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Cruel utopia of the seas? Multiple risks challenge the singular hydrogen hype in Finnish maritime logistics

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ABSTRACT

To address the global climate crisis, maritime logistics are undergoing a transition away from fossil-based energy sources. The transition is envisaged to be both *green* (involving renewables) and *digital* (involving various kinds of digitalization). Much of the hope rests on *the new hydrogen economy*, involving the build-up of infrastructure for hydrogen-derived alternative fuels such as methanol and ammonia. Indeed, the new hydrogen economy is often portrayed as set to revolutionize maritime transport. The hope behind the hype reflects a belief in the performativity of hypes: some technological phenomenon will eventually materialise in innovation and business practices. In this paper, we critically analyse the current hydrogen hype in the field of Finnish maritime logistics as a paradigmatic case of performative techno-optimism. Based on causal network analysis and thematic analysis of expert interviews and workshop data, we argue that the phenomenon of performative techno-optimism is more nuanced than hitherto presented in the related literature. We showcase a variety of stances along a spectrum ranging from radical optimism to radical pessimism. Furthermore, our causal network analysis indicates that the current green and digital transition of maritime transport is caught in a systemic catch-22: transitioning to alternative fuels in maritime logistics faces a lock-in of between overly cautious demand for alternative fuels leading to overly cautious investment in supply, which only secures the modest demand. Finally, our thematic analysis of techno-optimist stances suggests the following two major ways out of the systemic dilemma: large-scale technological innovations and global regulatory solutions.

1. Introduction

To address climate change, maritime logistics is currently undergoing a transition away from its main fossil-based energy sources. This energy transition is envisaged to be both *green*, involving renewables, and *digital*, involving various kinds and processes of digitalisation. When it comes to sustainable transition and decarbonisation, much is still to be done. Maritime transportation accounts for around 3 % of total anthropogenic CO_2 emissions [1]. As oil has contributed more than 99 % of the total energy demands of the shipping industry, it has historically been more heavily fossilised than other industries [1,2]. Currently, the industry operates an ageing fleet that runs almost exclusively on fossil fuels, making it a considerable challenge for the Paris Agreement to limit global warming under 1.5 degrees Celsius [1,3]. While the International Maritime Organization (IMO) has adopted a strategy calling for a 70 % reduction from greenhouse gas (GHG) emissions from international shipping by 2040 compared with 2008 [2], the fact remains that despite the operational and technical improvements shipping emissions have been *growing* since this base year [1,3]. This highlights that the importance and urgency of transitioning the maritime transport sector is not quite reflected in extant sustainability transitions research [4,5]. As a result, the maritime sector faces increasing pressure to transition to more sustainable operations.

Much of the industrial vision for a green transition in maritime logistics is hedged by the development of a green hydrogen infrastructure that would allow for a preferably cost-competitive fuel switch to low-carbon alternative fuels. The versatility of hydrogen makes it, in theory, a very attractive energy carrier in the transition away from the use of fossil fuels [6–8]. However, recent theorizing and practical experience shows that, in order to convert the promising theory into practice, policy

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interventions at multiple levels are needed [3,9]. Based on the causal network analysis performed in this study, we argue that formulating such policy interventions firstly requires an understanding of the essentially catch-22 ‘loop’ structure of transitioning away from fossil fuels: the risk in transitioning to alternative fuels in maritime logistics is a lock-in involving overly cautious demand for alternative fuels leading to overly cautious investment in supply, which only secures the modest demand. Furthermore, on the basis of our subsequent content analysis, we argue that, secondly, the proposed solutions need to be formulated in a way that transcends this catch-22 loop. Finland – with its heavy dependence on marine transport in trade, long tradition in seafaring, and forerunner status in environmental and digital technologies – offers a unique opportunity for studying these intricacies in the green and digital transition in maritime logistics [10]. In this paper we ask the following research question: *Given the lock-in, what kind of policy interventions would be needed to convert the promising theory into practice as a green fuel in maritime logistics*?

In order to map out the solution space for our research question, we engaged a broad range of experts in workshops on devising pathways towards a green and digital future for maritime logistics. We aimed to scan their expert views on the required policy interventions, a standard procedure in the context of uncertain futures (see, e.g., [11]. More specifically, in the workshops the expert stakeholders were tasked to devise pathways for a transition to the new hydrogen economy. Our initial observation from both the qualitative data and the on-site drawing of causal networks indicated that the experts diverged in their views about the role of hydrogen and the required policy interventions in maritime logistics. In particular, the preliminary results indicate that the devised transition pathways produced their own problematic transition risks [12,13]. Finnish maritime logistics would seem to have little space to deliberate amidst the hydrogen hype/dominant frames, on the one hand, and the high level of risk awareness, on the other. The hope behind the hype seems to be based on an insight into the performativity of hypes [14]: making much ado about some technological phenomenon will eventually materialise in innovation and business practices.

These results made us curious about the reasons for the spread of views and led us in the direction of hype cycles and the performativity of hypes and risks. In our consequent analytical turn, made to make sense of the observed expert view divergence, we relied on analysis of performativity [14] understood through the lenses of techno-optimism and techno-pessimism [15,16]. We were particularly intrigued by the observation that, in this case, the hype appeared to be ‘stuck’ in the gesture of uttering the performative future representations [14], with no ensuing action in one direction or the other. In the case of hydrogen, the production of such future representations appears over-saturated, for example, with a new paper on hydrogen published every 20 min [9]. However, these acts of performative utterances of future representations are not received in a way that would make those utterances have an effect in the world. Such a lack of a *reception that makes a difference* constitutes a communicative failure from the point of view of effect. In terms of Luhmann’s theory of communication, one could say that only the first two parts of meaningful communication – information and utterance – are being provided, while the final part, understanding (i.e., that which makes the former two have an effect in the world), is indefinitely missing [17]. Recent literature on the hydrogen economy refers to this situation of stuckness with the notion of ‘an implementation gap’ [18]. Our aim thus transmuted into articulating, in both words and images (causal networks), the more specific nature of the observed communicative stuckness and we aim to analyse what kinds of policy interventions the experts envisioned as pathways out of the situation.

The significance of our work is to present a detailed diagnosis of the implementation gap in the hydrogen economy. Our analysis revealed a systemic catch-22, where the different levels of proposed policy interventions were contradicting each other in ways that led to an overall policy paralysis, with policy stuck between overly cautious demand for alternative fuels and overly cautious investment in supply. Our innovation is in introducing two germinating ideas on how to break the dilemma, one as technological intervention at the niche level and the other as regulatory intervention at regime and landscape levels, c.f. [14,15].

The paper is structured as follows. The next section outlines the main theoretical notions needed to make our argument about an abundance of performative utterances on future expectations that do not meet the understanding reception that makes a difference in the world [17]. *Performativity* means that expectations, scenarios and other forms of anticipation of future events affect what may happen [14]. *Techno-optimism* is the stance that the good will probably prevail over the bad and that technology plays a key role in ensuring this [14,16]. *Techno-pessimism* claims the opposite to be the case. Optimism becomes *cruel* when something one desires is actually an obstacle to one’s flourishing, for instance, when desiring a shift to a global hydrogen economy entails the diminishing of the preconditions for global ecological sustenance [15]. The third section details the qualitative and quantitative materials and methods that we use in our analysis. As our ontological and epistemological starting point, we take the notion that expectations of the future are constitutive of socio-material realities as they unfold. In Section 4, we present the results of our qualitative analysis: the causal network analysis yielding the backbone of the catch-22 and the thematic analysis yielding two possible ways to escape the dilemma. The fifth and sixth sections discuss and conclude our results regarding the communicative stalemate over hydrogen.

