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# Potential Impact of Maritime Activities on the Arctic Footprint

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**Abstract:** Understanding the Arctic footprint concept and its components is crucial, particularly in the context of Arctic shipping activities. This study aims to evaluate the relationship between the Arctic footprint and maritime activities, with their related components. The gradual retreat of Arctic sea ice due to climate change has posed serious environmental challenges. Moreover, the emergence of new shipping routes has added a new dimension to these concerns. It seems inevitable that this situation, which represents a new development in maritime trade, will have an exponential impact on the Arctic footprint. In recent years, all climatic and economic projections regarding the region's future have included direct and indirect effects of Arctic shipping. The potential of the routes between East and West, to turn to the North, combined with the rich underground resources of the Arctic, attracts the attention of the industry to this region. This study reviews the literature to assess the potential threats to the Arctic footprint and includes future scenarios of Arctic utilization. Additionally, the Liner Shipping Bilateral Connectivity Index and the Climate Change Performance Index are evaluated to understand the Arctic footprint for countries that could potentially use the Arctic for trade between East Asia and Western Europe.

**Keywords:** climate change, Arctic Region, Arctic footprint, maritime, carbon emissions

## 1. Introduction

The oceans play a crucial role in reducing the harmful impacts of climate change caused by global warming, such as absorbing excess carbon dioxide ($CO_2$). However, recently, this situation has been putting significant pressure on ocean ecosystems and negatively affecting their health (Bijma et al. 2013). Excessive intake of $CO_2$ causes a decrease in seawater pH, which is called ocean acidification. The pH of global surface waters has decreased from 8.2 to 8.1 since the pre-industrial era and is expected to decline by another 0.3 pH units by the end of this century (Kroeker et al. 2010, Pörtner et al. 2022, Turley et al. 2010).

Ocean models predict a 1-7% decrease in global ocean dissolved oxygen levels over the next century, and these decreases will continue for many years (Keeling et al. 2010). The decrease in dissolved oxygen is caused by ocean warming (Pörtner et al. 2022). Global ocean temperatures increased by 0.10°C from the surface to a depth of 700 meters from 1961 to 2003 (Bindoff et al. 2007). Rising sea levels are caused by the thermal expansion of oceans and the mass loss from glaciers, both of which increase the volume of ocean water (Dutton et al. 2015, Pörtner et al. 2019). Global sea levels have risen throughout the 20th century. It is expected that these increases will accelerate in the 21st century and beyond (Nicholls & Cazenave 2010).

The IPCC's (Intergovernmental Panel on Climate Change) climate models, based on RCPs (Representative Concentration Pathways) 4.5 and 8.5, predict that by 2081-2100, the North Polar ice caps will completely melt, due to changes in greenhouse gas (GHG) levels (Hoegh-Guldberg et al. 2014). These changes significantly affect and change the economic functioning of the region as well as the Arctic ecosystem, because the opening of Arctic sea routes greatly reduces transit times between Europe and Asia (Howell & Yackel 2004, Lasserre 2014, Li & Lynch 2023, Liu & Kronbak 2010, Makarova et al. 2022, Omre 2012, Smith & Stephenson 2013, Wang et al. 2016, Xu et al. 2011, 2018).

This new situation creates an alternative trade route that important players in the world economy cannot ignore. As interest in Arctic natural resources increases day by day, the potential of using Arctic routes as a heavy traffic sea route will enable the rapid commercialization and industrialization of the region. As a result, the anthropogenic footprint in the region is expected to increase exponentially.

Therefore, one of the most critical issues to address when evaluating the Arctic footprint is maritime trade activities. Besides the negative effects of climate change in the Arctic, it's also important to understand the environmental stress caused by maritime activities. Some of these potential critical impacts on the sensitive Arctic environment include air pollution, GHG emissions, the release of ballast water containing invasive aquatic species, cargo residue discharges, oil spills from ships, underwater noise pollution, grounding or sinking of vessels, and widespread sediment pollution in ports and piers etc. (Walker et al. 2019). Considering the now accessible natural resources of the Arctic region, this new economic attraction center requires that the Arctic footprint be evaluated comprehensively from economic, social, and environmental perspectives. All scenarios that highlight the future of the Arctic are crucial for raising public awareness to prevent jeopardizing the region's ecosystem and the sustainability of the vital activities of its living creatures. Only a shared understanding among Arctic stakeholders in global trade will ensure that the measures to be taken and the policies to be developed are based on solid foundations.

In light of all this information, this study conducted evaluations to understand the concept of the Arctic footprint and all potential threats that could increase it. To understand the connections between the Arctic footprint concept and maritime trade, the Liner Shipping Bilateral Connectivity Index (LSBCI) and the Climate Change Performance Index (CCPI) were included to understand better the Arctic usage infrastructures of selected port cities between Asia and Western Europe and to assess the potential impacts that may occur in the region due to climate change.

