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Blue Economy and Resilient Development

Natural Resources, Shipping, People, and Environment

Edited by

Gao Tianming, Vasilii Erokhin, Konstantin Zaikov, Andrei Jean Vasile and Jonel Subić

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Preface to ”Blue Economy and Resilient Development ”

Since ancient times, the blue economy has played a crucial role in humankind and in assuring the resilient development of all communities. Oceans and seas cover over 70% of the Earth’s surface, constitute more than 95% of the biosphere, and provide a substantial portion of the global population with food and livelihoods. As the economic globalization has evolved in recent decades, the concept of the blue economy has been extended to include not only fisheries and marine product, but also extraction of mineral resources, intercontinental trade routes between major markets, cargo shipping and marine transport, energy production, tourism, and many other types of economic activity. As the oceans have emerged to become one of the global resource bases and transport corridors, it is crucial to identify the dangers that such a boom in human development activities may bring. In economic, social, and environmental terms, both the coastal territories and water areas are now changing at an unprecedented pace, in ways that fundamentally affect ecosystems, people, biodiversity, and sustainability. These transformations are likely to be felt globally, not only in coastal states. The most vulnerable regions include circumpolar territories (Arctic and Antarctic), the Atlantic Ocean (Northern Atlantic and the Mediterranean), and Asia (East, Southeast, and South Asia, the Pacific Ocean, and the Indian Ocean).

The papers included in this book address critical challenges to the blue economy in view of the growth in exploration and utilization of natural resources, transport connectivity, effects of climate change, sustainable fisheries management, food security, and social and economic issues of human well-being in coastal areas. In this context, this publication supplements the existing literature by summoning political, economic, environmental, and social factors that influence various dimensions of the sustainable development of blue economy, as well as translating the findings into workable approaches and policies for the benefit of the economic actors, people, and the environment.

Gao Tianming, Vasilii Erokhin, Konstantin Zaikov, Jean Vasile Andrei, Jonel Subic
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Article

Planning for Sustainability: An Emerging Blue Economy in Russia's Coastal Arctic?

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Abstract: The main research objective of this study is to examine how coastal urban communities in the Arctic Zone of the Russian Federation (AZRF) organize the sustainable development (and emerging blue economy) strategy planning process. Along with this general objective, this study focuses on four more specific questions: First, to examine whether the sustainable development and blue economy concepts are integrated into the urban development strategies and whether they are a real priority for the northern coastal communities? Second, to figure out which local government and civil society institutions are involved in the policy planning process and whether this sphere of local politics is transparent and open to public discussions? Third, to find out which specific aspects of the sustainable development and coastal blue economy concepts are given priority in the municipal development strategies? Finally, to discuss whether the AZRF coastal sustainable development/blue economy strategies aim to solve short-term/most pressing problems or they suggest long-term policies built on sustainability principles and are oriented to solve fundamental socioeconomic and ecological problems of the AZRF coastal communities? The hypothesis of this study is that a properly designed strategy planning system would be helpful for both familiarizing northern municipalities with the blue economy concept and its effective implementation. This research is based on several empirical cases, including major Arctic coastal urban centers/ports—Anadyr, Arkhangelsk, Dudinka, Murmansk, Naryan-Mar, Pevek, Sabetta, and Severodvinsk.

Keywords: Arctic Zone of the Russian Federation; blue economy; coastal areas and municipalities; regional and urban planning; sustainable development strategies

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1. Introduction

"Blue economy" (BE) has become a popular buzz word over the past decade starting from Gunter Pauli's report to the Club of Rome in 2009 [1]. Drawing from the notion of a "green economy", it refers to the control of the Earth's oceans and marine life. However, the BE concept has different, and often conflicting, meanings for different people, resulting in incompatible or blurred definitions and applications.

Normally, the BE is defined in terms of sustainable use of ocean resources. For example, according to the World Bank, the BE is the "sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystem" [2]. However, this approach ignores the fact that the marine-based economic activities, such as fisheries, aquaculture, shipping, offshore oil and gas extraction, offshore wind energy, ocean energy, desalination, and marine tourism, to a greater extent depend on marine-related coastal activities.

To our understanding, the EU's approach to the BE definition is more correct from the scientific point of view and more relevant for the description of coastal states' existing economies, including the Russian Arctic sector. According to the European Commission, the BE concept embraces "All economic activities related to oceans, seas and coasts. It covers a wide range of interlinked established and emerging sectors" [3] (p. 5).

In the EU's view, the BE's coastal component includes the marine-related activities, which use products and/or produce products and services for the ocean and marine-based activities, for example seafood processing, marine biotechnology, shipbuilding and repair, port activities, communication, equipment, maritime insurance, and maritime surveillance [3] (p. 16).

A number of other sectors and activities, which seriously affect the marine-based BE component, can be added: onshore energy (including its decarbonization, development of alternative energy sources, energy savings), reduction in coastal air and water emissions, waste disposal management, coastal tourism, creation of nature reserves and parks, food security, health, and integrated coastal and marine area management.

The BE concept is a relatively new one for the Russian social sciences. Most Russian scholars prefer to focus either on the general description of this phenomenon or the study of foreign experiences in this field (European, U.S., Chinese, and other countries' BE strategies) [4–7]. Very few works touch upon the BE issue with regard to the Arctic Zone of the Russian Federation (AZRF), mostly focusing on conservation of biodiversity and prevention of pollution in the Arctic Ocean [8–10]. The coastal component of the AZRF BE is largely ignored by the Russian academic community in spite of its obvious importance for the region's sustainable development.

To identify at least some elements of Russia's emerging BE, we should choose a broader focus and pay attention to its sustainable development (SD) strategies in the AZRF. For example, its recent Arctic strategy designed up to 2035 outlines a number of important priorities for the AZRF sustainable development, including those related to the BE concept:

- Economy: introduction of a cycle-type economy; support for the indigenous peoples' traditional economy; digitalization of the AZRF economy; support for sustainable fisheries, forestry, and Arctic tourism.
- Infrastructure: port and Northern Sea Route (NSR) infrastructure development; further Polar Code implementation; building a satellite group providing communication above the 70° latitude and the AZRF's remote sensing.
- Environment protection: establishment of land-based natural reserves and marine-protected areas; cleaning up the environmental mess both on the coastline and archipelagos; creation of a state ecological monitoring system, and establishment of an international Arctic Sustainable Development Fund [11].

It should be noted that in order to develop an adequate SD/BE strategy, the Russian Arctic coastal cities and regions need an effective planning system. In other words, planning is an integral part of any urban and regional development strategy, including for the AZRF. City and regional administrators understand that planning gives more power over the future. Planning is deciding in advance what to do, how to do it, when to do it, and who should do it. This bridges the gap between where the city/region is to where it wants to be. The planning process involves establishing goals and arranging them in logical order. Well-planned cities and regions achieve goals faster than local and regional actors that do not plan before implementing their development strategies.

Planning is especially important for designing a proper SD/BE strategy for the coastal part of the AZRF because such a strategy requires an integrated approach to the developmental policies where all its aspects—economic, social, and environmental—

should be harmonized and coordinated. Planning is also important, because all potential stakeholders—municipal, regional, and federal authorities; companies; universities; civil society institutions and NGOs—should be involved in the SD/BE strategy formulation and implementation in order to make such strategies efficient and feasible.

The novelty of this study is that it contributes to the discussion on how AZRF coastal urban communities organize the SD/BE strategy planning process. Along with this general objective, this study focuses on four more concrete unexplored research questions: First, to examine whether the SD and BE concepts are integrated into the urban development strategies and whether they are a real priority for the ASZRF coastal municipalities? Second, to find out which local government and societal institutions are involved in the policy planning process and whether this sphere of local politics is transparent and open to public discussions? Third, to find out which specific aspects of the SD and coastal BE concepts are given priority in the municipal development strategies? Finally, to discuss whether the AZRF coastal SD/BE strategies aim to solve short-term/most pressing problems or they suggest long-term policies built on sustainability principles and are oriented to solve fundamental socioeconomic and ecological problems of the AZRF communities?

To address these questions, a hypothesis was formulated: we believe that an effective strategy planning system could be crucial for increasing awareness of the BE concept, its embedment in the municipal developmental plans, and successful implementation by the coastal urban communities.

The field component of research is based on the following AZRF coastal urban communities—Anadyr, Arkhangelsk, Dudinka, Murmansk, Naryan-Mar, Pevek, Sabetta, and Severodvinsk (Figure 1).

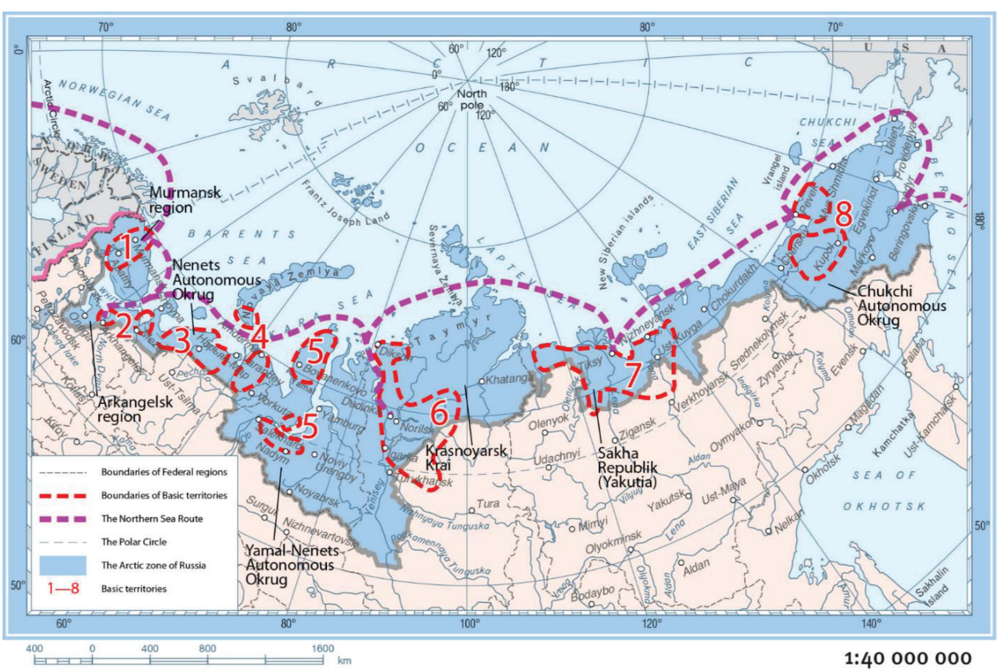

Figure 1. The Arctic Zone of the Russian Federation. Note: 1 = Kola Peninsula; 2 = Arkhangelsk Region; 3 = Nenets Autonomous District; 4 = Vorkuta (Komi Republic); 5 = Yamal-Nenets Autonomous District; 6 = Taimyr; 7 = Northern Yakutia; 8 = Chukchi Autonomous District. Source: [12].

2. Materials and Methods

The data for this research are drawn from various sources:

- Twenty-two urban development strategies/plans of eight coastal cities and towns;
- City and regional administration reports on the implementation of the above strategies;
- Official statistics that can be found on the websites of the Russian governmental agencies dealing either with official statistics, such as the Federal State Statistic Service (Rosstat), or specific areas of domestic policies, such as the Ministry of Natural Resources and Environment (Minpriroda), and Ministry of Construction, Housing and Communal Services (Minstroi);
- Analytical papers produced by various expert centers and NGOs;
- Media publications.

The focus of our research is on the AZRF coastal/port cities and towns that form the basic structure of the AZRF economy. There are 23 coastal/port urban settlements in the AZRF: Anadyr, Arkhangelsk, Belomorsk, Beringovsky, Dikson, Dudinka, Egvekinot, Igarka, Kandalaksha, Khatanga, Mezen', Murmansk, Naryan-Mar, Novy Port, Onega, Pevek, Provideniya, Sabetta, Severodvinsk, Severomorsk, Tiksi, Varandei, and Vitino.

Eight relevant urban settlements were selected for this study: Anadyr, Arkhangelsk, Dudinka, Murmansk, Naryan-Mar, Pevek, Sabetta, and Severodvinsk (Figure 1). They were chosen on the basis of three criteria: the coastal location, significance for the AZRF BE development as largest AZRF ports, and gravity of socioeconomic, climate change-related, and ecological problems that pose challenges to their sustainability. In some cases, such as that of Arkhangelsk, Murmansk, and Severodvinsk, two or even all three criteria are applicable. In addition, Anadyr, Arkhangelsk, Murmansk, and Naryan-Mar are regional capitals (administrative centers of members of the Russian Federation).

Among the research methods available, the preference was given to the development of an indicator system, because it provides us with a scientific and systematic approach to the study of the SD/BE strategy planning process by measuring its quantitative and qualitative aspects and identifying problems and gaps, which may remain invisible for a scholar without such an accurate research instrument.

Based on previous research [13–20] and comparative analysis of the AZRF city development strategies and plans, a system of indicators to assess urban SD/BE planning was developed and taken as an organizing principle for this study (see Table 1). In the case of environment protection and urban planning strategies, the data provided by urban/regional development plans/strategies were correlated with statistics provided by Rosstat, Minpriroda, and Minstroi, because these agencies have more detailed data than city/regional documents.

The above indicators reflect the most important aspects of the SD/BD strategy planning process, including specific BE sectors, as well as planning organization and procedures. For this reason, they allow an assessment of efficacy of this process. The value of each indicator ranges from 0.0 to 1.0 (Table 1).

The value each indicator (or group of indicators) was defined differently. Some indicators, such as, for example, "Does a special municipal SDE strategy exist?", "Does a special municipal BE strategy exist?", "Are all three components of SD represented in the municipal strategic documents?", "Does the municipality pay attention to the environmental problems?", and so on are developed on the basis of the qualitative content analysis of municipal strategic documents. In total, 22 municipal development plans, socioeconomic forecasts, and target programs designed by eight AZRF urban settlements were studied.

Table 1. The AZRF urban sustainable development strategy and blue economy planning index.

Indicator	ARK	MUR	SEV	DUD	PEV	ANA	NAR	SAB
Does a special municipal SD strategy exist?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Do the elements of a municipal SD strategy exist?	0.7	0.8	0.6	0.6	0.3	0.3	0.3	0.0
Are all 3 components of SD represented in the municipal strategic documents?	0.6	0.7	0.6	0.6	0.6	0.3	0.3	0.0
Does the municipality pay attention to the environmental problems?	0.9	0.8	0.6	0.3	0.2	0.3	0.1	0.0
Do the city development plans pay attention to the human dimensions of SD strategies?	0.7	0.9	0.6	0.5	0.4	0.3	0.3	0.0
Does a special municipal BE strategy exist?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shipbuilding and repair	1.0	0.5	1.0	0.2	0.0	0.1	0.0	0.2
Ports and related services	0.9	1.0	0.8	0.7	0.6	0.5	0.4	1.0
Decarbonization, alternative energy sources, energy savings	0.2	0.3	0.1	0.1	0.5	0.1	0.1	0.3
Reduction in coastal air and water emissions	0.7	0.7	0.2	0.2	0.8	0.7	0.7	0.5
Waste disposal management	0.7	0.4	0.5	0.3	0.7	0.2	0.7	0.7
Seafood processing	0.8	1.0	0.2	0.0	0.0	0.1	0.0	0.0
Marine biotechnology	0.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Aquaculture	0.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Marine-related communications	0.2	0.2	0.2	0.0	0.1	0.2	0.1	0.7
Maritime insurance	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Maritime surveillance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Digitalization	0.5	0.6	0.7	0.3	0.1	0.1	0.0	0.5
Coastal and maritime tourism	0.9	0.5	0.3	0.5	0.2	0.2	0.2	0.0
Nature reserves and national parks	0.5	0.0	0.3	0.0	0.0	0.2	0.0	0.0
Sustainable forestry	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Food security	0.0	0.2	0.0	0.0	0.5	0.0	0.0	0.0
Health	0.7	0.7	0.8	0.3	0.4	0.3	0.0	0.3
Integrated coastal and marine area management	0.5	0.4	0.3	0.4	0.3	0.3	0.1	0.5
Has a municipality all three types of strategic documents (strategy, prognosis, and target programs)?	1.0	1.0	1.0	1.0	0.6	0.6	0.3	0.0
Are the municipal strategic documents of a long-term character?	1.0	1.0	1.0	0.6	0.8	1.0	0.3	0.0
Do the urban development plans include a proper problem definition, clearly outlined strategic goals, and policy alternatives?	1.0	1.0	0.9	0.9	0.8	0.7	0.8	0.0
Do the municipal strategic documents include a detailed implementation mechanism?	0.5	1.0	0.9	0.9	0.8	0.5	0.6	0.0
Do the municipal strategic documents contain indicators and/or benchmarks to monitor implementation strategies?	0.7	1.0	0.9	0.8	0.8	0.7	0.6	0.0
Does the city put out a progress report?	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0
Is there a special planning office in the city/town?	0.5	0.5	0.5	1.0	0.3	0.3	0.3	0.0
Do cities cooperate with regional and federal levels? Have they addressed regional and federal priorities in their SD plans?	0.5	1.0	0.5	0.6	0.5	0.6	0.6	0.0
Are the plans publicly available, e.g., on a website?	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0
How transparent is the planning process? Does a city have capacity to engage communities, community inputs?	0.5	0.4	0.8	0.6	0.5	0.7	0.5	0.0
Presence of NGOs and other organizations working on SD issues and collaborating with a city administration	0.5	0.4	0.7	0.5	0.3	0.7	0.5	0.0
Does the city administration engage the local business community in the strategy planning process?	0.2	0.3	0.5	0.4	0.3	0.5	0.1	0.0
Does the municipality cooperate with the local academic community in the strategy planning process?	0.7	0.5	0.3	0.0	0.0	0.0	0.0	0.0
To what extent does a municipality acknowledge the importance of international cooperation for the success of its SD/BE strategies?	1.0	1.0	0.5	0.0	0.1	0.2	0.1	0.0
Total	22.9	22.1	19.3	14.3	13.4	12.7	10.0	5.0

Note: ARK = Arkhangelsk; MUR = Murmansk; SEV = Severodvinsk; DUD = Dudinka; PEV = Pevek; ANA = Anadyr; NAR = Naryan-Mar; SAB = Sabetta; green cells = leaders; yellow cells = in betweens; red cells = outsiders. Source: authors' development.

The data on other indicators, for instance, "Has a municipality all three types of strategic documents (strategy, prognosis, and target programs)?", "Is there a special planning office in the city/town?", "Are the plans publicly available, e.g., on a website?", "Does the city administration engage the local business community in the strategy planning process?" are driven from municipalities' websites, local mass media, and other sources.

Indicator assessment methodology varies as well. For example, in the case of indicators, such as whether special municipal SD or BE strategies exist or not, assessment is very simple because none of the AZRF cities/towns had such documents and, hence, receive a zero score. The assessment is also simple in the cases of indicators, such as, for example, "Does the city put out a progress report?" or "Are the plans publicly available, e.g., on a website?" because all AZRF coastal cities do that and, respectively, receive a 1.0 score. The situation is more difficult if an indicator has a complex/multidimensional structure/composition. For instance, to assess the value of the indicator "Are all 3 components of SD represented in the municipal strategic documents?" one should thoroughly analyze the content of a municipality's strategic documents. If all three components of sustainability—economic, environmental, and social ones—are identified, the city receives the highest score—1.0. If one or two components are found, the city receives 0.3 or 0.6, respectively. Since most of the indicators have a complex/multidimensional/multilevel structure, the team spent considerable time making a qualitative content analysis of municipal strategic documents in order to define a value of each indicator. Based on the indicator system, a comparative method was used for further analysis. As Wolff and Haase [21] rightly put it, this research approach gives a better understanding of the urban SD/BE strategy planning process by analyzing similarities and differences of several cases. The results of the comparative analysis are discussed in the next section.

3. Results and Discussion

From the data represented in Table 1, Arkhangelsk (22.9) Murmansk (22.1), and Severodvinsk (19.3) demonstrate the best scores, being leaders in terms of SD/BE strategy planning efficiency, while Naryan-Mar (10.0) and especially Sabetta (5.0) have the least ratings falling into a category of outsiders. Dudinka (14.3), Pevek (13.4), and Anadyr (12.7) form a group in-between with average indicators. It should be noted that ratings of specific urban settlements are determined by a combination of various factors rather than depend on one or two indicators. For example, the Arkhangelsk, Murmansk, and Severodvinsk leadership can be explained by their relatively good record in nearly all areas of strategy planning, ranging from paying attention to all major aspects of SD/BE strategy and having a proper implementation mechanism to incorporating the local stakeholders into the planning process and having well-established cooperation with international partners. On the other hand, the outsiders, such as Naryan Mar and Sabetta, failed to demonstrate their ability to organize SD/BE strategy planning in a proper manner in many important spheres. The problem with Sabetta, however, is that it is a unique urban settlement, which has no permanent residents and functions mainly on a shift basis. The employees of the Yamal LNG plant (owned by the Russian energy giant Novatek, French Total, and Chinese stakeholders) work on the shift basis. The Sabetta seaport and airport are owned by other companies. As a result of such a unique situation, Sabetta simply has no single administration that could design development plans and strategies. The data on Sabetta are driven not from such plans or strategies but, rather, from information provided by companies and Russian federal statistic and executive agencies.

