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Future scenarios of commercial freight shipping in the Euro-Asian Arctic

Elena Rovenskaya [a,b], Nikita Strelkovskii [a,*], Dmitry Erokhin [a], Leena Ilmola-Sheppard [a]

[a] International Institute for Applied Systems Analysis, Schloßplatz 1, Laxenburg, Austria
[b] Faculty of Computational Mathematics and Cybernetics, Lomonosov Moscow State University, Moscow, Russia

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ABSTRACT

As climate warms and modern technologies advance, the Artic waters may offer new opportunities for shipping, notably in the Euro-Asian Arctic. This paper presents five alternative scenarios for commercial destination and transit shipping in the region until 2050. Using a pluralistic backcasting approach to foresight, these scenarios were co-created by the authors of this paper together with thirteen experts in relevant fields from seven different countries. The scenario-building exercise integrated global and regional factors and demonstrated that the future of commercial shipping in the Arctic is subject to vast uncertainties in global politics and global development trajectory alongside the sea ice conditions and technological progress. While the current volumes of commercial shipping in the Euro-Asian Arctic are insignificant, its future will largely depend on the development of these factors and how they will interface with each other. Plausible futures of commercial shipping in the region range from extensive international transit shipping through the Northern Sea Route to restricted shipping by vessels with Arctic flags only or even no shipping, to shipping over the transpolar route. The scenarios presented here can be used to inform national policymaking as well as to support strategic decision-making within corporate entities operating in related industries.

1. Introduction

The Euro-Asian Arctic is a part of the Eastern-Hemisphere Arctic stretching from the Norwegian Sea to the Bering Sea, including the adjacent land areas of Northern Russia and Northern Fennoscandia (Haavisto et al., 2016). This part of the Arctic currently experiences the most significant sea ice retreat in the entire Arctic region evident in the decreasing sea ice extent and thickness. Recent research suggests that the Euro-Asian Arctic may become nearly ice-free in summer by the middle of this century (Guarino et al., 2020). This sea ice retreat is of particular importance for commercial shipping, as it extends the navigable season in the region (Melia et al., 2016). It is projected that by mid-century, the shipping season for polar-class and open-water vessels in the Euro-Asian Arctic may become noticeably longer than now, with up to 200–250 navigable days for polar-class vessels and up to 100–150 navigable days for open-water vessels (Min et al., 2022). Although currently the entire Arctic region accounts for less than 10 % of the global shipping traffic (Eguíluz et al., 2016), growing trends have already been observed in both the number of vessels and the distance sailed in the Arctic waters (PAME, 2020).

* Corresponding author.
E-mail address: strelkon@iiasa.ac.at (N. Strelkovskii).

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The Euro-Asian Arctic is a storehouse of mineral resources including deposits of strategic minerals such as rare-earth metals, nickel, copper, diamond, gold, platinum-group elements, and other critical metals (Dobretsov & Pokhilenko, 2010). The region also hosts about 25 % of the global reserves of hydrocarbons (Zolotukhin & Gavrilov, 2011). With global warming, the extraction of resources, particularly oil and gas, becomes economically more viable (Eliasson et al., 2017) increasing the potential for destination shipping in the region (Huntington et al., 2023). The shipping of extracted resources is a crucial component of destination shipping in the Euro-Asian Arctic, with maritime transportation playing a vital role in the export of these commodities from the region (Huntington et al., 2023; Gunnarsson & Moe, 2021; Müller et al., 2023).

The potential for transit shipping along Arctic routes has also gained attention in recent years (Theocharis et al., 2023). As the Arctic sea ice continues to retreat, the possibility of using these routes as a shorter alternative to traditional shipping lanes becomes increasingly attractive. Modern technologies enabling greater vessel autonomy, higher navigation safety, and lower pollution are expected to further facilitate the use of Arctic routes (Bartenstein et al., 2022). About two thirds of executives of 74 European shipping companies,[1] who participated in a survey evaluating the perception of decision-makers regarding economic viability of the Arctic routes from an operational point of view, anticipated at least some commercial potential (Fournier et al., 2020). These results are consistent with the outcomes of an expert survey in which 59 % of participants agree that the Northern Sea Route (NSR) has potential for transit shipping (Karamperidis & Valantasis-Kanellos, 2022).

Shipping costs is a key factor to influence business optimism towards using the shipping routes of the Arctic for transit. Recent estimates suggest that re-routing vessels via the NSR instead of the Suez Canal can shorten the travel time from Yokohama to Rotterdam by more than one-third and reduce the total cost by 17–33 % (Li et al., 2023). In a survey covering about 20 % of Korean shippers and forwarders, 10 % of companies expressed preference towards the Arctic routes by 2030 if the costs of shipping through the Arctic were within 120 % of the costs of the Suez Canal-based routes. If these costs fell to 70 %, 96 % of respondents favoured the Arctic routes (Lee & Song, 2014). This survey was conducted in the early 2010s, and when considering a horizon until 2015, the respondents were much less optimistic regarding their preference of the Arctic routes, with 0.1 % and 20 % favouring these routes for costs being 120 % and 70 % of the costs of the Suez Canal-based routes, respectively. These results highlight that besides costs, other factors, such as infrastructure readiness will influence the scalability of commercial shipping in the Arctic and emphasize the long-term planning horizon of the shipping industry.

Thus, the Euro-Asian Arctic holds potential for both transit and destination freight shipping. Unlocking this potential would require massive and synchronized long-term private and public investment in infrastructure, such as ports and vessels, as well as related economic activities including extraction projects, tourism, production of renewable energy, or fishing (Makarova et al., 2022).

Climate change alongside other future uncertainties, including disruptive technologies and geopolitical developments, will interfere into the future of shipping in the Euro-Asian Arctic (Bergström, Leira, & Kujala, 2020). For example, in a model-based study, Yumashev et al. (2017) projected that under the scenario of extreme global warming (RCP8.5), smaller bulk carriers may start to utilize the route that passes the Sannikov and Laptev straits from the mid-2030s, and small to medium-sized container ships around 2050. Larger vessels will need to use alternative paths to the north of the Anzhu islands (see Fig. 1), leading to time loss from re-routing. In scenarios of moderate climate change (RCP4.5), re-routing of different vessel classes occurs from the early to mid-twenty-second century. Large container ships might not be able to re-route at all during this period.

Models are useful to inform major investments such as those needed to scale up shipping in the Euro-Asian Arctic. However, due to their quantitative nature, they have only limited ability to capture uncertainty, and their outcomes depend crucially on the plethora of the underlying assumptions. This is conceivably why a recent literature review by Theocharis (2023) revealed that existing model-based assessments provide mixed conclusions regarding economic viability of shipping routes in the Arctic, particularly, the Northern Sea Route (NSR) and the Transpolar Sea Route (TSR) (see Fig. 1). This underscores the need for incorporating a wider range of scenarios and assumptions into the cost-effectiveness analyses (Theocharis, 2023).

Foresight approaches can be used to operationalise incorporation of uncertainty into strategic planning for the Arctic, including the shipping context (Petrov et al., 2021). Foresight is a process of anticipating what may happen in the future in order to make better decisions today (Sardar, 2010). Scenario Building (SB) is one of the primary foresight techniques aimed at outlining plausible directions, in which the current situation may develop, by hypothesising about uncertainty surrounding the future (Mietzner & Reger, 2005). SB informs the subsequent process of Scenario Planning (SP) aimed at devising decisions of reasonable performance independently from which alternative future eventually materialises (Martelli, 2014). For more than 50 years, scenario building and planning have been used by policy and corporate planners to inform strategic decision-making. One well-known example is Shell's scenarios, which, several years beforehand, anticipated the 1973 oil shock as a threat, which allowed the company to respond appropriately to the situation when it actually materialised and turn it into an opportunity (Schwartz, 1991). Today, SB often engages experts and stakeholders possessing in-depth knowledge about the considered system in a transdisciplinary process and involves conducting a series of scenario-building workshops (Berg et al., 2016). SB is utilized across various sectors by many think tanks, governments, private corporations, and international organisations and can be a suitable instrument for imagining plausible alternative futures of such a complex and multi-dimensional system as the Arctic.

A large number of foresight studies presenting future scenarios of various dimensions of the Arctic development have been published to date. A recent review of Arctic scenarios can be found in Erokhin & Rovenskaya (2020); since 2020, a few more publications came out which presented new scenarios – these include Kauppila and Kopra (2022a), Kauppila and Kopra (2022b), Keys and Meyer

[1] The list of companies is available in (Lasserre et al., 2016).

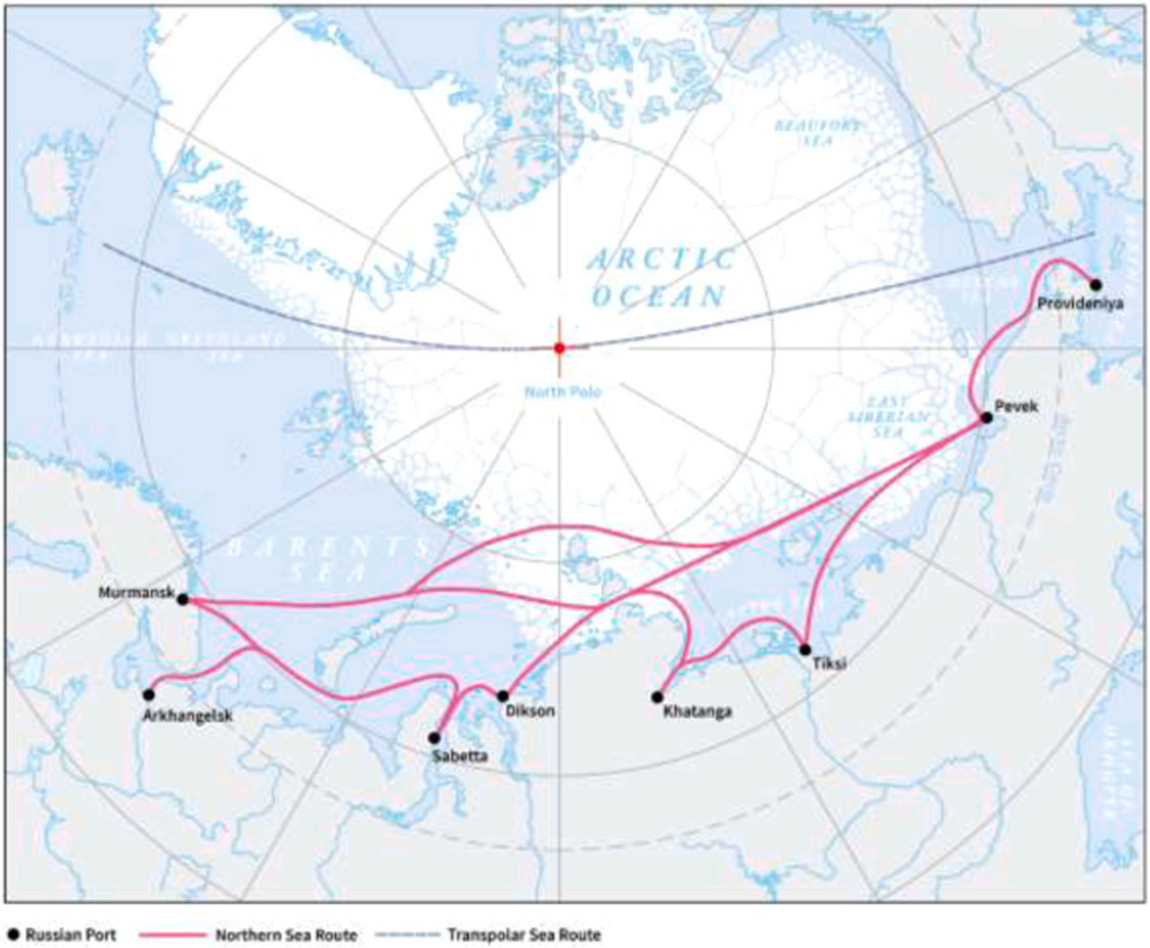

Fig. 1. The Euro-Asian Arctic and major sea routes transgressing the region.

(2022), Krivorotov (2022), Mineev et al. (2022), Middleton et al. (2021), Petrov et al. (2021), Valeeva et al. (2021), and Bergström, Leira, & Kujala (2020). These studies vary in two main characteristics: (1) the geographical scope – from local scenarios studying futures of small Arctic communities (e.g., Berman et al., 2004) to pan-Arctic scenarios (e.g., Lovecraft, 2019), and (2) the content breadth – from sector-specific scenarios, e.g., scenarios of Arctic fisheries (e.g., Tai et al., 2019) to integrated socio-economic-environmental scenarios (e.g., Petrov et al., 2021).

Most of these foresight studies focus on governance-, resource-, and environment-related issues, whereas trade- and transport-related issues receive far less attention (Erokhin & Rovenskaya, 2020). Among the plethora of published Arctic scenarios, few focus specifically on shipping in the Arctic. These include, first and foremost, the Arctic Marine Shipping Assessment Report (AMSA) scenarios by the Arctic Council (2009), which were developed in the framework of a comprehensive foresight exercise involving more than 60 maritime experts and stakeholders who identified nearly 120 factors that could shape the future of Arctic marine activity by 2050. Scenarios from this report are still widely referred to by the community, however, since 15 years ago when these scenarios were developed, the geopolitical and geoeconomic context has changed, and new information has become available. For example, decarbonization and its role in reshaping the global markets has come to the fore (Mineev et al., 2022). This calls for an update of the scenarios (van den Berg et al., 2021). Another, more recent publication focusing on the future of shipping in the Arctic by Bergström, Leira, & Kujala (2020) discusses major trends relevant to various types of shipping in the Arctic. This publication, however, does not present alternative futures, but rather outlines key variables which will define these futures.