2. The theoretical background

2.1. The versatility of hydrogen

Green hydrogen is widely assumed to play a critical role in the green transition, in particular for decarbonising hard-to-electrify sectors (see, e.g., [18,19]). The allure of hydrogen is rather straightforward. It is the most abundant element in the universe, it is energy dense, and it is versatile. This has led to a long history of highlighting the future promise of hydrogen as a fuel, ranging from Jules Verne’s novel *Mysterious Island* in 1874 (highlighting the option of isolating it from water and producing only water when used as fuel), moving through twentieth century interest in space travel requiring dense fuels and onto twenty-first century visions of a zero-carbon economy [20]. The combination of its abundance, density and versatility makes hydrogen a very attractive energy carrier in the transition away from the use of fossil fuels [8]. If not used directly, green hydrogen can be a source for low-carbon or carbon-neutral alternative fuels like methanol and ammonia. This form, hydrogen-derived fuels, is the main solution highlighted by the experts within this article’s data.

Also, in the maritime sector, much hope is placed on *the new hydrogen economy*, involving the build-up of infrastructure for hydrogen-derived alternative fuels. Indeed, grand claims have been made that this new hydrogen economy will ‘revolutionize’ maritime transport [21], with particular interest from shipping in regard to the hydrogen-derived fuels [9] such as ammonia [22]. The interest in hydrogen for maritime purposes appears particularly strong in Northern European contexts, for example, in Norway [23,24] and Sweden [25,26]. Reflections of this are also evident in neighbouring Finland, which is the empirical setting for this study.

Numerous countries have published national hydrogen strategies to support the transition from the hype of hydrogen to the actual implementation of hydrogen use, with the strategies of the regions of the USA, the EU, Japan and China accounting for over 80 % of planned hydrogen supply [9,27,28]. For example, the EU Hydrogen Strategy prioritises green hydrogen, but needs to increase funding in order to keep up with other international players [9,29]. The governments of the Nordic countries align with the aims of the industry to invest on the supply side, yet such ambitions are limited by currently modest regional demand and by the current lack of export infrastructure to Europe, and the Baltics in particular [8,29]. The current ambitions by the national-level Finnish National Hydrogen Network focus on the development of supply and infrastructure, with ongoing national and cooperative pipeline projects [28,30].

Access to a well-functioning infrastructure and supply for green hydrogen (i.e., hydrogen produced from zero-carbon or near zero-carbon sources), would indeed help the maritime sector to address a formidable challenge. As emissions from international shipping grew from 2008 to 2022, realising sectoral emission targets will require a very, very sharp deviation from current trends. In addition to, for example, energy efficiency improvements [31,32], alternative fuels would be an essential technological lever in this regard [4]. In this paper, we concentrate on hydrogen-derived fuels, specifically ammonia and methanol, rather than on hydrogen itself as fuel. While hydrogen can indeed be utilised as a fuel, its application is associated with several disadvantages related to its handling and storage challenges, as well as safety concerns [33].

Having established the need for substantial change and the attractiveness of hydrogen as a means to this end, some important modifiers are needed. First, for the use of hydrogen in the maritime sector, there are technical, social, and infrastructural issues that need to be solved along the whole value chain. For example, the use of hydrogen for maritime applications provides its own challenges, also at the use stage [33]. Hydrogen, as a light gas, has a low volumetric energy content under atmospheric conditions, practically necessitating the use of technologies to concentrate the hydrogen and make storage more efficient, to avoid significantly reducing the cargo capacity of ships [33]. Compression or liquidation processes help reduce the storage issue, but these processes induce energy losses [34]. As said, more sectoral interest is seen for solutions based on hydrogen-derived fuels, but ammonia, for example, is highly toxic, flammable and corrosive [35], bringing its own new sets of risks for maritime logistics. In addition, maritime usage of hydrogen or hydrogen-sourced solutions as fuel requires significant upfront investments in vessels [34]. Second, for an energy carrier heralded for its potential to fuel the green transition, the current production of hydrogen still mainly depends on fossil fuels. In fact, more than 96 % of all current hydrogen production is fossil-fuels based and considered as black, grey or brown hydrogen rather than the required green hydrogen. From the point of view of reaching a carbon-free sustainable environmental state, only cleanly produced green hydrogen is meaningful [33]. Low-emission hydrogen is being taken up very slowly in its existing applications, accounting for just 0.7 % of total hydrogen demand [6].

To meet the Net Zero Emissions by 2050 Scenario targets, the production of low-emission hydrogen would need to grow 100-fold by 2030 [6,p. 14]. In turn, such growth presumes the radical electrification of the energy system, because low-emission hydrogen is produced by water electrolysis [6,pp.,46–48]. The build-up of green hydrogen production is therefore closely tied to both a radical electrification and a rapid build-up of renewable electricity production. In 2024, the total energy consumption by energy source in Finland consisted of around: 28 % wood fuels, 19 % oil, 26 % nuclear fuel, 4 % coal, 3,5 % natural gas, 1 % net imported electricity, 1.5 % peat, 4 % hydropower, 5,5 % wind power and 6 % other types of renewable energy [36]. In the context of Finland, offshore wind power represents a promising renewable energy source while the seabed characteristics and wind conditions create optimal conditions for offshore wind farms [37]. In Finland the build-up of green hydrogen is likely to come from offshore wind energy investments (see, e.g., [38], while, for example, solar-driven solutions are key pieces in the hydrogen puzzle in other parts of the world [39,40].

Based on a recent review of the green hydrogen implementation and ambition gap [18], the good news is that many projects are being planned. The more challenging part is that 97 % of the capacity announced by 2030 is still in the concept or feasibility study phase, and analysis of previous years shows that significantly less than 10 % of announced capacity tends to make it to the operational phase on time [18]. To realise the planned ambition – which is still less than needed for the zero-carbon visions – cumulative subsides of US$1.3 trillion until 2030 could be needed [18].

Stripped to its bones, we argue that the singular expectation for hydrogen in the maritime logistics sector is that radical changes can be avoided within the sector as long as the right radical changes happen in other sectors. This is illustrated in Fig. 1 below. Large changes in the outer layers of Fig. 1 are a prerequisite for the desired smaller changes in the inner layer. Relying to this extent on rapid changes *outside* the maritime sector would seem to carry inherent risks for living up to the very ambitious targets for transformation *within* the maritime logistics sector. Finally, accepting that green hydrogen is likely to remain a scarce source, the versatility of its use most likely induces competition for it. Hydrogen is already widely used today in refining, the chemical industry (as a feedstock), the steel industry (as a reducing agent) and for special applications in other industries [6]. These other sectors that are facing hard choices about decarbonisation could also set their techno-optimist eyes on green hydrogen. Within the case context of Finland and during the time the data was collected, for example, discussions were ongoing regarding major industrial green hydrogen-related investments in the steel industry and the fertilizer industry. This suggests that even if the conditions of the two outer layers of Fig. 1 are in place, competition for hydrogen might still make it unavailable or unattractive for the inner circle of maritime logistics, reinforcing the notion that a sectoral bet on future hydrogen solutions solving its green transition challenges could be risky techno-optimism.

2.2. *Performative techno-optimism*

Techno-optimism as a phenomenon has received much criticism lately (e.g. [41,42]). It has, for instance, been labelled as ‘irrational and superstitious—a faith-based initiative with little grounding in reality’ [15]. However, lately, a case has been made for ‘a *contingent, techno-social form of optimism*’ [16]. This interpretation of techno-optimism starts from the premise that it is not irrational to believe that ‘human agency—which encompasses our attitudes, our goals, our actions, and our collective institutions—has some role to play in ensuring a positive future’ [16,p. 24]. This kind of moderate techno-optimist will then cultivate the modest *techno-optimist stance* that consists of believing that ‘humanity can, as a collective, (a) select valuable goals (i.e. goals that will ensure the preponderance of perceived good over bad) and (b) use technology in a way that will help us to achieve those goals’ [ibid.]. The diametrical opposite of this view would then be the modest techno-pessimist stance of believing that human agency has very little going for it in this regard. The view of techno-optimism as based on the preponderance of good over bad has been critiqued by [43], who argued that it is sufficient for techno-optimist purposes to only know whether technology can be expected to make things better or worse: ‘The more important question, from a social and political point of view, is whether technology can be expected to improve the human condition or not’ [43, p. 2].