To summarize the results of comparative analysis of the AZRF coastal cities' SD/BE strategy planning, the following findings can be presented.

First of all, Russia's northern coastal cities try to establish and further develop a proper strategy planning system. The success or failure to do that depends on whether the city leadership understands the importance of having an SD/BE strategy or not. As local governments' strategies demonstrate, the Arctic municipalities generally acknowledge the need of having such strategies. However, none of these cities has a special SD or BE strategy. Instead, city development plans/strategies have sections that can be titled, for example, "Sustainable socioeconomic development", "Sustainable ecological development", "Human/social capital development", "Creating a comfortable urban environment", etc. These documents address specific climate change-related threats and challenges, such as air pollution generated by the AZRF heavy industries and transport, forest impacts (change in forest composition, shift geographic range of forests, forest health and productivity), water resource impacts (changes in water supply, water quality), impacts on coastal areas (erosion and inundation of coastal lands, damage to port infrastructure, costs to defend coastal communities), and impacts on species and natural areas (shift in ecological zones, loss of habitat and species).

None of the considered plans clearly addressed emissions of greenhouse gas that are seen as the main source of global warming, including the High North. Methodology for doing this in the AZRF context would be a challenge. Climate policy actions, which many cities of the world prioritize, e.g., controlling building quality, dense development, or the introduction of parking restrictions, can hardly be found in the AZRF urban strategic documents. Unfortunately, climate change adaptation and/or mitigation, which is an important aspect of contemporary urban agenda, was not distinctively reflected in any planning documents that we reviewed in this research.

Meanwhile, AZRF coastal cities as well as the region at large are on the forefront of climate change challenges, and resiliency planning tools would be an appropriate addition to their planning. Perhaps, only the next generation of city strategic documents will represent integrated strategies for urban SD rather than a set of separate strategies for each or selected sectors of city activities as it is now.

The AZRF municipal development plans pay significant attention to the local environmental problems. First and foremost, the Russian northern urban centers now try to prevent and reduce pollution in the region rather than to focus on elimination of accumulated ecological damage [22–28]. For example, the Murmansk City Government believes that a reduction in air pollution will help to mitigate climate change and suggests a number of specific measures to reduce dangerous emissions [29–32]. These policies are viewed as more adequate and efficient than eliminating the environmental damage mostly created by the Soviet economic and defense activities in the North. Rehabilitation of damaged ecosystems, including measures, such as strategic environmental assessment; targeting the priority (i.e., most problematic) areas; clean-up initiatives in those cities where such programs are still incomplete; establishing monitoring systems, and so on, is another priority for the urban ecological strategies. Waste (solid and liquid) treatment is viewed by all Russian northern urban settlements as an important problem whose solution is still pending. Given the significance of the problem, building of waste treatment plants and/or safe storages is an important priority for many AZRF municipalities [22–36].

To protect endangered species both on the urban territory and in the adjacent coastal areas, some AZRF municipalities launched a series of targeted programs aimed at conservation of biodiversity. For example, Arkhangelsk is responsible for running the national reserve "The Russian Arctic", which among other priorities, aims to protect unique marine mammals, such as polar bear, walrus, sealion, narwhal, beluga, and so on. It appears these programs are rather successful because these animals' population is growing.

In line with international standards [37], building of public-private partnerships to implement ecological projects became an integral part of the Arctic cities' environmental strategies [22–32,38,39]. These partnerships emerged because, on the one hand, the state lacks money for such projects and, on the other hand, companies operating in the AZRF feel it is their responsibility for the protection and improvement of the local environment (especially given the fact that they were and still are the major source of pollution in the Russian North). For instance, environmental cooperation between Nornickel (one of Russia's leading extractive and metallurgical companies) and Norilsk city administration as well as with several municipalities in the Murmansk Region, where this company has production, it exemplifies such a public–private partnership.

Trying to promote environmental studies at the local level, some AZRF municipalities financially and administratively support universities and research institutions dealing with ecological problems [22–25,29–32]. In turn, these universities provide city governments with SD-related expertise and help them to design development plans and strategies. Promotion of ecological education and culture as well as increasing awareness of the local communities about the AZRF environmental problems became an important policy priority for most of the Russian northern municipalities. To develop "green" culture among the local communities and mobilize the latter for the implementation of environmental projects, some Arctic urban centers establish cooperation with civil society institutions and mass media specializing on the ecological issues [40–43]. Some Russian northern municipalities (Arkhangelsk, Murmansk, and Severodvinsk) tried to organize regular monitoring of the most problematic areas in terms of ecological security: climate change negative consequences, protection of endangered species, conservation of biodiversity, control over air and water pollution, prevention of natural and technogenic catastrophes, etc. [22–32].

Depending on the gravity of ecological problems, the Russian Arctic local governments differ by their opinion on the importance of this problem for them. For example, Anadyr, Arkhangelsk, Naryan-Mar, Pevek, and Sabetta consider ecological problems as important ones, but for them, this issue is only one of many questions on their SD/BE agenda. On the other hand, the Dudinka, Murmansk, and Severodvinsk city administrations, which face much more acute environmental problems than other northern municipalities, pay a greater attention to the ecological aspects of their developmental programs. Since the Soviet era, these urban settlements were traditionally developed as strongholds in areas, such as extractive, machine- and ship-building industries, metallurgical production, and port services.

As for the typical BE agenda, only ports and related services are given due attention in the coastal city development plans (Table 1). Issues, such as shipbuilding and repair, reduction in coastal air and water emissions, digitalization of the local economy and management, coastal tourism, and integrated maritime and coastal management, represent some importance for the AZRF municipalities as well. Decarbonization of the coastal economies, development of alternative energy sources, energy savings, seafood processing, marine biotechnologies, aquaculture, food security, marine-related communications, establishing natural reserves, and national parks are among the lowest priorities for the AZRF coastal urban communities. Only Arkhangelsk, Murmansk, and Sabetta mentioned the significance of sustainable forestry, maritime insurance, and maritime surveillance (BE's important sectors), respectively.

It should be noted that the Russian northern coastal municipalities pay rather little attention to the human dimension of their SD/BE strategies identifying mainly the ecological and economic challenges and risks. The societal/human security problem is rarely reflected in the municipal strategic documents, and it is often limited to civil defense programs, which are mainly about protection of city residents from natural disasters and technogenic catastrophes [22–36,38–42]. Quite rarely, some city strategic documents mentioned the need to take care of food security, although this problem is quite acute for most coastal communities—both indigenous and non-indigenous ones [29–32,35,36].

Characteristically, only large AZRF cities have all three types of strategic documents envisaged by the 2014 Russian law on strategic planning: strategy and prognosis of socioeconomic development, as well as target programs aimed to implement the above general documents [44]. Mid-size and small urban centers usually have only the third kind of documents—"target programs" that are devoted to specific urban problems and only partially reflect the SD/BE agenda. For instance, Anadyr, Naryan-Mar, and Pevek (rather small urban communities) have only target programs on the creation of comfortable urban environments or sometimes short- or mid-term forecasts of urban development, but they have never adopted full-fledged strategic documents on their socioeconomic development [33–36,40–42]. Noteworthy, since 2012, Severodvinsk (a quite big city by the

AZRF standards with 185,000 inhabitants) abandoned the practice of having long-term socioeconomic strategies. Instead, the city preferred to adopt three-year forecasts and targeted programs [26]. The local authorities believed that long-term strategies are too general, declarative, and often unfeasible, while less ambitious but more specific programs were more effective in terms of implementation.

However, as the 2014 law on strategic planning stipulated, all tiers of Russian authorities, including the municipal ones, were obliged to develop socioeconomic development strategies of their own. In 2018, even Dudinka (a small port town), had to adopt a strategic development plan [39]. In 2019, the Severodvinsk city administration, following a series of consultations with local business community, experts, and NGOs, finally approved an integrated municipal socioeconomic strategy up to 2030, instead of a set of target programs [28].

Another important aspect of an effective planning process is whether the city administration has a special planning unit within its structure or not? Dudinka is the only AZRF coastal town that has a special forecast and implantation control department responsible for strategic planning [45]. Urban settlements that prefer to have sectoral development plans or target programs usually split planning functions among different administrative units responsible for specific policy areas (economy, social policy, environment, culture, etc.). However, most Russian northern coastal municipalities assign planning functions to their economic departments rather than establish a special strategy planning office or involve in a coordinated manner various units responsible for activities other than economic policy. Naturally, this leads to the dominance of economic issues on the developmental agenda, while the social/humanitarian and environmental problem can be largely ignored or paid less attention.

As a result of this technocratic approach, most municipal strategies focus on a single-issue rather than integrated/comprehensive character. For instance, while the Murmansk and Severodvinsk programs of socioeconomic development contain all the most important components of the SD concept [26–32], the Arkhangelsk and Dudinka strategic documents addresses only a limited number of problems (transportation, education and health care systems, environment, preservation and development of local cultural heritage), neglecting key dimensions of sustainability, such as political, community, personal, and food security [22–25,38,39].

Strategy planning units that are normally a part of economic departments are usually small and staffed with only several employees even in the largest urban centers such as Arkhangelsk, Murmansk, and Severodvinsk. That is why for the AZRF city planning offices, it is uneasy to follow the widely accepted planning management standards and principles. For the same reason, they are unable to properly interact with other municipal structures participating in strategic planning and implementation activities. Since northern city administrations often lack planning offices that have the requisite powers to coordinate the whole process of planning and program implementation, it is quite problematic for these urban settlements to harmonize municipal SD plans and guarantee that all units of the local government have the same motivation and stakes in achieving the strategic goals.

In line with international planning standards, most AZRF urban development plans include proper problem definition, clearly outlined strategic goals, policy alternatives, and implementation/monitoring mechanisms, including a system of indicators. However, they are different from each other in terms of structuring strategic documents and the nature of implementation procedures and indicators. On the one hand, some city strategic documents, such as Arkhangelsk's [22–25], Dudinka's [38,39], Murmansk's [29–32], and Severodvinsk's [26–28] development plans, describe in detail implementation procedures and contain a system of indicators. On the other hand, some other Russian northern coastal towns such as Anadyr [40–42], Naryan-Mar [33,34], and Pevek [35,36] prefer to outline only some general principles of implementation strategies.

The Russian Arctic coastal cities try to develop an adequate legal framework for their SD/BE strategies by adopting local normative acts and, as required by federal law, through coordination of their SD/BE strategies with national and regional ones. However, in practice, this goal is achieved by different methods. While the Anadyr [40–42], Dudinka [38,39], Murmansk [29–32], and Naryan-Mar [33,34] development plans aim to harmonize its strategic priorities with the regional and federal ones, other city strategic documents only vaguely mention the need to coordinate their SD strategies with other tiers of the Russian government [22–28,35,36].

It should be noted that Russian northern cities are often wary of Moscow's undertakings in the strategic planning sphere. In 2014, when the federal center decided to apply principles and standards set by the law on strategic planning to the municipal level, this initiative got a rather cold reception in the AZRF cities. Moscow selected about 80 Russian municipalities representing different parts of the country to participate in the experiment. However, in the Russian North, only the Murmansk Region agreed to partake in this project. Several region's cities, towns, and districts were chosen to serve as pilot subnational units. However, most of them were able to implement only certain elements of a new strategy planning philosophy. Murmansk was the only city that incorporated the 2014 law standards into its strategic documents. Emelyanova [46] explained this by the status factor: being a capital city of the region, Murmansk had more human and financial resources to successfully execute the project than other municipalities.

According to the planning theory, the success of any urban development strategy largely depends on public/community support and engagement [37]. To this end, it is important to make the local planning process as transparent and interactive as possible. There are several possible ways to ensure openness of the planning process and engaging civil society institutions into both strategy formulation and implementation: hearings in the so-called public chambers (which exist under the auspices of the local legislatures), dialogue with NGOs, independent expertise of municipal projects, regular opinion polls, public debates in the local mass media, and so on.

Unfortunately, only Naryan-Mar and Severodvinsk adopted some municipal programs to maintain a regular dialogue with NGOs on the most important aspects of the local developmental strategies [28,34,43]. The Anadyr, Dudinka, and Murmansk strategic documents refer to the local NGOs as potential stakeholders in the planning and implementing municipal developmental projects, but do not provide any roadmap for such a dialogue with them [29–32,38–42]. Other Russian northern urban centers largely ignore the problem of cooperation with the civil society institutions seeing the SD/BE strategy planning process as purely a local government's prerogative.

With rare exceptions, the AZRF municipal development strategies demonstrate that most northern coastal cities and towns favor intensive international cooperation in the field of SD. These northern subnational actors identify the following international institutions and forms of cross-national cooperation: the UN-related bodies (UN Development Program, UN Environment Program, UNESCO, Intergovernmental Panel on Climate Change, etc.), subregional institutions (Arctic Council, Northern Forum, Nordic Council, Nordic Council of Ministers, Northern Dimension partnerships, Barents Euro-Arctic Council), scientific organizations and initiatives (International Arctic Scientific Council, International Polar Year, International Arctic Social Science Association, etc.), region-to-region and company-to-company contacts, city-twinning, and so on. The Russian Arctic cities and even relatively small towns and other municipalities consider cooperation with foreign partners as not only a means of solving specific problems, but also an important instrument of their capacity building and long-term SD strategy [47,48].

4. Conclusions

As follows from the above analysis, while most AZRF coastal urban communities accepted the SD concept and tried to apply it in their development strategies, these subnational actors are largely unfamiliar with the BE concept. It should be also noted that Russian northern municipalities still lack even special SD strategies, preferring either to have sections on various aspects of sustainability in their strategic documents or develop specific target programs that address concrete SD-related problems. For this reason, some important economic, environmental, and social/human (not to mention BE-related) dimensions of urban SD strategies are often missing or not properly harmonized with one another.

It is obvious that to properly cope with challenges to its sustainability, the AZRF coastal towns and regions should develop SD strategies of their own in the form of either special documents or separate sections in their development plans. Such documents should have a detailed list of concrete measures to ensure their sustainability and eventually move to the BE. This would be in tune with the most recent Russian Arctic doctrine of 2020, which demonstrates that Moscow bases its northern strategy on the principles of sustainability and climate change action and contains some BE-related elements.

The AZRF coastal urban settlements consider strategy planning and having adequate municipal developmental programs as an important policy priority. Although, they sometimes resist Moscow's pressure to develop unified strategies for the whole region. Instead of having twin-like documents, they prefer to tailor their municipal strategies based on the local needs and realities.

Many Arctic coastal communities managed to establish proper legal frameworks, institutions, and procedures for strategy formulation and realization, including planning offices within city administrations, clearly defined goals and division of responsibilities between various administrative units, indicator and monitoring systems, power sharing with regional and federal authorities, etc.

The strategy planning system created by the northern urban centers was rather helpful in the successful implementation of some municipal projects (mostly of ecological and economic nature) during the last decade. Generally, there was an obvious trend from the AZRF municipalities' short-term survival tactics to long-term capacity-building strategies.

However, it would be an exaggeration to state that the AZRF urban or regional strategy planning system is perfect and in line with the best international standards. A number of problematic issues can be identified.

First of all, the BE problem is not properly addressed by the urban development plans. Only ports and related services are viewed by coastal cities and regions as an important priority. Other BE-related issues, such as shipbuilding and repair, reduction in coastal air and water emissions, digitalization of the local economy and management, coastal tourism, integrated maritime and coastal management, decarbonization of the coastal economies, development of alternative energy sources, energy savings, seafood processing, marine biotechnologies, aquaculture, food security, marine-related communications, and establishing natural reserves and national parks, are paid much less attention or almost completely ignored (sustainable forestry, maritime insurance, and maritime surveillance).

It is important to note that there is still a gap between strategy formulation and implementation. It is no surprise that a large number of urban SD-related programs are of declarative nature, and only a few of them were executed in full.

We should also mention the non-transparent character of the municipal strategy planning procedures as well as insufficient involvement of civil society institutions in this process. Public–private partnerships and corporate social and environmental responsibilities remain underdeveloped in the AZRF, including its coastal areas. Unfortunately, both strategy formulation and realization are still of the hierarchical character (the top-down approach still dominates over the bottom-up one). Moreover, the monitoring and feedback mechanisms are often missing or inadequate. In turn, this can lead to mistakes in identifying strategic priorities and the lack of public support for the local government's initiatives and policies.

The AZRF city planning offices are often times understaffed and lack expertise in strategy planning. For this reason, the AZRF municipalities have to look for external expertise and ask some external analytical centers to develop SD strategies for them; although, these centers may be unaware of the local needs and realities.

One more problem is that quite often, the AZRF urban development programs lack proper funding and they are not always backed up by financial and administrative arm from the top tiers of the Russian government. The Russian northern cities hope that the launch of 12 national projects in 2018 can help to solve this problem by integrating the local SD strategies to larger regional and federal programs and providing them with adequate funding.

To conclude, although there are some residual problems with familiarization of northern coastal actors with the BE concept and organization of an effective strategy planning system at the local level, the AZRF coastal municipalities are generally cognizant of the need to develop at least proper SD strategies. They favor reorganization and further improvement of their planning systems and strategies to solve existing socioeconomic and ecological problems and ensure the sustainability of the AZRF coastal cities and regions.

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Article

The Importance of Maritime Transport for Economic Growth in the European Union: A Panel Data Analysis

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Abstract: Maritime transport is one of the main activities of the blue economy, which plays an important role in the EU. In this paper, we aim to assess the impact of maritime transport, related investment, and air pollution on economic growth within 20 countries of the European Union, using eight panel data regression models from 2007 to 2018. Our results confirm that maritime transport, air pollutants (NO_x and SO_2) from maritime transport, and investment in maritime port infrastructure are indeed positively correlated with economic growth. In other words, an increase of 10% in these factors has generated an associated increase in economic growth rate of around 1.6%, 0.4%, 0.8%, and 0.7% respectively. Alongside the intensity of economic maritime activities, pollution is positively correlated with economic growth, and thus it is recommended that policymakers and other involved stakeholders act to diminish environmental impacts in this sector using green investment in port infrastructure and ecological ships, in accordance with the current European trends and concerns.

Keywords: blue economy; maritime transport; economic growth; pollution; sustainability; panel data analysis

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1. Introduction

People's lives and economies would not be the same in the absence of the activities carried out in seas and oceans. Therefore, the blue economy is a very important part of the European economy, as it provides food and other resources, supports tourism, facilitates transport, and generates the production and use of renewable energy. Regarding the blue economy of the EU, seven established sectors sum up all the blue activities: marine living and non-living resources, marine renewable energy, port activities, shipbuilding and repair, maritime transport, and coastal tourism. These seven established sectors have a contribution of around 1.5% to the European Union's economy in terms of gross value added, and they employ over 2.2% of the employed persons in the EU [1]. Coastal tourism, maritime transport, and its related sectors are the largest sectors in terms of the value added at factor cost.

Coastal tourism accounts for 45% of the total value added at factor cost of the blue economy, while maritime transport and its related sectors (shipbuilding and repair and ports activities) sum up around 40% of the total value added at factor cost of blue economy activities (Figure 1).

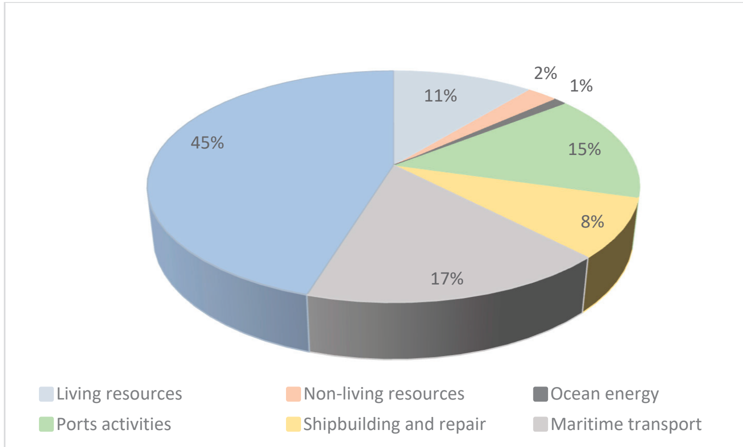

Figure 1. Value added at factor cost (% of total value added of the blue economy, 2019). Source: Eurostat, authors' calculations.

As coastal tourism requires the intensive use of hospitality services, which employ a lot of workers, a large share (64%) of the employees of the blue economy work in the sector of coastal tourism, while the maritime transport and its related sectors (shipbuilding and repair and ports activities) account for 24% of the employees of the blue economy (Figure 2).