## 2. Arctic Footprint

The Arctic region, which is heavily affected by anthropogenic activities, is changing in many ways due to climate change, and the rate of warming is twice the global average (Cereja et al. 2023). Accordingly, Arctic sea ice is decreasing, land ice is melting, and permafrost is thawing. These Arctic components are interconnected, and many of these interactions are hastening the pace of change (Moon et al. 2019). The rapid and severe changes (including sea level rise, worsening storms and hurricanes, and increased warming) in the Arctic are impacting the infrastructure, economies, and cultures of people both inside and outside the Arctic (especially noticeable in mid- and low-latitude regions). Permafrost carbon feedback is a direct example of this impact; thawing permafrost releases additional greenhouse gases into the atmosphere, contributing to global warming that impacts the entire world population (Schuur et al. 2022). These rapid changes also affect the Arctic marine ecosystem through changes in the marine light environment, stratification, and benthic-pelagic connections (Moon et al. 2019).

To understand the causes and effects of these interactions thoroughly, it is important to evaluate and comprehend the Arctic footprint. When Rees (1992) first used the term "footprint", it was expressed in the following meaning as the land area directly or indirectly affected by human activities. Scientists have been developing comprehensive indicators to measure humanity's influence on Earth's vital systems; environmental footprints are the most widely recognized and used (Matuštík & Kočí 2021). The concept of environmental footprints involves quantitative measures of human impact on natural resources and can be categorized as environmental, economic, social, or a combination of these. Each footprint type corresponds to specific pressures associated with a process, product, or activity from a life cycle perspective (Čuček et al. 2015). In this context, the Arctic footprint is shaped by factors such as carbon emissions and environmental changes caused by human activities, including industry, transportation, tourism, and natural resource use. This concept can also be evaluated by considering ecosystem health in this region, local community lifestyles, and climate change. From this perspective, it becomes clear that the Arctic footprint's larger contribution comes from the combined effects of increased activity by other countries in the region and the climate change experienced there, rather than from the impact of the local community (Cavalieri et al. 2010).

When the subject is evaluated in terms of maritime transportation, the number of ships entering the region has increased over the years with the growing use of Arctic routes. The number of ships entering the Arctic Polar Code area increased by 37% from 2013 to 2023 (1298 to 1782 ships, respectively, each ship counted once) (PAME 2024). Therefore, it is unavoidable that ship emissions will rise, and environmental damage in the region may also increase. For instance, Comer et al. (2017) reported that rerouting ships from the Suez and Panama Canals to the Arctic could increase black carbon (BC) emissions. Without any diversion, BC emissions in the IMO Arctic are expected to increase modestly, from 193 tons in 2015 to 199 tons in 2020 and 204 tons in 2025 (under a BAU scenario). The Arctic has a fragile ecological environment, and BC emissions from Arctic shipping pose a threat, such as accelerating the melting of local glaciers and potentially warming the climate by darkening ice and snow surfaces (Chen et al. 2024, Stephenson et al. 2018). In addition, Jing et al. (2021) stated that the total $CO_2$ emission from shipping on the Northern Sea Route by 2050 will be approximately 5.5 tons (under the business-as-usual scenario), which is 1.76 times higher than the emission level in 2020. Therefore, measuring these $CO_2$ emissions is important for assessing the damage they have caused or will cause to the environment (Jing et al. 2021, Liu et al. 2024). Carbon footprint is a good way to measure the impact of activities from people, industries, companies, governments, and others (Wiedmann & Minx 2008). So, it is also important to understand the impact of maritime activities on the Arctic region and their feedback. Also, it should be noted that evaluating carbon emissions is a useful tool for understanding the impact of shipping on the Arctic footprint of countries.

## 3. Future of Arctic Use and Shipping Based on Climate Change Projections

Climate models help us understand how the global climate has changed over time and forecast future climate trends (Buis 2020). Models simulate the global climate for the upcoming decades (up to 2100) using scenarios that consider variables such as greenhouse gases, land use, and concentrations of atmospheric components that affect the radiative balance of the planet (O'Neill et al. 2020). In this sense, the RCPs (Representative Concentration Pathways) developed by the IPCC in 2007, which were selected from over 40 scenarios spanning a wide range of GHG emissions from low to high (IPCC 2001, Pachauri et al. 2014), form the basis for many scalable regional projection studies, including those focused on the Polar regions. Especially due to the Arctic amplification phenomenon (Hoegh-Guldberg et al. 2014), these studies in that field need to be examined in more detail to understand the Arctic footprint.