Regardless of the outcome of this philosophical debate, for our analytical purposes it is enough to define *a modest techno-optimist stance* as being based on a positive valuation of both the above-mentioned (a) and (b). When this techno-optimist stance is linked to the notion of *performativity* – the view that expectations, scenarios, and other forms of anticipation of future events affect what may happen [14] – we get the notion of *hype* as a particularly positive variant of techno-optimism involving *optimistic expectations*. The term “performativity” originally derives from the so-called speech act theory presented by language philosopher John Austin [44]. In a nutshell, the notion refers to the ability to ‘do things with words’. An example from language philosophy could be the utterance ‘I promise!’, where the very ‘speech act’ of uttering these words simultaneously effects a change in the world. From these origins, the notion has traveled across various fields of knowledge, among them science and technology studies (STS) (e.g., [45–47]),

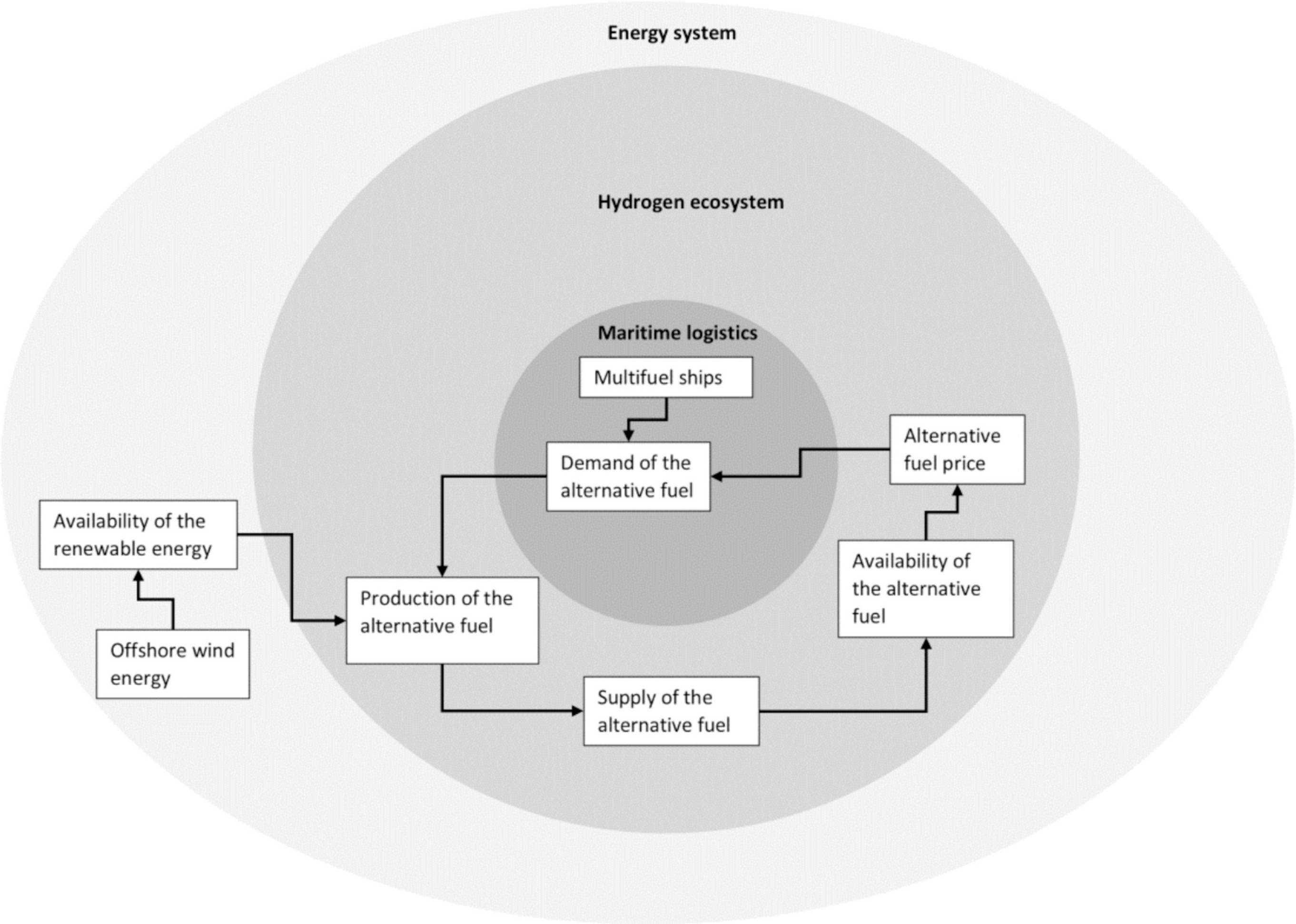

Fig. 1. The figure shows maritime logistics as part of the hydrogen ecosystem and as part of the energy system. The inner circle presents maritime logistics, the middle circle presents the hydrogen ecosystem, and the outer circle presents the energy system. The figure also shows a part of the causal network, presenting the causalities in the maritime green transition system. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

feminism (most famously [48]), and economic sociology (see, e.g., [49]). Within STS focused on expectations, visions and imaginaries, a key concern has been to study the performativity of future representations [14]. More specifically, studies within the field of STS show ‘how future-oriented discourses, practices, and materialities shape the way society makes sense of science and technology, adjust how actors create strategies, and contribute to the shaping of technologies, as well as the development of entire technology fields’ [14]: 5. This is also how we understand performativity in this paper: that the very act of ‘uttering’ ‘future representations’ simultaneously effects a change in the world.

The diametrical opposite of *hype* would then be a particularly negative variant of techno-pessimism involving *pessimistic expectations,* especially in the form of expectations related to *problems and risks*. According to [14], these expectations form part of the *modes of future orientation*. The notion of a ‘mode of future orientation’ is defined as ‘a heterogenous set of practices, patterns of desire, forms of knowledge and ethical imperatives which hang together with a degree of consistency in producing and reproducing social forms in the present, and which also help to shape the future itself in intended and unintended ways’ [14,p. 26].

Anticipatory infrastructuring again is what happens when mental expectations collide with the real world; it is a process through which the present is intervened in, transformed, and ultimately governed in the name of the future [50]. The notion thus comes fairly close to what [14] mean with the term ‘mode of future orientation’. Another closely related concept is ‘sociotechnical imaginaries’, which are defined as ‘collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology’ [51,p. 4]. This type of anticipatory knowledge – expectations – is not produced in a vacuum, but within sociocultural collectives and assemblages [52]. As [52] noted, they rely on ‘infrastructures of anticipation’ (i.e. specific vast machines, epistemic infrastructures, and social institutions (cf. [53]), that all play their parts in shaping the development and uptake of the anticipatory knowledge. Anticipatory infrastructuring also relies on material-semiotic constellations of actors, practices, discourses and material artefacts that reach beyond language. Going beyond narratives and expectations, hypes are ‘not free-floating cultural structures, any more than are imaginaries and representations. They are always stitched into material environments, both socio-technical and socio-natural’ [54,p. 4], see also [55].