Our paper contributes to the understanding of the futures of commercial shipping in the Euro-Asian Arctic, considering it as an integral part of the global shipping enterprise operating within the broader global economic and geopolitical framework. We distinguish between two types of commercial freight shipping, destination and transit, and focus on the 2050 time horizon. The selection of the time horizon was guided by two key considerations. Firstly, our intention was to ensure that the majority of experts who were involved in co-creation of scenarios could align themselves with the envisioned scenarios, which sets an upper bound based on life expectancy. Secondly, we allowed sufficient time for uncertainties to unfold across a broad range of possibilities, delineating our lower bound as the horizon of disruptions (De Jouvenel, 1999; Brier, 2005). The scenario building exercise underlying this paper was conducted as part of the International Institute for Applied Systems Analysis (IIASA) project in 2020–2021 in the framework of the Northern Dimension Institute (NDI) Think Tank Action.

2. Methodology

By design, the goal of our scenario building exercise was to construct explorative narrative scenarios in order to explore how the interplay of uncertainties can emerge into various plausible futures for commercial freight shipping in the Euro-Asian Arctic. Explorative, narrative scenarios are “plausible, challenging, and relevant stories about how the future might unfold that can be told in both words and numbers” (Kok et al., 2006). Explorative scenarios (see typology suggested by Börjeson et al., 2006) aim neither at predicting the future (cf. predictive scenarios) nor at determining a desirable (normative) future vision (cf. normative scenarios). Rather, by virtue of their nature, explorative scenarios can play a crucial role in informing strategic planning (Börjeson, Höjer, Dreborg, Ekvall, & Finnveden, 2006; Erokhin & Rovenskaya, 2020) in the context of complex systems which may experience rapid and irregular changes rendering their future impossible to predict. Explorative scenarios help to navigate uncertainties and develop robust strategies (Varum & Melo, 2010).

We followed “an expert-led, desk-based process” (Kok et al., 2006) to produce exploratory scenarios benefitting from existing, well-established, and widely used global scenarios to account for global factors which are expected to impact the development of shipping in the Euro-Asian Arctic. Furthermore, we involved a multidisciplinary team of experts hailing from and working in various Arctic states, to elicit professional knowledge and practical experience concerning the regional factors stemming from the Euro-Asian Arctic and to establish connections between global and regional factors.

To incorporate critical factors which are inherently difficult to quantify, such as political factors, we developed scenarios in the form of narratives (Hichert et al., 2021). Using a narrative-based approach also enabled integration of multiple expert points of view without the need to dive into specific technical details and made the resultant scenarios more accessible to a wider (also non-expert) audience (Mallampalli et al., 2016).

To craft scenario narratives, we followed the Intuitive Logics (IL) approach (Jungermann & Thüring, 1987) as a general Scenario Building (SB) paradigm and used the Morphological Analysis (MA) (Zwicky, 1969) as a technique for a systematic analysis of the key factors and combinations of their possible future developments yielding scenarios (Carlsen et al., 2016). Commonly regarded as a ‘standard’ approach to scenario planning (Derbyshire & Wright, 2017), the IL SB facilitates uncovering causal relations between factors and logical sequences of key underlying events, thereby helping to anticipate how the considered system may develop in the future (Wright et al., 2013). The IL SB is a qualitative group-process-based approach (Wright et al., 2019), which allows integration of the available expert knowledge, usually through participatory co-design workshops (McBride et al., 2017). Employing MA enables exploring combinations of uncertainties, which may be not so evident (Börjeson et al., 2006) and allows overcoming typical drawbacks of the IL approach, such as focusing only on two major axes of uncertainty and limiting the number of scenarios to the maximum of four (Johansen, 2018).

The process of scenario building included four major steps consistent with the Intuitive Logics paradigm (Fig. 2).

Step 1. Analysis of key factors. We collected and analysed factors that are likely to influence commercial freight shipping in the Euro-Asian Arctic. While a myriad of global and regional factors are relevant, arguably, a few can be prioritised as key factors, i.e., factors that can significantly influence the future (CGMA, 2015). First, we assembled a longer list of factors based on a broad literature review (including existing scenarios) and diverse input from experts. This list was then narrowed down to several key factors based on expert assessment.

Step 2. Delineation of uncertainty space. We analysed uncertainties associated with each key factor identified over the 2050 time horizon and, on this basis, defined alternative developments (values) of each key factor using the morphological analysis approach (Zwicky, 1969).

Step 3. Assembly of scenarios. We examined the logical consistency and plausibility of combinations of alternative values of the

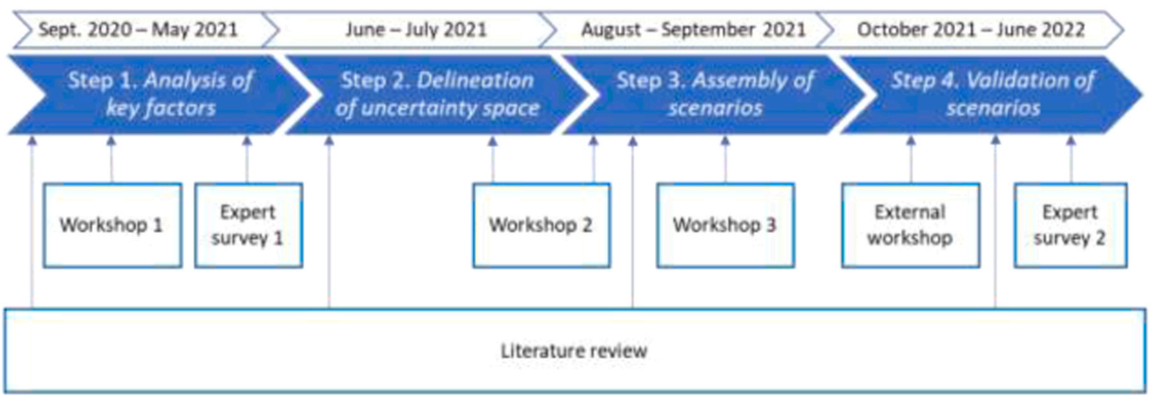

Fig. 2. Four steps of the scenario building process followed in this study.

identified key factors through Cross-Consistency Assessment (Ritchey, 2015) and selected five plausible, distinct, and diverse combinations, which broadly cover the space of uncertainty associated with the future of shipping in the Euro-Asian Arctic. These resulted in five scenarios of commercial freight shipping in the Euro-Asian Arctic.

Step 4. Validation of scenarios. After fleshing out five scenario narratives, we validated them to ensure that they are plausible, consistent, relevant, novel, and different from each other.

A dedicated group of thirteen experts from academia, policy, and business coming from seven Arctic countries, which we referred to as the Foresight Exercise Expert (FEE) Group, was involved in the SB activities, see the expertise matrix in Appendix A. Three workshops involving the FEE Group members were held to support Steps 1–3 of the SB process. Between the workshops, the FEE Group members were asked to provide written input on specific requests and fill in a survey that informed the final selection of key factors in Step 1. Moreover, drafts of the scenario narratives (the outcome of Step 3) were presented in an additional workshop involving twenty-five experts external to the FEE Group, which served as validation. Engaging experts from multiple backgrounds allowed benefiting from their professional expertise combined with their context-specific (national and sectoral) knowledge and practical experience (Houet et al., 2017).

Below we describe the four methodological steps and their outcomes in greater detail.

Step 1. Analysis of key factors.

Selection and prioritisation of factors for constructing scenarios is a daunting task (Mietzner & Reger, 2005). In a world where social, economic, and environmental processes are strongly intertwined among themselves and across scales, selecting several meaningful key factors can be challenging. Ultimately, such a prioritisation depends on the scope of the study.

It has been consequently highlighted by many experts that the Arctic is ‘global’, i.e., the role of global factors in this region is particularly important (Heininen & Finger, 2018; Finger & Rekvig, 2022). The world-Arctic intertwinement is “simultaneously local and global, regional and hemispheric, Global North and Global South, colonial and post-colonial, indigenous and non-indigenous” (Dodds, 2018). To incorporate the influence of both global and regional factors on the development of shipping in the Euro-Asian Arctic in a systematic manner, we used a multi-scale scenario framework. Multi-scale scenarios link geographical scales in settings where processes at one scale directly depend on the processes at another scale (Zurek & Henrichs, 2007).

We analysed both global and regional factors that are likely to influence the development of commercial freight shipping in the Euro-Asian Arctic. First, to determine the most relevant *global factors*, we used three existing, well-recognised global scenario frameworks:

- Four Scenarios for the Future of Trade and Investment by the World Economic Forum Global Future Council on International Trade and Investment (WEF, 2019);
- Representative Concentration Pathway Scenarios by the Intergovernmental Panel on Climate Change (IPCC, 2014);
- Long-Term World Energy Scenarios by the World Energy Council (WEC, 2019).

Second, we conducted an extensive literature review of earlier foresight studies focusing on the development of the Arctic to come up with the initial list of relevant *regional factors*.

The preliminary list of eleven global and nineteen regional factors was extensively discussed in Workshop 1 with the FEE Group members. This discussion emphasised that the nature of destination and transit shipping in the Euro-Asian Arctic is very different, and thus, different factors are relevant for each of these two types of shipping. *Destination shipping* refers to shipping from outside the Arctic to the Arctic or from the Arctic to outside the Arctic, i.e., ships going to the Arctic to load, unload, or perform an economic activity there (Arctic Council, 2009; Gunnarsson, 2021). At present and in the foreseeable future, destination shipping is largely coupled with the activities of the extraction industry in the Arctic and is used to transport extracted resources to the global markets as well as to deliver bulky mining equipment and supply the surrounding settlements (Gunnarsson and Moe, 2022). *Transit shipping* refers to the maritime transportation of goods between ports located outside of the Arctic via the Arctic waters (Arctic Council, 2009; Gunnarsson, 2021). The future of transit shipping via the Arctic is linked predominantly with the development of the global trade (Gunnarsson and Moe, 2022).

To leverage the power of systems thinking (Chermack, 2011) and address causal dependence between global and regional factors, we engaged the participants of Workshop 1 in an exercise of drawing a systems map connecting candidate factors with each other by pairwise causal relationships (Schmitt Olabisi et al., 2010). The developed systems map was used to better understand the logic of connections between the considered factors and facilitate the selection of key factors, i.e., the most influential factors in the system. Based on these deliberations, a total of five global and seven regional factors were selected for further analysis (see Figure B1 in Appendix B).

To further narrow down the list of key factors, an expert survey on the impact of these factors on two selected types of shipping in the Euro-Asian Arctic, transit and destination, was conducted, which provided a ranking of the most important factors for each type of shipping. The survey distinguished between effects over a medium time horizon (up to 2030) and a long time horizon (up to 2050).

Finally, based on the survey results, seven key factors (three global and four regional) were identified, of which six factors were considered critical for destination shipping and four factors for transit shipping; three of these factors overlapped (see Figure B1). The entire process of key factor selection is sketched out in Fig. 3.

Step 2. Delineation of uncertainty space.

Following the morphological analysis methodology (Zwicky, 1969), we formulated several (two to four) distinct plausible developments (values) for each of the seven key factors based on a literature review. These realisations of uncertainty were discussed with the FEE Group members in Workshop 2, and their feedback was incorporated into the next steps of the analysis. The key factors and their plausible developments (values) are summarised in a morphological matrix (Fig. 4). Their detailed descriptions are presented

Fig. 3. The process of elicitation of key factors for destination and transit shipping.

Global			Regional			
Climate change effects	Decarbonization pace	Global order	Infrastructure investment	Arctic governance	Technologies for shipping and safety	Regulatory framework
Extreme	Slow decarbonization	Unilateral action	Low investment	No cooperation in the Arctic	Gradually upgraded technologies	Restricted access to ships with non-Arctic flags
Moderate-to-severe	Radical decarbonization	Several competing blocs	Mainly Russia invests	Arctic for Arctic	Disruptive technologies	Unstable rules
Limited		Strong international cooperation	Large international investments	Open Arctic for all states		High barriers from Russia
						Low barriers

Legend

Factors

Relevant for destination shipping Relevant for transit shipping Relevant for both shipping types

Fig. 4. Morphological matrix illustrating key factors relevant for shipping in the Euro-Asian Arctic and their future developments. Factors highlighted in green are relevant for destination shipping, while factors highlighted in blue are relevant for transit shipping, and factors highlighted in both colours are relevant for both types of shipping. Factors highlighted with a semi-transparent colour are relevant only on the time horizon of 2030–50.

in Section 3.1.