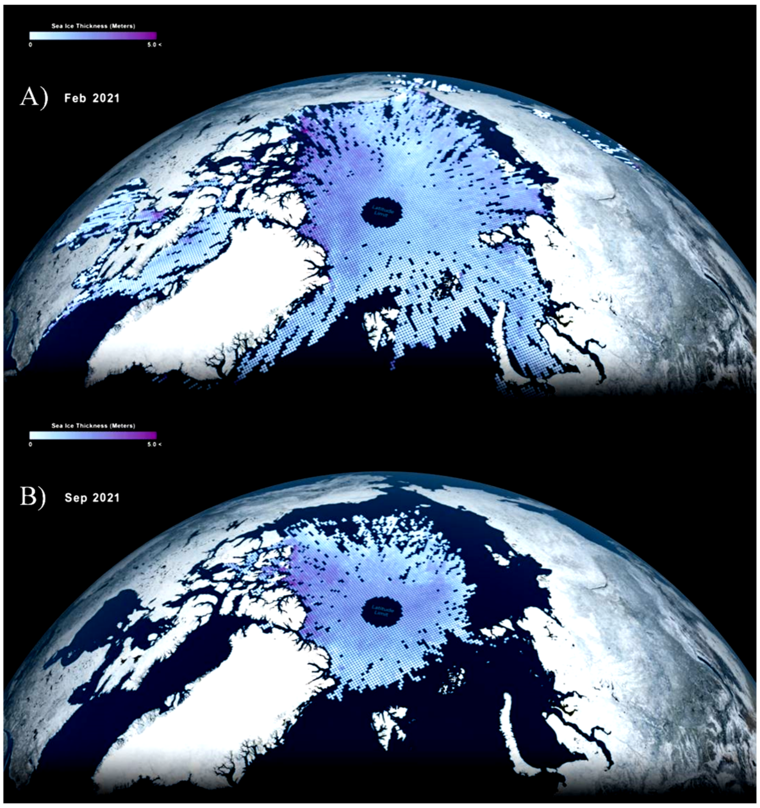


**Fig. 1.** View of the Arctic Ocean with monthly mean sea ice thickness data, A) February 2021; B) September 2021. (Lower values are shown in light blue, higher values in magenta) (ICESat-2, 2023)

Figure 1 shows the Arctic Ocean view with monthly average sea ice thickness data (Scott et al. 2016). Accordingly, satellites have observed a decrease in Arctic sea ice extent for all months since 1979. However, long-term and accurate observations of the thickness distribution are also required to fully understand how changes in Arctic sea ice cover affect our global weather and climate (Tilling et al. 2018).

The gradual retreat of the Arctic sea ice cover (see Fig. 1) is unfortunately making its development as an economic field more accessible. The geopolitical importance of the Arctic mainly comes from its geographical location between the three most industrialized and developed continents (Asia, Europe, and North America) and its wealth of important industrial resources (Ostreng et al. 2013). The distance advantage provided by Arctic routes can nearly cut the travel distance to these trade hubs in half compared to traditional routes through the Suez and Panama Canal (PAME, 2020).

The factors influencing the future of Arctic maritime activities are the changing trend of the Arctic climate, the feasibility of natural resources in the region, and the environmental policy regulations of the relevant authorities. In studies that include the possibilities for these activities (Vihanninjoki 2014), various modeling methods and assumptions are used; they include the development of sea ice conditions, comparison of alternative routes, and emissions.

According to the AMSA (Arctic Marine Shipping Assessment) report, the melting of Arctic sea ice creates opportunities for longer sailing seasons in maritime access, and the future globalization of the Arctic and the extraction of its natural resources are the main drivers of this. In this context, AMSA presents four different scenarios. Two main factors and key uncertainties are chosen as the axes of uncertainty for the scenario matrix. These are, on one hand, "resources and trade", and, on the other hand, "management". Resource and trade refer to the "level of demand for Arctic natural resources and trade". At the same time, management/governance consists of "the relative degree of stability of rules for sea use, both within the Arctic and internationally" (PAME, 2009). The *Arctic Race* scenario is not a geopolitical "race" for sovereign rights or new lands involving demand for Arctic natural resources, but rather an "economic rush" for development based on global markets. The low-use (*Polar Lows*) scenario represents a future of low demand for resources and unstable management. There is little maritime traffic in the Arctic Ocean. The *Polar Preserve* scenario represents a stable and developed state of marine use and low demand. The optimum scenario (*Arctic Saga*) projects a future of high demand for resources and trade, with stable marine use management (PAME, 2009). The report states that the increase in natural resource extraction and maritime traffic in the region is contributing to the globalization of the Arctic. Secondly, the global shipping industry is likely to have significant environmental impacts on the Arctic Ocean as the number of trans- and intra-Arctic voyages by large tankers, cruise ships, and bulk carriers increases. Thirdly, despite the overall increase in maritime activity, no major international policy has been established. As a result, maritime governance is quite coercive and inadequate, leaving both stakeholders and the environment vulnerable to potential threats (PAME, 2009, 2020).