The assemblage brings together heterogenous elements that are more than just the sum of their parts when combined. In this case, it means that while the ‘road towards a global hydrogen market is not just a function of technical and economic factors’ [56]: 2, technical and economic factors and the material impact of existing infrastructures play important parts. Expressive and material components form heterogenous anticipatory assemblages through which space is territorialised [57]. The material components can also help explain why expectations are not always enough for a certain development to materialise. We may think of hype as an act of exaggeration in regard to the promises and expectations of a technology [50]. Famously, hydrogen is one of those fields that has already survived multiple hype cycles (e.g. [57]), although, of course, this time may be different. Assemblages happen both locally and globally, occurring in different spaces while at the same time connecting to one another. The territorialised space is here a reference to specific arrangements of actors, practices, rules and institutions, and spaces may reflect distinct spatial and temporal dynamics. In this case, the primary assemblage space is the maritime logistics sector in Finland in the year 2024.

Finally, in the context of techno-optimism, a *utopia* can be regarded as the one ultra-positive extreme end of techno-optimism [15,16]. Optimism becomes *cruel* 'when something you desire is actually an obstacle to your flourishing' [58,p. 1]. It has been argued by [15,p. 10] that one example of a 'cruel utopia' as an example of extreme techno-optimism can be found in Silicon Valley's imaginaries of outer space. This imagined socio-technological future "expresses a desire for a 'better way of living and being' through socio-technical advancements in human space flight". Yet it 'runs the risk of being an obstacle to human flourishing on this planet' because of what it is *not* concerned with – that is, 'finding ways for humans and the Earth to get along' [15,p. 434] – instead offering a cruel utopia in the sense of [58]. By analogy, then, it could be argued that the singular hydrogen hype in maritime logistics (the 'imaginary of outer space'), by *not* attending to the radical changes in other sectors upon which it is conditional ('life on Earth'), runs the risk of offering a similar cruel utopia of hydrogen in maritime logistics. The specifics of this mode of orientation, or package of 'heterogenous sets of practices, patterns of desire, forms of knowledge and ethical imperatives', might risk precluding the attainment of the radical change needed for a sustainability transformation in maritime logistics. We suggest that a singular belief in hydrogen might end up in a kind of *cruel utopia of the seas* [15,58].

2.3. *Transition risks*

Transition risks were defined by [12] as risks associated with transition to a low-carbon economy. They arise from policy, legal, technology and market changes that intend to address mitigation and adaptation requirements related to climate change, and can result in stranded assets, loss of markets, reduced returns on investment and financial penalties. A considerable amount of research in economics conceptualises transition risk as a financial risk for companies. According to [59], renewable energy companies are well aware of transition risks, which are mostly perceived as risks caused by changing regulations, or *policy risk*: this means risks caused by local-, national-, or EU-level regulations (e.g., regulations restricting biomass use, or changing the emissions trading system). Investing in green hydrogen is therefore a way for these companies to manage transition risk and prevent the stranded assets associated with fossil fuels.

For oil companies, the transition risk means *financial risks* resulting from the process of transition towards a low-carbon economy [60]. Other definitions of *transition risk* found in the literature include 'exposure to price risk caused by uncertainty over the mix of technologies used to achieve decarbonization' [61], and 'the financial risk associated with activities that are incompatible with a low carbon economy' [62].

However, transition risks are a relatively new area of study and lack a comprehensive understanding of structural effects and societal impacts. The work of [63] emphasised that – through abrupt asset revaluations, debt defaults, and the formation of bubbles in emerging industries – transition risks can profoundly impact broader societal structures as well. The work of [64] further highlighted that disparities in technology access can be exacerbated by the energy transition, potentially widening inequalities between countries and demographic groups. Moreover, the energy transition and the electrification of new sectors, such as transportation, introduce new cross-sector interdependencies [64].

3. Materials and methods

3.1. *Materials*

The materials used for this study consist of 10 interviews and two workshops with experts in the maritime sector. In 2023, we conducted 10 semi-structured interviews with 12 interviewees in total. The interviewees were experts such as university professors and research directors (4); specialists and managers in the private sector (4), public sector (1) and NGOs (2); and researchers in state research institutes (1). They were selected using snowball sampling [65] based on their expected expertise on the future of maritime logistics. Some of the interviews were conducted face to face, some online, and their duration ranged between 55 and 103 min. The interviewees were asked how sustainability thinking and sustainable development goals manifest in the maritime sector, as well as what prerequisites exist for the sustainability of maritime actors' operations in the green transition, particularly in Finland. Furthermore, visions for a sustainable green transition in maritime logistics were discussed.

In addition, we held two workshops in 2024. In total, 15 experts participated: four representing companies operating in the maritime or fuel sector, four from universities, four representing state authorities and research institutes, and three appearing on behalf of environmental NGOs. Eleven of them participated in person and four via a Zoom call. Besides the experts, researchers from the project consortium attended the workshops as organizers and observers. The workshops lasted approximately 2 h and 40 min each.

During the workshops, the participants were asked to discuss the long-term situational picture of the green transition in maritime logistics. This included exploring what needs to happen for alternative fuels to serve as a sustainable partial solution, particularly in Finland, and examining the risks and opportunities associated with the production, distribution, and use of carbon-neutral alternative fuels. We pre-selected biofuels, green methanol, and green ammonia as the alternative fuels for discussion. The participants were encouraged to consider sustainability from three perspectives: that of the economy (from the perspectives of state, consumers, and companies), that of the environment (species and habitats, emissions into the air, water, and soil) and that of society (well-being, the security of supply, and justice). However, the first workshop ended up having a slight focus on the economic dimension associated with the transition towards renewable carbon-neutral alternative fuels, while the environmental aspects of this transition were more emphasised in the second workshop. The second workshop also included a discussion on the future of winter navigation.

Both the interviews and workshops were recorded and transcribed. In accordance with the Finnish National Board on Research Integrity TENK 2019 guidelines [66], no prior ethical review of the research was conducted. The data that support the findings of this study are available on request from the first Author. None of the data is publicly available because they contain information that could compromise the privacy of the research participants. The workshops invoked the Chatham rule: the participants were free to use the information received, but the information is attached to neither individual participants nor their organizational affiliation. All the experts workshop who were participants, interviewees and evaluators were informed of the purpose of the research and their anonymity was protected. The informed consent of the actors involved in the process was collected, and the participants were informed about the archiving of the gathered data. In all research outputs, the identity of the participants is protected through pseudonymisation.

3.2. *Methods*

We conducted a methodological triangulation on the same empirical interview and workshop data, first to specify the causal logic of expert arguments on the risks of transitioning to alternative fuels, and, second, to describe the broader themes of the green transition with which the experts contextualised the transition risks.

To specify the causal logic of expert arguments, we conducted a causal network analysis of the experts' argumentation that was specifically on transitioning to alternative fuels in maritime transport. To address the second task, we conducted a thematic content analysis of qualitative data to outline the experts' stances on a green transition in maritime logistics (see Fig. 2 for the steps of the empirical analyses).

The gathered materials were analysed using thematic analysis [67]. While our interview and workshop data also included discussions on biofuels, we excluded them from the analysis and only included discussions on hydrogen and hydrogen derivatives – methanol and ammonia.

The interviews as well as the workshop transcriptions were coded in two rounds. First, we read through the material and marked all relevant excerpts using the notions of the *stance (techno-optimist* vs. *techno-pessimist)*, *performativity* and *risk*. However, after identifying significant overlaps between these analytical notions, we re-coded the excerpts using a four-tier categorization based on their perceived stance on hydrogen technology, ranging from optimistic to pessimistic. We call these categories – or clusters of expectations – *Type 1 radical hype (*addressing the opportunities and positive visions for the future), *Type 2 optimism prevails over risk (*recognising risks while noting that they can be overcome or sufficiently reduced*)*, *Type 3 pessimism prevails over hype* (recognising the possibilities while lamenting the risks overshadowing them), and *Type 4 radical risk* (emphasising threats, problems and pitfalls) (see Table 1).

Finally, after coding the excerpts with these four categories, we grouped them further based on their specific topics and themes. For instance, within the radical risk category, we identified themes such as disaster risk (e.g., disastrous accidents and spills), a lack of sufficiency (e.g., resource scarcity and the impossibility of rapid growth), and a limited perspective (e.g., a lack of life-cycle thinking and an incomprehensive approach to the energy puzzle).