Imagining extreme, possibly not very likely (yet, plausible) developments of factors is often challenging for participants of a scenario building process, as people are prone to the extrapolation bias tending to think about the future as a continuation of the past (Beach, 2021; Schirrmeister et al., 2020). To facilitate broader and more diverse thinking among participants of our scenario building exercise, we exposed them to a matrix of possible end states for shipping in the Euro-Asian Arctic. In this matrix, destination and transit shipping each may develop either into "high" or "low" state (Fig. 5). No quantitative metrics for "high" or "low" were specified, but in the discussion with experts, it was a general consensus that "low" would be around the currently observed shipping volumes and "high" would be compatible with targets of the Russian Arctic Development Strategy (Presidential Executive Office, 2020), which envisages an increase in the volume of cargo transportation over the NSR from 31.5 million tons in 2019 to 130 million tons in 2035, including an increase in transit shipping from 0.7 to 10 million tons. In 2022, the total volume of actually transported cargo over the NSR reached 34 million tons, with LNG being the main type of cargo, while the volume of transit shipping is estimated to have reached just 0.2 million tons in 2022 (Rosatom, 2023). At the same time, the recently commissioned Russian Northern Sea Route development plan and the initiative for socio-economic development "Year-round Northern Sea Route" envisage the growth of the total cargo volume transported over the NSR up to 150 million tons already by 2030 and 220 million tons in 2035 (Government of the Russian Federation, 2022).

The approach of mapping a number of pre-determined scenario end-states with multiple future developments of uncertain factors back to the present time is known in the foresight literature as pluralistic backcasting (Tuominen et al., 2014; Kauppila & Kopra, 2022a; Kauppila & Kopra, 2022b). Contrary to the normative backcasting approach, which usually considers a single normative (desirable) future vision, pluralistic backcasting considers several plausible alternative end states (Tuominen et al., 2014). Using this approach allowed us to encompass the diversity and multiplicity of plausible futures and remain impartial as to which future is more desirable.

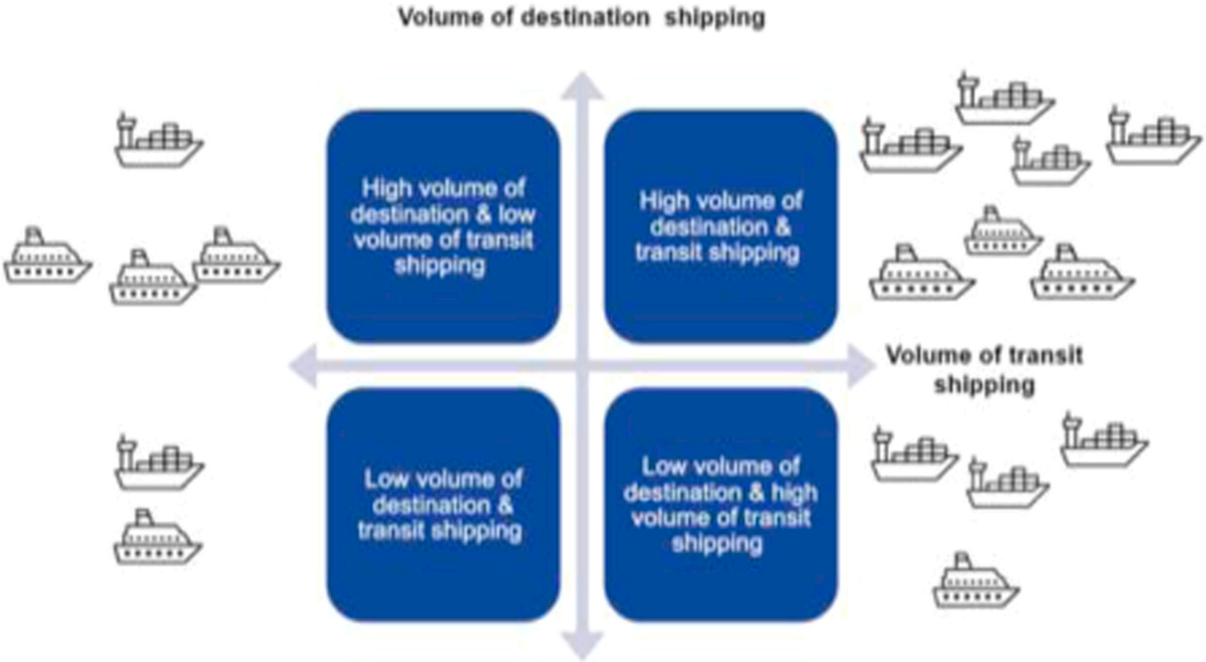

Fig. 5. Four alternative visions for the future of shipping in the Euro-Asian Arctic.

We utilized a 7 × 4 morphological matrix (7 factors introduced above and up to 4 possible values for each factor) instead of a 2 × 2 scenario matrix which has been traditionally used in scenario building exercises employing the Intuitive Logics paradigm (Jungermann & Thüring, 1987). This allowed us to enhance the multidimensionality of uncertainty (i.e., include seven key factors instead of two factors and up to four values instead of two values), while keeping the number of considered combinations of the key factors' values manageable.[2]

Step 3. Assembly of scenarios.

In the framework of the Cross-Consistency Assessment (Ritchey, 2015), the distinct realisations of uncertainty (values) for each key factor presented above were examined in terms of logical consistency and plausibility with each other. Logically inconsistent and/or implausible combinations were excluded. Therefore, distinct, logically consistent and plausible combinations of key factor values leading to each end state for the future of shipping in the Euro-Asian Arctic were assembled. These combinations became a basis for scenario skeletons (raw scenarios), i.e., sets of statements reflecting the developments of the key factors.

Using the systems maps developed in Step 1, these statements were also supplemented by statements representing consistent developments of auxiliary factors logically leading to a certain scenario end state. In Workshop 2, the logical consistency and plausibility of combinations of the key factors' values, as well as the initial scenario skeletons, were discussed with experts.

As a result of this step, two distinct scenario skeletons emerged, both leading to the "Low volume of destination and transit shipping" end state, while one scenario skeleton was identified for each of the other three end states (depicted in different colours in Fig. 6). Thus, this process delivered a total of five plausible, distinct, and diverse combinations of the developments of the key factors.

Traditionally, scenario studies include between two and six scenarios for a given system (Amer et al., 2013). As highlighted by Henrichs (2003), the number of scenarios often adheres to a rule-of-thumb that balances two considerations. On the one hand, there is a desire for a multiplicity of scenarios to ensure that a diversity of perspectives and potential futures is covered. On the other hand, there is a need to prevent cognitive fatigue and maintain manageability of scenarios. Empirical evidence suggests that typically individuals can distinguish and interpret up to five scenarios for a given system (Chermack, 2011; Durance & Godet, 2010; Greeuw et al., 2000; Eurofund, 2003). A larger number of scenarios allows accommodating more diverse target groups, as each group can identify a scenario matching their anticipations (Dammers et al., 2019). In the Arctic context, there are studies proposing as many as seven (Lovecraft, 2019) or even twelve scenarios (Petrov et al., 2021). This reflects a large number of uncertainties pertinent to the future of the Arctic (Amer et al., 2013).

Based on the developed scenario skeletons, draft scenario narratives were created to detail how the current situation might develop into the corresponding future. According to the established practice in scenario building studies (Ogilvy & Schwartz, 1998), each scenario was given a distinct name: "Global Resource Base", "Global Route", "Abandoned Land", "Sanctuary", and "Transpolar

[2] In principle, there may be altogether 1296 possible combinations of uncertainty realizations (values) of the seven key factors, however, not all of them are logically consistent and plausible, and furthermore, different logically consistent and plausible combinations have different contribution to describing the deep uncertainty.

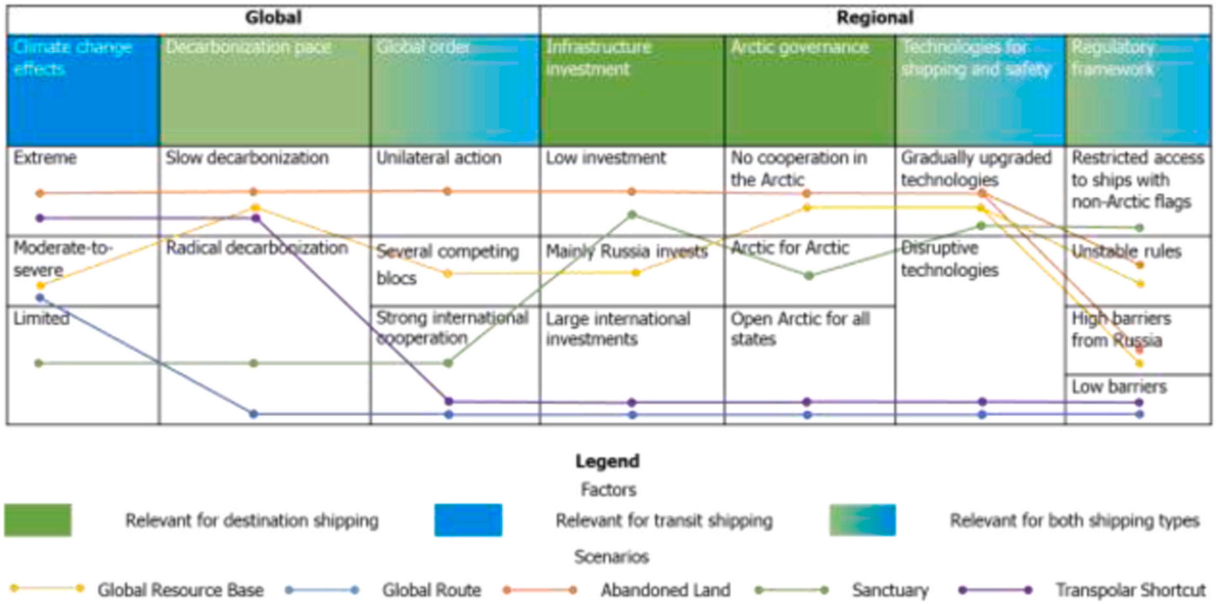

Fig. 6. Morphological matrix with scenario skeletons depicted. Each scenario skeleton, i.e., a logically consistent and plausible combination of future developments of various factors, is represented by a distinct colour line.

Shortcut".

The five scenario skeletons and draft narratives were further discussed in Workshop 3, which helped sharpen and finalise the narratives. Shorter versions of the resultant scenario narratives outlining five plausible futures of shipping in the Euro-Asian Arctic until 2050 are presented in Section 3.2. Longer versions can be found in Appendix D where they are complemented by the influence diagrams developed using the systems map created in Step 1 to help the audience grasp the narratives at a glance.

Step 4. Validation of scenarios.

According to Wilson (1998), five criteria can be used for scenario validation: (i) plausibility, (ii) consistency, (iii) utility/relevance, (iv) challenge/novelty, and (v) differentiation. In the last phase of our scenario building exercise, the full scenario narratives were shared with the FEE Group members for validation and further feedback. Another workshop, where the narratives were presented to experts external to this scenario building exercise, served as additional validation.

Our scenarios were essentially completed in January 2022. To test their plausibility in the rapidly evolving global geopolitical and economic context following the escalation of the military conflict in Ukraine, we conducted a post-exercise survey. Such plausibility assessments may be necessary to ascertain that the conceived scenarios could occur in the current conjuncture, especially in light of significant global events that may have transpired after the scenario development process. The expert evaluation of scenario plausibility from the standpoint of mid-2022 was carried out via an online survey. In this survey, eleven experts external to the original scenario-building exercise assessed plausibility of our Euro-Asian Arctic shipping scenarios and changes in their plausibility in the present global environment.

Figure C1 (see Appendix C) summarises the results of the ex-post survey on scenario plausibility. The "Global Resource Base" emerged as the most plausible scenario with a high certainty). It is followed by the "Global Transportation Route" scenario and the "Transpolar Shortcut". The "Abandoned Land" scenario and the "Sanctuary" scenario were assessed as the least plausible scenarios. Evidently, experts had more diverse views on the plausibility of these four scenarios. Figure C2 (see Appendix C) summarises the survey results on the change in the scenario plausibility. According to the survey results, the plausibility of the "Global Resource Base" scenario and the "Abandoned Land" scenario are expected to increase, however, some experts felt that, on the contrary, it is decreasing. The plausibility of the "Transpolar Shortcut" scenario and the "Global Transportation Route" scenario are expected to decrease, but again, this opinion is not unambiguous among the experts. Experts are more certain however that the "Sanctuary" scenario is becoming less plausible.

Consistency of our scenarios was achieved as a result of the cross-consistency analysis, a part of the morphological analysis approach (see details in Step 3). Pluralistic backcasting relying on four alternative end states covering the entire space of possible developments of transit and destination shipping in the Euro-Asian Arctic by 2050 (see details in Step 2) warranted both relevance and differentiation of the developed scenarios. Novelty was achieved by relying on the most recent state-of-the-art literature to inform on major factors and plausible factor developments. Notably, one of our scenarios, 'Transpolar Shortcut', presents a future in which a transpolar route becomes feasible; such a scenario has not been considered in a scenario framework so far, but, based on the recent insights, it may well become a reality in a not-so-distant future (Bennett et al., 2020). Another novel element of our study is a focus on the impacts of global decarbonization on the Arctic (cf. (Mineev et al., 2022)); to our knowledge, the scenarios presented in this paper are the first to explicitly consider the impact of the decarbonization pace on shipping in the Arctic.

3. Results

3.1. Description of the key factors

The in-depth analysis of the literature and discussions with experts resulted in the list of key factors (three global and four regional) relevant to commercial freight shipping in the Euro-Asian Arctic and elaborated their detailed developments (values), which are presented in this subsection.

