
15. Hekkert MP, Janssen MJ, Wesseling JH, Negro SO. Mission-oriented innovation systems. Environ Innov Soc Transit. 2020; 34: 76–79.
16. Ghazinoory S, Nasri S, Ameri F, Montazer GA, Shayan A. Why do we need 'Problem-oriented Innovation System (PIS)' for solving macro-level societal problems? Technol Forecast Soc Change. 2020; 150: 1–18. https://doi.org/10.1016/j.techfore.2019.119749
17. Schlaile MP, Kask J, Brewer J, Bogner K, Urmetzer S, De Witt A. Proposing a Cultural Evolutionary Perspective for Dedicated Innovation Systems: Bioeconomy Transitions and Beyond. Journal of Innovation Economics & Management. 2021;Prépublica: Ie-XXVI. https://doi.org/10.3917/jie.pr1.0108
18. Klerkx L, Begemann S. Supporting food systems transformation: The what, why, who, where and how of mission-oriented agricultural innovation systems. Agric Syst. 2020; 184: 1–8. 102901. https://doi.org/10.1016/j.agsy.2020.102901 PMID: 32834403
19. Jütting M. Exploring mission-oriented innovation ecosystems for sustainability: Towards a literature-based typology. Sustainability (Switzerland). 2020; 12: 6676–6684. https://doi.org/10.3390/su12166677
20. Haddad CR, Bergek A. Towards an integrated framework for evaluating transformative innovation policy. Res Policy. 2023; 52: 1–17. https://doi.org/10.1016/j.respol.2022.104676
21. Janssen MJ, Bergek A, Wesseling JH. Evaluating systemic innovation and transition programmes: Towards a culture of learning. PLOS Sustainability and Transformation. 2022; 1: 1–6. e0000008. https://doi.org/10.1371/journal.pstr.0000008
22. Tödtling F, Trippl M, Desch V. New directions for RIS studies and policies in the face of grand societal challenges. European Planning Studies. 2022; 30: 2139–2156. https://doi.org/10.1080/09654313.2021.1951177
23. Alford J, Head B. Wicked and less wicked problems: A typology and a contingency framework. Policy Soc. 2017:397–413. https://doi.org/10.1080/14494035.2017.1361634
24. Mazzucato M. Mission-Oriented Research & Innovation in the European Union. 2018. https://doi.org/10.2777/36546
25. Alford J, Head B. Wicked and less wicked problems: A typology and a contingency framework. Panel T04P06—Policy responses to 'wicked problems'–theory and practice International Conference on Public Policy. 2015; 4035: 1–26. https://doi.org/10.1080/14494035.2017.1361634
26. IPCC. Chapter 2: Mitigation Pathways Compatible with 1.5˚C in the Context of Sustainable Development. IPCC special report Global Warming of 15 oC. 2018.
27. Rehfeld D, Terstriep J, Welschhoff J, Alijani S. Comparative Report on Social Innovation Framework. Proyecto SIMPACT. 2015.
28. Pel B, Haxeltine A, Avelino F, Dumitru A, Kemp R, Bauler T, et al. Towards a TSI theory: a relational framework and 12 propositions. Res Policy. 2020; 49: 24. https://doi.org/10.1016/j.respol.2020.104080
29. David M. Moving beyond the heuristic of creative destruction: Targeting exnovation with policy mixes for energy transitions. Energy Res Soc Sci. 2017; 33: 138–146. https://doi.org/10.1016/j.erss.2017.09.023
30. Kivimaa P, Kern F. Creative Destruction or Mere Niche Creation? Innovation Policy Mixes for Sustainability Transitions. Res Policy. 2016; 45: 205–217. https://doi.org/10.1016/j.respol.2015.09.008
31. Trencher G, Rinscheid A, Rosenbloom D. Mapping the contours of an emerging phase out science. Working paper. 2022; 0–29.
32. Rinscheid A, Rosenbloom D, Markard J, Turnheim B. From terminating to transforming: The role of phase-out in sustainability transitions. Environ Innov Soc Transit. 2021; 41: 27–31. https://doi.org/10.1016/j.eist.2021.10.019
33. Wittmann F, Hufnagl M, Lindner R, Roth F, Edler J. Governing varieties of mission-oriented innovation policies: A new typology. Sci Public Policy. 2021. https://doi.org/10.1093/scipol/scab04
34. Markard J, Bento N, Kittner N, Nuñez-Jimenez A. Destined for decline? Examining nuclear energy from a technological innovation systems perspective. Energy Res Soc Sci. 2020;67. https://doi.org/10.1016/j.erss.2020.101512