All four stances were present across the data, although optimistic perspectives were slightly more often invoked by the participants from the private sector and tech-focused academia, while risk-oriented perspectives were more prominent in the second workshop, which mainly involved actors focused on environmental and safety issues. However, not all of the expressed views reflected personal opinions, as participants also conveyed other commonly heard perspectives from the field.

4. Analysis and the results: causal networks showing the catch-22 loop and content analysis showing the ways out of it based on the four varieties of performative technological optimism

In what follows, we will first present the results of the causal network analysis of the expert arguments in Section 4.1. The analysis shows that, in a collective sense, the experts perceive the transition risk to be a catch-22: the risk to transitioning to alternative fuels in maritime logistics is a lock-in involving *overly cautious demand for alternative fuels* leading to *overly cautious investment in supply*, which only *secures the modest demand* (see Fig. 1). In Section 4.2., we present the content analysis of the expert arguments, which in turn shows that the experts can provide several potential policy interventions to facilitate a green transition in maritime logistics (see Table 1).

Table 1
Policy interventions reflecting the varieties of performative techno-optimism.

Varieties of performative techno-optimism	Policy intervention
Radical hype	-Maximise production of carbon-free electricity -Increase innovation on hydrogen-based economy
Optimism prevails over risk	-Develop marine pollution response -Predictable regulations on emissions and alternative fuel production
Pessimism prevails over hype	-International trade agreements -Develop situational picture of green energy policy -Build consensus on reducing consumption -Major marine player's technological intervention
Radical risk	-Sensitise regulatory and investment regime to fluctuating circumstances -Problematise continuous growth of material and energy flows -Extend life-cycle assessment to entire energy systems

4.1. *The results of causal network analysis: visualising the causal structure of the stuckness/implementation gap*

Based on the two workshop discussions, where the participants were discussing what should happen for alternative fuels to serve as a sustainable partial solution, we drew a causal network where the key variables and their causal connections are presented. This causal network visually shows the dependencies in the system presented in Fig. 1. Without a build-up of renewable energy, we cannot produce hydrogen-derived alternative fuels and then finally use them in maritime logistics. According to the causal network, for maritime logistics to use hydrogen-derived fuels we need renewable energy, which means building offshore wind energy (see Fig. 1). On the other hand, to be able to produce and supply the alternative fuels, the whole production and supply chain needs to function. Finally, producing alternative fuels is not enough alone, but we also need shipping companies that are both willing and able to use the alternative fuels. This leads to the situation where parties are dependent on decisions made by others. Since it is not clear, for example, what is the alternative fuel to invest in and the regulation is even incomplete, there are high economic risks related to the green transition. This means that it can be safer for parties to wait rather than make a move and take a high risk. The causal structure of this stuckness is visualised in Fig. 1. The network presented only represents a small part of the whole causal network. Therefore, only a few variables are included.

4.2. *Results of content analysis: policy interventions to break the catch-22 loop*

We found four varieties of performative techno-optimism and techno-pessimism in our material: radical hype, optimism prevails over

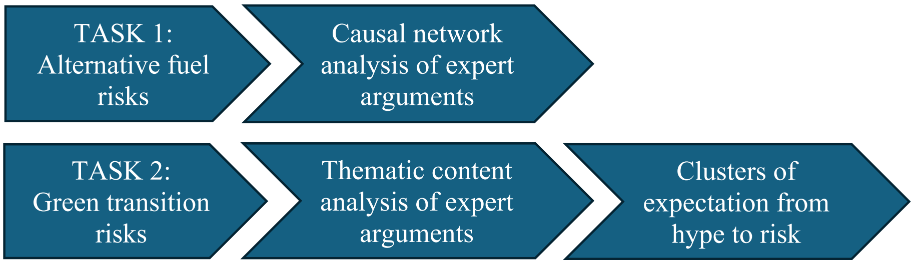

Fig. 2. The methods: the steps of the empirical analyses.

risk, pessimism prevails over hype and radical risk (see Table 1). Each variety is associated with a specific set of policy interventions.

4.2.1. *Radical hype*

Under the category *radical hype*, the different possibilities related to the production of alternative fuels are discussed. Our informants highlighted that hydrogen-derived fuels give the possibility to produce fuels in places where it has not been possible before. Fuels can even be produced in Finland, and the country can economically benefit from this transition and become a fuel exporter. Excess green electricity can be highly valuable. The informants even stated that Finland should use more electricity in the summer to increase the level of basic electricity consumption. Here, maritime transportation using green electricity could serve as a buffer if more fuel can be produced during times when electricity is cheap. In addition, being a pioneer is seen to be a competitive advantage that is not to be missed. Finally, environmental challenges are not only negative, because solving them together can make parties successful:

> When we produce these fuels and if we can establish processes where they are only made during times of cheap solar, cheap hydro and cheap electricity, then we get exactly the balancing base power that we need more of.

> We've also been very compartmentalized here in Finland, so that shipping companies and shipbuilders didn't talk to each other, but when we brought those startups to the same event, they solved common problems and came up with a completely different drive. So, this cluster not only copes with environmental challenges, but can even thrive because of them. So this, that such a drive emerged, the whole industry sort of changed into something else because of this environmental issue.

The technological possibilities with which to solve some of the problems related to the green transition are also hyped. Technological development and innovations can make the green transition profitable. Finland has the know-how and just needs to meet the requirements in time. The transition is possible with adequate input on research and innovations:

> We even have the opportunity to become an exporting country when it comes to these solutions and more, but it can also be a business for Finland to be a pioneer.

The informants note that hydrogen is coming and maybe even faster than anyone is expecting. Further, hydrogen production has the potential to solve some other environmental problems, such as solving the lack of oxygen at the bottom of the Baltic Sea by pumping the production by-product oxygen to the bottom.

> And personally, I believe that this hydrogen economy, this green energy hydrogen economy, it's going to break through so quickly, that I believe we won't even realise its speed.

4.2.2. *Optimism prevails over risk*

Under the category *optimism prevails over risk*, the importance of a holistic approach is discussed. The informants point out that the whole chain related to the production, distribution and use of alternative fuels should be considered to recognise all the possible risks and synergies. The pace is seen to be a bit too fast for careful consideration of the big picture of the green transition. On the other hand, the experts stated that Finland does have an excellent situational picture of regional and global maritime transportation. Now the country needs to already take a holistic approach in the planning phase and secure that the green transition also produces benefits locally (e.g. by offering jobs). One expert noted that Finland must:

> examine the impacts that such joint development will have on shipping, fishing, and other recreational activities.

Various kinds of environmental impact resulting from the use of alternative fuels were recognised. However, it was highlighted that it is possible to increase dozen-fold, for example, the amount of the offshore wind power without significant harm to the marine environment. In addition, the decreasing of GHG emissions due to the use of alternative fuels will have a positive environmental impact. When alternative fuels can be produced in new places, it can also decrease the need for long fuel transportation. New ships are already considered more environmentally benign with, for example, better energy efficiency. Even greenwashing is acknowledged as a positive sign since it is a first step towards environmental sustainability. As one expert expressed the issue:

> On the other hand, I personally like greenwashing. It's a good thing because it means it's the first step. Then the shipping company has started to think.

The importance of predictable regulation in preparing for the future is acknowledged. With predictable regulations, achieving the IMO goals for decreasing GHG emissions in maritime transportation is seen to be possible. However, shipping companies must be careful when ordering new ships and ensure they can also be used in the future, regardless of the future fuels. The fuel production in Finland is seen to decrease the dependence on other countries and also secure self-sufficiency in fertilizers since ammonia can be used as fertilizer. When discussing preparedness for future accidents where new fuels are spilled, the experts were optimistic that the recovery of the new fuels will be developed, although their recovery with current oil recovery equipment has poor efficiency. As one expert put it:

> We will probably learn pretty well how to minimise those types of damage too.