Global factors.

Global order. Significant expansion of shipping in the Euro-Asian Arctic requires a long-term investment and development strategy, which are too risky without a favourable long-term vision and commitment of key countries (Gunnarsson and Moe, 2022). Hence, ultimately, the future of shipping is strongly dependent on geopolitics, which will shape the economic conditions for this enterprise (Heininen, 2018). Relevant geopolitical factors include the degree and format of trade liberalisation (Gnangnon, 2018) as one of the most important determinants of global trade flows; global ocean governance (Mahon & Fanning, 2019); and freedom of navigation (Bouffard, 2021), all of which facilitate globalisation, trade, and ultimately economic development. The rise of the global middle class (Kharas, 2017) is a possibility, which can have a major impact on economic development and trade patterns in the world. The COVID-19 pandemic has already made a significant impact on the global economy and may have long-lasting consequences on growth and hence, trade, too (Petrov et al., 2020; Skufina & Baranov, 2021). Sanctions against Russia following the outbreak of the war in Ukraine have led to major changes in investment patterns and natural resources markets (Moe, 2022).

Against this background, "Global order" is a factor that describes the degree and patterns of cooperation of countries. Extreme future developments of this factor for the purposes of this study were informed by the Four Scenarios for the Future of Trade and Investment by the World Economic Forum Global Future Council on International Trade and Investment (WEF, 2019), which provides relevant foresight. Three alternative extreme future developments of this factor include:

- "strong international cooperation", a setting where international rules prevail, and countries actively cooperate on various kinds of issues through global governance mechanisms and complementary multipolar frameworks;
- "several competing blocks", a setting where countries come together in competing coalitions and regional blocks; and
- "unilateral action", a setting where countries do not cooperate, and economic conflicts and trade wars intensify.

Decarbonisation pace. It is broadly understood that significant decarbonisation is needed to avoid catastrophic effects of climate change already in the near future (Goldstein et al., 2020). A high degree of decarbonisation will have a strong impact on the demand for natural resources, both fossil fuels and metals, whose extraction currently constitutes the absolute majority of economic activities in the Euro-Asian Arctic (Valero et al., 2018). Two extreme scenarios from Long-Term World Energy Scenarios by the World Energy Council (WEC, 2019) provide for two alternative developments of this factor:

- "radical decarbonisation" (corresponds to the "unfinished symphony" scenario in (WEC, 2019)), whereby carbon emissions are decoupled from economic growth, and new energy-efficient technologies, together with the support of governments and citizens, make an affordable and deep decarbonisation possible for all, resulting in about 50% reduction in CO_2 emissions by 2050; this leads to the reduction of the dependence on traditional fossil resources, scaling up negative emissions, and a transition to low-carbon fuels.
- "slow decarbonisation" (corresponds to the "hard rock" scenario in (WEC, 2019)), whereby clean energy technologies are being introduced very slowly, and governments consider decarbonisation to be very expensive and even naive, resulting in about a 10% increase in emissions by 2050; in this extreme future, fossil fuels continue to dominate energy production and consumption, given their low cost as well as established and diversified supply chains; renewables are growing at a much slower rate than in case of "radical decarbonisation", and the electro-mobility revolution has failed.

The consideration of two developments of this factor allows for a comprehensive coverage of the spectrum of potential responses to climate change and enables an exploration of the extremes of potential outcomes (Mineev et al., 2022; Bernstein et al., 2023). We opted to exclude an intermediate value of decarbonization as it might dilute the analysis and blur the contrast between alternative pathways.

Climate change effects. Ice conditions have a crucial impact on the duration of the navigation season, the speed, and the type of ships to navigate in the Arctic (Afonin et al., 2018; Wei et al., 2020). At the same time, sea ice melting does not automatically create enabling conditions for shipping across the Arctic. Permafrost degradation may destabilise subsurface conditions and put infrastructure built on it at risk of failure (Schneider von Deimling et al., 2021). Currently, according to some estimates, up to 70% of infrastructure in the permafrost domain lies in the area with a high thaw potential, with one-third of pan-Arctic infrastructure and 45% of the hydrocarbon extraction fields in the Russian Arctic under the threat of severe damage (Hjort et al., 2018). Infrastructure lifecycle replacement costs across the circumpolar permafrost may rise by 27% and may require an increase in annual spending of more than 1% of annual gross regional product to maintain the existing infrastructure (Suter et al., 2019). Sea ice could become more dynamic (Itkin et al., 2017; Kauko et al., 2017) and create more difficult navigation conditions (Khan et al., 2020).

Different global carbon circulation models provide different forecasts for future global warming and its effects. Widely accepted is the Representative Concentration Pathways (RCP) framework (Van Vuuren et al., 2011), which is also used by the Intergovernmental Panel on Climate Change (IPCC). The RCP framework provides scenarios for changes in atmospheric greenhouse gas concentrations and global warming by the end of the century. For the purpose of this foresight study, three alternative plausible extreme developments informed by the RCP framework can be foreseen:

- "limited" – corresponding to radiative forcing of 1.9-2.6 W/m2 in the year 2100 (RCP1.9-2.6),

- "moderate-to-severe" – corresponding to radiative forcing of 4.5-7.0 W/m2 in the year 2100 (RCP4.5-7.0),
- "extreme" – corresponding to radiative forcing of more than 8.5 W/m2 in the year 2100 (RCP8.5).

Note that in the most recent IPCC 6th Assessment Report (IPCC, 2021), each of the five considered RCPs is paired with a certain Shared Socio-Economic Pathway (SSP), a scenario describing an alternative socio-economic development of the world by 2100. As more combinations between SSPs and RCPs are in principle feasible (O'Neill et al., 2020) and to focus on factors relevant for shipping in the Arctic, this report uses its own socio-economic-political-technological factors (described above – global order and decarbonisation pace) and considers diverse combinations of the plausible future developments of these factors and the plausible climate change effects.

Regional factors

Infrastructure investment. Reliable infrastructure is key to enabling shipping in high latitudes (Ho, 2010). Infrastructure includes all objects that are necessary for economic activity in the Arctic, such as transport, telecommunications, energy, search and rescue as well as social infrastructure. Currently, there is a lack of infrastructure in the Arctic. In 2016, Guggenheim collected an inventory of 900 planned, in-progress, completed and cancelled infrastructure projects for the entire Arctic; an updated version of such an inventory made by the Wilson Center in 2020 included already 8000 projects, of which almost 7000 were in the Euro-Asian Arctic (Wilson Center, 2020). This indicates that investment in infrastructure will be a key factor for shipping in the Euro-Asian Arctic. However, the harsh climate, small population, and long distances have so far discouraged large investments in the region. Investment activity is unstable and dependent upon the hydrocarbon markets (Larchenko et al., 2019). Private investors only have a limited interest in the Arctic, whereas public funds are tight (Tsvetkov et al., 2020). Three alternative plausible developments can be foreseen:

- "low investment", when a lack of national and international investment leads to the obsolescence of technology and high wear and tear on the existing infrastructure (Pestryakov et al., 2021; Quillérou et al., 2020; Tsvetkov et al., 2020);
- "mainly Russia invests", when Russia invests in mining projects in their Arctic area as well as in building new icebreakers and providing search and rescue operations, though these investments remain insufficient to use the full potential of the Northern Sea Route (Drewniak, Dalaklis, Kitada, Ölçer, & Ballini, 2018; Pilyasov & Putilova, 2020; Corell, Kim, Kim, & Young, 2017);
- "large international investments", when the global community, including private investors, identifies the Arctic "as a global asset that should be maintained" (Nicol, 2018) as well as a "global investment opportunity" (Blom et al., 2015); a free international investment regime is set in the Arctic, which creates favourable conditions for large flows of investments going into the development of the region (Kröger, 2019).

Arctic governance. In addition to the global order and geopolitics, the Euro-Asian Arctic governance, which includes the Arctic Council, the Barents Euro-Arctic Council, the Northern Dimension and other Arctic institutions, plays an important role in determining the future of shipping (Stokke & Hønneland, 2007). Three alternative plausible extreme developments can be foreseen:

- "open Arctic for all states", where Euro-Asian Arctic is recognised as international, and all countries, both the Arctic and non-Arctic, have access to the region; making the Arctic "like the moon: Open for all to explore and exploit" has been long argued for by, for example, Chinese scholars; this idea, however, was rejected by the Arctic countries (Breum, 2013);
- "no cooperation in the Arctic", where conflicts between countries in the region prevail and even the possibility of a military conflict cannot be excluded (Blunden, 2009);
- "Arctic for Arctic", where the international community determines the status of the Arctic similarly to the current status of the Antarctic, which is accessible only "for peaceful and … scientific purposes" with very limited economic activities, for example, fishing that makes a minimal ecological impact (Gupta, 2009).

Technologies for shipping and safety. Technologies are another important factor for the future of shipping in the Arctic. Currently, the lack of technologies suitable for the harsh conditions of the North as well as unsatisfactory communication technologies are a challenge for the development of shipping in the Arctic (Golubev et al., 2019; Plass et al., 2015; Buixadé Farré et al., 2014). Two alternative plausible extreme developments can be foreseen:

- "gradually upgraded technologies", when there is a slow renewal of ships, which is accompanied by a gradual introduction of the associated basic technologies necessary to maintain navigation;
- "disruptive technologies", when new breakthrough technologies emerge, markedly contributing to Arctic shipping, such as satellites and communication systems operating at high latitudes (Mingalev et al., 2021; Buixadé Farré et al., 2014), autonomous ships (Munim et al., 2021), advanced clean-fuel ship engines (Messner, 2020), and others.

Regulatory framework. The stability of the rules and the ability to plan over the long term is important for the global shipping enterprise to decide on the use of a shipping route (Li et al., 2021; Buixadé Farré et al., 2014). The position of Russia as the owner of the Northern Sea Route (NSR) is key for this factor. Four alternative plausible extreme developments can be foreseen:

- "low barriers", when Russia returns to the NSR management regime introduced in 2013 (and abolished from 2014 onwards), which aimed at attracting international users and transit shipping to the NSR, or even goes a step further by internationalising the NSR management (Moe, 2020);
- "unstable rules", when Russia promotes volatile and ambiguous regulatory and legal systems in the Arctic (Tsvetkova, 2020);
- "high barriers from Russia", when Russia views the NSR as an inward-looking project and continues the trend of restricting the use of the NSR to Russian-flagged ships only, creating serious barriers to the admission of foreign ships (Moe, 2020);
- "restricted access to ships with non-Arctic flags", when the Arctic states jointly agree to severely restrict access to the Arctic by ships of non-Arctic states, in a collaborative spirit reflective of the Ilulissat Declaration aiming to uphold regional order in the Arctic (Rahbek-Clemmensen & Thomasen, 2018).

3.2. Scenario narratives

Five plausible alternative scenarios which reasonably cover the uncertainty space were developed as the outcome of the scenario building exercise. Each scenario constitutes a unique combination of factor developments and their implications for destination and transit shipping between Europe and Asia via the Arctic. The condensed scenario narratives are presented below; full stories are available in Appendix D.

- **Global Resource Base.**
  The world is divided into several geopolitical and geoeconomic blocs. Technological progress and decarbonisation have been slow. Climate change has brought about moderate-to-severe effects, including more frequent and dangerous navigational hazards such as drifting ice and icebergs, as well as stronger winds and higher waves. The demand for Arctic fossil resources has increased. Vessels of low ice classes can operate over the Northern Sea Route (NSR) in summer; destination shipping that transports resources to global markets throughout other seasons is undertaken with the support of icebreakers. Infrastructure has been developing gradually and is often of dual purpose. Militarisation of the Arctic has increased, however, it has not led to an armed conflict. The global trade has shifted from Asia-to-Europe to other regions, which, together with Russia's restrictive rules regarding the passage through the NSR, have made this route unviable for transit shipping. As a result, in 2050, the volume of destination shipping is high, and the volume of transit shipping is low.
- **Global Transportation Route**.
  Global cooperation has facilitated rapid technological progress. International organisations have been leading the collective action of countries to combat climate change. Despite this, high climate sensitivity has hampered reaching the Paris agreement goals. The warming of the Arctic has continued. Increased ship traffic and harsh weather conditions have increased the risk of navigational hazards. The Euro-Asian Arctic acts as a key source of indispensable metals for the low-carbon economy. Modern infrastructure has been deployed to support destination shipping which has been developing rapidly. Favourable conditions agreed upon as part of the global cooperation and decreased costs due to technological progress have enabled extensive Europe-Asia transit via the NSR. Increased ship traffic and harsh weather conditions have increased the risk of navigational hazards. As a result, in 2050, both the volume of destination and transit shipping is high.
- **Abandoned Land.**
  Countries have been acting on a unilateral basis. Recession has plagued the global economy. Innovation is lacking. Energy security concerns have slowed down decarbonisation worldwide. Extreme climate change effects have manifested. Innovation is lacking. Activities and investments in the Arctic have been limited and have focused on extracting fossils which are mostly used domestically. As the global demand for fossils extracted in the Arctic is low, the volumes of destination shipping are also low. Global recession and increased confrontation in the Arctic have made the Euro-Asia transit shipping economically unviable and politically infeasible. As a result, in 2050, both the volume of destination and transit shipping is low.
- **Sanctuary.**
  Strong political and economic cooperation among all countries has developed. Growing national and citizen aspiration for modern green technologies has facilitated rapid decarbonisation. The climate change effects in the Arctic have been relatively limited. The Arctic Council has been playing a prominent role in the governance of the Arctic. The Arctic states have banned economic activity of non-Arctic actors in the Arctic and have stopped any new fossil extraction projects to conserve the unique nature. Infrastructure development has been limited. The Arctic economies have diversified. International agreements have severely restricted both destination and transit shipping in the Arctic. Infrastructure development has been limited. As a result, in 2050, both the volume of destination and transit shipping is low.
- **Transpolar Shortcut.**

Countries have been cooperating in the economic and technological spheres. The Earth has continued to get warmer following suboptimal decarbonisation paths undertaken by the international community. Melting permafrost has destroyed the existing onshore infrastructure. The population has left the Arctic. Economic activities have declined. Mining in the Arctic has become impossible, and destination shipping has diminished. A significant retreat of the sea ice in the Central Arctic Ocean is observed. Icebreakers banned for environmental reasons have been replaced by large open-water ships. New navigation technologies have made the use of the Transpolar Sea Route viable. As a result, in 2050, the volume of destination shipping is low, and the volume of transit shipping is high.