35. Azar C, Sandén BA. The elusive quest for technology-neutral policies. Environ Innov Soc Transit. 2011; 1: 135–139. https://doi.org/10.1016/j.eist.2011.03.003

36. Weber KM, Rohracher H. Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive "failures" framework. Res Policy. 2012; 41: 1037–1047. https://doi.org/10.1016/j.respol.2011.10.015

37. Smith A, Stirling A. Moving Outside or Inside? Objectification and Reflexivity in the Governance of Socio-Technical Systems. Journal of Environmental Policy & Planning. 2007; 9: 351–373. https://doi.org/10.1080/15239080701622873

38. Hekkert MP, Suurs RAA, Negro SO, Kuhlmann S, Smits REHM. Functions of innovation systems: A new approach for analysing technological change. Technol Forecast Soc Change. 2007; 74: 413–432. https://doi.org/10.1016/j.techfore.2006.03.002

39. Bergek A, Jacobsson S, Carlsson B, Lindmark S, Rickne A. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Res Policy. 2008; 37: 407–429. https://doi.org/10.1016/j.respol.2007.12.003

40. Janssen M. What bangs for your buck? Assessing the design and impact of Dutch transformative policy. Technol Forecast Soc Change. 2019; 138: 78–94. https://doi.org/10.1016/j.techfore.2018.08.011

41. van Mierlo B, Leeuwis C, Smits R, Woolthuis R. Learning towards system innovation: Evaluating a systemic instrument. Technol Forecast Soc Change. 2010; 77: 318–334. https://doi.org/10.1016/j.techfore.2009.08.004

42. Wieczorek AJ, Hekkert M. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Sci Public Policy. 2012; 39: 74–87. https://doi.org/10.1093/scipol/scr008

43. Wesseling J, Edquist C. Public procurement for innovation to help meet societal challenges: a review and case study. Sci Public Policy. 2018; 45: 493–502. https://doi.org/10.1093/scipol/scy013

44. Scott WR. Institutions and organizations: ideas, interests, and identities. Los Angeles: Sage; 2014.

45. Sandén B, Hillman K. A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden. Res Policy. 2011; 40: 403–414. https://doi.org/10.1016/j.respol.2010.12.005

46. Bergek A, Hekkert M, Jacobsson S, Markard J, Sandén B, Truffer B. Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. Environ Innov Soc Transit. 2015. https://doi.org/10.1016/j.eist.2015.07.003

47. Loorbach D. Transition management for sustainable development: A prescriptive, complexity-based governance framework. Governance. 2010; 23: 161–183. https://doi.org/10.1111/j.1468-0491.2009.01471.x

48. Fink H. Arenabegreber—mellem ørkensand & ørkensand. In: Fink H, editor. Arenaer—om politik & inscenesættelse. Aarhus: Aarhus Universitetsforlag; 1996. pp. 7–22.

49. Mapping Jørgensen U. and navigating transitions—The multi-level perspective compared with arenas of development. Res Policy. 2012; 41: 996–1010. https://doi.org/10.1016/j.respol.2012.03.001

50. Janssen M, Wesseling J, Torrens J, Matthias Weber K, Penna C, Klerkx L. Missions as boundary objects for transformative change: understanding coordination across policy, research, and stakeholder communities. Sci Public Policy. 2023: 1–18. https://doi.org/10.1093/scipol/scac080/7030831

51. Arnouts R, van der Zouwen M, Arts B. Analysing governance modes and shifts—Governance arrangements in Dutch nature policy. For Policy Econ. 2012; 16: 43–50. https://doi.org/10.1016/j.forpol.2011.04.001

52. Marks G, Hooghe L. Contrasting Visions of Multi-level Governance. In: Bache I, Flinders M, editors. Multi-level Governance. Oxford University Press; 2004: 15–30.