Developing technology required for the production and use of alternative fuels can still take some time but it is not seen as a problem that cannot be solved.

4.2.3. *Pessimism prevails over hype*

Under the expectation that *pessimism prevails over hype*, some of the interviewees and the workshop participants highlighted a number of use-related risks. First, despite all the strategic-level talk about hydrogen, the field is not prepared; there are not enough prospective alternative fuels, nor are the technologies developed enough:

> And then, on the other side there's the fact that that the technologies are still underway. Yes, we talk a lot about hydrogen, but show me a hydrogen engine that works. Ammonia will probably be the big factor, but it's a cold fact that today, not one engine producer can make an ammonia-based engine that would not kill the crew.

This highlights the second use-related concern, that of the safety of use for humans and, especially in case of accidents, for the environment. All alternative fuels are more or less toxic and involve a number of risks if released into the sea. In addition, ammonia eutrophicates. Third, a number of practical logistical concerns exist related to the scheduling of vessels and capacity of batteries. However, all these use-related concerns pale in the face of the issue of price. The view that the price of alternative fuels is too high was voiced throughout the interviews and workshops. Raising the cost of maritime transport would have a significant impact on the export of Finnish industrial products. The political risks of engaging in alternative fuels in the form of investments are enormous, especially given the current geopolitically tense global situation. The workshop participants even foresaw the degradation of the fundamentals of global trade, which in turn would endanger the already strained peaceful communication between different cultures. But most importantly, it is money that steers shipping companies:

> It's the money that steers the shipping company and the business activity, so whatever the cheapest solution is, then they get rather far with that.

The topic of money leads over to the by far most abundant view of this type – the view that alternative fuels are predominantly a matter of greenwashing. According to the interviewees and workshop participants, greenwashing occurs both in the life cycles of materials and in emissions. Ultimately, turning to alternative fuels buys more time for the combustion engine. Whatever the maritime logistics field does here, someone will still extract oil somewhere and use it up. Due to their size, those controlling large vessels can do whatever they want anyhow. Furthermore, there are significant differences between the alternative fuels depending on where they are produced. All alternative fuels involve some kind of continued use of fossil fuels and, in the case of biofuels, calculations of emissions are downright untruthful. In short:

> That's very good, but I think – again, criticizing the strategy – why do people tend to say 'zero' on everything. 'Zero emissions', 'zero accidents', that's not going to happen.

One of the reasons for why 'that's not going to happen' is the lack of an overall situational picture; nobody is looking at the whole picture, and no one is responsible for the reconciliation of conflicting demands. Instead, environmental consequences are outsourced elsewhere according to the principle 'do first, evaluate after'. Decreasing transport is never an option and the ordering of stuff from China is not going to stop in the foreseeable future:

> For example, when restrictions on emissions are coming, there's a terrible kerfuffle around it: what technologies are we going to invent for this? I always think this would all be solved by decreasing these transports. Nobody would have to think of any technologies. This is a bit of a provocation, but anyhow. But that's never the option. I don't know why. We just want to go on causing a ruckus as we have done so far.
> X: Maybe we also need a big societal change in our thinking…
> Y:…that the consumers would then not just buy from China and elsewhere, order stuff and… It's not going to happen in 20 years [laughter]."

However, according to these experts, even if there would be a technological solution, that would not be enough since it would never become mainstream. In fact, according to these interviewees and workshop participants, history teaches us that what we think is a good solution may turn out to be a terrible mistake. The main warning examples here is those of liquid natural gas (LNG) and scrubbers:

> I don't know, I just have problems, no solutions [laughter]. [Thinks 3 s.] It would probably take some crazy mad inventors with a lot of money, they would be able to start experimenting with the new solutions, but they won't become mainstream either. So … mmm.

4.2.4. Radical risk

Under the expectation of *radical risk*, the interviewees/workshop participants highlighted the risks related to accidents and safety. Alternative fuels pose unknown risks in the case of leaks and accidents. Responders are not equipped to manage them; they can only contain the leaks. Biofuels can pose environmental risks, despite their name suggesting eco-friendliness. An ammonia leak and the associated explosion risk can be deadly safety hazards, with unknown effects on marine environments. This is why the worst-case scenarios related to environmental impacts should be considered and evaluated:

> I talked to a director of a shipping company about these solutions, who just said about these solutions that something always happens there, and when there's a leak, he doesn't want it to be an ammonia leak on his ship. That would be fatal.

Transition risks were discussed, too. Regulations may become outdated before they are enacted, and investments made early on could become unsustainable in the long run: even the major players act carefully. Nonetheless, there is a risk that the low-carbon transition could turn into an economy of winners: those companies and states with money decide and act, while others struggle to keep up:

> And then, if a decision is made, leading to something believed to be a breakthrough solution, and then ten years pass and it's realized that it was actually crap. And then millions and millions are invested. Well, that's quite a big risk.

The sufficiency of alternative fuels was doubted. Fierce competition for alternative fuels is expected, and the maritime sector is likely to lose to other, more financially sound industries. Additionally, water is needed in large amounts for hydrogen derivative production – who owns the water, and can (or should) it be used profusely?

Attention was also paid to the fact that the current discussion largely lacks life-cycle thinking. Calculating emissions from the end product is not enough; life-cycle assessment and the entire production chain must be considered, including emissions from mining, the decommissioning phase, et cetera. Even though wind power itself is 'emission free', constructing and decommissioning wind turbines still produces emissions. Fairness in raw material production origin countries must also be considered:

> Somehow, there's this thinking that once those offshore wind farms are built, we'll have a lot of emission-free energy, but we forget about the fact that there were emissions generated in creating that energy source.

In addition, the lack of comprehensive thinking was lamented. Although visions discussed during maritime spatial planning have a positive tone, the nitty-gritty details are more complicated as no one wants to relinquish their rights to land or sea areas or resources. The entirety of offshore wind power is beyond anyone's control, with numerous projects underway and significant impacts on maritime traffic:

> There are an insane number of offshore wind power projects underway now, and each one is described individually, but no one thinks about the overall picture. This has huge impacts on winter navigation and many other things, so I don't automatically see it as a good alternative.

The ideal of continuous growth was also criticised on a more general level. Production, consumption, and traffic cannot increase endlessly. Some participants also pointed to conflicts of values, due to which there is no reason for optimism. Humanity tends to view nature merely as a resource. When different pressures conflict, nature and the environment lose out to energy security and money:

> It has become clear that if there is a conflict between, say, a protected area and an energy production area, then […] The protected area always loses.

4.2.5. Performative techno-optimism and techno-pessimism summarized as policy interventions

The policy interventions proposed by the experts reflect the varieties of performative techno-optimism and techno-pessimism (see Table 1). The experts inclined to radical hype thought that Finland should maximise its production of carbon-free electricity and increase inputs to research and innovation to launch a green transition to a hydrogen-derived economy. Those whose optimism prevailed over risk called for a holistic approach to ensure that the green transition produces benefits while managing risks. Predictable regulations are needed to decrease GHG emissions in maritime transportation, to produce alternative fuels in environmentally sound locations, and to develop recovery technologies for new fuels in case of spills. The experts inclined to pessimism over hype foresaw a much narrower range of policy options. To prevent an erosion of global trade and cultural interaction, international trade agreements are necessary, supported by an overall situational picture of green energy policy and a broad consensus on the need to reduce consumption. Finally, those cautioning of radical risks could only imply potential policy interventions by articulating hazards. Since regulations and investments may become outdated before they are put in place, the policy implication is to move towards a regulatory and investment regime that is more responsive to rapidly changing circumstances. Overall, policies should be based on more comprehensive thinking that problematises the continuous growth of material and energy flows, and extends the life-cycle assessment of energy systems, ranging from the mining of natural resources to the decommissioning of infrastructures.