4. Discussion

4.1. Strengths, limitations, and future research

Shipping connects the world economy, facilitating international trade of consumer goods as well as the delivery of raw materials to the production sites. Today, international shipping is responsible for the carriage of around 90% of the value of the world trade (Goodwin, 2016). Global maritime traffic is expected to multiply between three to thirteen times by 2050 compared to 2014 (Sardain et al., 2019). The exploration of alternative shipping routes for global trade is, therefore, of crucial importance for the development of humanity.

The scenarios presented in this paper were informed by the most recent science and co-produced with experts representing diverse backgrounds and expertise in a transdisciplinary fashion. This is in line with the call for inclusion of more nuanced assumptions and stakeholder expertise into formal cost-effectiveness analyses evaluating viability of Arctic routes for freight transportation (Theocharis, 2023). Furthermore, the deliberation process that led to the formulation of the scenario set allowed participants to learn from each other and see the debated issue from a different perspective, which is why our foresight can also be seen as a science diplomacy tool (Colglazier, 2017).

We recognized the importance of validating the plausibility of scenarios through expert participation, particularly when significant global events may have transpired after the scenario development process. Plausibility assessments are crucial to ascertain whether the conceived scenarios could occur in the present context, considering the potential impact of recent global events on the assumptions and drivers underlying the scenarios (Baer et al., 2023). For example, the validity of the AMSA scenarios (Arctic Council, 2009) – arguably the most comprehensive scenarios of Arctic marine navigation – has been evaluated recently in the context of the current global situation (Ryan, Thomas, & Stagonas, 2020). The inclusion of external experts in the plausibility assessment provides an additional layer of validation, ensuring that the scenarios are not only internally consistent but also relevant and plausible in the face of evolving global circumstances. This process helps to identify potential gaps or limitations in the scenarios and allows for necessary adjustments to maintain their credibility and usefulness for decision-making and strategic planning in the rapidly changing Arctic context.

The study presented in this paper could be extended, both in terms of methodology and scope. In terms of scope, domestic shipping could be considered in addition to transit and destination, and cruise shipping could be considered in addition to freight (Bergström, Leira, & Kujala, 2020). In terms of the methodology, qualitative scenarios could be complemented by quantitative estimates (Goldstein et al., 2022).

Our scenarios, like many other Arctic futures studies, focused on a limited set of large-scale drivers of change and paid limited attention to the impact of wild cards (Nilsson & Sarkki, 2022) – developments, which are rare and very difficult to predict, but which may have a massive impact (Mineev, Dietz, Nore, Vakulchuk, & Bourmistrov, 2022; Van Rij, 2013). In fact, as part of our foresight exercise, in a survey conducted in mid-2021, experts were asked to evaluate different disruptive events potentially relevant to the development of shipping in the Arctic (Strelkovskii, Erokhin, & Rovenskaya, 2021). A military conflict was regarded as an event with a low plausibility, medium warning signs, and the highest impact – a typical "black swan" event (Taleb, 2007). As of mid-2023 (the time when we finalized this paper), in retrospect, we concluded that with a military conflict manifesting in Ukraine, this wild card has been played (Mineev et al., 2022). Albeit not directly affecting the Arctic, the global repercussions of this event have had an apparent indirect impact on the region (Hilde et al., 2024), necessitating an ex-post assessment of our scenarios to confirm their plausibility which we conducted as Step 4 of our approach.

As the world seems to have entered a turbulent period, wild cards are becoming increasingly relevant. For example, more recent events, such as the incident involving the Baltic Connector gas pipeline, potentially linked to the Chinese ship NewNew Polar Bear launched in 2023 as a part of Chinese Polar Silk Road (Puranen & Kopra, 2023), underscored the vulnerability of critical infrastructure associated with increased maritime activity in the Arctic and its adjacent waters. The geopolitical ramifications are also considerable, as the incident has raised suspicions of sabotage and brought attention to the delicate balance of power in the region. Increased geopolitical tensions, as seen in the context of the recent escalation of the Israel-Gaza relations and ongoing attacks on ships in the Red Sea by the Houthi movement, can lead to heightened security concerns and the need for rerouting of maritime traffic (Balci, 2023). This can have repercussions for the Euro-Asian Arctic shipping by altering global shipping patterns, potentially increasing traffic through Arctic routes as vessels seek to avoid conflict-affected areas (Webb, 2024).

The NSR itself may be affected by geopolitical tensions, given its strategic importance and the interests of Arctic and non-Arctic states in the region (Nikitina, 2023). Moreover, the introduction of novel technologies such as stealth capabilities, advanced propulsion systems, unmanned surface vessels (USVs), smart ship technologies, and maritime drones can lead to shifts in the strategic balance, necessitate new safety and security measures, and influence the design and operation of commercial vessels in the region (Burt, 2024).

Wild card events can significantly impact Arctic shipping scenarios acting as bifurcation points that can drastically alter the course of future developments (Nilsson & Sarkki, 2022). Incorporating wild cards in further analysis of the future of the Arctic and Arctic shipping can help identify potential risks, vulnerabilities, and opportunities that may arise from unexpected events (Nilsson & Sarkki, 2022; Strelkovskii, Erokhin, & Rovenskaya, 2021). By considering a wide range of wild cards, such as those suggested by Strelkovskii, Erokhin, & Rovenskaya (2021) and Nilsson and Sarkki (2022), researchers and decision-makers can develop more robust and adaptable strategies for navigating the uncertain future of the Arctic.

Another promising avenue for future research could employ a normative backcasting approach (Börjeson et al., 2006) to craft scenarios leading to stakeholder-envisioned desirable future states of shipping in the Euro-Asian Arctic in 2050. The goal would be to identify the necessary steps and actions required to reach those desired futures and avoid others (Vergragt & Quist, 2011; van Vliet & Kok, 2015). This participatory approach would not only enhance the relevance and credibility of the scenarios but also increase stakeholder ownership and engagement with the results (Robinson et al., 2011; Reed et al., 2013). Such an exercise could be conducted as a Delphi study to facilitate stakeholder collaboration and build consensus around key milestones towards the desired future of Arctic shipping (Dinwoodie et al., 2014). In this vein, it would be crucial to recognize the importance of integrating Indigenous and Local Knowledge (ILK) and ensuring meaningful participation of Indigenous Peoples and Local Communities (IPLCs) in the making of Arctic futures (Maraud & Roturier, 2023). While IPLCs are now integrated as legitimate stakeholders in three main arenas where Arctic futures are manufactured, i.e., the global reviewing foresight arena, the foresight forums arena, and the local participatory foresight arena, their agency in shaping the futures remains limited (Maraud & Roturier, 2023). Incorporating ILK in the scenario-building process can provide a more nuanced and inclusive perspective on the future of commercial freight shipping in the Euro-Asian Arctic and its impact on IPLCs.

4.2. Scenario use

Strategic planning is an important element of both national policy-making and corporate decision-making. Policy- and decision-makers increasingly recognize that “future orientation” beyond the near term can help to cope with ever-more complex and turbulent times (Ramírez et al., 2010).

The greatest danger in turbulent times is not the turbulence itself but rather the inclination to act with yesterday’s logic (Drucker, 2003). Scenario building and planning assist in grasping uncertainty about the future and hence support policy- and decision-making over a medium to long term which ultimately helps to increase resilience of systems in focus (McCann et al., 2009).

The Arctic and, more recently, even some non-Artic states develop national Arctic strategies and general policies, which provide normative visions of national policymakers regarding the future of their countries’ activities in the Arctic and serve to aspire both national and international actors to undertake development projects (Krivorotov, 2022). National Arctic strategies and general policies typically include economic development, climate change, and environmental protection as major topics; governance, international cooperation, and human capital are also covered (Heininen et al., 2020). The current versions of these documents have significant differences across states, for example, in terms of what concerns the future of resource extraction. While the EU states the goal to “work with partners towards a multilateral legal obligation not to allow any further hydrocarbon reserve development in the Arctic or contiguous regions, nor to purchase such hydrocarbons if they were to be produced” (European Commission, 2021), Russia presents ambitious plans for mineral extraction in the Arctic (Presidential Executive Office, 2020). China, a major non-Arctic state with strong interests in the region, is planning to benefit from the extraction of natural resources in the Arctic (Manushi, 2019), with the Russian Arctic becoming one of China’s important oil and gas suppliers (Du & Liu, 2021). As another example, Arctic countries have different views regarding the interpretation of the United Nations Convention on the Law of the Sea with respect to the legal status of the Northern Sea Route in the wake of the ice retreat as a result of climate change (Lynch et al., 2022).

Often, national strategies focus on one single future and brush aside numerous uncertainties, which, however, will inevitably interfere with the declared goals. Hence, the strategic objectives of a particular country may clash with the normative visions of other nations and uncertain developments in systems pertinent to the strategy. The capacity of a scenario approach to reduce vulnerability of judgements and decisions with respect to uncertainty has already been recognized in various other fields of policymaking, e.g., climate policy (Pedersen et al., 2022) and water management (Haasnoot & Middelkoop, 2012). Recognizing the limitations of the reliance on a single, most likely scenario, a paradigm shift towards employing multiple scenarios accounting for a broader range of uncertainties has enabled more robust and flexible decision-making in the face of uncertainty in a number of policy areas.

In the case of shipping in the Arctic, the primary constraints on the capacity of national governments to formulate successful policies are not due to their lack of understanding of changes occurring in the Arctic, such as the consequences of increasing ice melting, but rather due to rapid geopolitical dynamics influencing the region and inadequate infrastructure for managing these evolving conditions (Swanström, 2023). Faced with limited options when devising policies at any given moment, governments are compelled to make decisions based on incomplete information amidst escalating tensions in order to safeguard their security and economic interests (Swanström, 2023). Our scenarios could help governments anticipate possible futures, identify strategic opportunities and risks, and develop more robust and flexible approaches to achieving their objectives in the Arctic.

For example, in its 14th Five-Year Plan, China declares the intention to develop the “Polar Silk Road” (Eiterjord, 2023). Our scenarios highlight global and regional developments that can be conducive to this intention (e.g., melting Arctic ice opening new shipping lanes, advancements in icebreaker technology, or stronger global cooperation) or can hinder these plans (e.g., tightening environmental regulations or escalating geopolitical tensions).

Moreover, in its Arctic Policy, China aspires to participate actively in the Arctic governance and international cooperation. On the other hand, the US National Strategy for the Arctic Region points at increased strategic competition in the Arctic, particularly with Russia and China. Our scenarios outline various models of governance that might emerge, ranging from strengthened multilateral cooperation under existing frameworks to more fragmented approaches characterized by competition and unilateral actions. Thus, our scenarios can aid national policymakers in tailoring their strategy to better leverage opportunities for cooperation and mitigate risks associated with geopolitical rivalries and environmental challenges.

Finally, given the uncertainties of ice conditions, fluctuating global markets, governance changes, and technological advancements, the concrete target volumes of cargo shipping over the Northern Sea Route outlined in the Russian Arctic Development Strategy face significant unpredictability (Ampilov & Grigoriev, 2023). Our scenarios can mitigate this by illustrating a range of development possibilities, thereby enabling more informed and flexible planning to meet these ambitious transportation goals amidst such uncertainties.

Similarly, our scenarios of future shipping in the Euro-Asian Arctic can be helpful for various commercial actors interested in engaging in or scaling up their business which involves shipping operations over the NSR. The scenarios can be used to inform development of resilient business strategies, which is especially critical in the currently very turbulent times when market research alone cannot provide comprehensive guidance (Xavier & Hunt, 2002).

A literature review by Gokmen & McKiernan (2019) shows that scenario planning has only recently become a part of the toolkit of business actors in the maritime industry (Wärtsilä Corporation, 2010; Lehmacher & Lind, 2022). Under increased volatility, uncertainty, complexity, and ambiguity of factors impacting shipping operations worldwide, and particularly in the Arctic, judgmental forecasts can produce more reliable results in comparison to the forecasts by quantitative methods (Duru & Yoshida, 2009; Huang et al., 2014). This facilitates the uptake of the use of expert scenarios for strategic planning in this industry (Gokmen & McKiernan, 2019). However, until this point, there have been no publicly available scenarios that specifically focus on shipping in the Euro-Asian Arctic.