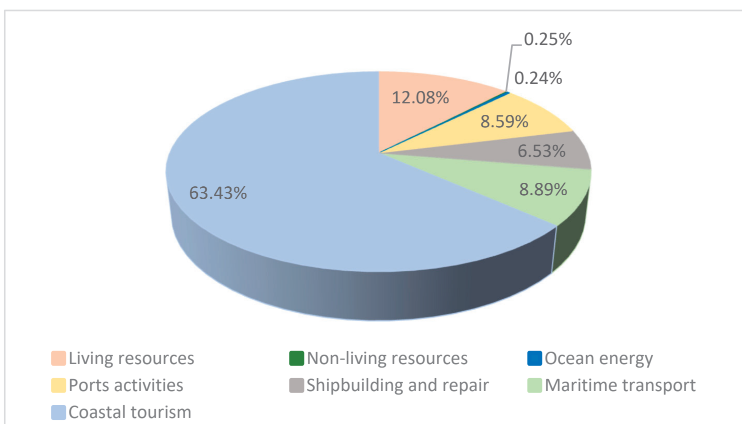

Figure 2. Persons employed by sector (% of total employment in the blue economy, 2019). Source: Eurostat, authors' calculations.

Twenty-two of the EU member states practice maritime transport. Thus, European shipping possesses a large share of the world's fleet (over 40%), accounting for some of the world's biggest maritime clusters. According to the Eurostat data, the total gross weight of goods transported through EU short sea shipping amounted to 1.8 billion tons, consolidating the recovery registered after the economic crisis of 2009. In recent years, ship sizes have been increasing, leading to the intensification of the activities for shipbuilding and repair and port activities. These new larger ships have a reduced impact on the environment, following the European Green Deal. Member states' contributions to the European blue economy are heterogeneous, depending on the geographical position, sectoral structure, and specificities of the economy. As expected, the blue economy has larger shares within the national economies of insular countries or member states with wide sea openings, such as Greece, Croatia, Malta, Cyprus, or Portugal. However, when it comes to the contributions of member states to the EU blue economy, particularly in terms of gross value added, the structure/type of blue activity provided commands the main influence. For instance, economies with significant gas and oil industries, which imply a large share of gross investments and low employment intensity, are likely to provide a larger contribution to the gross value added of the blue economy at the EU level. Yet, countries specialised in coastal tourism, which is labour intensive, have a larger contribution to the EU blue economy in the area of employment when compared to gross value added or to gross investment [1].

Maritime transport is of great importance for the global economy, as it accounts for around 80% of worldwide trade [2], highly affecting economic development. Both maritime transport and its related activities have a great overall impact on the economy, influencing a lot of industries, directly or indirectly. While maritime transport is considered the lynchpin of global trade [3], a lot of other industries rely heavily on it, as an array of resources are transported to manufacturing centres.

As aforementioned, maritime transport and its related activities (shipbuilding, repairs, and ports activities) account for around 40% in terms of value added and 24% in terms of employment within the blue economy. Maritime transport implies a wide range of activities and, together with port activities and logistic nodes, has a great impact on the development of the maritime sectors and trade, which in turn fosters economic growth and job creation.

Besides affecting economic growth and development, maritime transport has a great influence on sustainable development, as it is considered an environmentally friendly mode of transport [2]. Although maritime activities do harm the environment, this impact is lower compared, for example, to road transport, and therefore shipping seems subject to less intensive regulation [4]. While maritime transport is the most efficient way of transport in terms of carbon emissions, notice that within the EU, maritime transport accounts for over three-quarters of external trade and one-third of internal trade. However, in the context of the current concerns and policies regarding reducing pollution within the EU, embodied in the Green Deal, action would be necessary to reduce pollution of the sector.

Within this paper, we aim to analyse the impact of maritime transport, related investment, and air pollution on economic growth in the EU. We used eight panel data regression models from 2007 to 2018, for 20 EU countries practicing maritime transport. Although a lot of research papers emphasize the importance of maritime transport for international trade, economic success, and global development patterns, the richness of professional literature for the EU in this context is less than one may first anticipate. Usually, studies for the EU on this theme include microeconomic analyses, while our study assesses the macroeconomic influence of maritime transport, which is of great importance within the European Economy. One would think that common sense says that increasing pollution from increasing maritime infrastructure would generate increasing GDP per capita no matter what region, country, or continent is subject to this research, but we consider that every country, region, or continent is different and has its particularities. Plus, someone may think that, when talking about the EU, decreasing pollution would generate higher GDP per capita as there are constant policies oriented toward sustainable growth within the European Union. In these conditions, it would be interesting for policymakers to see where the EU stands during the transition to a green economy.

The remainder of the paper is extended as follows. Section 2 briefly reviews the related literature. Section 3 describes the data used in this research. Section 4 describes the panel regression models. Section 5 presents the empirical results and discussions. Section 6 concludes the study.

2. Literature Review

Generally, well-developed transport infrastructure ensures returns through certain macroeconomic drivers of productivity, such as "expansion of business activity, innovations, investments, labour market, competition, domestic and international trade global mobile activity, regional economic development, population wellbeing, environment safety, and health" [5]. Maritime transport is an important component of the transportation system, and it accounts for a large part of world trade. Moreover, it is considered that participating in the global maritime trade is a very important factor for attracting global capital [6].

Given its great importance, maritime transport is highly discussed within the literature and, in the past decades, many papers regarding all kinds of topics related to maritime transport have been published. While major academic concerns related to maritime transport regard the micromanagement of ports and liner shipping, over the past decades, the overall research trends shifted towards efficient and sustainable maritime transport, from regulations and policy management, that had formerly been of interest [3].

Therefore, a lot of research papers analyse the impact of maritime transport on economic growth and development and emphasize the importance of maritime transport for international trade, economic success, and global development patterns.

For instance, Akbulaev and Bayramli [7] study the relationship between maritime transport development and the dynamics of economic growth for several countries on the Caspian Sea (Russia, Azerbaijan, Turkmenistan, Kazakhstan, and Iran) and find that the development of maritime transport through better management promotes sustainable economic development. Gherghina et al. [8] evaluated the impact of different transport infrastructure systems (including maritime transport) on economic growth. They used panel data regressions with fixed effects for EU countries from 1990 to 2016. The authors obtained a positive link between maritime transport, related investments, and economic growth and a negative link between air pollutants and economic growth. Khan et al. [9] obtained, also, a positive link between container port traffic and income per capita, using a panel of 40 heterogeneous countries. Likewise, Saidi et al. [10] concluded that transport infrastructure positively influences economic growth, by using the generalized method of moments.

Niavis et al. [11] estimate the importance of maritime transport for the economy, society, and environment of the Adriatic–Ionian region through value estimation methodologies to develop an integrated assessment tool for a comparative evaluation of maritime transport against other drivers of the region. The authors find that maritime transport is the second most important factor of change in the Adriatic–Ionian region, after coastal tourism. Likewise, Özer et al. [12] analyse the impact of maritime transport and rail container transport on economic growth in Turkey, between 1991 and 2016, using the Autoregressive Distributed Lag-based bounds testing approach. They find no significant relationship between rail transport and economic growth, but a positive and statistically significant relationship between maritime container transport and economic growth, both in the short run and long run. Another paper that analyses the impact of maritime transport in France by an input–output approach shows that maritime transport has a strong effect on output, as the multiplier obtained in the empirical research is 2.16 for the year 2016, above the values in other papers within the literature regarding maritime transport [13]. Moreover, using an augmented Solow model, Park and Seo [14] found that container port activities can positively influence regional economic growth.

Lane and Pretes [6] examine the impact of five major factors in maritime dependency on economic development and they find a significant relationship between maritime dependency and gross domestic product per capita. The authors define maritime dependency as" the ability of a country to participate in maritime trade as determined by their geographic access to international waters and trade dependency".

A few studies aim to simultaneously find the correlation between different ways of transport and economic growth [8,15,16]. For instance, Park et al. [15] compare the impact of maritime, air, and land transport on economic growth in OECD and non-OECD countries by using a hybrid production approach that combines economic growth with the supply of and demand for transportation. The researchers obtained that maritime transport has a stronger impact on economic growth than air and land transport, which sometimes have no influence or even affect economic growth negatively, especially in developing countries.

Other studies focus on the influence of investments in port infrastructure on economic growth. Ports are essential for the support of economic activities in the surrounding areas, as they act as a critical association between sea and land transport [17]. The benefits of seaports analysed in the literature include [18] reducing transport costs [19,20], increasing private investment, encouraging trade [21], fostering employment [22,23], improving logistics [24], and other port-related activities [23,25]. Mudronja et al. [18] analysed the impact of seaports on the growth of regional economies within the endogenous growth theory using a sample of 107 EU port regions from 2005 to 2015. The authors obtained that seaports have a significant impact on the economic growth of the EU port regions. Meersman and Nazemzadeh [26] quantified the impact of transport infrastructure investments on the Belgian economy using an economic growth model. The authors obtained that investment in port infrastructure by the government contributes to economic growth. Song and Geenhuizen [27] examined the effects of port infrastructure investment in China on the growth of the regional economies by applying panel data analysis from 1999 to 2010. Their results indicate positive effects of port infrastructure investment in all regions. These results are also confirmed by Shan et al. [28], who studied the impact of seaports on the economy of an associated port city in China, using data from 41 major port cities between 2003 and 2010. Hong, Chu, and Wang [29] conducted a study on 31 Chinese provinces and concluded that water transport infrastructure investment positively influences economic growth only after the investment scale goes above a threshold point. Song and Mi [30] investigated the relationship between port investments and economic growth. In their study, they found bidirectional causality between port investment and economic growth over the short run, and a unidirectional causality running from port investment to economic growth in the long run.

A lot of research papers focus on maritime transport pollution. This kind of pollution is highly discussed in literature, academia, and international institutional circles, focusing on both impact assessment and the measures to effectively reduce pollution from maritime transport. Among the different ways of transport (aviation, road, navigation and railway), maritime transport is considered to be the most environmentally friendly.

For instance, Bagoulla and Guillotreau [13] evaluate the impact of several types of air pollutants and greenhouse gas emissions (SO_2, NOx, CO_2, $PM_{2.5}$, PM_{10}) resulting from shipping transport and find that SO_2 and NOx are the most polluting air pollutants, as they obtain the larger multipliers of all industries for these two types of air pollutants. The authors state that assessing the gas emissions caused by maritime transport is very important in the context of the implementation of more stringent regulations regarding the SO_2 emissions of the shipping sector, by imposing the SO_2 Emission Control Areas limits. Ben Jebli and Belloumi [31] concluded in a study on the Tunisian transportation network that over the short run, a bidirectional causality occurred between CO_2 emissions and maritime transport, whilst a unidirectional causality occurred running from real GDP, combustible renewables, waste consumption, and rail transport to CO_2 emissions. In the long run, GDP drives a reduction in CO_2 emissions, whereas combustible renewables and waste consumption and maritime and rail transport exhibit positive effects on emissions. Taghvaee et al. [32] examined the relationships among maritime transport, environmental pollution, and economic growth by using a dynamic log-linear model in Iran. The authors obtained a positive relationship between maritime transport, environmental pollution, and economic growth, confirming the Pollution Haven Hypothesis.

In addition, Goleblowski [33] states that water transport is the most energy-efficient form of transportation. However, maritime transport might increase its contributions to the impact on the environment in future years [34], so efforts should be made to reduce emissions from maritime transport, alongside other efforts for mitigating all kinds of negative impacts on the environment.

In the debate regarding sustainability among industry, government, and international organizations [35] around the world, many efforts concern mitigating the negative effects of pollution on waters, both rivers [36] and seas.

Regarding the efforts towards reducing maritime pollution, it must be mentioned that the International Maritime Organization (IMO) designed in 2018 is a strategy that set its main aims as reducing greenhouse gas emissions from international shipping by 50% until 2050 and the CO_2 emissions intensity by 40% until 2030, as compared to the 2008 levels. This will call for a combination of operational measures, efficient investments in less polluting technologies, and more competitive market-based measures [37]. The targets set by the IMO are considered rather ambitious [38].

In the context of growing stringency in environmental regulations regarding the maritime sector, a shift to cleaner fuels is considered a very good way of achieving less pollution. However, technical and financial factors can undermine a complete transition to clean fuels within the maritime transport sector [39].

Some other authors argue that levies would be the best ways to induce technological change over the long run and logistical measures could work over the short run, among the changes that need to be executed in order to meet pollution reduction targets [2]. Such measures would have the advantage of determining technological change regarding both ships and port infrastructure that would lead to a more economic/energy-efficient and less polluting sector. However, such changes would require a great number of investments needed over the medium term, while the benefits would amount over the long term. Therefore, taxes, fees, or regulations regarding maritime transport would be internalized within the transport costs [4], affecting decisions and all the related activities in the field. It is considered that ports have considerable potential for enhancing environmental change toward reducing pollution, through promoting lower complexity of the tool implementation by a stronger collaboration within global value chains, and by promoting alliances with cargo-owners and regulators to enhance emission visibility [40]. However, some authors concluded that network design measures can be effective in reducing pollution from maritime transport. Serra et al. [34] conducted a study on an innovative two-hub freight network for shipping services in the Mediterranean Sea compared to the existing connections within that region, and concluded that the redesign of the networks used in shipping transport would help to diminish air pollutants and the greenhouse gas emissions and would promote the emergence of more sustainable transport networks within the Mediterranean Sea.

3. Data Description

We used annual data starting from 2007 until 2018. We selected this time interval after excluding the years for which data are unavailable, in order to obtain a clear and homogenous cross-sectional database. At the time of writing this research, 2018 was the latest available data for maritime transport. The research sample consists of 20 EU countries with maritime transport activities: Belgium, Bulgaria, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Netherlands, Poland, Portugal, Slovenia, Finland, and Sweden. Malta and Romania are excluded from the research, as they have several data gaps. Likewise, we excluded the UK from our sample, as it is no longer a member state of the EU. Brexit impacts on maritime transport activities of the EU and a lot of maritime routes that formerly included the UK are being redesigned to exclude them [41].

The data sources are Eurostat [42], OECD [43], and the World Bank [44] databases. The data consist of gross domestic product per capita (as a proxy for economic growth), maritime transport infrastructure, air pollutants from maritime transport, investment in maritime port infrastructure, and country-level controls. We chose these indicators as they are documented in the literature to be the most relevant for the aim of our research [8,18,27,45].

Regarding the air pollutants resulting from maritime transport, we selected the emissions of SO_2 and NOx, as they are documented in the literature [13] to have the greatest impact of all the air pollutants and greenhouse gas emissions implied by this specific sector. We know that since 2015, International Maritime Organization and thereafter the European Parliament stipulated that all ships in SECA (Sulphur Emission Control Areas, set in 2005 and 2012) should use low-sulphur marine fuel not exceeding 0.1% [13,46] and this kind of regulation has a great impact on the data regarding the emissions of SO_2. We consider that this kind of regulation is captured intrinsically within the data as the member states have to comply. Table 1 shows a list of used variables.

Table 1. The list and explanation of the variables.

Variables	Description	Formulation	Source
GDPpc	Gross domestic product per capita	Expressed in purchasing power standards (PPS) in EUR	Eurostat
MT	Gross weight of goods handled in all ports	1000 tons	Eurostat
MI	Investments in maritime port infrastructure	Expressed in constant euro	OECD
NOx	Emissions of NOx from maritime transport	Tons	Eurostat
SO_2	Emissions of SO_2 from maritime transport	Tons	Eurostat
Services_trade	Services trade openness	Expressed as sum of exports and imports of services measured as share of GDP	Eurostat
Unemployment	Unemployment rate	Expressed as % of unemployment in active population	Eurostat
HICP	Harmonised index of consumer prices	Average index (2015 = 100)	Eurostat
GINI	GINI coefficient of equivalised disposable income	Scale from 0 to 100	Eurostat
Gov_e	Government effectiveness	Expressed as aggregate indicator, in units of a standard normal distribution, i.e., ranging from approximately −2.5 to 2.5	World Bank

As expected, the developed economies within the EU register higher levels of maritime transport or related activities, such as investment in maritime port infrastructure. Country specificities and the characteristics of the economy play an important role regarding maritime transport activities and their efficiency. For instance, the Netherlands is the member state of the EU that accounts for the greatest annual average value for the gross weight of goods handled in all ports between 2007 and 2018 (Figure 3), but accounts for a much lower level of NOx emissions from maritime transport compared to other countries (Figure 4), which means it is more environmentally friendly, probably due to using larger and less-polluting ships.

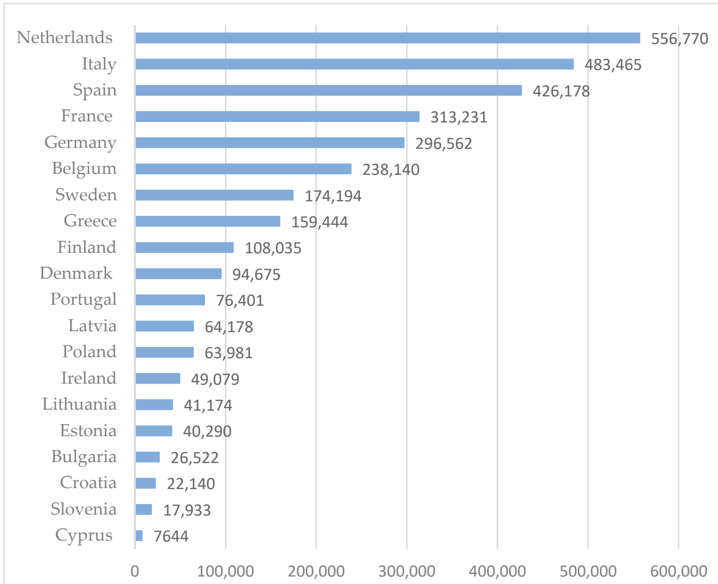

Figure 3. Gross weight of goods handled in all ports (tons, average annual value, 2007–2018). Source: Eurostat, authors' calculations.

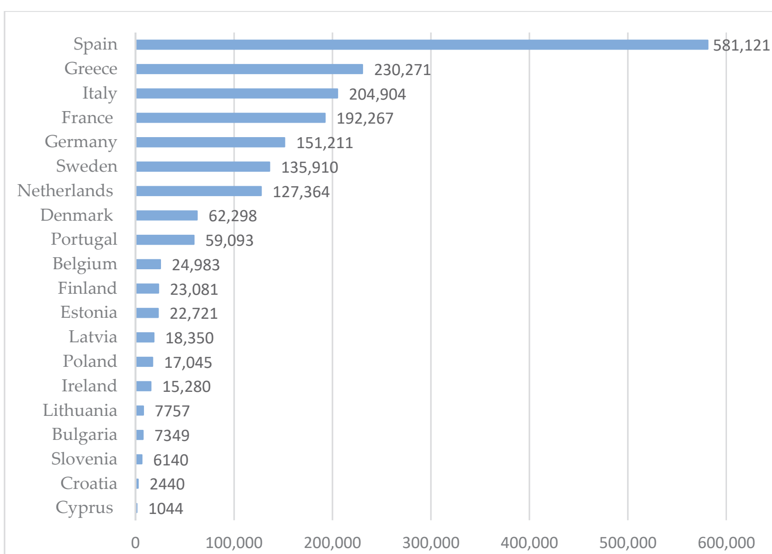

Figure 4. Emissions of NOx from maritime transport (average values). Source: Eurostat, authors' calculations.

Spain registers the highest level of NOx emissions from maritime transport in the EU, over two times larger than Greece, Italy, and France, which are the next greatest pollutants, according to Eurostat data (Figure 4).

Between 2007 and 2018, Spain reported the highest average value of investments in maritime transport of the EU member states, followed by Italy, Germany, and France (Figure 5). However, it is worth mentioning that the data for Cyprus, Latvia, Lithuania, and the Netherlands are not available.

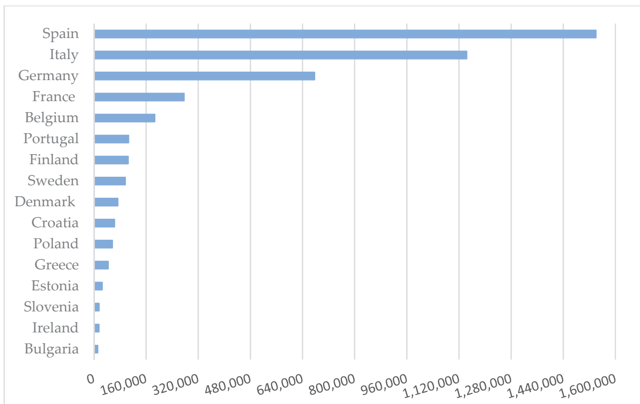

Figure 5. Investments in maritime port infrastructure (average values in thousands of euros). Source: Eurostat, authors' calculations.

Regarding the developing economies of the EU, they account for much lower intensity of maritime transport, which leads, of course, to much lower NO_x emissions from maritime transport. However, when computing the number of tons of NO_x per the number of tons of goods transported, Greece seems to be the most inefficient in terms of maritime pollution, followed by developed countries such as Spain, Sweden Portugal, and Denmark (Figure 6).