Assessing the extent of Arctic maritime activities, Corbett et al. (2010) use the global assessment of maritime transport provided by the International Maritime Organization. As a result of this calculation, an estimate of future global demand levels is obtained, including reasonable upper and lower bounds, and annual growth rates are also calculated. Two parallel scenarios with different rates of intra-Arctic growth and trans-Arctic deviations are defined, namely the *Business as Usual* (BAU) and *High Growth* (HiG) scenarios. The BAU (similar to AMSA scenarios that involve high levels of resources and trade, such as Arctic Race and Arctic Saga) scenario involves a moderate increase in maritime activity. In contrast, in the HiG scenario, the Arctic experiences a significant change in maritime activity, also presenting considerable challenges and threats for humans and the environment.

Eide et al. (2010) presented a detailed technical and economic assessment of the feasibility of future Arctic shipping. In this study, sea ice conditions served as the basis for the analysis, and the potential increase in Arctic shipping activities was assessed with this in mind. The analysis includes a projection of future ice concentrations from 2007 to 2100, obtained using the Community Climate System Model (CCSM3) developed by the National Center for Atmospheric Research. It is a scenario with larger reductions in $CO_2$ emissions compared to "business as usual". The report estimates future Asia—Europe cargo volumes by converting IPCC A2 scenario estimates into global seaborne trade volumes, assuming a 40% growth from 2006 to 2030 and 100% from 2006 to 2050, which corresponds to a total trade potential of 3.9 million TEU and 5.6 million TEU, respectively (Eide et al. 2010).

Khon et al. (2010) stated in their model study that the use of sea routes from the North Atlantic to Asia will increase significantly in this century. The model, based on the IPCC's A1B scenario (a moderate scenario characterized by rapid economic growth, a global population growth of nine billion by 2050, and a balanced emphasis on all energy sources), predicts an extension of the free shipping season. It is stated that the passage from Western Europe to the Far East via this route could be up to 15% more profitable than the Suez Canal passage by the end of the 21st century. Wang and Overland (2009) predicted in their study that the Arctic Ocean would experience sea ice-free Septembers as early as 2037, with ship traffic increasing between 100% (under a *low growth economic* scenario) and 500% (under a *high growth* economic scenario).

The EU Arctic Footprint Future Scenarios outline three different possibilities for 2030 based on varying assumptions about four main parameters: the rate of climate change in the Arctic, the effectiveness of managing environmental pressures in the Arctic, economic growth in the EU, and the efficiency of resource use by EU actors (Cavalieri et al. 2010). In the *Race for Resources* scenario, high economic growth and low resource productivity are expected in the EU in 2030. This interacts with rapid climate change, resulting in a high EU footprint in the Arctic. The EU has also fallen short of many of its environmental targets set for 2020. In the *Business-as-Usual* scenario, moderate EU economic growth (around 2% annual GDP growth) is substantially offset by an almost comparable increase in resource productivity. All the 2020 European targets have been achieved. However, efforts to manage Arctic pressures are failing to contain the effects of climate change, and environmental conditions in the Arctic continue to deteriorate. The balance between the variables in this scenario is very delicate. In the *Eased by Efficiency* scenario, economic growth in the EU combined with high resource efficiency creates lower resource demand and products, enabling greater steps towards sustainable consumption rates and reducing global GHG emissions. While the acceleration of climate change continues to exert pressures in the Arctic, these challenges are being addressed through strong international cooperation on Arctic adaptation and ambitious regulation of BC and GHG (Cavalieri et al. 2010).

Future increased shipping across the Arctic will worsen existing environmental impacts, especially the decline in air quality caused by carbon monoxide, nitric oxide, and other chemicals released by combustion engines of ships. Summertime Arctic surface ozone concentrations could double or triple in the coming decades due to ship operations through the northern passages (Granier et al. 2006). The three future scenarios are based on the assumption that the extent of the EU's influence on the Arctic depends not only on pressures from the EU but also on the Arctic's vulnerability to these pressures. The scenarios investigate how the EU Arctic footprint will affect the analysis of the following determinants: biodiversity, chemicals and transboundary pollution, climate change, energy, fisheries, forestry, tourism, transport, and Arctic indigenous and local livelihoods.