Therefore, our scenarios can be a useful addition to companies' own feasibility analyses of routing freight over the Arctic seaways. Corporate managers and strategists can gain new insights into major forces driving industry evolution, which can help them anticipate possible impacts of these forces on their rivals, suppliers, and customers and thereby on their company (Vecchiato, 2015). Larger companies with their own strategy departments can also use these scenarios for benchmarking (Stopford, 2009).

5. Conclusions

Five scenarios presented in this paper represent distinct alternative futures of commercial freight shipping in the Euro-Asian Arctic by 2050. Our foresight study was conducted in 2020–2021 and involved a diverse group of experts from various countries and backgrounds in the midst of challenging geopolitical and socio-economic circumstances. This study highlights the significance of transdisciplinary collaboration and the inclusion of diverse perspectives in addressing complex, multi-dimensional issues such as the future of the Arctic. Fostering dialogue and collaboration among experts from different nations is crucial for tackling global challenges and creating a shared vision for the future. This research serves as an example of how transdisciplinary, international collaboration can contribute to a better understanding of the complexities and uncertainties surrounding the future of the Arctic and its implications for shipping and beyond.

Our scenario-building exercise provides valuable insights into the complex interplay of a wide range of global and regional uncertainties and their potential impacts on the development of shipping in the region. We demonstrate the importance of global factors, re-asserting that the future of the Arctic is largely determined outside of the Arctic (Bertelsen, 2022). The study addressed trade- and transport-related issues which are under-represented in the Arctic scenario literature (Erokhin & Rovenskaya, 2020).

To conclude, we would like to point out that the global environment is changing rapidly and often unpredictably, even on a short time horizon, such as the timeframe of a scenario-building study (Van den Berg et al., 2021). For example, new scientific evidence suggests that the magnitudes of sea ice retreat in the Arctic may be even higher than reported previously (Jansen et al., 2020; Rantanen et al., 2022) and that trans-Arctic shipping routes are becoming available earlier than anticipated (Cao et al., 2022). Geopolitical and economic shocks strongly influence commodity prices as well as trade and cooperation agreements leading to abrupt changes in supply chains (Farrell & Newman, 2022; Sardesai et al., 2021). These and other developments make it necessary to constantly revisit foresights in general and foresights on the Arctic in particular. Rapidly produced interdisciplinary future scenarios designed in a co-production manner serve not only the academic interest but are of use for agile strategic planning by policymakers and corporate decision-makers. The process of co-designing scenarios facilitates social learning, which can influence the future in the direction of recognizing diverse views and reaching a compromise (Garmendia & Stagl, 2010).

CRediT authorship contribution statement

Leena Ilmola-Sheppard: Writing – review & editing, Methodology, Conceptualization. **Dmitry Erokhin:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Data curation. **Nikita Strelkovskii:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Elena Rovenskaya:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

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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Declarations of interest

none.

Appendix A. Expertise matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	Sum
Area	Business	x		x					x				x		4
	Politics				x							x			2
	Research		x			x	x	x		x	x			x	7
Gender	Female							x	x	x	x				4
	Male	x	x	x	x	x	x					x	x	x	9
Country										x					1
					x										1
									x				x		2
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Expertise: 1 – state policy, 2 – Arctic research, 3 – industry, 4 – European affairs, 5 – Arctic technology, 6 – science administration, 7 – economics & law, 8 – trade policy, 9 – anthropology, 10 – world economy, 11 – diplomacy, 12 – sales & Arctic policy, 13 – environmental science.

Appendix B. Expert survey results on factors relevant for shipping in the Euro-Asian Arctic

Original factor names	Final factor names	Destination		Transit	
		2020 2030	2030 2050	2020 2030	2030 2050
Global factors					
Navigation conditions (sea ice, weather, etc.)	Climate change effects	3.67	3.83	4.5	4.67
Non-fossil fuel-based energy	Decarbonisation	3.33	4.17	2.33	2.67
Demand for Arctic transit of cargo	Demand for Arctic transit of cargo	2.67	3.17	3.6	3.4
Economic growth & consumption	Economic growth & consumption	3.17	3.5	3	3.67
Global governance, cooperation & ease of international trade	Global order	3.33	4.17	3.5	4
Regional factors					
Infrastructure development in the Arctic	Infrastructure investment	4.33	4.5	3.67	3.83
Governance of the Arctic	Governance of the Arctic	4	4	3.5	3.83
Advanced technologies for shipping and safety	Technology for shipping and safety	3.33	4	3.33	4
Regulatory and financial barriers to use Arctic Sea routes	Regulatory framework	3.33	4	3.83	4.5
Disruptive technologies	Disruptive technologies	2.5	3.17	2.6	3.83
Extraction of renewable and non-renewable Arctic resources	Arctic resource extraction	3.33	3.83	2.83	2.67
Commitment to untouched nature and indigenous cultures	Commitment to untouched nature and indigenous cultures	2.5	2.83	2.33	2.67

Fig. B1. Results of the expert survey on the impact of various factors on two major types of shipping, destination and transit, in the Euro-Asian Arctic on time horizons until 2030 and until 2050. Six experts took part in the survey. The displayed numbers are means across all experts on the scale from 0 to 5: 5 – a factor has a critical impact on a particular type of shipping on a particular time horizon, 0 – a factor has no impact. The factors in frames were identified as the key factors (the threshold score was 4.0). Some of the original factors selected as important were renamed for their further use following the workshop discussions.

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Appendix C. Post-study expert survey results on scenario plausibility

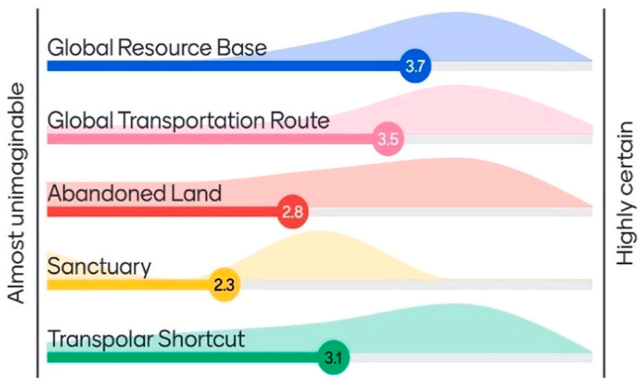

Fig. C1. Results of the expert survey on the plausibility of the developed scenarios. Eleven experts took part in the survey. Response options included: almost unimaginable (score=1), unimaginable, but probable (score=2), imaginable, but improbable (score=3), imaginable and probable (score=4), and highly certain (score=5). The average score indicates the expected scenario plausibility, while the standard deviation indicates the degree of agreement among the experts..

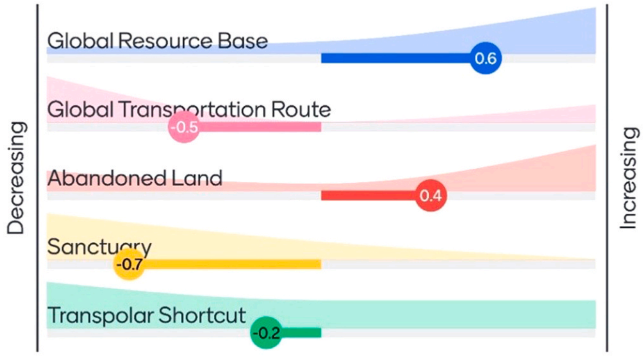

Fig. C2. Results of the expert survey on the change in plausibility of the developed scenarios. Eleven experts took part in the survey. Change in plausibility varies between decreasing (score=−1), no change (score=0), and increasing (score=1). The average score indicates the expected scenario plausibility, while the standard deviation indicates the degree of agreement among the experts.

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Appendix D. Full scenario narratives

Scenario "Global Resource Base".

Global context.

In this future scenario, the mutual trust among major geopolitical powers has deteriorated and globalism has lost its attractiveness. COVID-19 had convinced the world that economies built on the international division of labor and production are not reliable. The pandemic had intensified economic nationalism worldwide. As a result, the world has moved to a multipolar order defined by the competition and limited, pragmatic interaction of several strong geopolitical blocs of countries. The global market has turned into regional, bloc-based markets. In this global order, countries were forced to choose which bloc to join. Following this, nearly all countries in the world including countries of the Global South have become part of one bloc or another. Economic leaders of major blocs have been investing significant amounts of resources into their less developed bloc partners to develop regional markets and ensure security. Maintaining and developing blocs has been costly to their leaders, and hence renewable energy transition has been de-prioritized and proceeding overall rather slowly. Generally, technological developments and innovation have been slow, too.

In 2050, the level of trust among blocs remains low, international institutions such as the Arctic Council are weak and the idea of the environment as a global good is not high on the agenda. Instead, energy security has been prioritized, and fossil fuels continue to play a significant role. Most blocs and countries, however, have been working on eliminating coal and substituting it with natural gas or other cleaner energy sources. As a result, global CO_2 emissions continued to rise and reached their peak in the 2040 s. Global temperature is on the way to increase by more than 3 °C by 2100.

Euro-Asian Arctic context.

High demand for Arctic fossil resources.

Slow decarbonization, strong energy security concerns within blocs, and, notably, rapid economic growth of many countries in the Global South thanks to the support of the blocs to which they belong have substantially increased the demand for fossil resources worldwide. With more than 25 % of the global fossil resources being in the Arctic, the demand for Arctic resources including mineral resources has risen substantially. Commodity prices are high. Exploitation of natural resources prevails over environmental concerns and dominates the Arctic economy.

Gradual development and dual-purpose nature of infrastructure.

Russia has been benefiting from high demand and prices on the global market of fossil resources which have also helped to maintain a bloc around it. The natural resource revenues have been providing a basis for investment in the infrastructure of the Russian part of the North-East Passage, which has allowed for a gradual upgrade of vessels, safety tools, ports, and other necessary components. Although development of land-based transport infrastructure has also been considered, climate risks and unstable geopolitical landscape have made the required long-term investment infeasible.

Investors from a China-led bloc have contributed to LNG 3, LNG 4, and a few other selected resource extraction projects in the Russian Arctic, all of which have required particularly high volumes of investment. In return for its investments in extensive infrastructure, China has been receiving natural gas from Russia at a low price. China has built own icebreakers and ice-class LNG carriers (very large gas carriers; VLGCs) to deliver LNG from the North of Russia.

Militarization of the Arctic region has increased; however, it has not led to an open armed conflict in the region. The developed infrastructure has dual purpose – it is used both by the military as well as by the extraction companies. Several search and rescue (SAR) centers in the Russian Arctic have been deployed.

Ice-strengthened vessels can operate throughout the summer.

By mid-century, with the Arctic warming by almost 5 °C and the annual sea ice concentration in the Arctic Ocean decreasing by about 18 %, the Northern Sea Route (NSR) has become accessible for vessels with high and medium ice-breaking capability nearly all summer (July to October). As a result, destination shipping from out of the Arctic has become economically viable. Open-water (OW) vessels may navigate for over three months, though their navigation remains highly variable, which has made the use of OW vessels less attractive.

Climate change has brought about more frequent and severe navigational hazards such as drifting ice and icebergs, as well as stronger winds and higher waves. While larger ships are well-equipped, smaller vessels are more vulnerable. Combined with a rapid increase in domestic and destination shipping, this led to several accidents with fatalities. The ban on heavy fuel oil has been routinely ignored which has led to environmental damage.

Russia's restrictive policy.

Russia has been benefiting from the high demand and prices on the global market of fossil resources and has been leading a Eurasian regional bloc. The country has concentrated on developing destination shipping and internal transit, such as Murmansk-Vladivostok with a potential extension to Saint Petersburg and has developed necessary port infrastructure. To exploit this advantage outside of the summer season, Russia has built icebreakers to extend the navigation period to the all-year-round navigation.

Rising fossil fuel prices have made the Arctic offshore drilling more attractive and economically viable. Exclusive rights of some of the Arctic states to extract resources offshore in the waters adjacent to their territories have been disputed by other countries. Territorial conflicts around drilling and fishing have occurred between Russia and the U.S. in the Chukchi Sea, and between Russia and Norway in the Barents Sea.

Moreover, improvement of ice conditions in the Arctic and related prospects of commercial shipping encouraged other blocs to try to internationalize the NSR. Freeing of the Arctic seas from ice called into question the legitimacy of Article 234 of the UN Convention and offered arguments to challenge the rights of Russia to monopoly control of the NSR. This has accelerated the militarization of the Arctic even further.

No major transit flows over the Northern Sea Route.

The main markets for China have shifted to Asia and some countries of the Global South affiliated with a China-led bloc. Europe has relocated production back to its territory and the territory of its neighbors constituting a European bloc. The generally low demand for transit and the restrictive policy of Russia regarding the access to the NSR have kept the global shipping enterprise away from extensively using this route. Suez Canal satisfies the needs of Europe-Asia transportation.