53. Pahl-Wostl C, Knieper C. The capacity of water governance to deal with the climate change adaptation challenge: Using fuzzy set Qualitative Comparative Analysis to distinguish between polycentric, fragmented and centralized regimes. Global Environmental Change. 2014; 29: 139–154. https://doi.org/10.1016/j.gloenvcha.2014.09.003

54. Zeben J Van, Bobic A. Polycentricity in the European Union. Cambridge University Press; 2019.

55. Torfing J. Governance network theory: Towards a second generation. European Political Science. 2005; 4: 305–315. https://doi.org/10.1057/palgrave.eps.2210031

56. Ojo A, Mellouli S. Deploying governance networks for societal challenges. Gov Inf Q. 2018; 35: S106–S112. https://doi.org/10.1016/j.giq.2016.04.001

57. Ansell C, Gash A. Collaborative governance in theory and practice. Journal of Public Administration Research and Theory. 2008; 18: 543–571. https://doi.org/10.1093/jopart/mum032

58. Valderrama Pineda A, Jørgensen U. Creating Copenhagen's Metro—On the role of protected spaces in arenas of development. Environ Innov Soc Transit. 2016; 18: 201–214. https://doi.org/10.1016/j.eist.2015.05.002

59. Loorbach D, Frantzeskaki N, Avelino F. Sustainability Transitions Research: Transforming Science and Practice for Societal Change. Annu Rev Environ Resour. 2017; 42: 599–626. https://doi.org/10.1146/annurev-environ-102014-021340

60. Bickerstaff K, Walker G. Shared visions, unholy alliances: Power, governance and deliberative processes in local transport planning. Urban Studies. 2005; 42: 2123–2144. https://doi.org/10.1080/00420980500332098

61. Stirling A. "Opening Up" and "Closing Down": Power, Participation, and Pluralism in the Social Appraisal of Technology. Science, Technology & Human Values. 2008; 33: 262–294.

62. Fogelberg H, Sandén B. Understanding reflexive systems of innovation: An analysis of Swedish nanotechnology discourse and organization. Technol Anal Strateg Manag. 2008; 20: 65–81. https://doi.org/10.1080/09537320701726593

63. Carlsson B, Stankiewicz R. On the nature, function and composition of technological systems. J Evol Econ. 1991; 93–118.

64. Edquist C. Systems of Innovation: perspectives and challenges. Fagerberg/The Oxford Handbook of Innovation. 2004. pp. 181–204.

65. Malerba F, Orsenigo L. Technological Regimes and Sectoral Patterns of Innovative Activities. Industrial and Corporate Change. 1997; 6: 83–118. https://doi.org/10.1093/icc/6.1.83

66. Edquist C, Lundvall B. Comparing the Danish and Swedish systems of innovation. In: Nelson R, editor. National Innovation Systems. New York: Oxford University Press; 1993.

67. Geels F. From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. Res Policy. 2004; 33: 897–920. https://doi.org/10.1016/j.respol.2004.01.015

68. Markard J, Hekkert M, Jacobsson S. The technological innovation systems framework: Response to six criticisms. Environ Innov Soc Transit. 2015; 16: 76–86. https://doi.org/10.1016/j.eist.2015.07.006

69. Bugge M, Andersen A, Steen M. The role of regional innovation systems in mission-oriented innovation policy: exploring the problem-solution space in electrification of maritime transport. European Planning Studies. 2022; 30: 2312–2333. https://doi.org/10.1080/09654313.2021.1988907

70. Wesseling J, Van der Vooren A. Lock-in of mature innovation systems: The transformation toward clean concrete in the Netherlands. J Clean Prod. 2017; 155: 114–124. https://doi.org/10.1016/j.jclepro.2016.08.115

71. Turnheim B, Geels F. Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997). Energy Policy. 2012; 50: 35–49. https://doi.org/10.1016/j.enpol.2012.04.060

72. Rosenbloom D. Framing low-carbon pathways: A discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario. Environ Innov Soc Transit. 2018; 27: 129–145. https://doi.org/10.1016/j.eist.2017.11.003

73. Isoaho K, Markard J. The Politics of Technology Decline: Discursive Struggles over Coal Phase-Out in the UK. Review of Policy Research. 2020; 37: 342–368. https://doi.org/10.1111/ropr.12370

74. Kivimaa P, Sivonen M. How Will Renewables Expansion and Hydrocarbon Decline Impact Security? Analysis from a Socio-Technical Transitions Perspective. SSRN Electronic Journal. 2022; 48:1–18. https://doi.org/10.2139/ssrn.4015105

75. Ghosh B, Kivimaa P, Ramirez M, Schot J, Torrens J. Transformative outcomes: Assessing and reorienting experimentation with transformative innovation policy. Sci Public Policy. 2021; 48: 739–756. https://doi.org/10.1093/scipol/scab045

76. van Mierlo B, Beers P. Understanding and governing learning in sustainability transitions: A review. Environ Innov Soc Transit. 2020; 34: 255–269. https://doi.org/10.1016/j.eist.2018.08.002

77. Janssen M, Torrens J, Wesseling J, Patterson J. Position paper 'Mission—oriented innovation policy observatory'. Utrecht University; 2020: 1–17.