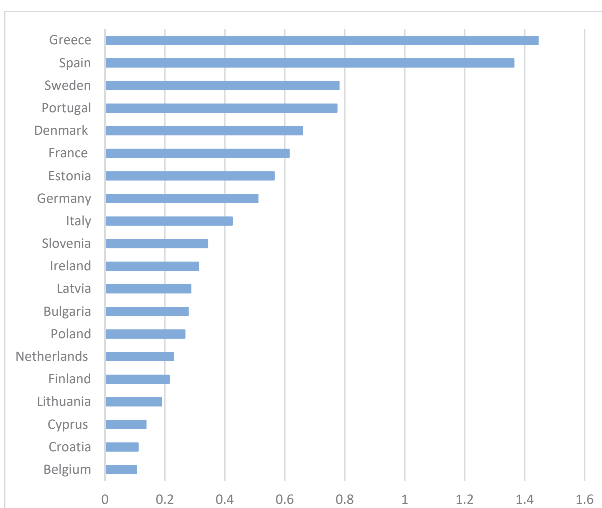

Figure 6. Environmental efficiency of maritime transport (number of tons of NOx per number of tons of goods transported). Source: Eurostat, authors' calculations.

Likewise, the investments in maritime port infrastructure are much lower in developing countries compared to the developed member states of the EU (Figure 5).

Table 2 shows the statistical indicators of the variables used in the panel regression models. The standard deviation shows greater variations in GDP per capita because there are significant differences in the development of selected EU member states. The "MT" variable records larger variations, indicating that there are large differences in the levels of the gross weight of goods handled in ports in the selected countries. Such a phenomenon was anticipated because some of the EU member states' geographical position is more favourable for maritime transport. The minimum value of the MT variable belongs to Cyprus in 2012, while the maximum value belongs to the Netherlands in 2018.

Table 2. Descriptive statistics of variables.

Variable	Number of Observations	Mean	Standard Deviation	Minimum	Maximum
GDPpc	240	25,431.66	8054.66	9963.9	57,648.3
MT	240	163,002	164,618.22	6236	604,542
MI (in thousands of euros)	174	293,941	503,140	2714	2,670,698
NOx	240	94,531.28	135,582.29	571	657,054
SO_2	240	29,878.06	52,103.1	10	208,068
Services_trade	240	30.88	21.4	9.4	123.29
Unemployment	240	9.8	4.79	3.4	27.5
HICP	240	97	5.39	77.25	108.05
GINI	237	30.5	3.79	22.7	40.2
Gov_e	240	1.16	0.56	−0.05	2.35

The standard deviation shows greater variations with air pollutants from maritime transport and investment in maritime port infrastructure. This makes sense as air pollutants from maritime transport should be correlated with maritime transport. In the case of the "NOx" variable, the minimum value belongs to Cyprus in 2016, while the maximum value belongs to Spain in 2008. The minimum value of the SO_2 variable belongs to Croatia in 2015 and the maximum value belongs to Spain in 2007. Regarding investment in maritime port infrastructure ("MI" variable), Bulgaria registered the minimum value in 2013 and Spain registered the maximum value in 2008.

4. Panel Regression Models

In this paper, we investigated the effects of maritime transport, specific air pollutants, and related investments on economic growth in 20 EU countries. We ran 8 panel regression models during 2007–2018. We chose these countries as they are all the countries from EU-27 that practice maritime transport. We used the panel technique to increase the number of observations. In other words, by using the panel technique, the number of observations increased, so the problems related to data stationarity are diminished and several tools for mitigating the common problems of the models are available [47].

Within panel data analysis, the observations have two dimensions: a cross-sectional dimension and a time-series dimension. Consequently, panel data represent large samples, which make them appropriate for estimations and their analysis has several advantages [48]. First, the econometric estimates are more efficient—in particular, the parameters have a more accurate inference, as the panel data contain a larger number of degrees of freedom and larger sample variability. Second, the capacity of a panel data analysis to capture many phenomena and behaviours is greater than that provided by time series or cross-sections. Panel data analyses also have the advantage of ensuring accurate predictions regarding individual results by pooling the data and not by using the data on a certain individual. In addition, they represent an appropriate way for investigating homogeneity and heterogeneity, providing individual background for assessing aggregate data and phenomena. They also allow for simplifying the analysis, as the problem of data stationarity diminishes due to the central limit theorem for cross-sectional units, which argues for the asymptotical normality of the limiting distributions of the estimators [49]. In addition, panel data show flexibility in order to determine different and deductible variations of the estimators and allow for the observation of measurement errors. The main disadvantage of panel data is the variables being likely to be dependent on one another, and modelling this dependence might create different models.

We used the software EViews 11 in order to run the panel regression models.

Before performing an in-depth analysis, it was necessary to consider the characteristics of the time series underlying the empirical study. We checked for the stationarity of data using several tests: Levin, Lin, and Chu test (LLC), Breitung t-stat, Im, Pesaran and Shin W-stat (IPS), ADF—Fisher Chi-Square, and PP—Fisher Chi-Square. All these tests have as a null hypothesis the fact that the series contains a unit root. From an economic point of view, a series is stationary if a shock on the series is temporary, meaning it is absorbed in time. Stationary models are therefore based on the assumption that a process remains in equilibrium over time, around an average value. In order to select the optimal number of lags, the Schwarz (SIC) criterion was used.

The correlation between variables was verified before testing the models, using the correlation matrix. This shows all the correlations between pairs of variables and has the advantage of clearly summarising the main characteristics of a large dataset. Moreover, it can help identify certain patterns within the dataset.

Based on the results obtained, we considered the selected variables in 8 distinct regression models. In these conditions, we solved the issue of multicollinearity.

Before estimating the models, it was necessary to choose an optimal method of estimating the effects because the panel, although eliminating some problems, faces problems related to heterogeneity between data. These issues can be solved by the correct specification of the effects. For this purpose, the Redundant Fixed Effects Test Likelihood Ratio was used. The results obtained are that the estimation method is compatible with fixed effects models, but to solve ex ante heteroskedasticity and cross-sectional dependence, Period SUR should be applied as a weighting method. This method cannot be applied in the case of fixed effects models. That is why we had to make a trade-off and to choose the method with smaller problems. As a result, we chose to apply the panel least square method with no effects and with Period SUR (Seemingly Unrelated Regressions) as a weighting method. Even if we face a limitation of the models (the challenge of heterogeneity is not addressed), the problems would have been bigger in the case of applying fixed effects. Period SUR corrects for heteroskedasticity and general correlation of observations within a cross-section. The SUR method, which was first used by Arnold Zellner in 1962 [50], simplifies the general linear model, where some of the coefficients in the matrix are set to be zero or some of the regressors are different in each equation. Within the SUR model, equations are joint within a certain structure and this aggregation is also explained by the covariance matrix for the associated disturbances. Therefore, this aggregation leads to some additional information as compared to the information available with the individual equations.

In order to investigate the effect of maritime transport, specific air pollutants, and related investments on the economic growth, we employed the following panel regression models:

Model 1:

$$\text{lnGDPpc}_t = a_1\ \text{lnMT}_{t-2} + b_1\ \text{Services\_trade}_t + b_2\ \text{Unemployment}_{t-1} + b_3\ \text{HICP}_{t-1} + b_4\ \text{lnGINI}_{t-1} + b_5\ \text{lnGov\_e}_t + c_0 + u_t$$

where

t = 2007, 2008 . . . 2018

a_1 = coefficient of lnMT

b_1, b_2, b_3, b_4, b_5 = coefficients of country-level control variables

c_0 = constant

u_t = error term

Model 2:

$$lnGDPpc_t = a_2\ lnSO_{2t} + b_1\ Services\_trade_t + b_2\ Unemployment_{t-1} + b_3\ HICP_{t-1} + b_4\ lnGINI_{t-1} + b_5\ lnGov\_e_t + c_0 + u_t$$

where
t = 2007, 2008 ... 2018
a_2 = coefficient of ln SO_2
b_1, b_2, b_3, b_4, b_5 = coefficients of country-level control variables
c_0 = constant
u_t = error term

Model 3:

$$lnGDPpc_t = a_3\ lnNOx_t + b_1\ Services\_trade_t + b_2\ Unemployment_{t-1} + b_3\ HICP_{t-1} + b_4\ lnGINI_{t-1} + b_5\ lnGov\_e_t + c_0 + u_t$$

where
t = 2007, 2008 ... 2018
a_3 = coefficient of lnNOx
b_1, b_2, b_3, b_4, b_5 = coefficients of country-level control variables
c_0 = constant
u_t = error term

Model 4:

$$lnGDPpc_t = a_4\ lnMI_{t-2} + b_1\ Services\_trade_t + b_2\ Unemployment_{t-1} + b_3\ HICP_{t-1} + b_4\ lnGINI_{t-1} + b_5\ lnGov\_e_t + c_0 + u_t$$

where
t = 2007, 2008 ... 2018
a_4= coefficient of lnMI
b_1, b_2, b_3, b_4, b_5 = coefficients of country-level control variables
c_0 = constant
u_t = error term

Model 5:

$$lnGDPpc_t = a_1\ lnMT_{t-2} + a_2\ lnSO_{2t} + b_1\ Services\_trade_t + b_2\ Unemployment_{t-1} + b_3\ HICP_{t-1} + b_4\ lnGINI_{t-1} + b_5\ lnGov\_e_t + c_0 + u_t$$

where
t = 2007, 2008 ... 2018
a_1 = coefficient of lnMT
a_2 = coefficient of $lnSO_2$
b_1, b_2, b_3, b_4, b_5 = coefficients of country-level control variables
c_0 = constant
u_t = error term

Model 6:

$$lnGDPpc_t = a_2\ lnSO_{2t} + a_3\ lnNOx_{t-2} + b_1\ Services\_trade_t + b_2\ Unemployment_{t-1} + b_3\ HICP_{t-1} + b_4\ lnGINI_{t-1} + b_5\ lnGov\_e_t + c_0 + u_t$$

where
t = 2007, 2008 ... 2018
a_2 = coefficient of $lnSO_2$
a_3 = coefficient of lnNOx
b_1, b_2, b_3, b_4, b_5 = coefficients of country-level control variables
c_0 = constant
u_t = error term

Model 7:

$$lnGDPpc_t = a_2\ lnSO_{2,t-2} + a_4\ lnMI_t + b_1\ Services\_trade_t + b_2\ Unemployment_{t-1} + b_3\ HICP_{t-1} + b_4\ lnGINI_{t-1} + b_5\ lnGov\_e_t + c_0 + u_t$$

where

$t = 2007, 2008 \ldots 2018$

a_2 = coefficient of $lnSO_2$

a_4= coefficient of lnMI

b_1, b_2, b_3, b_4, b_5 = coefficients of country-level control variables

c_0 = constant

u_t = error term

Model 8:

$$lnGDPpc_t = a_3\ lnNOx_{t-2} + a_4\ lnMI_t + b_1\ Services\_trade_t + b_2\ Unemployment_{t-1} + b_3\ HICP_{t-1} + b_4\ lnGINI_{t-1} + b_5\ lnGov\_e_t + c_0 + u_t$$

where

$t = 2007, 2008 \ldots 2018$

a_3 = coefficient of lnNOx

a_4= coefficient of lnMI

b_1, b_2, b_3, b_4, b_5 = coefficients of country-level control variables

c_0 = constant

u_t = error term

We applied logarithmic transformation in the models to ensure that the estimates coefficients are robust to the measurement units of the variables. It is a routine procedure not only in maritime economics literature, but also in the economics literature in general [18,27,28]. In order to estimate the coefficients from all 8 models, we applied the panel least square method with no effects and with Period SUR as a weighting method. A more detailed methodology can be seen in Baltagi [51].

After the estimation of the models' results, the following tests were performed in order to verify the maximum likelihood of the estimators:

- Model validity: Fischer test was used (probability < 5%).
- Significance of estimators: checking of their associated probability (probability < 5%).
- The existence of non-zero standard errors, but not much different from zero.
- Absence of residuals' autocorrelation: Durbin–Watson test has the advantage of being based on the estimated residuals, which are generally determined within the regression analysis [52]. The null hypothesis is considered valid or not according to the positioning of the value of the Durbin–Watson statistic within a certain interval determined by some limits that have been tabulated by the two authors.
- Normal residuals' distribution: Jarque–Bera test (probability >5%) is an asymptotic, or large-sample test, based on the OLS residuals [52]. The null hypothesis refers to the residuals being normally distributed, so, asymptotically, the JB statistic follows the chi-square distribution with 2 degrees of freedom. For the acceptance of the null hypothesis, the value of the computed statistic should be close to 0 and the p-value should be high.
- Absence of dependence between cross sections (probability >5%): Breusch Pagan LM and Pesaran scaled LM. The cross-sectional dependence may result from common shocks and some unobserved components that affect the error, the spatial dependence, and idiosyncratic pairwise dependence regarding the disturbances without a pattern of common components or special dependence [53]. The Breusch Pagan LM test is suitable for testing cross-sectional dependence in panels. Under the null hypothesis, the test statistic is asymptotically chi-square distributed with $n(n-1)/2$ degrees of freedom [54]. Given the fact that the Breusch Pagan LM test is not appropriate for large samples, the standardised version of the LM test was introduced [49]. We use both tests for assessing the existence of the dependence between cross-sections.
- Linearity of the model: R-squared (coefficient of determination).
- Absence of multicollinearity: correlation matrix.

5. Empirical Results and Discussions

In the first phase, we tested the stationarity of the data. Table 3 summarises the outcome of the panel unit root tests. As we can see, some of the variables are integrated at I(1) and some at I(0). In other words, a part of the variables was not stationary in level, but in the first difference.

Table 3. Panel unit root tests output.

Variable	Level—Individual Intercept and Trend				
	LLC	Breitung	IPS	ADF	PP
lnGDPpc	−19.1780 ***	2.32959	−8.55462 ***	106.955 ***	57.2319 *
lnMT	−14.3030 ***	0.16832	−5.63158 ***	101.536 ***	95.4038 ***
lnMI	−4.88361 ***	2.50397	−0.66579	38.9663	38.0995
lnNOx	−6.29546 ***	1.99138	−3.32316 ***	87.9797 ***	77.1056 ***
$lnSO_2$	−7.80266 ***	0.38992	−2.02398 **	66.4199 ***	36.9825
Services_trade	−14.5281 ***	−0.10619	−6.52585 ***	114.749 ***	87.5906 ***
Unemployment	−13.1816 ***	3.65470	−2.39590 ***	67.7357 ***	25.6041
HICP	−8.01232 ***	−2.38944 ***	−2.00334 **	62.6765 **	54.4576 *
lnGINI	−7.04141 ***	2.31291	−1.85141 **	75.9441 ***	81.4968 ***
lnGov_e	−5.62726 ***	−1.05582	−1.02065	50.4070	46.7934
Variable	**First Difference—Individual Intercept and Trend**				
	LLC	**Breitung**	**IPS**	**ADF**	**PP**
lnGDPpc	−28.2747 ***	−4.96016 ***	−11.1369 ***	209.571 ***	253.799 ***
lnMT	−22.1740 ***	−5.26555 ***	−7.64395 ***	158.476 ***	200.929 ***
lnMI	−8.09441 ***	0.36848	−1.20382 *	54.5193 ***	68.9395 ***
lnNOx	−13.2303 ***	−2.51307 ***	−4.94830 ***	122.873 ***	152.557 ***
$lnSO_2$	−12.5274 ***	−2.97424 ***	−4.55593 ***	112.065 ***	143.600 ***
Services_trade	−13.8096 ***	−5.15360 ***	−5.62210 ***	115.935 ***	140.172 ***
Unemployment	−11.8828 ***	−1.99291 **	−4.45867 ***	110.206 ***	144.391 ***
lnGINI	−15.5880 ***	−1.85241 **	−6.12254 ***	125.505 ***	177.835 ***
lnGov_e	−14.5148 ***	−3.48785 ***	−5.45307 ***	117.998 ***	206.494 ***

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Lag lengths are determined via Schwarz Info Criterion.

Then the correlation between variables was verified before testing the models. Table 4 shows the correlation coefficients of the variables.

Table 4. Correlation coefficients.

	lnGDPpc	lnMT	lnMI	lnNOx	$lnSO_2$	Services_trade	Unemployment	HICP	lnGINI	lnGov_e
lnGDPpc	1									
lnMT	0.5064	1								
lnMI	0.3664	0.8286	1							
lnNOx	0.3776	0.8780	0.6857	1						
$lnSO_2$	0.2263	0.7849	0.7191	0.8131	1					
Services_trade	0.3258	−0.3463	−0.4668	−0.3567	−0.3932	1				
Unemployment	−0.2862	0.1418	0.0501	0.2568	0.0711	−0.0381	1			
HICP	0.1681	0.0143	−0.1917	0.0199	−0.1606	0.1551	0.2599	1		
lnGINI	−0.5377	0.0825	0.0642	0.2352	−0.1147	0.4429	0.4429	0.0601	1	
lnGov_e	0.7649	0.2023	0.2271	0.1359	0.2327	−0.3142	−0.3142	−0.0502	−0.6314	1

A positive or a negative correlation that is greater than 0.8 serves as a threshold for a correlation presence [18,55]. The review of the correlation coefficients shows there are strong linear associations between several variables. In these conditions, we solved the issue of multicollinearity by considering the selected variables in distinct regression models.

The effects of maritime transport, specific air pollutants, and related investments on economic growth are presented in Table 5. The empirical results provide support for a positive influence of all variables (except for GINI and unemployment) on economic growth. In line with previous studies [8,9,18,32], the gross weight of goods handled in all ports has a positive impact on GDPpc. Moreover, in line with previous literature, investments in maritime port infrastructure have a positive effect on economic growth [8,27]. Similar to

Taghvaee et al. [32], air pollutants are positively correlated with GDPpc, confirming the Pollution Haven Hypothesis.

Table 5. Results of the panel regression models (1–4).

	Model 1	Model 2	Model 3	Model 4
	lnGDPpc	**lnGDPpc**	**lnGDPpc**	**lnGDPpc**
lnMT	0.1649 *** (0.0124)			
lnMI				0.0706 *** (0.0091)
lnNOx			0.0803 *** (0.0064)	
$lnSO_2$		0.0451 *** (0.0061)		
Services_trade	0.0062 *** (0.0004)	0.0045 *** (0.0008)	0.0054 *** (0.0005)	0.0068 *** (0.001)
Unemployment	−0.0086 *** (0.0010)	−0.0075 *** (0.0015)	−0.0112 *** (0.0012)	−0.0076 *** (0.0022)
HICP	0.0112 *** (0.0010)	0.0122 *** (0.0013)	0.01 *** (0.0009)	0.0169 *** (0.0021)
lnGINI	−0.4419 *** (0.0664)	−0.7185 *** (0.0955)	−0.5199 *** (0.0701)	−0.5269 *** (0.1379)
lnGov_e	0.1425 *** (0.0128)	0.1709 *** (0.0178)	0.1751 *** (0.0151)	0.1862 *** (0.0249)
Constant	8.5220 *** (0.2838)	10.9048 *** (0.3427)	10.0155 *** (0.2583)	8.8341 *** (0.5458)
R^2	0.8368	0.6999	0.7929	0.7024
Durbin–Watson	1.7861	1.7374	1.7567	1.7143
Jarque–Bera (*p*-value)	0.0646	0.7952	0.05	0.1412
Breusch Pagan LM (*p*-value)	0.7995	0.4873	0.9366	0.2202
Pesaran scaled LM (*p*-value)	0.3963	0.9980	0.1390	0.4513
Observations	198	216	216	153
Number of countries	20	20	20	17

Notes: *** $p < 0.01$. Standard errors are in parentheses.

The first model aims to establish the influence of the gross weight of goods handled in all ports on economic growth and living standards of the population. The results show that an increase of 10% of the gross weight of goods handled in all ports (lagged two years) is positively correlated with a 1.649% increase of the GDPpc, on average. This confirms that maritime transport positively influences economic growth and living standards. The obtained coefficient is statistically significant. This correlation might be explained by the fact that maritime transport fosters trade and also investment, two important components of gross domestic product. Moreover, by fostering trade and investment, it subsequently leads to higher employment in the related sectors, which has a positive influence on the living standard of the population. However, the channels through which maritime transport influences economic growth might be different from one country to another and our results show a general tendency for our cross-sectional sample. For instance, for some developing countries, importing capital goods could diminish the net export, but, on the other hand, this category of goods would foster investment, which will positively influence economic growth on the medium term.