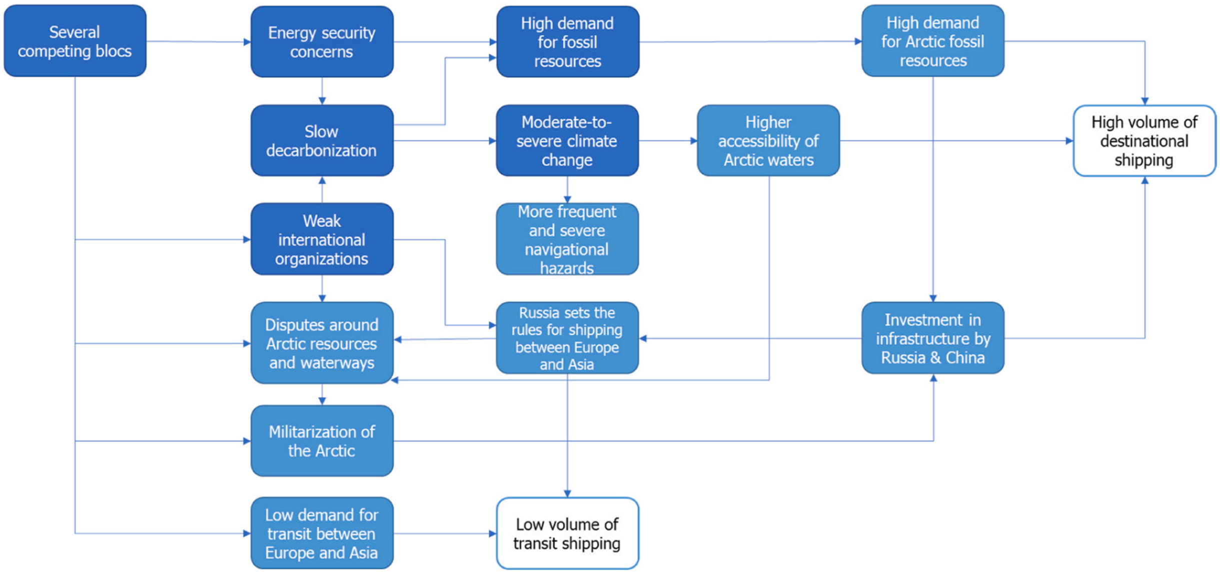

Fig. D1. Influence diagram illustrating scenario "Global Resource Base". Dark-blue polygons depict global developments and light-blue polygons depict regional (Eastern hemisphere Arctic) developments.

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Scenario "Global Transportation Route".

Global context.

In this future scenario, globalization and global cooperation have come back to the fore. Barriers between countries have largely fallen. Strong international cooperation has succeeded to trigger economic and social development in the Global South. The global supply and value chains have spanned across continents and the volume of global trade has been rapidly increasing. Global cooperation has facilitated a rapid technological progress and digital transformation in major sectors worldwide.

International organizations have been leading the collective action of countries to combat climate change and other major global challenges. Extensive deployment of green technologies and international trade of emission allowances have allowed to reach carbon neutrality by 2050 and decouple carbon emissions from economic development in many sectors and regions. In 2050, fossil fuels are still used for producing about 30 % of electricity and heat, but mainly this is natural gas. However, higher-than-expected climate sensitivity to carbon emissions has made these efforts insufficient to keep the global warming in the limits of the Paris Agreement goal, and in 2050 the global temperature has increased by more than 2 °C already with a potential to reach 3.5 °C in 2100.

Euro-Asian Arctic context.

Arctic as a source of indispensable metals for the low-carbon economy.

In this scenario, the Euro-Asian Arctic provides oil, LNG and, most importantly, metals to the global market. Extraction of gas and oil offshore have become possible with new, cheaper and safer technologies. The demand for metals has been growing rapidly as the global economy has been transiting to the net zero emission target, and the mining of platinum, palladium, lithium, nickel, tin, copper and rare earth metals such as neodymium, praseodymium, terbium, and dysprosium in the Arctic has expanded dramatically. As a result, destination shipping from out of the Arctic has been drastically increasing.

Extraction and transportation are run by international corporations. Stable rules and regulations and low barriers for using the Northern Sea Route (NSR) have made these operations economically viable.

Timber and freshwater are other two commodities which are being exported out of the Arctic and which require destination shipping.

Increased risk of navigational hazards due to rising ship traffic.

By 2050, the Arctic has warmed by at least 4 °C and the sea ice concentration in the Arctic Ocean has decreased by at least 17 %. Though harsh weather conditions, low visibility, and intermittent fog remain natural barriers to shipping in the Arctic, technological innovations have advanced to allow safe and efficient shipping under all conditions. Towards 2050, crewless ships that can operate reliably have replaced conventional vessels.

Initially, the dramatic increase in the shipping traffic over the NSR led to an upsurge in shipping accidents. Although high technological advancements helped to prevent a catastrophe, countries came to see the need for more stringent regulation and greater investment in catastrophe-prevention infrastructure. Thanks to these developments, ships have become safer, better navigation assistance (including charting of depths by crowdsourcing data from operating ships, on-demand icebreaker assistance, new elliptic orbit satellites, new achievements on modelling of weather, wind, and ice conditions in the Arctic) has become available while search and rescue facilities have improved, and their capacity has increased. While ships compliant with the Polar Code and the regulations of the Northern Sea Route Administration are more expensive to build, high capital investment and lower operational expenses (also through reduced insurance costs) have made shipping in the Arctic not only safer but also cheaper which has driven the demand for it even further.

Modern infrastructure development.

International corporations have been investing also in all aspects of infrastructure, including vessels, emergency response resources, and shoreside facilities. Major investment has come through China's Polar Silk Road project, which has included an actively developing collaboration with Iceland and Greenland. Infrastructure development has put a strong emphasis on the environmental and navigation safety.

Despite slowing climate change due to international efforts and the resulting decreased pace of sea ice melt, summers in the Arctic are still quite mild. Disruptive technological solutions and comprehensive modernization of vessels and infrastructure have made it possible to open the NSR to ice-strengthened vessels throughout the whole summer.

The carbon footprint of shipping has significantly decreased after ships shifted from the heavy fuel oil (HFO) to the LNG fuel. The deployment of hydrogen as the ship fuel of the future is well underway. The necessary infrastructure has been built along the Arctic route, including hydrogen production facilities and hydrogen refueling stations for ships. Banning HFO around the world as well as the introduction of carbon pricing has also increased the price of shipping fuel and made the NSR more attractive to the global shipping enterprise, given its shorter distance, faster passage, and consequently lower fuel consumption.

Europe-Asia transit via the Arctic.

Stable rules and regulations of navigation and trade, as well as attractive conditions of using the NSR (low fees and quality infrastructure) have opened this route for the global transit. The NSR is being used extensively because, as countries actively trade with each other across the globe, the capacity of the Suez Canal has not been enough to accommodate the needs. Moreover, a high carbon price has set a strong incentive for global shipping companies to choose shorter routes for Europe-Asia voyages. As a result, in summer about half of the voyages between Asia and Europe are diverted to the NSR.

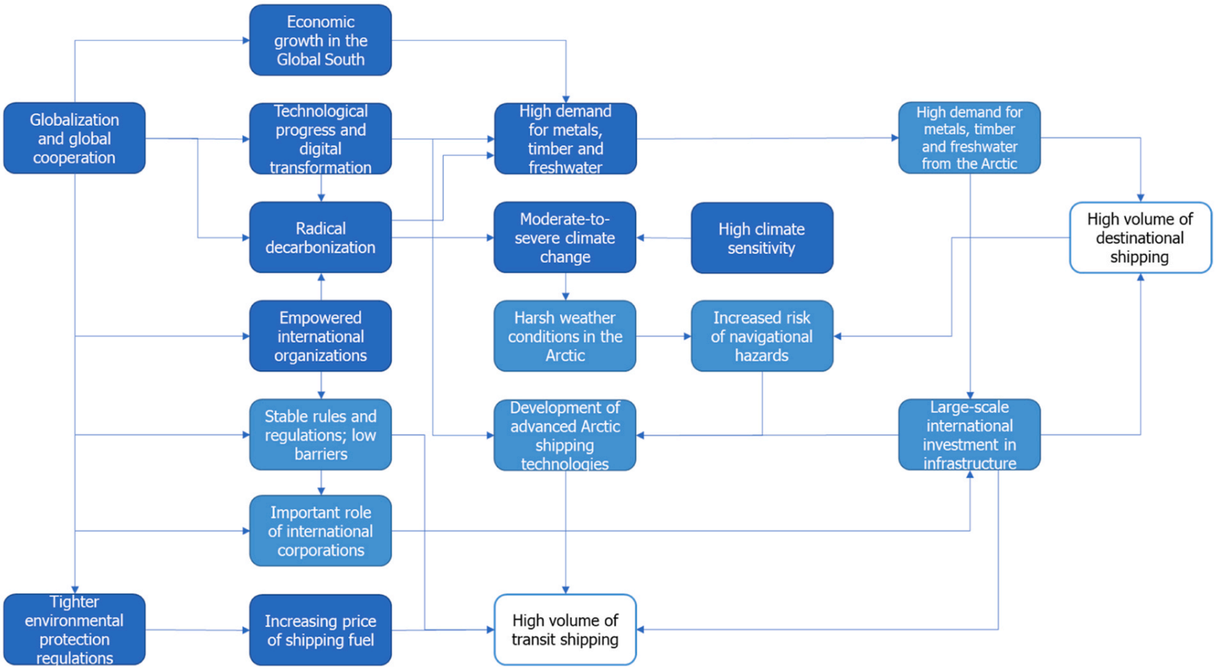

Fig. D2. Influence diagram illustrating scenario "Global Transportation Route". Dark-blue polygons depict global developments and light-blue polygons depict regional (Eastern hemisphere Arctic) developments.

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Scenario "Abandoned Land".

Global context.

The recovery from COVID-19 had been slow, unequal, and dividing. National economies have been struggling to identify viable sources of growth. Protectionist sentiments have dominated. Some countries fell apart. Countries and regions engaged into economic conflicts and trade wars among each other hoping to gain some advantage over others, but instead have got bogged down in these and have lost efficiency and positive spirit.

Established in the early 2000s global supply chains broke down. Global North countries have moved production back home and concentrated on domestic markets. Global South countries have struggled to develop and in some cases have become even poorer.

The global economic recession has led to even the most developed countries having very limited resources for investment. Conflicts have forced countries to turn inward in search of energy security solutions and to use all the resources at their disposal. Being virtually cut off from energy sources from abroad and reluctant to develop new oil and gas deposits itself, Europe has continued its path towards a higher share of renewables in the energy mix complemented by green hydrogen-based energy produced using clean energy sources like wind and solar power. Outside Europe, depending on availability, most other countries have chosen to use the cheapest coal- and oil-based energy ignoring climate change concerns.

As a result, in 2050 the global average temperature is on the way towards a rise of 4.5 °C by 2100. This has led to rising ocean levels and imbalances in all natural systems. The Atlantic meridional overturning circulation has slowed down dramatically. Precipitation patterns have changed, temperature anomalies occur, and the frequency and severity of extreme events such as hurricanes, floods, and droughts have increased. These events are global in nature, resulting in countries blaming each other, leading to further escalation of tensions.

Euro-Asian Arctic context.

Climate calamity in the Arctic.

At the regional level, this has led to a marked deterioration of living conditions in Arctic cities, caused not only by a more extreme and unpredictable climate (with the mean annual temperature increasing by more than 6 °C around 2050), but also by a decrease in the food supply due to the outmigration of fish and other species.

Lack of innovation The lack of global cooperation and resources has hindered innovation. Thus, there have been no developments in Arctic shipping technologies as well. Only few new icebreakers have been built, mainly to secure safe shipping in winter in the Western part of the NSR. Other infrastructure except for military has not been updated either.

Limited investment into the Arctic focused on extraction of fossils.

The development of projects in the Arctic has slowed down. Russia has been operating a few extraction projects and minimal critical infrastructure that is necessary for these projects. Russia has been maintaining a limited icebreaker fleet.

In 2020–2030, Russia's exports of oil and gas were decreasing as Europe was gradually developing renewable and hydrogen-based energy. In 2030, following its Arctic strategy, Europe mandatorily banned the extraction of resources in the Arctic, as well as the purchase of resources extracted in the Arctic. China switched to Asian, Arab, and African energy markets, while also continuing to actively use coal and developing nuclear power. This significantly reduced the demand for Russian resources. As a consequence, in 2050, most resources extracted in Russia are used for domestic consumption.

Anthropogenic disasters on extraction sites happen due to weak compliance of the actors with environmental regulations.

No Europe-Asia transit shipping.

Due to lingering economic recession and trade wars, the global trade has visibly shrunk. Even conventional trade routes stand idle. Neither there is demand nor technological capacity for transit shipping in the demanding conditions of the Arctic. Increased militarization of the Euro-Asian Arctic region has also contributed to this. The NSR is used only for voyages between Russian ports.