78. Suurs R, Hekkert M. Competition between first and second generation technologies: Lessons from the formation of a biofuels innovation system in the Netherlands. Energy. 2009; 34: 669–679. https://doi.org/10.1016/j.energy.2008.09.002

79. Wieczorek A, Hekkert M. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Sci Public Policy. 2012; 39: 74–87.

80. Smits R, Kuhlmann S. The rise of systemic instruments in innovation policy. International Journal of Foresight and Innovation Policy. 2004; 1: 4–32. https://doi.org/10.1504/IJFIP.2004.004621

81. Suurs R. Motors of sustainable innovation: Towards a theory on the dynamics of technological innovation systems. Utrecht University; 2009.
82. Howlett M, Rayner J. Patching vs Packaging in Policy Formulation: Complementary Effects, Goodness of Fit, Degrees of Freedom, and Feasibility in Policy Portfolio Design. Politics and Governance. 2013; 1: 170–182. https://doi.org/10.12924/pag2013.01020170
83. Howlett M, Rayner J. Design Principles for Policy Mixes: Cohesion and Coherence in 'New Governance Arrangements.' Policy Soc. 2007; 26: 1–18. https://doi.org/10.1016/S1449-4035(07)70118-2
84. Yin R. Case study research, Design and Methods. London: Sage Publications; 2003.
85. DePoy E, Gitlin L. Mixed Method Designs. In: DePoy E, Gitlin L., editors. Introduction to Research. Amsterdam: Elsevier; 2016: 173–179.
86. van Nieuwenhuizen C. Kamerbrief bij Green Deal Zeevaart, Binnenvaart en Havens. 2019.
87. Deal Green. Green Deal on Maritime and Inland Shipping and Ports. 2019.
88. IEA. International Shipping. Paris; 2022.
89. UN. Review of maritime transport 2022, Navigating stormy waters. New York; 2022.
90. Alamoush A, Ölçer A, Ballini F. Ports' role in shipping decarbonisation: A common port incentive scheme for shipping greenhouse gas emissions reduction. Cleaner Logistics and Supply Chain. 2022; 3: 1–15. https://doi.org/10.1016/j.clscn.2021.100021
91. CBS. Emissies naar lucht op Nederlands grondgebied; totalen. In: Statline. Feb 2023. [cited 13 Jun 2023]. Available: https://www.cbs.nl/nl-nl/cijfers/detail/37221
92. European Commision. Emissions-free sailing is full steam ahead for ocean-going shipping | Research and Innovation. 2022 [cited 14 Feb 2023]. Available: https://ec.europa.eu/research-and-innovation/en/horizon-magazine/emissions-free-sailing-full-steam-ahead-ocean-going-shipping
93. van den Bossche M, de Jong O, Janse R, Streng M, van der Lugt L, van Houwelingen R. Maritieme Arbeidsmarkt- en Haven Monitor 2022. Rotterdam; 2022.
94. Bergek A, Bjørgum Ø, Hansen T, Hanson J, Steen M. Sustainability transitions in coastal shipping: The role of regime segmentation. Transp Res Interdiscip Perspect. 2021; 12:100497. https://doi.org/10.1016/j.trip.2021.100497
95. Spoelstra J. Green Deal markeert begin transitie naar emissieloze scheepvaart. 12 Jun 2019. [cited 13 Jun 2023] In: https://www.maritiemnederland.com/nieuws/green-deal-markeert-begin-transitie-naar-emissieloze-scheepvaart.
96. Bryman A. Social research methods. 4th ed. Oxford University Press; 2016.
97. Strauss A, Corbin J. Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory. Basics of Qualitative Research Grounded Theory Procedures and Techniques. London: Sage; 2008. https://doi.org/10.4135/9781452230153
98. Charmaz K. Constructing grounded theory: A practical guide through qualitative research. London: Sage; 2006.
99. Trencher G, Wesseling J. Roadblocks to fuel-cell electric vehicle diffusion: Evidence from Germany, Japan and California. Transp Res D Transp Environ. 2022; 112: 1–21. https://doi.org/10.1016/j.trd.2022.103458
100. Krippendorff K. Reliability in Content Analysis. Hum Commun Res. 2004; 30: 411–433. https://doi.org/10.1111/j.1468-2958.2004.tb00738.x
101. IGU. 2020 World LNG Report. International Gas Union. 2020.
102. Safety4Sea. Number of ships using LNG, scrubbers to increase from 2020. Jun 2019 [cited 13 Jun 2023]. Available: https://safety4sea.com/number-of-ships-using-lng-scrubbers-to-increase-from-2020/
103. Henningsgård S. Someone has to go first. In: Maritime Impact. Apr 2019 [cited 13 Jun 2023]. Available: https://www.dnv.com/expert-story/maritime-impact/Someone-has-to-go-first.html
104. Geertsma C, Krijgsman M. Alternative fuels and power systems to reduce environmental impact of support vessels. Proceedings of Marine Electrical and Control Systems Safety Conference (MECSS). 2019; 1: 1–9. https://doi.org/10.24868/issn.2515-8198.2019.003
105. Transport & Environment. CNG and LNG for vehicles and ships—the facts. Brussels; 2018.
106. Wärtsilä Corporation. Wärtsilä customised LNG solution chosen for four next-generation short-sea cargo vessels. Jan 2020 [cited 13 Jun 2023]. Available: https://www.wartsila.com/media/news/13-01-2020-wartsila-customised-lng-solution-chosen-for-four-next-generation-short-sea-cargo-vessels-2616149