Although the policy interventions displayed in Table 1 cover diverse themes, two germinating policy ideas can be observed. On the one hand, the experts discussed various technological solutions, such as carbon-free electricity, innovations in hydrogen systems, marine pollution response, and a technological intervention by a major marine operator. On the other hand, the experts presented regulatory solutions, such as regulations on emissions and alternative fuels, trade agreements, consumption reduction, flexible regulations, and life-cycle assessments (see Table 1). When the structure of maritime logistics as part of the hydrogen ecosystem, as part of the energy system (see Section 2), is combined with the causal network presenting the causalities in the maritime green transition system (see Section 4), we can discern how the two germinating ideas among the experts regarding how to break the catch-22 are placed across levels (niche, regime, and landscape levels; see Fig. 1).

The *large-scale technological* solution for breaking the dilemma is at the *niche* level (the innermost circle). It does this by breaking the market logic of the loop (i.e., the supply of and demand for alternative fuels) by being a monopsonistic intervention (see Fig. 1). Large shipping companies that have the resources and capacity could work as pioneers and show the direction to take in the maritime green transition. Maersk, for example, has already ordered several methanol multifuel ships (workshop 1). It is such a major player that it can negotiate agreements with fuel suppliers, thereby ensuring fuel production. This, in turn, allows smaller operators to feel confident in ordering similar vessels. In addition, multifuel vessels reduce the shipping company's risk, as the vessel can utilise multiple types of fuel if necessary. The *global regulatory* solution for breaking the dilemma is situated at the *regime* and *landscape* levels (the two outermost circles, respectively). It does this by reforming the rules of the game (i.e. by reducing the intensity of the material and energy flows with global regulation (see Fig. 1). Both solutions demand that the links holding the catch-22 loop together are explicitly transcended.

5. Discussion

In this paper we asked the following question: Given the structure of the lock-in of hydrogen utilisation in maritime transport, what kind of policy interventions would be needed to convert the promising theory into practice as a green fuel in maritime logistics? To answer this question, we probed expert views of the required policy interventions in workshops and interviews. Since the experts presented many interesting policy ideas yet showed little convergence, we turned to an analysis of hype cycles and the performativity of hype to make sense of the profusion of ideas [14,16]. We found that the role of hydrogen in Finnish maritime logistics can be seen as a case of performative techno-optimism as defined by, for example, [16] and specified by, for example, [14]. More specifically, our thematic analysis revealed that the field of maritime logistics in Finland contains two different kinds of performative techno-pessimism: the pessimistic expectations of *pessimism prevailing over hype* and *radical risk* (see Table 1). The issue of techno-optimism and techno-pessimism in Finnish maritime logistics would thus seem to be a more nuanced phenomenon than simply a matter of either 'pure' techno-optimism or techno-pessimism.

We identified two broad policy options for breaking the catch-22 identified in the content analysis: *large-scale technological policies* and *global regulatory policies* (see Fig. 1 and Table 1). The policy options do not exclude each other but are complementary. Both options have the capacity to break the loop but are not guarantees of success. The reason for the capacity to break the loop resides in transcending the logic that holds the loop together. The technological intervention breaks the dilemma in the market logic of the loop (i.e., the supply of and demand for alternative fuels) by being a monopsonistic intervention, because maritime logistics are dominated by a few large operators. A recent, concrete example of a policy solution in this direction is the agreement by The Marine Environment Protection Committee of the IMO in April on measures to reduce GHG emissions from ships [68,69]. Another concrete policy measure in this direction is standardisation (see, e.g., [70]. The regulatory intervention breaks the market dilemma by reforming the rules of the game (i.e., by reducing the intensity of the material and energy flows with global regulation). Two concrete policy solutions in this direction would be the introduction of carbon taxation and intensifying carbon emissions trading as part of the overall process of making the financing conditions for the fossil fuel incumbent less favourable (e.g., [9].The reason they do not guarantee success is that both the technological and the regulatory intervention are filled with uncertainties. There is no guarantee of the major tech investment being the right bet, and there is no guarantee of a global regulatory intervention attracting the necessary global support.

There is thus a meta-level catch-22 going on here. Various kinds of risks hold together the initial catch-22 of alternative fuel markets. To break it, you need extremely risky (uncertain) interventions. The meta-level dilemma is that you need to take an extreme risk to break free from the certainty of being stuck with small risks. The barriers to hydrogen adoption in industry (the maritime shipping industry included) listed by [18] – the absence of comprehensive, national and international frameworks for hydrogen adoption, the lack of consensus on the technology pathways that should be pursued as part of a global low-carbon energy transition, connecting suppliers and consumers at the global level via the most cost-effective means of transmission, and geopolitics – could all be viewed as representing small or *first-order* risks. In contrast, the insight of second-order risks is shown in the analysis by [18] of three ambition and implementation gaps in regard to the expectations concerning green hydrogen. In our view, their identification of a past, 2023 implementation gap (only 7 % of global capacity announcements are finished on schedule) and a future, 2030 implementation gap (enormous subsidies would be required to realise all the planned projects by 2030) represents a tentative approximation of the size of the extreme risks that would need to be taken. However, we recommend taking one of the extreme risks, because not taking either one of them is a decision that almost guarantees no green transition will ever take place in regard to the fuelling of maritime transportation, at least not for any foreseeable future. This would of course, given the nature of the challenges of climate change, leave us with very extreme risks on a societal level.

However, even if the green transition were to take place in maritime logistics, a number of issues pertaining to energy justice would remain (e.g., [71]). Recent energy research advises self-reflexivity and caution when resorting to notions used widely by social scientists related to energy transitions (see, e.g., [71–73]). Our claim of a more-than-local and contextually specific infrastructural grip risks falling prey to the kind of absolutist fantasy described by [74], when the notion of *planetary boundaries* (and by extension, *planetary habitability*) becomes *political pyrolysis*, that is, when it is only reduced to one dimension at the cost of others dimensions, especially sociocultural ones. The crucial political point in danger of being lost is 'that it is particular kinds of human societies that render disadvantaged people vulnerable' [71,p. 89]. This outlook is supported by recent research on the Global North's green hydrogen transitions deepening socioecological risks and neocolonial extractivist patterns in the Global South [13,75,76]. From a historical point of view, then, the observation by [77] that constructing a sustainable energy future requires grappling with the complex legacies of infrastructure would seem to take on a burning degree of actuality (see also [55]).

Perhaps it is telling that in our content analysis, the Type 1 stance (*radical hype)* refers to transition risk, but mostly in terms of the opportunities that could arise for some actors. Likewise, the Type 2 stance (*optimism prevails over risk)* focuses on transition-related risks (i.e. uncertainty about investment, the winners and losers in a new, low-carbon economy and the risks arising from changes in regulation), but also mentions physical risk, such as hazardous spills. Conversely, both the Type 3 stance (*pessimism prevails over hype*) and the Type 4 stance (*radical risk*) are more comprehensive in terms of risk. In addition to transition risk and physical risk, the Type 1 and Type 2 stances refer to broader, more systemic risk [78], such as volatile geopolitics, the lack of comprehensive thinking, and uncertainty about the feasibility of the currently available solutions. In particular, the Type 4 stance (*radical risk*) also critiques some of the field's underlying paradigms, like the pursuit of forever growth and human-centric values. If closing the implementation gap [18] in the green transition in maritime logistics implies severe consequences for the globe as a whole, then hydrogen techno-optimism, too, would run the risk of being cruel [15].