The control variables in the model are statistically significant and have the expected positive or negative impact on economic growth. For instance, we found that services trade openness encourages economic growth, although the influence is rather small: if services trade openness increases by 10 percentage points, the GDPpc will increase by 0.062%, on average. The influence could be more intense in some of the developed countries where high tech services with large value added are an important part of the economy. As expected, unemployment and economic growth are negatively correlated: when unemployment (lagged one year) increases by 10 percentage points, the GDPpc will decrease by 0.086%, on average, as fewer workers would produce less. Likewise, the GINI coefficient has a negative influence on economic growth: when the GINI coefficient (lagged one year) increases by 10%, the GDPpc decreases by 4.419%, on average, which means that rising inequalities hamper economic growth. Most often, rising inequalities undermine education opportunities for children and also create a vicious poverty cycle which in turn affects economic growth. On the other hand, we found that government effectiveness positively affects the GDPpc (an increase of 10% in the government effectiveness is associated with an increase of 1.4% of the GDPpc, on average). It is clear that the more effective the government is, the more support it offers for the population and business environment, which in turn positively affects economic growth. Finally, regarding the influence of the HICP on the GDPpc, the positive correlation is normal, as the higher the prices, the higher the GDP.

The influence of specific air pollutants from maritime transport on economic growth can be seen in the second and third models. The results of the research show that air pollutants are positively correlated with economic growth. The estimated coefficients are 0.0415 with SO_2 and 0.0803 with NOx and are statistically significant. The results show that when emissions of SO_2 from maritime transport increase by 10%, the GDPpc increases by 0.415%, on average (in the case of second model), and when emissions of NOx from maritime transport increase by 10%, the GDPpc increases by 0.803%, on average (in the case of the third model). These results are in line with the positive correlation we found between maritime transport and economic growth: alongside with the intensification of maritime transport, the pollution would rise, but economic growth would also be fostered. Therefore, the green transition goals that are at present of great interest for the EU countries are expected to determine, over the long run, the achievement of economic growth alongside declining pollution.

Model 4 assesses the impact of investments in maritime port infrastructure. According to our research, investments in maritime port infrastructure should encourage economic growth. Therefore, the estimated coefficient is 0.0706 and is statistically significant, which indicates that when investments in maritime transport (lagged two years) increase by 10%, the GDPpc increases, on average, by 0.706%. Investments in maritime transport influence both present and future economic growth. Moreover, they determine the intensification of port activities, which in turn favours maritime transport, which has already been proven to have a positive influence on economic growth and the living standards of the population. As in the first model, all the control variables are statistically significant and have the expected positive or negative impact in the other three models.

Tests for the absence of residuals' autocorrelation, normal residuals' distribution, and the absence of dependence between cross-sections are shown in the previous table. According to the Durbin–Watson test from all the four models, the errors are not autocorrelated. In addition, the residuals are normally distributed, according to the Jarque–Bera test. A p-value greater than 0.05 confirms the null hypothesis of the test, which claims that the residuals are normally distributed. Breusch Pagan LM and Pesaran scaled LM reveal there is no dependence between cross-sections in none of the four models. Their p-value greater than 0.05 confirms the null hypothesis of the tests, which claims the absence of dependence between cross-sections.

Because maritime transport, specific air pollutants, and related investments have a cumulated effect on economic growth, we combine all these factors to see a more aggregated impact. Due to the issue of multicollinearity, we cannot include all these variables in one single model. That is why we propose another four panel regression models. The results are similar to those obtained in the previous models (although, of course, the values of the obtained coefficients are different) and are presented in Table 6.

Table 6. Results of the panel regression models (5–8).

	Model 5	**Model 6**	**Model 7**	**Model 8**
	lnGDPpc	**lnGDPpc**	**lnGDPpc**	**lnGDPpc**
lnMT	0.1591 *** (0.0139)			
lnMI			0.0491 *** (0.0077)	0.0431 *** (0.0056)
lnNOx		0.0826 *** (0.0079)		0.0911 *** (0.0061)
$\ln SO_2$	0.0051 (0.0043)	0.0126 *** (0.0045)	0.0418 *** (0.0064)	
Services_trade	0.0065 *** (0.0005)	0.0066 *** (0.0006)	0.0069 *** (0.0003)	0.0073 *** (0.0002)
Unemployment	−0.0086 *** (0.0011)	−0.0113 *** (0.0013)	−0.0064 *** (0.0018)	−0.0125 *** (0.0013)
HICP	0.0116 *** (0.0011)	0.0128 *** (0.0013)	0.0185 *** (0.0017)	0.0164 *** (0.0015)
lnGINI	−0.4952 *** (0.0722)	−0.6551 *** (0.0902)	−0.7486 *** (0.1089)	−0.7961 *** (0.0945)
lnGov_e	0.1341 *** (0.0133)	0.1328 *** 0.0144	0.1565 *** (0.0181)	0.1184 *** (0.0146)
Constant	8.6784 *** (0.3)	10.038 *** (0.3466)	9.4705 *** (0.4281)	9.3876 *** (0.388)
R^2	0.8391	0.7936	0.8041	0.8981
Durbin–Watson	1.8038	1.7625	1.8176	1.9481
Jarque–Bera (*p*-value)	0.056	0.1499	0.7179	0.8153
Breusch Pagan LM (*p*-value)	0.3943	0.9377	0.4587	0.8867
Pesaran scaled LM (*p*-value)	0.8135	0.1370	0.9515	0.2356
Observations	198	198	138	138
Number of countries	20	20	16	16

Notes: *** $p < 0.01$. Standard errors in parentheses.

The impact of the gross weight of goods handled in all ports and the one of the SO_2 emissions from maritime transport on economic growth are examined by the fifth model. We found that when maritime transport (lagged two years) increases by 10%, the GDPpc increases, on average, by 1.591%. This positive influence is confirmed also by Lane and Pretes [6], who found a significant relationship between maritime dependency and gross domestic product per capita. Other authors obtained similar results as ours, using other methodologies. For example, Saidi et al. [10] used a generalised method of moments in some African countries, Özer et al. [12] used the Autoregressive Distributed

Lag based bounds testing approach in Turkey, and Park and Seo [14] used the Solow model in South Korea. In the case of emissions of SO_2 from maritime transport, the estimated coefficient is much lower (0.0051), showing a weaker but positive influence. The control variables in the model are statistically significant and have the expected positive or negative impact on economic growth. For example, government effectiveness should encourage economic growth and we have the confirmation in the results. We found that this indicator is statistically significant at 1% and the results should be interpreted as follows: if government effectiveness increases by 10%, the GDPpc will increase by 1.341%, on average. The influence channels and connections are the same as explained for the previous models.

The impact of specific air pollutants from maritime transport on economic growth can be seen in model 6. As in the previous models, the results of the research show that air pollutants are positively correlated with economic growth. These correlations confirm the fact that a higher intensity of maritime transport produces higher pollution, but also leads to GDP growth, which in turn will determine better living standards. The estimated coefficients are 0.0126 in the case of SO_2 and 0.0826 in the case of NOx and are statistically significant. The results should be interpreted as follows: if emissions of SO_2 oxides from maritime transport increases by 10%, the GDPpc will increase by 0.126%, on average, and if emissions of NOx oxides from maritime transport (lagged two years) increases by 10%, the GDPpc will increase by 0.826%, on average. On the other hand, as maritime transport might increase its contributions to the impact on the environment in future years [34], efforts should be made to reduce emissions from maritime transport, even if it is the most energy-efficient form of transportation [33].

Services trade openness, HICP, and government effectiveness encourage economic growth with the estimated coefficients 0.0066, 0.0128, and 0.1328, respectively. At the same time, unemployment and the GINI coefficient negatively affect economic growth, with statistical significance at 1%. These results are in line with the literature, as fewer workers produce less, and rising inequalities produces a vicious poverty cycle that hampers economic growth.

Model 7 reveals the impact of investments in maritime port infrastructure and emissions of SO_2 oxides from maritime transport. The estimated coefficients are statistically significant at 1%, indicating that if investments in maritime port infrastructure increase by 10%, the GDPpc increases by 0.491%, on average, and if emissions of SO_2 oxides from maritime transport (lagged two years) increase by 10%, the GDPpc increases by 0.418%, on average. The control variables in the model are statistically significant and have the expected positive or negative impact on economic growth. Our results are in line with the literature, as the effect of investments in maritime port infrastructure on the living standards is positive [8,27], even if some authors used regional data in different countries [27–30].

From our point of view, investments in maritime port infrastructure foster port facilities, which determine better handling capacities and have a positive impact on the volume of the goods that can be handled in ports. This also might require the employment of additional labour force, thus resulting in lower unemployment. On the other hand, in the absence of strong measures for green transition, the higher the intensity of maritime transport, the higher the related pollution.

The impact of investments in maritime port infrastructure and emissions of NOx oxides from maritime transport on economic growth is examined in the last model. The results of the research show that both factors have a positive effect on GDPpc. The estimated coefficients are 0.0431 with investments in maritime port infrastructure and 0.0911 with NOx and are statistically significant. The results show that when investments in maritime port infrastructure increase by 10%, the GDPpc increases by 0.431%, on average, and if emissions of NOx oxides from maritime transport (lagged two years) increase by 10%, the GDPpc increases by 0.911%, on average. Unemployment and the GINI coefficient are found to negatively affect the economic growth, with statistical significance at 1%; therefore, if unemployment (lagged one year) increases by 10 percentage points, the GDPpc will decrease by 0.125%, on average. If the GINI coefficient (lagged one year) increases by 10%, the GDPpc will decrease by 7.961%, on average. Government effectiveness and HICP are found to positively affect the GDPpc, their estimated coefficients being 0.1184 and 0.0164.

Tests for the absence of residuals' autocorrelation, normal residuals' distribution, and the absence of dependence between cross-sections are shown in Table 6. According to the Durbin–Watson test from all four models, the errors are not autocorrelated. Moreover, the residuals are normally distributed, according to the Jarque–Bera test. A p-value greater than 0.05 confirms the null hypothesis of the test, which claims that the residuals are normally distributed. Breusch Pagan LM and Pesaran scaled LM reveal that there is no dependence between cross-sections in all four models. Their *p*-value is greater than 0.05 and confirms the null hypothesis of the tests, which claims the absence of dependence between cross-sections.

All in all, regardless of the used models, the results obtained lead us to the conclusion that maritime transport fosters economic growth and the improvement of the living standards of the population through various channels. First, maritime transport contributes to trade development, as it encourages the mobility of goods. Therefore, it leads to better allocation of resources across countries and subsequently to higher production of consumer goods. Second, especially in but not limited to developing countries, maritime transport plays an important role in the imports of capital goods, which foster investment and technological development, leading to a higher economic efficiency and larger volume of production. Moreover, the intensified economic activities determined by larger production and investments (including in maritime ports infrastructure) would require higher employment, which would generally contribute to better living standards, alongside economic growth. However, the intensity of these influences might be different from one country to another, depending on country-specific factors.

Our results also show a positive correlation between pollution resulting from maritime transport and economic growth. Higher pollution is the result of intensified maritime transport, which was proven to have a positive influence on economic growth. As stated before, diminishing pollution from maritime transport by fostering the transition to green transportation facilities would be optimal and is expected to take place over the long term, in the context of the current concerns in this direction at the EU level.

6. Conclusions

The blue economy is a very important part of the European economy, providing many resources and services, and maritime transport and its related activities account for around 40% of this sector. In the current context of economic and technological development, transport systems are expected to become more efficient, safe, and sustainable [56].

Maritime transport is a very important way of transport, supporting global trade, the global value chains, resource allocation, and overall economic growth and development. It affects a wide range of industries, both directly and indirectly, and it is considered to have a lower impact on the environment compared to other ways of transport, such as road transportation.

Under these circumstances, in this paper, we examine the impact of maritime transport, related investment, and pollution (SO_2 and NOx) on economic growth within 20 countries of the European Union, through panel data regression models during 2007–2018. The empirical results provide support for a positive influence of all variables (except for the control variables GINI and unemployment) on economic growth. In line with previous studies [8,9,18,32], we obtained that the gross weight of goods handled in all ports has positive impact on GDPpc. Even if we used a different methodology and different countries—like Saidi et al. [10], who used generalised method of moments in some African countries, or Özer et al. [12], who used the Autoregressive Distributed Lag based bounds testing approach in Turkey, or Park and Seo [14], who used the Solow model in South Korea—we found, like these studies, a positive influence of maritime transport on economic growth.

As Taghvaee et al. [32] concluded, air pollutants are positively correlated with GDPpc, confirming the Pollution Haven Hypothesis. It would be interesting to see how the correlation will move in the future after we obtain new available data due to the fact that starting with January 2020, a standard of 0.5% sulphur rate is now imposed instead of the previous3.5% rate (MARPOL Annex VI) [13]. Plus, as of 2021, the emissions of NOx will be limited in the Baltic Sea by up to 80% [57]. Likewise, also in line with previous literature, investments in maritime port infrastructure have a positive effect on economic growth [8,32], even if some authors used regional data in different countries [27–30].

More specifically, the results of our empirical analysis show that an increase by 10% in maritime transport will generate an increase of around 1.6% in GDPpc; an increase by 10% in emissions of SO_2 from maritime transport generates an increase of around 0.4% in GDPpc; an increase by 10% in NOx emissions from maritime transport generates an increase of around 0.8% of GDPpc; and an increase by 10% in investments in maritime port infrastructure generates an increase of around 0.7% in GDPpc.

Our results are important as they offer a clear numerical influence of maritime transport, maritime air pollution, and maritime investments on economic growth, which could help when assessing the macroeconomic effects of different phenomena or regulations regarding maritime transport on economic growth. Our research could be interesting for policymakers to see where the EU stands during the transition to a green economy and could be a helpful tool when deciding what kind of policies they would need to adopt (a more restrictive or expansionary policy) to reach the final target.

As we stated before, maritime transport is an important part of the European economy, influencing a wide range of industries and activities and employing many people. Therefore, we considered it important to assess the macroeconomic influence of maritime transport.

The main limitation of our research regarded data availability. For instance, the latest data for maritime transport was from 2018, which constrained us from capturing more recent trends and influences. In addition, the data series for Romania and Malta, two member states that practice maritime transport, were largely filled with gaps, so we considered it better to exclude them from the analysis.

In addition, we faced a limitation regarding the models, as the challenge of heterogeneity is not addressed. We chose this alternative, as we had to solve ex ante heteroskedasticity and cross-sectional dependence, which we consider would have generated higher problems.

Despite an aggregated positive correlation between pollution from maritime transport and economic growth (that we obtained in our results), there are probably countries in the panel that have lower emissions of NOx and SO_2 from maritime transport combined with GDPpc increases. This negative link may occur in countries with a large and clean industry sector, in which high labour productivity supports complex techniques [58]. Therefore, future research could use country-level data in order to analyse country specificities and provide useful insights on how to accommodate higher economic growth with a decrease in pollution, possibly complementing policies that are already in practice or supported by the existing literature (for example, the adoption of more environmentally-friendly policies, the internalisation of externalities, or the adoption of regulations against pollution-havens).

All in all, in the context of the current high concerns and determinations regarding the transition to a green economy, there is scope for improving technologies used in port infrastructure and shipbuilding in order to reduce the impact on the environment. Even if port authorities have undertaken considerable efforts by adopting appropriate policy frameworks and investing in new technologies, there is still a long road ahead [59]. This would impose great investments and could be an important factor of future sustainable growth and development, both in the EU and around the world. However, given the large costs involved in such investments, financing could be a great challenge, as they involve the allocation of large amounts of financial resources in the short run, while the benefits would materialise over the long run. Nevertheless, owing to the pandemic and the concerns for recovery and resilience within the EU, member states have the possibility of accessing unprecedented financial resources to implement a wide range of reforms and investments, and the green transition is one of the main purposes of these programs, alongside the digitalisation of the economy.

In this context, and given the overall findings of our research, our view is that a green transition within the maritime transport and its related activities within the EU should be supported by financing and reform incentives rather than by imposing levies, as they would have a negative impact on aggregate supply and prices, with a subsequent poor influence on economic and social development.

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Blue Economy and Coastal Tourism: A Comprehensive Visualization Bibliometric Analysis

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Abstract: This paper aims to analyze the scientific production of the blue economy and coastal tourism research fields to identify research topics and publication patterns. Accordingly, bibliometric analysis was selected as a quantitative meta-analysis literature review method. Scopus was the main database for extracting the scientific production in blue economy and coastal tourism. Various bibliometrics analysis techniques were used to analyze 476 and 49 publications in blue economy and coastal tourism, respectively. The main results are summarized as follows: (i) the number of publications in the blue economy scientific sector has increased significantly, and (ii) contrarily, a relatively small body of blue economy literature is concerned with the coastal tourism sector despite its significant role in the blue economy.

Keywords: blue economy (BE); coastal tourism; bibliometric analysis; R language; CiteSpace; VOSviewer; visualization

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1. Introduction

According to international organizations, the blue economy (BE) concept seeks to effectively manage water resources, especially seas and oceans, to preserve them as significant natural resources for current and future generations [1–3]. The BE includes all the economic activities that directly correlate with the oceans, such as fishing, shipbuilding, maritime transport, coastal tourism, etc. [2]. Although the "BE" term seems to be new, the water resources and the awareness of their importance have been around since prehistoric times. The importance of water resources on the Earth's surface (oceans, seas, rivers, etc.) cannot be denied. Oceans cover two-thirds of the Earth's surface, produce about 50% of the world's oxygen, shape more than 95% of the biosphere, regulate the Earth's surface temperature, provide people with food, and host various economic activities [3–6].

The roots of BE emergence can be directly and strongly linked to the sustainable development concept. Since the 1960s, the scientific community has paid attention to sustainable development, especially in environmental, economic, and social dimensions [7].

The United Nations hosted its first sustainable development conference in Stockholm in 1972 to advance sustainable development from the environmental perspective. The second United Nations conference, held in Rio in 1992 and focusing on the economic dimension of sustainable development, was followed by the Johannesburg conference in 2002, which looked at the value of achieving the social dimension of sustainable development [7,8].

Before the Rio +20 conference in 2012, the global financial crisis occurred, leading to the emergence of the green growth term on the world stage. Green growth aims to boost economic growth, considering environmental factors. Therefore, the Rio +20 summit had two key pillars: sustainable development and green economy [2,3,5,6]. Coastal states, in general, and Small Island Developing States (SIDS) confirmed the importance of paying attention to the oceans and their climate in achieving a green economy during the Rio +20 summit preparations [3]. Subsequently, the "Green Economy in a Blue World" report emerged, which is widely regarded as the beginning and cornerstone of the modern blue economy [2]. Therefore, it can be said that the blue economy is an extension of the green economy theme and the environmental dimension of economic activities.

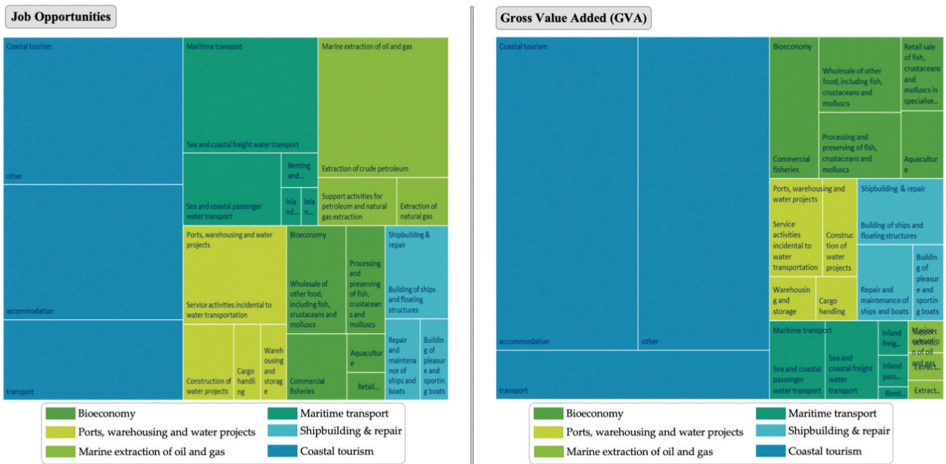
The term "Blue Economy" first appeared in 2012, following the United Nations Conference on Sustainable Development (UNCSD), also known as Rio +20 or the Earth Summit [3]. As a result, global conferences and international meetings of regional and global organizations have debated the BE term and attempted to define it, resulting in many definitions. These BE definitions varied depending on the entity issuing the identification and its purposes. For example, the United Nations Environment Program (UNEP) launched the BE term at the level of island countries, especially the Caribbean islands, and BE was defined as "the economy that leads to human well-being and enhances social justice, while significantly reducing environmental risks and scarcity of resources" [2] (p. 3). OCED describes BE as "the sum of the economic activities of ocean-based industries, together with the assets, goods, and services provided by marine ecosystems" [1] (p. 2). Furthermore, the European Commission adopted BE as a new development strategy for EU member states, defining it as "an economy that includes the maritime economy and all economic activities related to the oceans, seas, and coasts" [9] (p. 5). In addition, according to the European Union's initiative for sustainable development of BE, BE was considered a commitment and preservation of environmental aspects while developing various geographical areas and regions. This initiative also seeks to achieve three main goals: safer maritime domain, a smart BE able to achieve resilient development, and optimum utilization of water surfaces and their various resources [9].