107. Port of Rotterdam. Haalbaarheid methanol als transportbrandstof in maritieme sector. Feb 2019 [cited 13 Jun 2023]. Available: https://portofbusiness.nl/haalbaarheid-methanol-als-transportbrandstof-in-maritieme-sector/

108. IMO. Reducing greenhouse gas emissions from ships. Jan 2020 [cited 14 May 2022]. Available: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissionsfrom-ships.aspx

109. Harrabin R. $5bn fund unveiled for climate-friendly shipping. BBC. Dec 2019 [cited 13 Jun 2023] Available: https://www.bbc.com/news/science-environment-50827604

110. European Commission. Reducing emissions from the shipping sector. Brussels; 2019.

111. Smits P. Startups in de scheepvaart, het blijft vaak vallen en opstaan. Sep 2020 [cited 13 Jun 2023]. Available: https://www.nt.nl/scheepvaart/2020/09/22/startups-in-de-scheepvaart-het-blijft-vaak-vallen-en-opstaan/?gdpr=accept

112. Topsector Energie. Project overzicht. Nov 2020 [cited 13 Jun 2023]. Available: https://projecten.topsectorenergie.nl/projecten

113. Baresic D, Smith T, Raucci K, Rehmatulla C, Narula N, Rojon I. LNG as a marine fuel in the EU: Market, bunkering infrastructure investments and risks in the context of GHG reductions. London; 2018.

114. I&W. Duurzame mobiliteit. Jan 2019 [cited 13 Jun 2023]. Available: https://magazines.rijksoverheid.nl/ienw/duurzaamheidsverslag/2019/01/duurzame-mobiliteit

115. Kashyap V. Understanding Power Management System: How To Reduce Power Consumption On Ships. Marine Technology. Feb 2021 [cited 13 Jun 2023]. Available: https://www.marineinsight.com/tech/understanding-power-management-system-how-to-reduce-power-consumption-on-ships/

116. IMO. Sulphur oxides (SOx) and Particulate Matter (PM)–Regulation 14. 2020 [cited 13 Jun 2023]. Available: https://www.imo.org/en/OurWork/Environment/Pages/Sulphur-oxides-(SOx)-%E2%80%93-Regulation-14.aspx

117. European Commission. Guidance/Best practices document on monitoring and reporting of fuel consumption, CO2 emissions and other relevant parameters pursuant to Regulation 2015/757 on monitoring, reporting and verification emissions from maritime transport. Brussels; 2017.