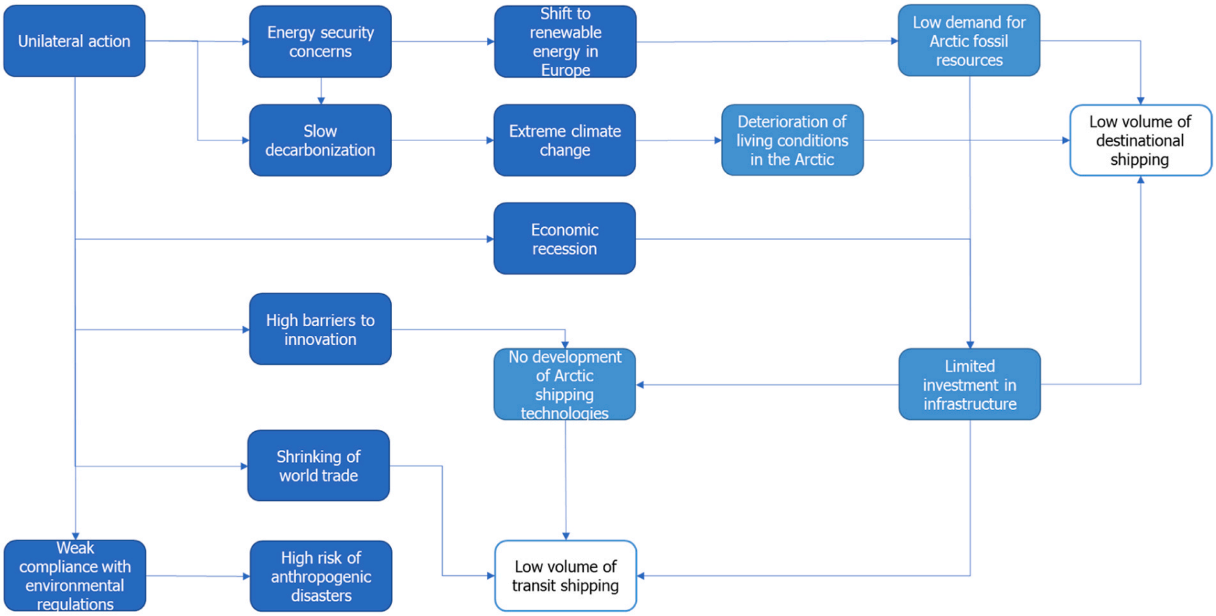

Fig. D3. Influence diagram illustrating scenario “Abandoned Land”. Dark-blue polygons depict global developments and light-blue polygons depict regional (Eastern hemisphere Arctic) developments.

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Scenario “Sanctuary”.

Global context.

Countries have come together to cooperate, and trade flows move easily across borders. Major economies have jointly committed to address points of conflict and regulatory challenges that spill across borders through multilateral frameworks. Stronger cooperation has lowered market uncertainty and has reduced production barriers, facilitating efficient allocation of capital across global value chains.

Trade policymakers have built cooperative mechanisms with other policy communities on relevant issues, including environmental protection. Countries have continued to implement the consensus reached in the Paris Agreement. The narrative of a better life for all on a healthy planet has gained popularity. Countries and citizens have been interested in modern green technologies, which enable rapid decarbonization. Carbon policies motivated companies to switch to clean energy, synthetic fuels, and renewable energy sources. These developments have fostered a slowdown of climate change with the global warming expected to stay below 2 °C by 2100.

Circular economy has been actively developing. International agreements have put environmental protection as the highest priority, over near-term, narrow economic objectives. To fulfil this aspiration, emphasis has been put on securing and improving existing trade routes rather than on building completely new infrastructure. Suez Canal has been deepened and secured, the problem of piracy around its southern entrance as well as in the Malacca Strait has been solved with joint international forces.

Euro-Asian Arctic context.

Limited demand for fossil energy resources, as well as international aspiration for environmental sustainability have led to the closure of the Arctic, given its critical role in the global ecosystem.

The ban by the Arctic states on economic activity by non-Arctic actors in the Arctic.

The role of the Arctic Council in the governance of the Arctic has become dominant. In the spirit of the Ilulissat Declaration, the Arctic states jointly continue to prevent non-Arctic actors, such as China, from using Arctic waters for economic activities.

Ban on new fossils extraction sites.

International commitment to rapid decarbonization and development of technologies based on renewables has led to declining demands for fossil energy resources. No new infrastructure facilities for oil and gas extraction have been developed. A general ban on offshore drilling has been introduced. Local energy demands are covered by renewable sources, like wind farms and tidal hydropower.

Diversification of the Arctic economies.

By 2050, the Arctic economy has diversified and has become more sustainable compared to 30 years ago. While mining and manufacturing activities have declined, the volume of services such as ecotourism in the regional economic structures has increased. The role of indigenous people in the local economies has increased, they are involved in economic activities with external actors and have gained more representation in governing bodies (similar to the Saami parliament).

Closer to 2050, a lack of resources on the global market – most notably, minerals – led to debates on re-opening the Arctic for untapped resource extraction using deep sea mining technologies.

Conservation of the Arctic.

Researchers have collected overwhelming evidence that the Arctic environment is highly responsive to climate change and Arctic ecosystems are more vulnerable than previously thought. The Arctic Council and Arctic states have developed and enforced strict environmental protection regulations. Large national reserves and parks have been created prohibiting any economic activities within their borders. By 2050, the warming of the Arctic has reached 3 °C.

Decrease in shipping volumes and infrastructure decline.

Only research and expedition (tourist) ships powered by green technologies and compliant with the strictest environmental regulations are allowed to enter the Arctic. An international agreement has been concluded prohibiting the use of the Arctic for transit shipping of goods to reduce local environmental impacts. Stable collaboration between the Arctic states has limited the military presence in the region with mostly patrol and coast guard ships sailing.

There has been no investment in new Arctic shipping technologies or port infrastructure. Due to a lack of demand for using the NSR, Russia has terminated its nuclear icebreaker program.

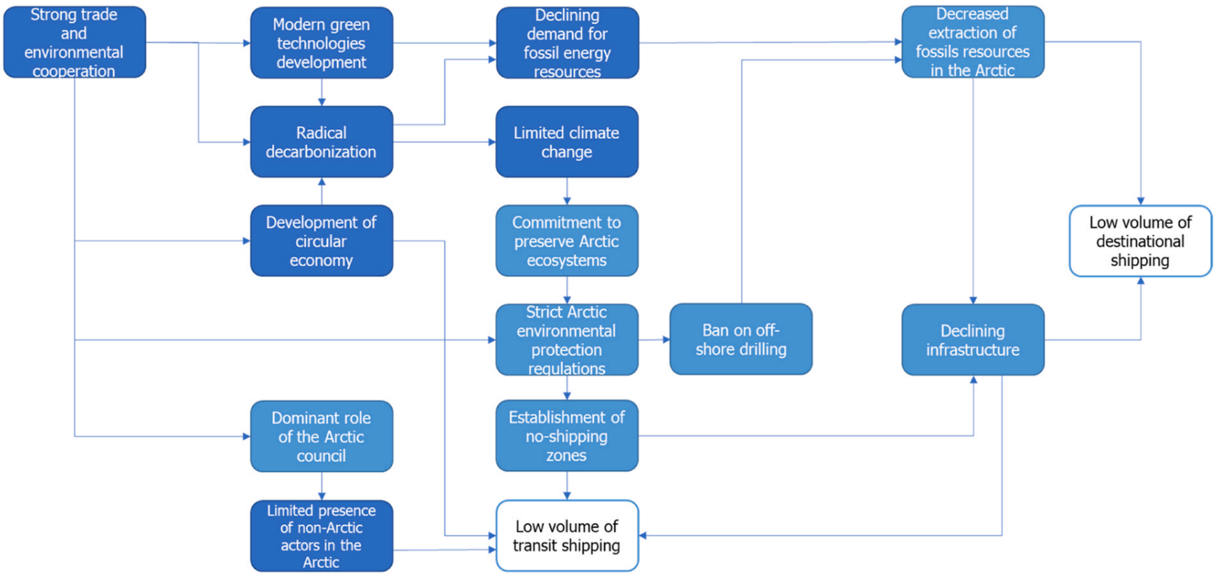

Fig. D4. Influence diagram illustrating scenario "Sanctuary". Dark-blue polygons depict global developments and light-blue polygons depict regional (Eastern hemisphere Arctic) developments.

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Scenario "Transpolar Shortcut".

Global context.

Climate change has continued despite the efforts of the international community. The global temperature is on the way to exceed 4 °C by 2100. Major states around the world have been concerned with the impact of climate change and have been in search of effective and efficient ways to combat it. However, the energy transition has focused mostly on LNG and blue hydrogen, and therefore has not enabled radical decarbonization. On the other hand, the Earth system appeared to be more sensitive, fragile, and inert than previously thought. Warming has accelerated noticeably due to the release of methane from thawing permafrost.

Countries have been cooperating in the economic and technological spheres. Economies have become highly specialized with a focus on circular *global* economy. These developments have required extensive shipping between Europe and Asia. Adaptation to climate change has played a major role.

Euro-Asian Arctic context.

Collapse of land infrastructure.

The rapid global warming – in 2050 the Arctic warms by more than 6 °C on average – has triggered the irreversible process of melting ice and permafrost. Thawing permafrost has destroyed onshore infrastructure in the Arctic and has complicated construction of new infrastructure. Methane released from beneath the ice has further intensified climatic processes in the Arctic.

De-economization and depopulation of the Arctic.

Decarbonization of economies worldwide has led to a decline of demand for fossil fuels. No new oil and gas fields have been developed in the Arctic. While emerging technologies have generated high potential demand for Arctic-specific metals, such as, for example, palladium, their extraction has not been feasible due to infrastructure damage caused by thawing permafrost. Instead, these metals have been recycled and, towards 2050, new technologies have become available which have reduced the need in these metals.

As there has been no economic activity in the Arctic, people have moved out from the Arctic cities to places with a more livable climate. Extreme climate change has destroyed traditional livelihoods of the indigenous peoples leading also to depopulation of rural areas.

All these developments have led to a significant reduction of shipping activity along the coast of the northern Eurasia. Low demand for Arctic resources and cooperative geopolitical environment have also led to decreasing military presence in the region.

Significant retreat of sea ice in the Central Arctic Ocean.

Further ice melting has opened up prospects for the emergence of shipping routes in higher latitudes, beyond the NSR, including through the North Pole. The Transpolar Sea Route (TSR) became accessible to seasonal navigation around 2040.

Shift from icebreakers to polar class vessels.

The use of nuclear-powered icebreakers has been forbidden due to its risks and the problem of nuclear waste. Diesel-powered icebreakers have been also discontinued due to environmental concerns. However, as of 2040, large open water vessels could operate along the TSR all year round without ice-breaking support. New technologies and benefits of the circular economy have made the construction and use of these vessels economically meaningful. Operating on clean fuels, these ships pose significantly lower environmental risks.

Development of new navigation technologies.

These voyages are supported by advanced digital surveillance technologies. Given the remoteness of the TSR from shore and hence the lack of onshore infrastructure, which complicates search and rescue operations, large investments have been going into the development of autonomous ships. The global shipping enterprise has given preference to such vessels to minimize human risks. Newly launched satellites have been used effectively to monitor autonomous ships. Increased availability of such technologies has also reduced navigational risks and has lowered related insurance costs. More accurate forecasts of sea ice conditions have made it feasible to transport not only bulk cargo but also more time-sensitive container shipments.

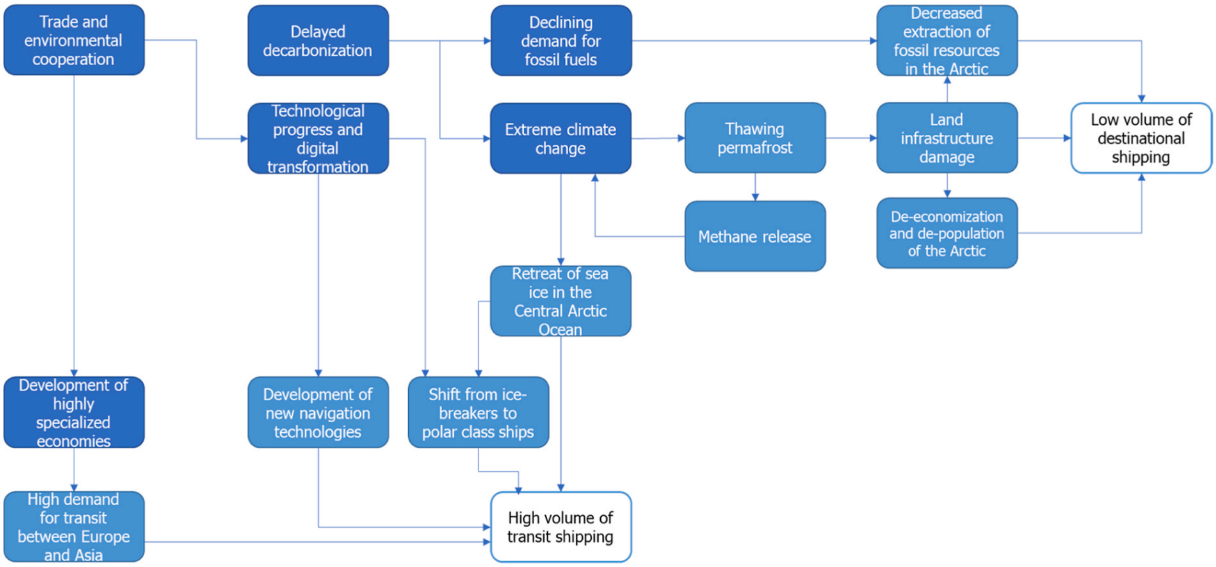

Fig. D5. Influence diagram illustrating scenario "Transpolar Shortcut". Dark-blue polygons depict global developments and light-blue polygons depict regional (Eastern hemisphere Arctic) developments.

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