Although our data comes from Finland, similar wavering between hype and risk exists elsewhere as well. Recent surveys indicate that maritime professionals are convergent on the importance of responding to the climate challenge yet divergent on how to do it. A 2021 survey with 222 maritime experts in industry, government, finance, academia, NGOs, and consultancies showed that the professionals think the most important maritime sustainability criteria are regulatory compliance, the life-cycle considerations of GHG emissions, fuel costs, air pollution, and occupational health and safety [79]. While there is agreement on the need for alternative fuel options to meet the sustainability challenge, their prioritisation varies. For example, a 2021–2022 Delphi panel survey with 27 mostly European marine industry professionals showed that while methanol was considered the most feasible alternative fuel for all types of shipping, there was considerable variation in how the experts ranked ammonia, LNG, biofuels and hydrogen [80]. A 2024 online survey with 174 young seafarers and maritime students, mostly from the Philippines, showed yet another way of prioritising the alternative fuels with the most potential in reducing greenhouse gas emissions: hydrogen, LNG, biofuels, methanol and ammonia [81].

Due to the urgent global need to transition away from carbon, the broad outlines of the dilemma apply everywhere. If a particular actor is in any way dependent on the hydrogen economy, then that actor will enter the basic catch-22. However, local instantiations of the dilemma vary depending on local conditions. For instance, the case of Denmark has been described as follows: 'With a concentration of renewable energy development firms, state ambitions of developing substantial green hydrogen production capacity infused with ideas of export-oriented climate pioneership, and considerable bureaucratic resources dedicated to the issue are, one would expect Denmark to be a hotspot for green hydrogen production […] Yet, investments are lacking' [82]. Here, the technology-oriented solution proposed by our study is a meaningful option. For very small islands where transportation in the form of small vessels is currently highly dependent on fossil fuel, the most meaningful action path could be integrating offshore renewable energy platforms with hydrogen propulsion systems based on existing solutions (see, e.g., [83]). In the Baltic Sea context, so-called green corridors are an example of a focus on an emphasis on the development of port-ship infrastructure (see, e.g., [28]). In other words, local conditions define the specificities on how to meaningfully act in light of the fundamental dilemma.

A major limitation of the current work is that it is primarily based on qualitative research. The results of the research can be further explored both in terms of broader qualitative research in other contexts and settings, and in terms of quantitative research (along the lines of, e.g., [79–81]). On the basis of our results, however, future research should not only focus on performing similar expert workshops and interviews in other countries with the aim of comparing similarities and differences across contexts. Future research should also focus on the existing research and especially on its suggestions for policy implications from the point of view of the fundamental catch-22 situation, on the grounds that the dilemma is as global as is the challenge of the sustainability transformation of maritime logistics.

6. Conclusion and policy recommendations

We have presented how the current green and digital transition of maritime transport is caught in a catch-22, a dilemma from which the only escape is by taking second-order extreme risks in a way that transcends first-order small risks. Our data is only from Finland, but they reveal a genuine systemic policy dilemma. The exact structure of the dilemma can be seen in the causal networks we constructed from expert views. Our analysis suggests the following two major ways out of the catch-22: a *large-scale technological solution* and a *global regulatory solution*. Our results add new knowledge to existing social scientific research on hydrogen as part of green and digital transitions. We have reason to believe that similar expert views can be found in other maritime logistics countries [18,82]; therefore, our Finland-based results speak to maritime green transition policies at national, regional and global levels.

Our results indicate that if the links of the loop are not broken, the current hype about the hydrogen economy runs the risk of becoming yet another failed element in the long chain of exaggerated hydrogen expectations. Our results thus give new flesh to the bone in relation to the hope expressed (in e.g. [84]) that this time it could be different. However, if the links of the loop are taken into account, they can (as can all second-order structures) modulate the degree of belief that we have in such expectations (see also [85,86]). In other words, when conjoined with the variety of stances on hydrogen, the links of the loop delineate the cognitive space for asking more nuanced questions about the reasons for embracing such stances. An example of a more nuanced question of justification could be the following: Given the possibilities of a monopsonistic intervention by major global players identified in our detailed analysis of the implementation gap related to solving the fundamental catch-22, is the extreme techno-pessimist stance of radical risk justified? Or, conversely, given the dependency of the hydrogen economy on reforming the current rules of the game, is the extreme techno-optimist stance of radical hype justified? Further research could take our hype typology as a starting point for country-based explorations of local configurations of techno-optimism or techno-pessimism in light of the constraints imposed by the second-order dilemma.

As the study has shown, Finnish maritime activity is heavily dependent on major global actors, be they commercial or regulatory. In relation to Finnish maritime industrial actors, the results of the study could act as an impetus to continue and even intensify local-level investment in alternative fuels, regional-level green corridors included, as this would increase the readiness for national-level uptake should the second-order, technology-based policy intervention of taking an extreme investment risk materialise. Doing so could also work to further increase the motivation for very large shipping companies to take the second-order, link-breaking investment leap in the first place. Our first, technology-oriented policy intervention thus addresses head-on the supply–demand side of what previous literature has called 'the three-sided chicken-and-egg problem' of simultaneous supply, demand and infrastructure coordination (i.e., the market logic loop) in a way that we have not seen cited in the literature before (see, e.g., [8,9]). In general, our results indicate that a wholly new category of policy recommendations geared towards persuading global major shipping companies to take the extreme second-order investment risk should be conceptualised. Our example of the IMO funding instrument for zero and near zero GHG ship fuels is one example of this type of persuasive measure, other Nordic and Baltic countries showing continued willingness to support (see, e.g., [88]), experiment (see, e.g., [89,90]) and invest (see, e.g., [91]) is another. Further research should be conducted to identify and systematise such first-level policy recommendations from the point of view of the central *niche* link of the catch-22.

In relation to global regulatory bodies, the study points to the crucial importance of also addressing the currently insufficient carbon regulation and emissions trading for the fundamental dilemmas of the hydrogen economy. In this, our study aligns with previous research that recommends placing high emphasis on the carbon pricing of fossil-free hydrogen-derived fuels (see, e.g., [9,18,87]). However, our results indicate that it is not enough to concentrate on the technology-neutral carbon pricing of fossil-free hydrogen. Our second policy intervention rather indicates that, in order to break the links of the loop, it is necessary to simultaneously and explicitly address the 'fourth circle' of the currently existing rules of the techno-economic game within which the fundamental catch-22 loop is situated across niches, regimes and landscapes. This has naturally been recognised in previous literature, but with the overall assessment that it is wise to wait until the dilemma resolves itself, as expressed in, for example, the following conclusion: 'For now, the most feasible and reasonable solutions are to implement the methodologies for increasing the energy efficiency design index, developing dual fuel systems and increasing the implementation of digitalization until the global situation stabilizes for the implementation of long-term solutions' [92,p. 20]. From the point of view of our results, such sweeping negative assessments of the unreasonableness of adjusting the rules of the game should be avoided. On the contrary, future second-order analysis of existing first-level policy recommendations should concentrate on identifying and developing compelling arguments for connecting the first-level requirements of the hydrogen economy with ways of implementing such an adjustment of the current rules at *regime* and *landscape* levels.

In sum, the catch-22 revealed by our detailed diagnosis of the implementation gap should organize the second-order search for and analysis of the massive and growing amount of existing research and policy recommendations currently only formulated at the first-order level. The analytical results should be packaged in ways that systematically support the breaking of the links holding it together. Here too, there is a significant need for further literature, policy and empirical research.

CRediT authorship contribution statement

Nina Janasik: Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – review & editing, Writing – original draft. **Emilia Luoma:** Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Writing – review & editing, Writing – original draft. **Mikkel Knudsen:** Visualization, Investigation, Writing – review & editing, Writing – original draft. **Maija Nikkanen:** Methodology, Investigation, Data curation, Writing – review & editing, Writing – original draft. **Janne I. Hukkinen:** Methodology, Conceptualization, Writing – review & editing, Writing – original draft.

Declaration of competing interest

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

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Data availability

The data that has been used is confidential.

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