Ocean Conservancy (2017) conducted an analysis of AMSA's snapshot of Arctic shipping traffic based on vessel types using Arctic waters, aiming to understand current operations and future growth trends in light of sea ice and global economic change. Generally, decreasing ice cover is expected to make Arctic routes more attractive in the future (Hansen et al. 2016). The report indicates that commercial and industrial activities driving growth in Arctic shipping will result in cumulative impacts. Natural resource extraction will create new infrastructure and stimulate other types of industrial development, which will, in turn, increase the need for additional ship support and potentially require new port facilities. In addition, local impacts from commercial and industrial operations may combine with global climate change effects, including warming temperatures, decreasing sea ice, and increasing ocean acidification. Minimizing negative impacts on the Arctic ecosystem will require coordinated and integrated planning. Switching from HFO to distillates or LNG will reduce both the negative impacts of oil spills and harmful sulfur and BC emissions. Spatial protection measures can protect the region from harmful discharges, protect marine mammals from ship strikes, and enhance marine safety.

The CMTS (U.S. Committee on the Marine Transportation System) conducted a 2019 study (CMTS, 2019) that evaluated four scenarios: *Reduced Activity* Scenario, *Most Plausible* Scenario, *Optimized Growth* Scenario, and *Accelerated but Unlikely* Scenario. Each of these scenarios presents different possibilities for ship activity in the Arctic and surrounding waters over the next decade, with annual growth rates ranging from 0.3% to 4.9% and total ship counts from 284 to 535 ships. The Most Plausible Scenario is the one that best aligns with mathematical projections based on available historical data for the region. Using conservative assumptions, the Most Plausible Scenario suggests that the number of ships operating in the Arctic in 2030 will be more than three times higher than in 2008. The highest estimates are found in the Accelerated but Unlikely Scenario, which predicts growth more than four times the 2008 figures and more than double the current numbers (CMTS, 2019). Factors that can be easily measured and translated into ship activity are considered sources of growth in these projections. These sources of growth fall into four main categories: natural resource exploration and development, infrastructure development, expansion of the Arctic fleet, and seasonal rerouting of ships across the Arctic. Among these, natural resource exploration and development are identified as the most significant contributors to projected traffic growth in all scenarios. By 2030, this sector is expected to add 11 ships in the Reduced Activity Scenario, 72 in the Most Moderate Scenario, 92 in the Optimized Growth Scenario, and 153 in the Accelerated but Unlikely Scenario. This result indicates that the Bering Strait is expected to become a major gateway for Arctic natural resource exports over the next decade, particularly for Russian LNG exports and to support the mineral resource extraction in Canada (CMTS, 2019).

As a result, the inferences about the impact of maritime activities on the Arctic footprint have remained largely unchanged over the past decade. The main reason for this is that the Arctic still does not have an optimal level of navigation, coupled with a lack of feedback. In addition, all projections and models are based on institutional sources (like IPCC) and literature-marked key years (2030, 2050, 2100). Overall, by any measure, the volume of ship traffic along the two main Arctic Sea routes, the Northeast and Northwest Passages, has increased in recent years, and this trend is expected to continue (Min et al. 2023, PAME, 2020). Based on this established trend, factors that could affect the Arctic footprint are increasingly included in relevant studies. These include disturbance to marine mammals and seabirds, as well as water and air pollution caused by emissions and discharges from ships (Chen et al. 2022, Halliday et al. 2022, Huntington et al. 2023). There are also initiatives aimed at developing more environmentally friendly and safer transportation options. A positive example of this is the Canadian Government's commitment to implement the Low Impact Shipping Corridors Initiative, which seeks to improve chart accuracy and other services along important routes despite the lack of bathymetric information. This initiative aims to identify routes where enhanced information and services, such as modern mapping, navigational aids, and emergency response capabilities, will be available (Holloway et al. 2024).

## 4. As a Recommendation for Evaluating the Arctic Footprint: CCPI and LSBCI

Potential users of new maritime trade routes emerging in the Arctic Ocean will be countries that are active in maritime trade and want to take part in the Arctic economy, to the extent of their geographical accessibility. In this sense, it is likely that east-west trade, which forms the main axis of global international trade, will shift from traditional routes to new northern routes. Therefore, the current maritime relations and climate change performance of these potential users, which make up the Arctic footprint, will provide a different perspective on understanding the future of the Arctic. For this reason, this section examines the CCPI and the LSBCI values of some European and Asian countries that have the potential to use the Arctic geographically.

The CCPI is an independent tool used to monitor countries' climate protection performance, published annually since 2005. This index aims to improve transparency in international climate policies, enabling a comparison of countries' climate protection efforts and progress (Burck et al. 2019). The climate protection performance of the EU and 63 countries—representing more than 90% of global GHG emissions – is evaluated across four categories: GHG emissions, renewable energy, energy use, and climate policy (Burck et al. 2023).