The importance of the BE term is achieved from the conceptual kernel of this approach, enhancing the sustainability concept. The Sustainable Development Goals (SDGs), which are also known as the Global Agenda 2030, are related to BE [10]. The 14th Sustainable Development goal, "life below water," seeks to promote the sustainable use and development of oceans, seas, marine resources, and ecosystems, which are the foundation of the BE approach and its economic sectors [10].

The concept of BE has presented a new perspective of the sustainable economic development in different countries or geographical areas such as coastal areas by using the oceans and marine resources at the various levels of development, regional, national, and international. BE depends on the growth of industries and activities based on marine and ocean resources, such as fisheries, shipping, ports, marine logistics, coastal, and recreational tourism [2,11,12]. Furthermore, there are many emerging sectors in BE such as renewable ocean and seas energy (wind, tides, waves, etc.), extraction of gas and oil from the seas and oceans, mining, aquaculture and marine, blue biotechnology, monitoring and controlling seas and oceans, conducting marine research, and others that are characterized by the use of cutting-edge technologies [13].

Because of this diversity in the economic sectors that formed BE, various classifications have emerged. Some international organizations have divided BE sectors into five main groups, while others divide it into six, seven, or 11 economic sectors. The main classification for BE sectors was developed by the European Union (EU), which divided BE into seven main sectors, named: "Marine Renewable Energy," "Shipbuilding and Repair," "Marine Living Resources," "Maritime Transport," "Marine Nonliving Resources," "Port Activities," and "Coastal Tourism" [14].

This paper aims to analyze the coastal tourism sector as a part of BE. According to the EU Blue Economy Report, BE sectors created nearly 5 million jobs and contributed EUR 218 billion in gross value added (GVA) in 2018 [9]. Coastal tourism is at the forefront of BE's economic sectors, offering job opportunities or sharing in the gross value added (GVA) [9]. Figure 1 shows the participation percentage of the different BE sectors in providing job opportunities and GVA, where the coastal tourism sector appears as the largest valuable economic sector in BE [9].



(a) (b)

Figure 1. Blue economy (BE) sectors contribution in the EU economy; (**a**) BE sector contributions in providing job opportunities; (**b**) BE sector contributions in the gross value added (GVA). Source: [9].

Coastal tourism choice as one of the two main focused scientific fields in this research can be attributed to its importance as an economic sector of BE and its contribution in the global tourism industry. Approximately 30% of global tourism activities take place in coastal areas and regions [15]. According to the United Nations World Tourism Organization (UNWTO), one out of every two tourists traveled to the coastal area for tourism purposes [16]. Further, coastal tourism in coastal areas such as Small Island Developing States (SIDS) is considered the main source of supply of foreign exchange [3]. The coastal tourism sector contributes about USD 220 billion of ocean consumer products and services globally [11].

Coastal tourism covers various activities, patterns, and infrastructure, making it the heart of the scientific research area when analyzing and studying the tourism industry's different patterns. It includes many tourism, recreation, and entertainment-oriented activities such as swimming, snorkeling, diving, beaches, recreational fishing, various water sports, cruises, sports competitions, recreational and sailing boats, etc. For example, as a critical sub-sector of coastal tourism, global cruise tourism has experienced massive growth in recent years, with a total 75% of growth in passenger numbers from 2008 to 2018 [14]. Simultaneously, a robust potential infrastructure serves the coastal tourism sector, such as accommodation, restaurants, tourist villages, hotels, ports, trade and shopping centers, logistic zones, and transportation hubs [11].

Aside from the positive aspects of coastal tourism, such as its enormous significance and effect on the global economy, there are some negative consequences of coastal tourism, especially in terms of the environment [17]. The main negative impacts of coastal tourism on the coastal area ecosystem are water pollution, beach and shoreline erosion, abuse and destruction of coral reefs, habitat destruction, extinction of certain threatened species, destruction of flora and fauna, increased plastic wastes, increased pressure on different energy resources, and physical and economic displacement of local communities [15,18,19].

It has been reported that the most important reasons that create these negative effects are the constant pressures on limited marine resources by various tourism activities, the expansion of urban development processes in coastal areas, and the permanent and continuous conflict between the priorities of development in coastal areas between the tourism sector and other economic sectors [15,17–20].

Because of these previous negative effects and in light of coastal tourism importance in the global economy, achieving sustainability is a pivotal matter. Therefore, it was necessary to apply the BE approach to achieve sustainability principles in coastal tourism.

This research sets out to study BE as one of the most important and latest approaches to achieving sustainable development related to water resources and shedding light on the coastal tourism sector. The bibliometric analysis as a meta-analysis literature review method was applied to achieve the purpose of the current study.

2. Materials and Methods

The quantitative method of bibliometric analysis was chosen for analyzing scientific production in BE in general and coastal tourism in particular, where it is considered one of the most reliable literature reviewing approaches [21]. Although it has been used since the 1890s [21], it appears to be a common literature review technique nowadays. The conceptual kernel of this method is to collect, describe, analyze, evaluate and monitor published academic papers on a particular research topic [21]. Using bibliometrics analysis in the current paper can be attributed to many reasons. Firstly, although most bibliometric analysis techniques are commonly used in topics with numerous publications over the years, this method is often reliable and valuable for analyzing the novel scientific areas to detect patterns and infer the future path for these topics [22]. Secondly, it is common as a literature review technique in the sustainable development scientific area [23–28]. Thirdly, the idea of bibliometric analysis is consistent with the aim of this research, which introduces the statistical measurement of BE and coastal tourism fields based on transparent and systematic techniques [22]. Finally, it is an objective, unbiased, and straightforward analysis [29].

This research applied a comprehensive bibliometric analysis based on three main analyzing levels: basic information of the extracted literature, basic contents of the extracted literature, and relation between bibliometric analysis units. Each level has different sub-levels of the analyzing process. Moreover, the two main focused scientific fields in this research (BE and coastal tourism) will be compared at each level. Coastal tourism, in particular, will be analyzed as one of the BE sectors.

Various software tools are used to conduct bibliometric analysis, such as HistCite [30], CitNetExplorer [31], VOSviewer [32], SciMAT [33], Science of Science (Sci2) [34], CiteSpace [35] and bibliometrix package in R [22]. However, according to Aria and Cuccurullo (2017), most of these tools did not have a complete workflow; in other words, some focused on analyzing bibliographic data, and others were designed to visualize the results and networks [22].

The bibliometric analysis in this research was developed using three separate software tools, R, CiteSpace, and VOSviewer, to overcome these obstacles. Furthermore, these three software tools are entirely free, giving preference and convenience in using different analytical tools that can be used without any commercial licenses [22,36]. Moreover, many scholars have used a combination of these programs to perform bibliometric analysis in various disciplines [24,37–39].

The bibliometrix package in the R programming environment was the first used software. R is a command-line programming language with open-source statistical packages and an ecosystem [40–42]. Compared to other scientific computation languages, scholars preferred R due to its ability to provide nearly comprehensive bibliometrics and scientometrics analysis [22], practical statistical algorithms, different numerical routes, and powerful visualization features [22]. CiteSpace and VOSviewer software are used to visualize all bibliometrics analysis outputs and develop conceptual and intellectual networks.

2.1. Data Collection

The imported data set of this research was extracted from Scopus (Elsevier's abstract and citation database). Scopus was chosen as a research engine in this paper over Web of Science (WOS) for these reasons: (i) Scopus is considered the largest database of different types of peer-reviewed literature documents, such as articles, conference papers, books, and review papers [43,44], and (ii) many other scholars have used Scopus to perform bibliometrics analysis in their studies [27,45–47].

To collect the required raw data, the researchers used the following two basic terminology and Boolean operators for each of the two focused scientific fields in this research (i.e., BE and coastal tourism):

The keywords set in double quotation marks were identified as a "loose phrase" in Scopus. Further, the Boolean operators "OR" and "AND" were used to retrieve records that contained any of these words and identify papers with both terms, respectively [48]. Furthermore, the asterisk (*) in the coastal tourism search query was used to find different shapes of a word. The search refinement was quite limited in this study, where any records before 2012 were excluded as it was the official emergence year of the BE term. Papers from 2021 were also omitted because the scientific publication had just begun and was not yet complete. It is worthwhile mentioning that search queries in this study went through four rounds to reach the final form (Figure 2), and this was followed by a deep revision by the authors to be sure that the collected articles corresponded with the study aim.

"Blue Economy scientific field"

"*blue economy*" OR "*ocean economy*"

"Coastal Tourism scientific field"

"*blue economy*" OR "*ocean economy*" AND "*touris**"

Figure 2. The Boolean operators used to extract data sets from the Scopus database.

While most previous bibliometric analysis studies used exclusion criteria to refine the collected data [23,49,50], we chose not to. Since the key scientific area of interest was BE (which appeared in 2012), we concentrated on gathering as many published papers in this field as possible. In addition, some exclusion criteria in bibliometric analysis studies would not be effective in this research, for example, the language of the collected papers, which is a continuous debate between scholars [51]. Some academics believe that the language criteria are the most important ones that affect the bibliometric analysis's efficiency, and that it is necessary to focus on articles published in the English language only, while others believe that non-English articles have a "very low" impact on the bibliometric analysis studies since these articles count only in the overall data set, and their contributions in different bibliometric analysis levels are low [51]. In the current research, the contribution of non-English articles was not great and would not produce significantly different outcomes. For example, in the BE data set, there were 13 non-English papers out of 476 research papers that were analyzed (four Chinese, three Russian, three Spanish, two Italian, and one Portuguese). The same was observed in the coastal tourism data set, where out of 46 research papers, there were only three non-English papers (two Chinese and one Russian). Therefore, our research did not use exclusion criteria to ensure collecting the most significant number of research papers possible related to BE and coastal tourism, which in turn gave richness in results and achieved the research aim.

Moreover, it is worthy to note that a deep screening of the extracted data occurred as a sub-data collection analysis to identify records relevant to the coastal tourism sector within the entire BE literature.

2.2. Data Retrirval and Management

On 18 November 2020, the data set was extracted by the four researchers separately and uploaded in R, CiteSpace, and VOSviewer in parallel. In R, using a bibliometrix package, data was converted to a data frame before extracting the bibliographic information. CiteSpace and VOSviewer were used to create and visualize the results and networks. The researchers also discussed any conflicting information and clarified it.

2.3. Anlysis Levels

The data was subjected to three main levels of analysis, namely, basic information of the extracted literature, basic contents of the extracted literature, and relation between bibliometric analysis units, as mentioned previously. In every analysis level, the research used different bibliometric techniques with various structural concepts (see Table 1).

In the first level of analysis, termed as "basic information of the extracted literature," the research presented a general overview of the extracted BE and coastal tourism literature. This analytical level included five central analysis units: scientific production analysis, source analysis, author analysis, document analysis, and country and institution analysis (see Table 1). In the second analysis level, called "basic contents of the extracted literature," the research focused on the bibliometrics analysis related to the extracted scientific production content, such as keyword analysis and reference analysis (see Table 1). Finally, in the third bibliometric analysis level, the so-called "relation between bibliometric analysis units," the research illustrated the relation between three different bibliometric analysis units using a three-fields plot.

In general, different bibliometric indicators and techniques were used in each analysis level and followed by co-citation, collaboration, and thematic networks based on specific features and algorithms.

Table 1. The bibliometric analysis, techniques, and software used in this study.

Bibliometric Analysis		Bibliometric Analysis Scientific Fields		Bibliometric Technique Taxonomy	Visualization Technique	Used Software
Levels of Analysis	**Units of Analysis**					
Basic information of the extracted literature	Scientific production analysis	Blue Economy (BE)	Coastal Tourism	Annual scientific production	Statistical diagram bar chart	R language
	Sources analysis			Most productive sources	Statistical diagram bar chart	R language
				Sources dynamics analysis	Dynamic line graph	R language
	Authors analysis			Collaboration analysis	Network	VOSviewer
				Authors production over time	Time-span line graph	R language
	Documents analysis			Most cited documents	Statistical diagram bar chart	R language
	Countries and institutions analysis			Collaboration analysis	Network	CiteSpace
Basic contents of the extracted literature	Keywords and burst analysis			Co-word analysis	Network	CiteSpace
				Burst analysis	Burst strength list	CiteSpace
	References analysis			Co-citation analysis	Network	CiteSpace
Relation between bibliometric analysis units				Relation analysis (keywords, authors, and sources)	Three-fields plot	R language

3. Results and Discussion

It is worthwhile mentioning that the coastal tourism scientific production was part of the BE scientific production, as it was one of the sectors that structured this type of economy. For example, the total number of published articles in the BE research area was 476 in the selected period from 2012 to 2020, while the scientific production in the coastal tourism sector represented approximately 10% (n = 49) of the whole BE production. The coastal tourism sector production volume was poor compared to its importance as one of the most valuable and productive sectors in BE [9].

3.1. Basic Information of the Extracted Literature

3.1.1. Scientific Production Analysis

The quantity of published papers in any academic research field is considered a key indicator of bibliometric analysis [23,24]. According to the published BE articles, over the eight years there was a rapid growth in BE scientific production, about a 60.48% annual growth rate (see Figure 3). The least active year was 2012, with just three papers, since it was the first year using the BE term, while the most BE publications were published in 2020 (132 papers). The total number of citations for BE articles was 2420, with 5.084 average citations per document, reflecting the importance of this research area in recent years.

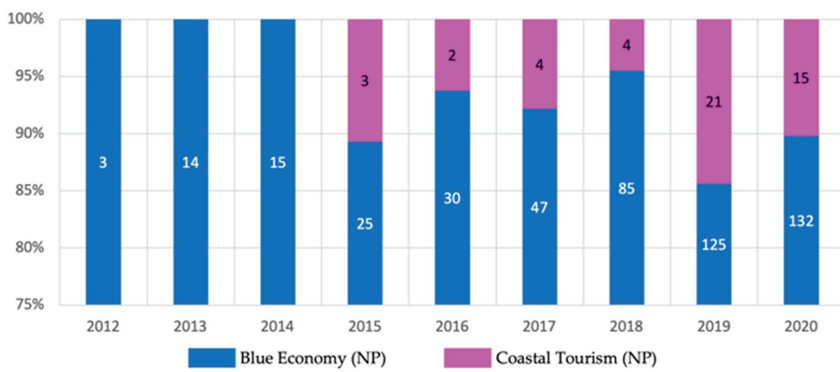


Figure 3. The annual scientific production in BE and coastal tourism. Note: NP: number of publications. Source: researcher, derived from R Programming Language (bibliometrix package).

Compared to BE, scientific production in the coastal tourism sector was different. The production volume in this sector did not reflect its importance relative to the other six BE sectors, where the number of published articles was 49. According to Figure 3, applying the BE concept in coastal tourism development was not great, especially from 2012 to 2018. The scientific production in this sector stuck on a kind of plateau with about four articles per year. The situation improved in 2019 and 2020, when the number of published papers in the coastal tourism sector jumped significantly to 21 and 15, respectively.

3.1.2. Source Analysis

With regards to source analysis in BE, the extracted 476 papers were reported in 249 sources. *Marine Policy*/H-index (15), *Frontiers in Marine Science*/H-index (6), *Journal of the Indian Ocean Region*/H-index (7), *Journal of Coastal Research*/H-index (2), and *Ocean and Coastal Management*/H-index (5), were the most productive sources in the BE research area, with 42, 21, 20, 12 and 10 publications, respectively (see Figure 4). Although within the broad range of the published articles' sources in the BE scientific field during the eight years only 5% (n = 12) sources had published more than five articles, which represented by the top five sources in addition to *Sea Technology* (NP = 10), *Sustainability Science* (NP = 10), *Marine Technology Society Journal* (NP = 9), *Maritime Affairs* (NP = 8), *Dialogues in Human*

Geography (NP = 7), *Journal of Political Ecology* (NP = 7), and *Journal of Ocean and Coastal Economics* (NP = 6).

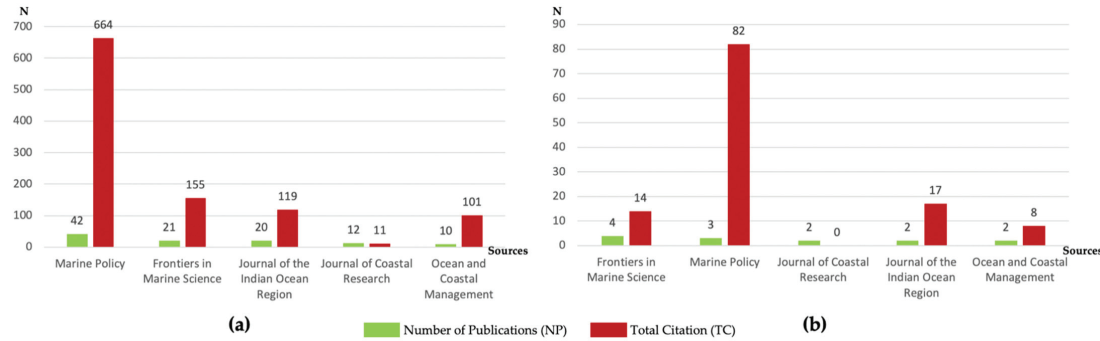


Figure 4. The relation between the source number of publications (NP) and total citations (TC); (**a**) BE scientific field; (**b**) coastal tourism scientific field. Source: researcher, derived from R Programming Language (bibliometrix package).

By investigating the Hirsch Index (H-index), which is defined as the journal's number of publications (h), each of which has been cited by other articles at (n) time [52], it can be said that *Marine Policy* was the most valuable journal in BE field, either in terms of the total number of publications (NP) or the total number of citations (TC), or H-index.

Concerning the coastal tourism field, the extracted 49 papers were published in 39 sources. The most abundant sources in the coastal tourism sector were: *Frontiers in Marine Science*/H-index (2), *Marine Policy*/H-index (3), *Journal of Coastal Research*/H-index (0), *Journal of the Indian Ocean Region*/H-index (1), and *Ocean and Coastal Management*/H-index (2) with total publications of 4, 3, 2, 2 and 2, respectively (see Figure 4). Analogous to the BE field method, only one journal, *Frontiers in Marine Science*, published four articles, while other sources only published one to three.

Comparing the most productive sources in the two studied scientific areas (BE and coastal tourism), it was obvious that there was a great similarity between them, where *Marine Policy*, *Journal of Coastal Research*, *Journal of the Indian Ocean Region*, and *Ocean and Coastal Management* were the most productive sources in these two research areas (see Figure 4). However, in the coastal tourism sector, *Journal Frontiers in Marine Science* ranked at the top of the most productive journal list in this field, which was not recorded in the same list for the BE field, indicating the specialization of this journal in publishing articles related to coastal tourism among all other sources.

Figure 4 shows the relation between the number of publications (NP) and the number of total citations (TC) for sources in the two scientific fields (i.e., BE and coastal tourism). The total citations of the sources did not correspond to the order in which they appeared in the most productive sources list, whether for BE or coastal tourism. For instance, in the BE scientific field, *Ocean and Coastal Management* received 101 citations obtained by only 10 published articles and ranked fifth in terms of the total number of citations for sources (see Figure 4a). Furthermore, *Journal of the Indian Ocean Region* published two articles in the coastal tourism scientific research area, which were cited 17 times, while *Frontiers in Marine Science journal* published four articles in the same research area and received just 14 citations (see Figure 4b).

3.1.3. Author Analysis

Author analysis seeks to find the significant analysis features related to the authors in the collected research articles and identify the structure of the scientific community in a specific field [22,53]. For example, this research discussed three bibliometric techniques related to author analysis for each of the two focused research fields (i.e., BE and coastal tourism).

Firstly, the most relevant author analysis technique was part of citation bibliometric analysis, which aimed to address the following questions: Which authors are the most prolific in the research field? Who are the subject matter experts in the specific science field? [53]. The most prolific authors are determined based on the number of published articles, while the experts in the field are indicated based on the total number of citations.

According to BE scientific production, the total number of authors was 1584. The five most relevant authors based on the number of publications were Na Na (n = 13), Failler P (n = 7), Voyer M (n = 7), Bennett NJ (n = 6), and Morrissey K (n = 6). Regarding ranking authors based on the total number of citations, the top five authors who wrote high citation documents were Pauly D (TC = 140), Halpern BS (TC = 107), Campbell LM (TC = 104), Bennett NJ (TC = 92), and Sumaila UR (TC = 84). Comparing the top five authors based on the number of publications and the total citations in the BE field, we can see that the author's number of publications did not reflect his or her number of citations. In other words, you can find that one author had more significant publications but received fewer citations than another author with fewer published articles. For example, the total 140 citations of Pauly D, which listed him at the top of the authors achieving the most citations, were obtained from just one published article, reflecting the specialization of some authors in the BE field.