118. Rijkswaterstaat. Vlootvervanging. 2020 [cited 13 Jun 2023]. Available: https://www.rijkswaterstaat.nl/water/waterbeheer/beheer-en-ontwikkeling-rijkswateren/rijksrederij/vlootvervanging

119. Hennigs N, Schmidt S, Wiedmann K, Karampournioti E, Labenz F. Measuring brand performance in the cruise industry: Brand experiences and sustainability orientation as basis for value creation. International Journal of Services, Technology and Management. 2017; 23: 189–203. https://doi.org/10.1504/IJSTM.2017.085473

120. Regeerakkoord. Vertrouwen in de toekomst. The Hague: 2017.

121. Anink D, Sakko S. EFSA Roadmap 2050. 2019. [cited 13 Jun 2023] Available: https://www.emissionfreeshipping.com/wp-content/uploads/2019/12/Emission-Free-Shipping-Association-Roadmap-2050.pdf

122. Stolper L, Bergsma J, Pruyn J. The significance of pilot projects in overcoming transition barriers: A socio-technical analysis of the Dutch shipping energy transition. Case Stud Transp Policy. 2022; 10: 1417–1426. https://doi.org/10.1016/j.cstp.2022.05.003

123. Lister J, Poulsen R, Ponte S. Orchestrating transnational environmental governance in maritime shipping. Global Environmental Change. 2015; 34: 185–195. https://doi.org/10.1016/j.gloenvcha.2015.06.011

124. Bach H, Bergek A, Bjørgum Ø, Hansen T, Kenzhegaliyeva A, Steen M. Implementing maritime battery-electric and hydrogen solutions: A technological innovation systems analysis. Transp Res D Transp Environ. 2020; 87: 1–22. https://doi.org/10.1016/j.trd.2020.102492

125. Bach H, Mäkitie T, Hansen T, Steen M. Blending new and old in sustainability transitions: Technological alignment between fossil fuels and biofuels in Norwegian coastal shipping. Energy Res Soc Sci. 2021; 74: 1–12. https://doi.org/10.1016/j.erss.2021.101957

126. Pel B, Wittmayer J, Dorland J, Søgaard Jørgensen M. Unpacking the social innovation ecosystem: an empirically grounded typology of empowering network constellations. Innovation: The European Journal of Social Science Research. 2020; 33: 311–336. https://doi.org/10.1080/13511610.2019.1705147

127. Kaldewey D. The Grand Challenges Discourse: Transforming Identity Work in Science and Science Policy. Minerva. 2018; 56: 161–182. https://doi.org/10.1007/s11024-017-9332-2 PMID: 29780179

128. Wanzenböck I, Frenken K. The subsidiarity principle in innovation policy for societal challenges. Glob Transit. 2020; 2: 51–59. https://doi.org/10.1016/j.glt.2020.02.002

129. Markard J, Truffer B. Technological innovation systems and the multi-level perspective: Towards an integrated framework. Res Policy. 2008; 37: 596–615. https://doi.org/10.1016/j.respol.2008.01.004

130. Rosa AB, Kimpeler S, Schirrmeister E, Warnke P. Participatory foresight and reflexive innovation: setting policy goals and developing strategies in a bottom-up, mission-oriented, sustainable way. European Journal of Futures Research. 2021;9. https://doi.org/10.1186/s40309-021-00171-6

131. Jackson T, Victor P. Unraveling the claims for (and against) green growth. Science. 2019; 366: 950–951. https://doi.org/10.1126/science.aay0749 PMID: 31753984

132. Hickel J, Kallis G. Is Green Growth Possible? New Political Economy. 2020; 25: 469–486. https://doi.org/10.1080/13563467.2019.1598964

133. Biermann F, Hickmann T, Sénit CA, Beisheim M, Bernstein S, Chasek P, et al. Scientific evidence on the political impact of the Sustainable Development Goals. Nat Sustain. 2022; 5: 795–800. https://doi.org/10.1038/s41893-022-00909-5

134. Lindner R, Edler J, Hufnagl M, Kimpeler S, Kroll H, Roth F, et al. Mission-oriented innovation policy From ambition to successful implementation. Karlsruhe; 2021.

135. Marks G, Hooghe L. Contrasting Visions of Multi-level Governance. In: Bache I, Flinders M, editors. Multi-level Governance. Oxford University Press; 2004. pp. 15–30.