When looking at the current status of the CCPI (Burck et al. 2023), India (7th), Germany (14th), and the EU (16th) are the only G20 countries or regions among the high performers. Meanwhile, Russia, Canada, the Republic of Korea, and Saudi Arabia remain the worst performers within the G20. Fourteen EU countries are categorized as medium or high performers, with Denmark (4th) and Estonia (5th) leading the overall ranking, while Poland (55th) is the lowest-rated EU country. In addition, the Philippines is rated high in GHG emissions and energy use, medium in renewable energy, and medium in climate policy. The Netherlands is rated as high in renewable energy, medium in climate policy, and GHG emissions. Consequently, the Philippines and the Netherlands are classified as high-performing countries. It is stated that Spain is rated as medium in the four main CCPI categories. France has a medium rating for its performance in GHG emissions and climate policy, but a low rating in renewable energy and energy use (Burck et al. 2023).

**Table 1.** CCPI values for 2023 of various European and Asian countries with geographical potential for using the Arctic (Burck et al. 2023)

| Climate Change Performance Index | Countries |
|---|---|
| 63.07 | United Kingdom |
| 62.24 | Netherlands |
| 61.11 | Germany |
| 52.97 | France |
| 59.59 | Spain |
| 79.61 | Denmark |
| – | Singapore |
| 38.8 | China |
| – | Hong Kong |
| 24.91 | South Korea |
| 40.85 | Japan |
| 62.75 | Philippines |

China (51st) is also the world's largest carbon emitter, so it receives a very low rating in the GHG emissions and energy use categories. In contrast, it receives a medium in climate policy and renewable energy. This is because its weak performance in emissions and energy efficiency still prevails, and it invests in new coal-fired power plants. In addition, population factors have put great pressure on the environment and have become one of the main causes of environmental problems. As the world's largest developing country with a large population, China's growing population has increased the burden on housing, transportation, water and electricity supply, education, and health facilities, leading to a continuous increase in energy demand and carbon emissions (Pan et al. 2021).

On the other hand, China is showing strong development in terms of renewable energy (Burck et al. 2023). Singapore, which is not included in the ranking, rates its climate targets and policies as "Critically inadequate" by Climate Action Tracker. This rating shows that Singapore has taken little to no action on its climate policies and commitments and does not align with the 1.5°C temperature limit of the Paris Agreement (Climate Action

Tracker, 2022). Table 1 shows the CCPI for 2024 for some countries included in this study, excluding Singapore and Hong Kong.

The other, the Liner Shipping Connectivity Index (LSCI), is an index that assesses a country's connectivity to maritime networks. The Liner Shipping Bilateral Connectivity Index was created by UNCTAD (United Nations Conference on Trade and Development) as a complement to the LSCI. It aims to measure the quality of maritime transport connections between countries. While the LSCI provides a single score for each country, the LSBCI is assigned based on country pairs (Guerrero et al. 2021). UNCTAD evaluates maritime connectivity between country pairs using five indicators: the number of transshipments required to get from country one country to another, the number of direct connections that are common one country to another, the number of common connections by country pair with one transshipment, the level of competition on services that connect country pair, and finally the size of the largest ship used on the weakest route between the two countries (Niérat & Guerrero 2019).

Based on the provided literature information, LSBCI values between ports are shown in Table 2. When examining Table 2, it is observed that geographical distances with a high potential to use northern routes also have a stronger connection in maritime trade. The Philippines and Singapore in East Asia and Spain in Western Europe are the countries that least frequently use the Arctic geographically in matches between opposing mainland countries. However, it is clear that trade between East Asian countries, especially China, the world's leading exporter, and Northwestern European countries with strong purchasing power parity, will frequently use Northern routes.

**Table 2.** LSBCI values of selected countries from the north (listed in the column) and east (listed in the row) (UNCTADstat, 2023)

| W / E | Singapore | China | Hong Kong | South Korea | Japan | Philippines |
|---|---|---|---|---|---|---|
| United Kingdom | 0.462 | 0.424 | 0.437 | 0.455 | 0.414 | 0.200 |
| Netherlands | 0.467 | 0.474 | 0.445 | 0.460 | 0.420 | 0.203 |
| Germany | 0.465 | 0.477 | 0.438 | 0.452 | 0.410 | 0.203 |
| France | 0.470 | 0.480 | 0.378 | 0.462 | 0.313 | 0.201 |
| Spain | 0.473 | 0.483 | 0.367 | 0.454 | 0.312 | 0.199 |
| Denmark | 0.364 | 0.366 | 0.272 | 0.364 | 0.272 | 0.191 |

The CCPI is assessed across four main categories and their respective indicators. Countries' total score is based on 40% of GHG emissions, 20% renewable energy, 20% energy use, and 20% climate policy. In this context, the contribution of the emissions produced by countries to their score is high (Burck et al. 2023). Liner shipping substantially contributes to $CO_2$ emissions in maritime transport, especially from containerships, which are often the primary vessels providing these services (Sun et al. 2024). The LSBCI provides information on the quality of maritime transport connections between two countries; thus, a higher index between two countries indicates a denser and higher-quality maritime transport between the two countries. In this sense, the more intensive the maritime transport connection between pairs of countries, the higher the emissions and overall carbon footprint, according to the common ship technology used today.