Regarding the 49 published articles in the coastal tourism sector, about 147 authors published them. Cisneros-Montemayor Am, Kolesnikova M, Na Na, Potts T, and Aguilar-Manjarrez J were the most relevant authors in this scientific field with 2, 2, 2, 2, and 1 articles, respectively. Based on the total number of citations in the coastal tourism field, the top five authors were Cisneros-Montemayor Am (TC = 17), Pauly D (TC = 13), Halpern BS (TC = 12), Cheung WWL (TC = 11), and McKinley E (TC = 11). Looking at these two lists in the field of coastal tourism, except for Cisneros-Montemayor Am, the authors in the two lists are completely different, indicating the diversity of scholars who publish articles in the coastal tourism field.

Secondly, the co-author analysis technique is suggested to answer some leading questions: Do the authors collaborate from different disciplines or remain with their disciplinary boundaries? Do more productive authors collaborate frequently? [53]. This analysis technique is depicted by a network named "author collaboration network," where nodes represent authors and links represent co-authorships [52].

Figure 5a presents the author collaboration network in the BE field, consisting of four primary colors: red, blue, green, and yellow; every color represents a cluster of authors with the same disciplinary area of interest under the BE umbrella. By examining this network, we can see that there was little interest from authors in the BE field to collaborate within different disciplinary boundaries. It was shown through the tangled links in the network between different clusters. In addition, the collaboration between some researchers from different groups was observed, such as the collaboration between Voyer M (green group) and Heron RL (blue cluster) and the collaboration between Foulton EA (yellow group) and the Cheung WWL (red group). It was noteworthy that most of the strong relationships that appeared from the link thickness were within the same cluster, indicating the extent of the excellent collaboration between authors in the same group to produce co-authored articles. Moreover, it is worth mentioning that there was an amazing collaboration between the most prolific authors (big nodes) in the BE field but inside the same cluster.

Figure 5b presents the author collaboration network in the coastal tourism field. It also has four main clusters: red, blue, green, and yellow. Unlike in the network in BE, it was found that most authors in the coastal tourism sector collaborated within the same cluster, resulting in a less tangled network with clean visualization and divided into four separate groups. This network in Figure 5b also shows a clear collaboration between the most productive authors in the coastal tourism sector and the same cluster, similar to the BE author collaboration network.

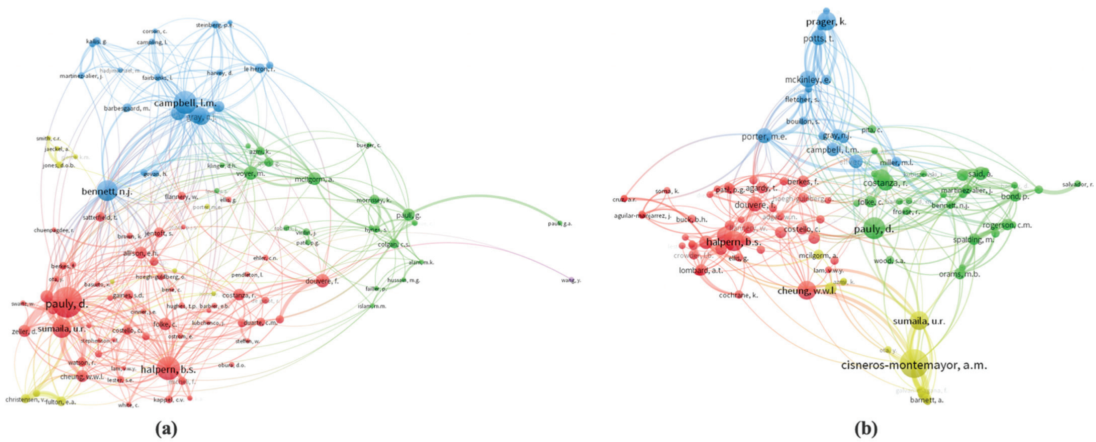


Figure 5. Author collaboration network; (**a**) BE author collaboration network visualization; (**b**) coastal tourism author collaboration network visualization. Legend: Color: represents a cluster of disciplines of interest in the research field; Nodes: represent authors (node size based on TC); Links: represent co-authorships; Link Thickness: represents the co-authorships strength. Note: clusters formed based on three parameters in VOSviewer software (clusters resolution 0.06; minimum cluster size 1; merge small clusters). Source: researcher, derived from VOSviewer.

Thirdly, we studied the top author's production during the time concerned with studying the relationship between three variables, namely: the author's number of publications (NP), the author's number of citations (TC), and the period (n) [54,55]. This analysis aimed to extrapolate the active periods in which the most significant number of articles and the greatest number of citations were produced and identify the authors responsible for the structure in the scientific research field [54].

Figure 6a depicts the top author's production over time in the BE field. It highlights that in the second half of the focused timespan, precisely from 2017 to 2020, the majority of authors achieved their highest production volumes, either in the number of published articles or the number of total citations. Na Na and Morrissey K were also the earliest scholars who published about BE after the first appearance of the term in 2012, although they did not achieve outstanding citations for these publications. Although we set the study period at eight years (from 2012 to 2020) in the coastal tourism sector, the first published paper did not appear in the first three years; it was published in 2015, then the scientific production stopped from 2015 to 2018, before restarting again in 2019 and reaching its peak (see Figure 6b).

Some interesting notes can be mentioned by comparing the author analysis between BE and coastal tourism sector. First, analyzing the top relevant authors in these two research areas showed that, despite many authors in both research areas, the scientific production was not monopolized or dominated by particular scholars, and the total scientific production had an unequal distribution among the authors. Secondly, in the most relevant author analysis, the two lists for the two research areas (BE and coastal tourism) were almost different, although the scientific production of the coastal tourism was part of BE, reflecting the specialization in the tourism sector when it related to authors. Thirdly, there was a vivid difference between the author names in the two research areas appearing in the most relevant author lists, based either on the number of publications or the number of citations. Fourthly, 2019 was the most productive year in both scientific fields, in either the total number of publications or the total number of citations.

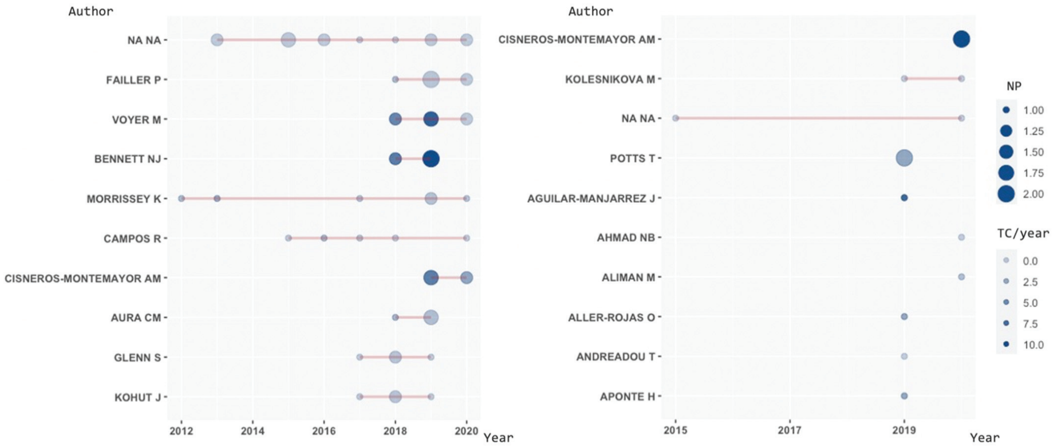


Figure 6. Author scientific production over time; (**a**) BE scientific field; (**b**) coastal tourism scientific field. Legend: Line: represents author's publishing timeline; Bubble Size: represents proportional to NP; Bubble Color Intensity: represents proportional to TC/year. Note: NP: number of publications; TC: total citations. Source: researcher, derived from R Programming Language (bibliometrix package).

3.1.4. Document Analysis

In this part, the research focused on answering the main question related to the published documents: What are the most cited papers in the two focused selected scientific areas (BE and coastal tourism)? And what is the relation between them?

Firstly, by analyzing and extracting the 10 most cited papers published in the BE scientific area, we saw that the highest number of citations was 109, which was obtained by Silver JJ's research paper entitled "Blue Economy and Competing Discourses in International Oceans Governance" [5]. Bueger C's article entitled "What is maritime security?" [56] ranked second in the most cited papers in BE academic production, and it received around 91 citations. These two published papers achieved approximately 8% of the total citations obtained by all research papers in BE, and it is worth noting that these two papers were also published in the same year, 2015. One of the most intriguing observations from the list of the top 10 most cited articles in BE was that half of the list (n = 5) was published in one journal, *Marine Policy*. These five papers were in the second [5], fourth [57], sixth [58], eighth [59], and tenth rank of the list [60] (see Figure 7).

Secondly, regarding the 10 most cited research papers in the coastal tourism sector, Pinto H's article entitled "Cooperation and the emergence of maritime clusters in the Atlantic: Analysis and implications of innovation and human capital for blue growth" [61] was ranked at the top of this list, with 39 citations. Hadjimichael M's paper, which was published in 2018 entitled "A call for a blue degrowth: Unravelling the European Union's fisheries and maritime policies" [62], came in second and obtained 27 citations. Noting the scientific sources in which the 10 most cited coastal tourism articles were published, it was revealed that the two papers at the top of the list were both published in the same journal, *Marine Policy* (see Figure 8), confirming the journal's importance, not only as the most productive source, as previously stated, but also because its published articles had high citation rates compared to other journals.

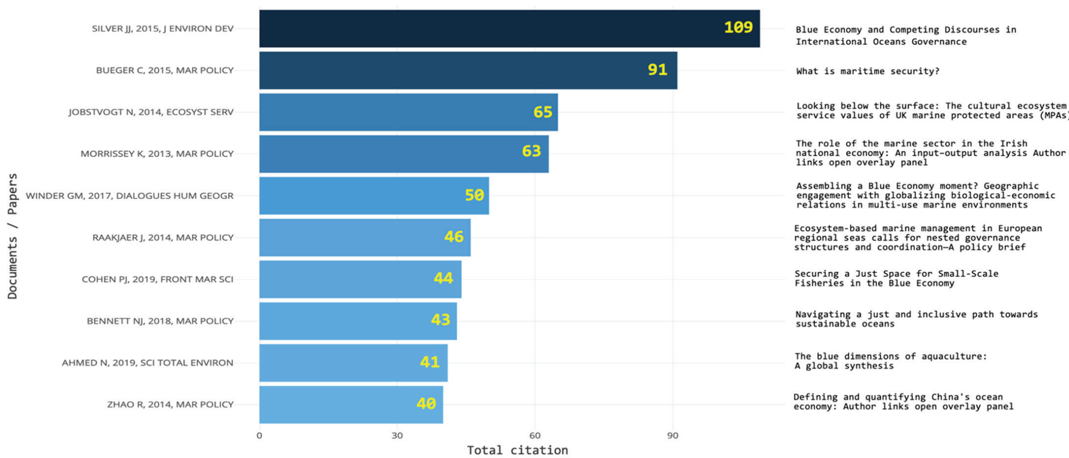


Figure 7. The top 10 cited articles in the BE literature. Legend: Left: authors of top 10 cited articles and publication year; Middle: bar charts of article's number of citations; Right: titles of top 10 cited articles. Source: researcher, derived from R Programming Language (bibliometrix package).

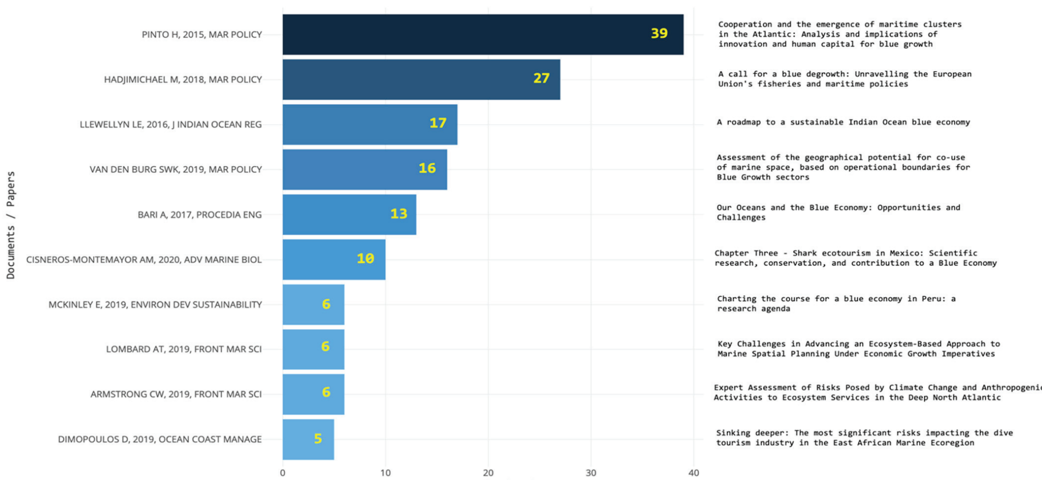


Figure 8. The top 10 cited articles in coastal tourism literature. Legend: Left: authors of top 10 cited articles and publication year; Middle: bar charts with article's number of citations; Right: titles of top 10 cited articles. Source: researcher, derived from R Programming Language (bibliometrix package).

Comparing the two lists of the 10 most cited papers in the BE and coastal tourism scientific fields, it was shown that there was no overlap between these two lists; in other words, no articles in coastal tourism scientific output had the potential to receive a large number of citations that would qualify them to be listed anywhere in the BE list. This indicated the weak percentage of scientific production in the coastal tourism field, and its invalid importance as a part of the scientific output of BE. Furthermore, the extrapolation of the 10 most cited papers list in the coastal tourism sector revealed another striking finding: only two of the ten articles included in the list discussed the tourism sector independently and separately [63,64]. However, the rest of the eight articles discussed coastal tourism as a sector within other sectors in the blue economy. In other words, these eight papers did not focus on the coastal tourism sector only, but in other BE sectors also, confirming the research conclusion related to the weakness of the relative importance of the coastal tourism scientific production as part of the BE scientific production, despite the importance of this sector in providing jobs and sharing in GVA [9].

3.1.5. Country and Institution Analysis

This analysis was considered one of the most noticeable bibliometrics analysis units, suggesting research collaboration and the flow of the scientific field between various entities (countries and institutions) [65].

Regarding the country collaboration network, BE literature was published by 124 countries. This diversity in the countries participating in the scientific production of BE (55% countries of the world) indicated the extended prosperity of the BE term as a future academic research topic in recent years, specifically from 2012 to the present day. Figure 9 represents the countries most contributing to the literature of the two focused scientific fields (BE and coastal tourism), where the circle size represents the country's scientific production and lines represent the country collaborations [66]. According to Figure 9a, which depicts the country contributions in BE outputs, the United States of America ranked first with 126 articles, far from the second place obtained by the United Kingdom with 80 articles. Australia, Japan, South Africa, Italy, France, Canada, Spain and Portugal, ranked third to tenth with a total numbers of articles of 53, 48, 36, 35, 30, 30, 25, 23, respectively.

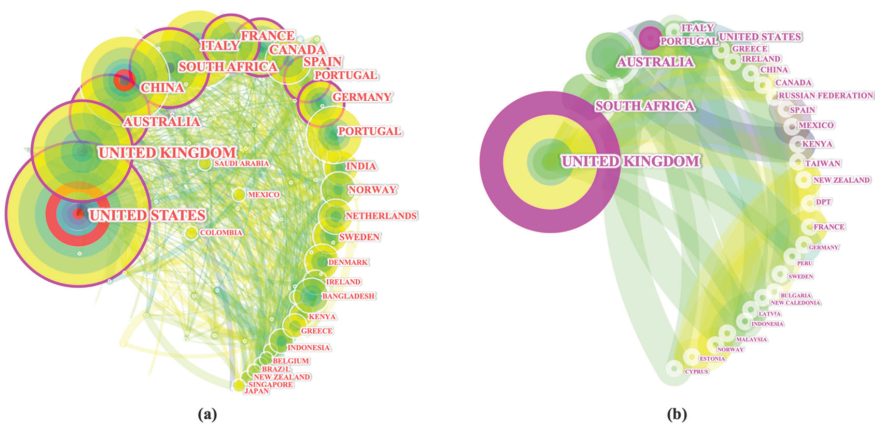


Figure 9. Country collaboration network. (**a**) BE scientific field; (**b**) coastal tourism scientific field. Legend: Node: represents countries (the size of the node represents the country's scientific production); Link: represents collaborative relations between countries; Colors: represent the temporal orders of co-occurrence links between countries (outside purple circle represents nodes with centrality above 0.1/key hub countries). Source: researcher, derived from CiteSpace.

Moving to the countries that contributed in the coastal tourism output, in Figure 9b, it was shown that the most collaborative country was the United Kingdom with 12 publications, followed by South Africa (5), Australia (5), Portugal (4), Italy (4), and the United States of America (3).

The total number of institutions involved in BE and coastal tourism scientific production were 747 and 90 articles, respectively. In BE literature, Ocean University of China and University of British Columbia were the two most productive academic institutions with 17 articles each, followed by Kenya Marine and Fisheries Research Institute (16), University of Washington (13) and University of Wollongong (11), as shown in Table 2. Comparing the most productive institutions and countries in the BE scientific field, it was shown that these two listed corresponded, where United States, United Kingdom, Australia, China and South Africa placed at the top of these lists, either for countries or institutions.

Table 2. The 10 most productive institutions in BE and coastal tourism literatures.

Affiliations/Institutions (Blue Economy)	TP	Affiliations/Institutions (Coastal Tourism)	TP
Ocean University of China/CHINA	17	Nelson Mandela University/SOUTH AFRICA	5
University of British Columbia/COLUMBIA (British)	17	Heriot Watt University/SCOTLAND	2
Kenya Marine and Fisheries Research Institute/KENYA	16	Independent Researcher/NA	2
University of Washington/USA	13	Kenya Marine and Fisheries Research Institute/KENYA	2
University of Wollongong/AUSTRALIA	11	Rhodes University/SOUTH AFRICA	2
Duke University/USA	9	Universidad Autnoma De Baja California SUR/MEXICO	2
Nelson Mandela University/SOUTH AFRICA	9	Universiti Malaysia Terengganu/MALAYSIA	2
University of California/USA	9	University of Aberdeen/SCOTLAND	2
University of Tasmania/AUSTRALIA	8	University of Extremadura/SPAIN	2
Lancaster University/ENGLAND	7	University of Glasgow/SCOTLAND	2

Note: TP: total publications (number). Source: researcher, derived from R Programming Language (bibliometrix package).

According to the coastal tourism scientific production, Nelson Mandela University was the most productive institution with five publications, followed by Heriot–WATT University, Independent Researcher, Kenya Marine and Fisheries Research Institute, and Rhodes University, with two articles each, as shown in Table 2.

3.2. Basic Contents of the Extracted Literature

3.2.1. Keywords and Burst Analysis

In general, keywords are considered to be one of the most important components of any research paper that aims to identify the core research topics in different scientific research fields [65]. In biometric analysis, there are two types of keywords: (i) Author's Keywords (DE) that are provided by authors, and (ii) Keywords Plus (ID), those produced by bibliometrics analysis software based on computer algorithms [67]. These two keyword categories were combined and analyzed together. Using CiteSpace software, the co-word analysis networks were mapped based on keywords frequency in the two studied research areas (BE and coastal tourism). Figure 10a shows the co-word analysis of BE literature; it shows that the most frequent keywords were blue economy (n = 197), sustainable development (n = 78), sustainability (n = 44), marine environment (n = 44), economics (n = 38), oceanography (n = 32), fishery (31), and blue growth (n = 30). This network also shows that the keywords that form the main conceptual kernel of BE, such as economy and sustainability, were ranked at the top of the most frequent keywords; this emphasizes the novelty of the BE scientific area, which has been under research since the term's appearance in 2012. It also appears in this network that there was a clear absence of keywords that referred to coastal tourism, despite its importance as one of the most economically valuable BE sectors, as mentioned previously.

Figure 10b shows the co-word analysis of the coastal tourism scientific production. Sustainable development, blue growth, sustainability, fishery, environmental economics and tourism were the most frequent keywords with frequency numbers of 27, 10, 7, 6, 4, 4, 4, respectively. This network in Figure 10b also shows an analogy between its keywords and BE keywords, which seems to be logical because coastal tourism is an integral part of BE sectors, and it cannot be discussed in isolation from the general idea of BE. It is noteworthy that terms related to tourism appeared directly and clearly in this network, such as tourism, tourism development and coastal tourism. It is also worthwhile mentioning that there were some keywords related to the two research fields (BE and coastal tourism) that did not appear in the co-word analysis networks. For example, "sustainable tourism," despite its direct and explicit link to the research field, was not represented by any node in the co-word analysis networks.