In this study, an equation was developed to quantitatively assess the impact of using Arctic routes in maritime activities on the Arctic footprint. For this purpose, the maritime interaction of country borders located at both ends of the Arctic routes should be taken into account. Therefore, as shown in the diagram in Fig. 2, a new "bilateral" scenario was introduced, where the variables in the LSBCI were adapted to Arctic routes, and maritime trade occurring from Country A to Country B (or vice versa). (The equation uses the symbols "Country *i*" and "Country *j*" to avoid confusion with other mathematical symbols).

The CCPI is a report card that shows how countries A and B perform on climate change, and it is scored on a scale of 100. The mathematical inference used to develop the equation in this study first created two missing country sets based on their CCPI scores. Then, according to the LSBCI bond between them, divide the multiplier value by 2 to obtain the Rating of Maritime in the Arctic Footprint (RMAF), for a maximum score of 100. To achieve this, Equation 2 gives the RMAF for country pairs below;

$$RMAF = \frac{[(100-CCPI_i)+(100-CCPI_j)].(LSBCI_{ij})}{2} \quad (1)$$

$$RMAF = [(200 - (CCPI_i + CCPI_j)].(LSBCI_{ij})/2 \quad (2)$$

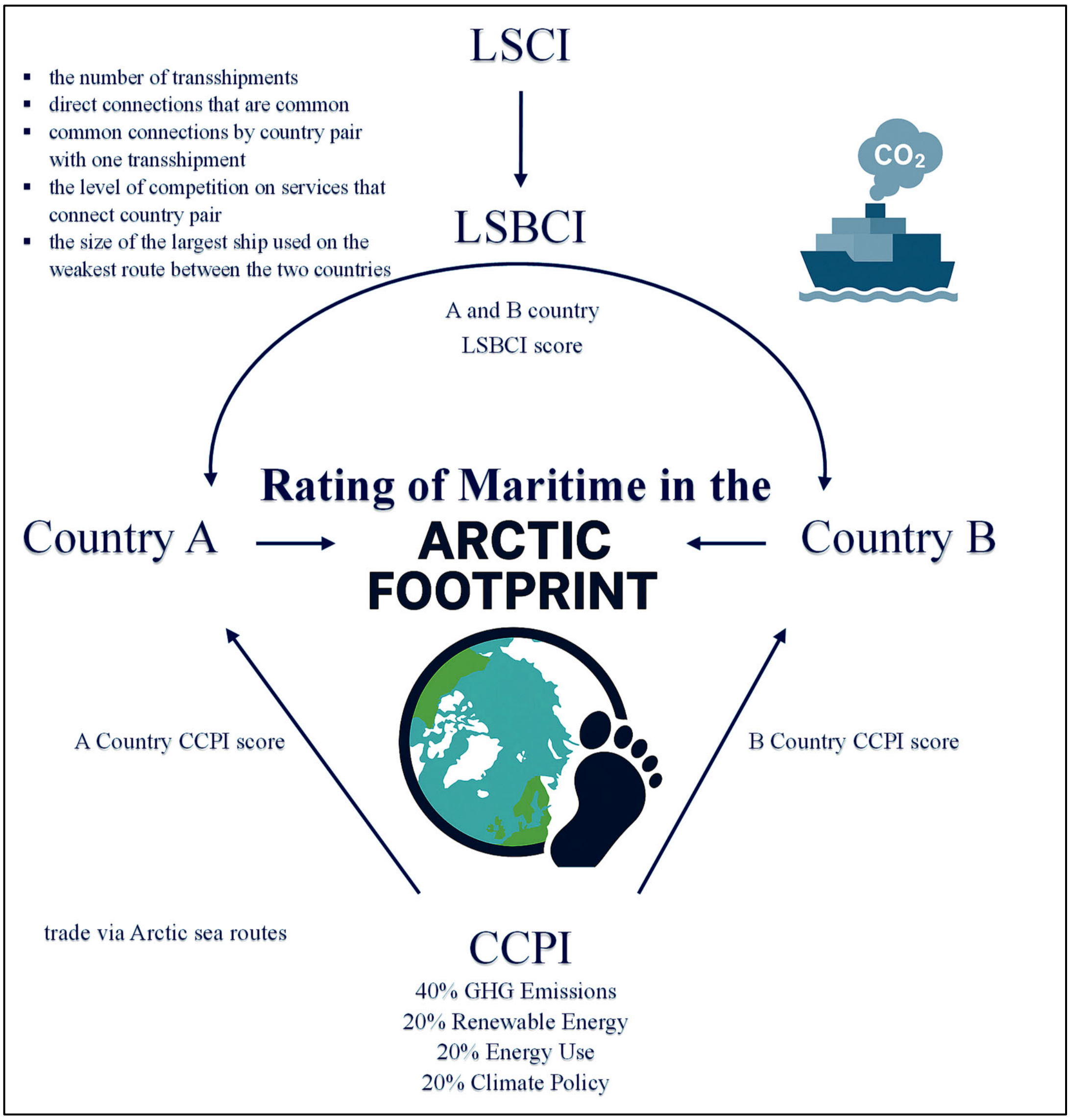


**Fig. 2.** The flowchart of the Rating of Maritime in the Arctic Footprint calculation steps and variables (Created by the authors)

LSBCI and CCPI scores are published for many countries. These are used here as examples to understand better how the countries in Tables 1 and 2 are positioned in potential Arctic maritime activities. Table 3 aims to explain the position of country pairs based on their total CCPI score and LSBCI connections, according to their RMAF values.

**Table 3.** Calculated RMAF values for selected countries from the north (listed in the column) and east (listed in the row)

| ***W / E*** | China | South Korea | Japan |
|---|---|---|---|
| United Kingdom | 20 | 25 | 19 |
| Netherlands | 23 | 25 | 20 |
| Germany | 23 | 25 | 20 |
| France | 25 | 28 | 16 |
| Denmark | 14 | 17 | 10 |

Accordingly, in the example where Spain, Singapore, and the Philippines, which use northern routes less frequently, and Hong Kong, which does not have a CCPI score, are excluded, the RAMF values of the east-west pairs, which are the most feasible to use northern routes, are given in Table 3. Since the scores of the Far-East countries are lower compared to those of European countries, it is clear that they have a negative impact on the climate performance score. However, the heavy loads originating from Asia in traditional international trade also increase the LSBCI. What should be here is to achieve the most sustainable maritime trade with the maximum CCPI score and the most effective maritime trade with the maximum LSBCI.

## 5. Discussion and Conclusions

New shipping routes, which are a key aspect in addressing the effects of global climate change on maritime trade, form the basis for investigating the main hypothesis that "global climate change has caused a change in maritime trade". In recent years, the Arctic Region has emerged as a large multidisciplinary field of study, primarily involving environmental sciences, transportation engineering, and marine sciences, due to its potential economic and environmental impacts.

The geography of the Northern routes creates an alternative route that provides a main port connection and is suitable for multi-modal transportation in maritime trade between East Asia and Western European countries. However, a transportation network with complex structures where seaways, railways, and highways intersect has not yet been established in the Arctic. Therefore, it remains challenging to develop a sustainable service for ships. Despite all these disadvantages valid today, the increasing commercial activity in the region should not be ignored. First, although the shorter distance of the Arctic routes will reduce ship emissions, it is essential to note that local emissions will spread in fragile areas, which are particularly sensitive to the polar environment. Preparations should be made now to prevent irreversible environmental effects from high-impact scenarios such as the Arctic Race. The extraction of non-renewable resources in the region (oil, gas, timber, etc.), their extraction methods, limited availability, and the high emissions produced during consumption are already considered in possible negative scenarios. In addition to the ecosystem changes caused by climate change in the Arctic, there is a possibility that protection efforts may be delayed against all the indirect and direct factors resulting from increased economic activity. Marine accidents that could cause environmental disasters, noise pollution, and rising market demand for tourism and fishery products will primarily threaten the Arctic biodiversity and put stress on the Arctic ecosystem.

Given this reality, the shift of global shipping toward the Arctic is expected to be a natural outcome of the current economic conjuncture. Therefore, among the countries with high potential for trade and new routes in this region, it is helpful to note that evaluations based on the CCPI and LSBCI values of these countries can serve as an indicator of the environmental threats they may pose when using Arctic routes. It is already possible to guide the role development of sustainable transportation policies and arrangements that do not harm the region or its transportation systems. Of course, the factors that contribute to the Arctic footprint are not limited to the GHG emissions included in the CCPI. Since the Arctic regulates many major Earth systems and significantly impacts global regions, as emphasized in the literature review, its sensitive ecosystem is vulnerable to numerous threats. Therefore, even noise and light pollution can cause irreversible damage (Qi et al. 2024). According to LSBCI, the countries examined in this study, even if they are not solely responsible for anthropogenic climate change, should at least recognize that this highly sensitive Arctic ecosystem cannot be tolerated with alternative methods such as carbon credits.

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