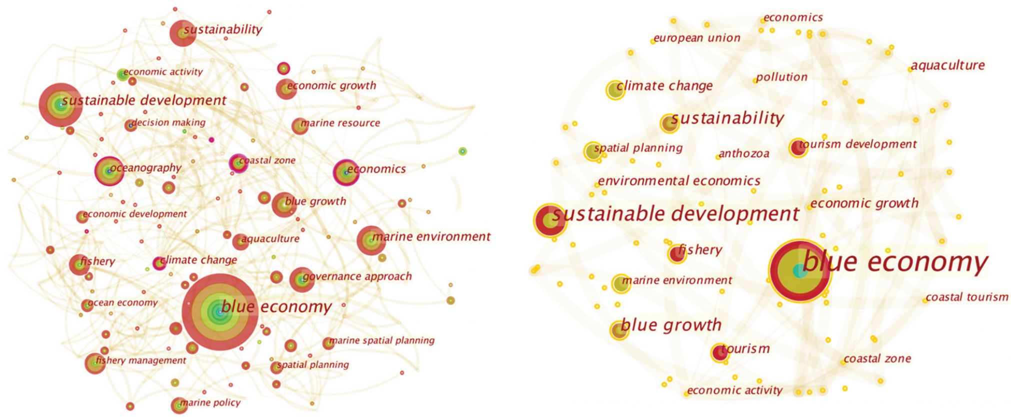


Figure 10. Co-word analysis. (**a**) BE scientific field; (**b**) coastal tourism scientific field. Legend: Node: represents keywords (the size of node represents the keywords frequency); Link: represents relations between keywords (keywords mentioned together in published articles); Colors: represent the temporal orders of appearance of keywords (lighter color means closer time); Outside circle: dark-red circle represents keywords with centrality above 0.1/pivotal keywords). Source: researcher, derived from CiteSpace.

Burst term represents the sudden increase in using a keyword or citing a paper for a certain period of time, and it is vital to identify the research frontier for the focused scientific field [68]. Figure 11a shows a list of nine keywords extracted from BE literature and ranked by the strength of citation burst. The red lines refer to the keyword citation burst, while blue lines refer to the time. In BE scientific production, the top three keywords with the strongest citation bursts were economic activity (4.28), marine engineering (3.06), and coastal zone (2.81). Moreover, by looking to the time period columns in Figure 11a, it can be seen that the early papers published after the emergence of the BE term in 2012 were focused on the main BE pillars. For example, the keywords with the strongest citation bursts were coastal zone and natural resource. Recent studies have discussed the spatial dimension of the BE approach, where the strongest citation burst keywords were Indian Ocean and South Africa, and this depicts the development of BE research frontiers.

Keywords	Year	Strength	Begin	End	2012 – 2020
economic activity	2012	**4.28**	2016	2017	
marine engineering	2012	**3.06**	2017	2017	
coastal zone	2012	**2.81**	2013	2016	
innovation	2012	**2.74**	2015	2018	
indian ocean	2012	**2.61**	2018	2020	
south africa	2012	**2.52**	2019	2020	
natural resource	2012	**2.36**	2013	2015	
ocean observation	2012	**2.1**	2019	2020	
economics	2012	**1.95**	2013	2014	

(a)

Keywords	Year	Strength	Begin	End	2015 – 2020
climate change	2015	**1.39**	2019	2020	
economic activity	2015	**1.22**	2016	2018	
economics	2015	**1.22**	2016	2018	
marine environment	2015	**1.04**	2019	2020	
spatial planning	2015	**1.04**	2019	2020	
blue economy	2015	**0.96**	2019	2020	

(b)

Figure 11. Keyword citation bursts. (**a**) BE scientific field; (**b**) coastal tourism scientific field. Legend: Blue line: represents the period of study; Red line: represents the citation burst period. Source: researcher, derived from CiteSpace.

Moving to the top six strongest citation burst keywords in the coastal tourism scientific field, which appear in Figure 11b, it can be seen that the top-ranked keywords were climate change (1.39), economic activity (1.22), and economics (1.22). Also, by focusing on the relation between the keyword burst and the timespan, it can be concluded that the interest in coastal tourism as a part of BE scientific production appeared in recent years, since four out of the six keywords in Figure 11b appeared between 2019 and 2020 (climate change, marine environment, spatial planning and blue economy). Simultaneously, only two keywords with the strongest citation bursts appeared between 2016 and 2018 (economic activity and economics), which were not considered an early period of time, either.

3.2.2. Reference Analysis

Bibliometrics analysis has many variant indicators, and the co-cited references is one of most significant citation networks in this type of analysis [69]. The reference analysis identifies the articles that received the most citations and that are considered a key reference in the scientific field and highlights these articles' authors [69,70]. Using CiteSpace, a co-cited reference network was built for the two focused scientific fields (BE and coastal tourism), as shown in Figure 12.

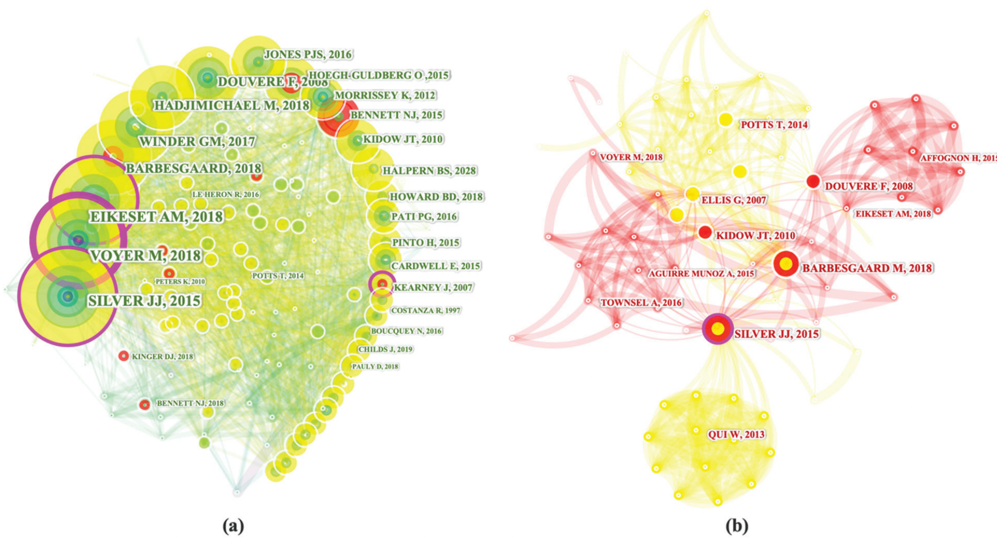


Figure 12. Co-cited reference network. (**a**) BE scientific field; (**b**) coastal tourism scientific field. Legend: Node: represents reference articles (the size of nodes represents the total citation of the references); Link: represents collaborative relations between reference articles; Colors: represent the temporal orders of co-occurrence links between reference articles (outside purple circle represents nodes with centrality above 0.1/key references articles). Source: researcher, derived from CiteSpace.

The co-cited reference clustering network related to BE literature is depicted in Figure 12a. The references that received the highest citations were authored by Silver JJ (2015) [5], Voyer M (2018) [12], Eikset A (2018) [7], Barbsegaard (2018) [71], Winder GM (2017) [72], and Hadjimichael M (2018) [62]. These articles were at the forefront of references cited by BE research papers' authors.

The BE co-cited reference network was divided into nine co-citation clusters and categorized according to time (see Figure 13). The largest cluster was cluster (#0), which was labeled as "blue economy" and contained 110 references. The second largest cluster (#1) had 67 references and was also labeled "blue economy." The third largest, so-called "Irish marine economy," had 43 references. The rest of the clusters were "UK marine" (#3), "sustainable ocean economy" (#4), "marine resource" (#5), "oceans governance" (#6), and "marine science" (#7 and #8).

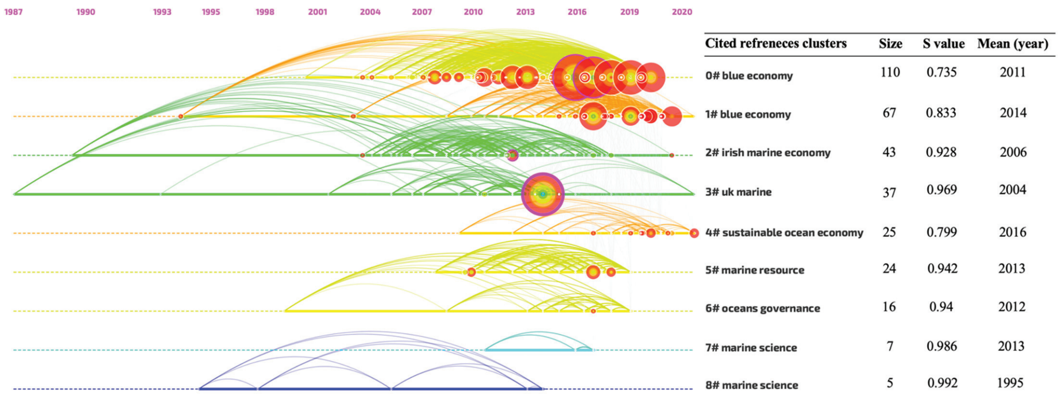


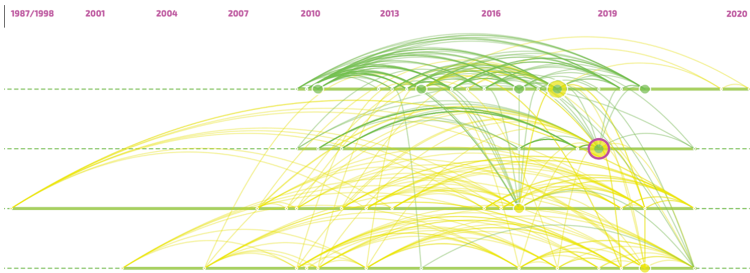
Figure 13. Timeline view of clustered co-cited references in BE scientific field literature. Legend: Node: represents reference articles (the size of nodes represents the total citation of the references); Straight Lines: represent the clusters of references based on the clustering algorithm in CiteSpace; Curved lines: the time periods of cited reference articles. Source: researcher, derived from CiteSpace.

As is clear from Figure 13, the first two clusters had the same title, "blue economy," and they also appeared in the early periods (2011 and 2014) directly after the release of the BE term. This indicates the focusing on references that discussed the definition of the BE concept in general without dealing with complex research studies or application of this approach and analyzing its results. It was also evident that most of the clusters flourished from 2014 to 2020, indicating the novelty of BE as a research field in recent years, which is expected to continue.

It is worthwhile mentioning that each cluster has its own silhouette value (S value), which is one of the structure metrics measuring the homogeneity of the created clusters and developed networks. It takes a value between (1, −1); the closer the S value to 1, the higher the precision and reliability of the cluster. Figure 13 shows the nine BE clusters' S values, ranged between 0.99 (the highest value, cluster #8) and 7.99 (the lowest value, cluster #4). These high S values reflected the validity and reliability of these clusters, which can be trusted in conducting the reference network analysis.

Regarding the co-cited reference network of coastal tourism scientific production, the most cited references were authored by Silver JJ (2015) [5], Barbsegaard (2018) [71], Douvere F (2008) [73], and Kidow JT (2010) [74], as shown in Figure 12b These cited references were divided into four clusters and presented in a time-view co-cited reference network (see Figure 14). The largest cluster (#0) had 27 references and was labeled as "marine national park" with a 0.918 S value. The second largest cluster (#1), also called "marine national park," had 16 references with a 0.961 S value. The third largest cluster (#2) had 15 references and was labeled as "blue economy" with a 0.89 S value. Finally, the fourth cluster (#3) had 15 references with a 0.919 S value and was labeled as "scientific research."

Comparing the co-cited reference networks for the two focused scientific fields (BE and coastal tourism), a vivid similarity was seen between the cited references in these two networks, indicating there was no specialization in the references used in published research papers for both scientific fields.



Cited refreneces clusters	Size	S value	Mean (year)
0# marine national park	27	0.918	2013
1# marine national park	16	0.961	2015
2# blue economy	15	0.89	2011
3# scientific research	15	0.919	2011

Figure 14. Timeline view of clustered co-cited references in coastal tourism scientific field literature. Legend: Node: represents reference articles (the size of nodes represents the total citation of the references); Straight Lines: represent the clusters of references based on the clustering algorithm in CiteSpace; Curved lines: the time periods of cited reference articles. Source: researcher, derived from CiteSpace.

3.3. Relation between Bibliometric Analysis Units

This third bibliometric analysis level demonstrates the relation between the different bibliometric analysis units used to extrapolate the most important observations based on this relationship. The three-fields plot, also known as a Sankey diagram, was the visualization diagram used to depict the relation between three different analytical units. Figure 15 shows the relation between keywords, authors, and sources in the BE scientific field as presented by a three-fields plot. By observing the flow between these three bibliometric analysis units, it can be seen that the main interests of BE scholars were blue economy, ocean economy and fisheries. Moreover, most BE articles were published by Bennett NJ, Voyer M, and Quirk G, while the most active source was *Marine Policy*.

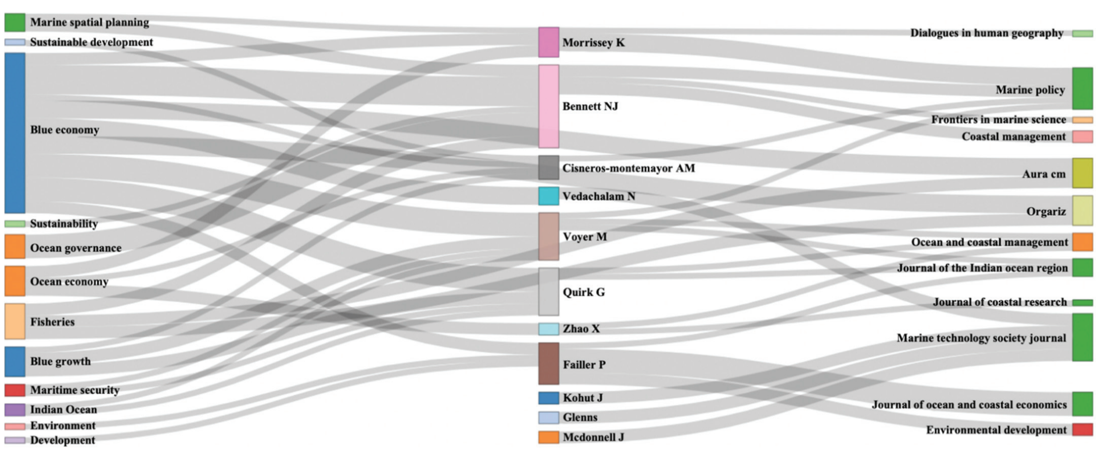


Figure 15. Three-fields plot, relation between keywords (**left**), authors (**middle**), and sources (**right**) for BE literature. Source: researcher, derived from R Programming Language (biblioshiny: web interface of the bibliometrix package).

Figure 16 shows the relation between the same three bibliometric analysis units (keywords, authors, and sources), but in coastal tourism literature. Blue economy was the most researched topic in the coastal tourism scientific field, and it was covered by the most scholars, such as Kolesnikov M and Potts T. Moreover, *Natural Resources Forum* was the leading source publishing articles in coastal tourism literature, based on its collaborations with various authors.

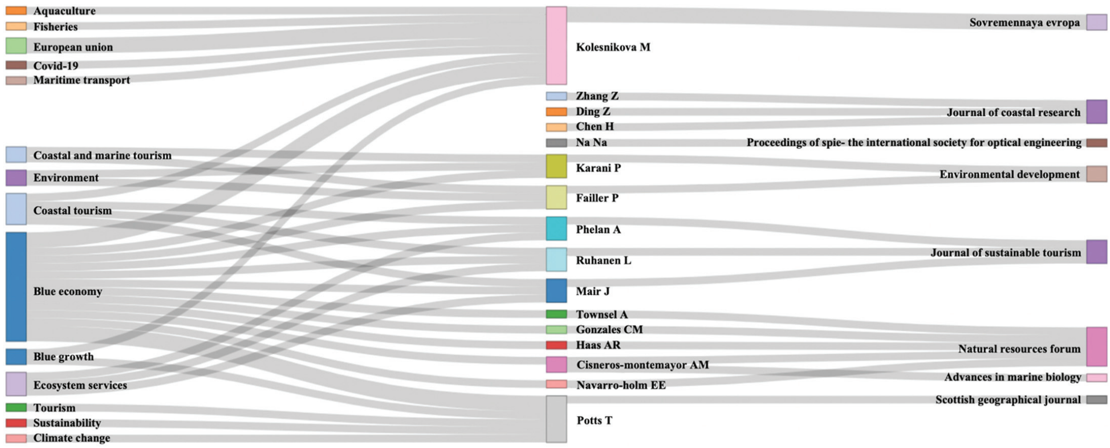


Figure 16. Three-fields plot, relation between keywords (**left**), authors (**middle**), and sources (**right**) for coastal tourism literature. Source: researcher, derived from R Programming Language (biblioshiny: web interface of the bibliometrix package).

4. Conclusions

The literature on the blue economy (BE) scientific field has been increasing dramatically since the term's emergence in the United Nations Conference on Sustainable Development (UNCSD) in 2012 (Rio +20). By reviewing the seven main sectors that formed the BE approach, we found that coastal tourism was the most active BE sector participating in providing job opportunities or sharing in the gross value added (GVA).

This paper aimed to identify and analyze global scientific production in both BE and coastal tourism. Bibliometric analysis was conducted to analyze 476 and 49 publications in BE and coastal tourism, respectively. These data sets were extracted from the Scopus database for 2012–2020, and they were analyzed using different bibliometric techniques and visualization tools, such as co-citation analysis, collaboration analysis, co-word analysis, burst analysis, and dynamics analysis. This paper focused on identifying the comprehensive principle in conducting this bibliometric analysis, so sets of different bibliometric units were precisely analyzed, such as authors, sources, documents, countries, institutions, references, and keywords. Also, this research used three main software packages to conduct the bibliometric analysis and visualize the results, R Programming Language, CiteSpace, and VOSviewer.

The BE bibliometric analysis results were very rich and had various core topics in different disciplines. Furthermore, it has increased significantly over recent years and this is expected to continue. This is in addition to the presence of many journals that participated in publishing BE articles, which reflect the diversity in the topics discussed relating to BE and prove the importance of its various economic sectors.

Through the author analysis of the research articles published in the BE field, we found that there was a collaboration between the most productive authors in this field, but it must be noted that this collaboration took place through specific disciplines within this field (BE sectors), and this reflects the lack of author collaboration between various BE sectors and only focuses on the enrichment of scientific research in each discipline. In the future, this may open the door to discussing the impact that will happen in the scientific production resulting from the collaboration between authors from different BE disciplines, which will enrich this field and create new ideas for future scientific research. Likewise, despite the official emergence of the BE term in 2012 and the abundance of scientific production in this field so far, the most prosperous period has been since 2017, when many scholars participated in publishing articles related to this field and received many citations.

By reviewing the analyses of BE scientific production throughout the countries and the academic institutions that participated in publishing, we found confirmation of the "universality/global" of this research field, and this was evidenced by the participation of about 55% of the countries of the world in the production of research articles related BE, in addition to the diversity of the countries that ranked at the top of the 10 most productive countries according to the scientific production of BE, where these countries represented five different continents (North America, Europe, Australia, Asia, and Africa).

Keyword and reference analysis for BE clearly showed that research trends in this field have gone in three directions: (i) economic and management dimension, which shows interest in economics, governance, fishery management, and decision making; (ii) environmental dimension, which shows interest in sustainable development, sustainability, marine environment, climate change, and blue growth; (iii) spatial dimension, which shows interest in ocean geography, spatial planning, and coastal zone. It also showed the novelty of the BE concept, as the word "blue economy" dominated as a major topic in most published articles with a far higher frequency than the nearest of other words. This indicated that this term still occupied the interest of scholars through its definition and origins; in other words, whatever the idea or the aim of the published articles, the authors discussed the BE definition and mentioned the roots of its appearance.

According to coastal tourism literature, a different manner was observed. In general, the coastal tourism scientific production was poor and most of the articles published in this field did not discuss coastal tourism separately, but discussed it in a combination with the other BE sectors, and this did not correspond with the importance of the coastal tourism sector in the BE approach. Bibliometrics analysis of coastal tourism showed the core topics and the future research interest in two scientific areas: (i) sustainable development, highlighting the negative effects of coastal tourism in the ocean ecosystem; (ii) economic development, which reflects the importance of the economic side of coastal tourism as one of the most significant sectors in the global tourism industry [15]. These two interest areas (sustainability and economy) are two main pillars in BE concept.

Table 3 shows the overall results of the different bibliometric analysis levels and units in this research, divided into the two main scientific fields, BE and coastal tourism.

Table 3. Overall bibliometric analysis results of BE and coastal tourism literatures.

(a) Blue Economy

Ranking	Sources		Authors		Documents		Countries		Institutions	
	Name	NP	Name	NP	Name	TC	Name	NP	Name	NP
Top 1	Marine Policy	42	Na Na	13	Silver JJ, 2015 (Blue Econo.)	109	USA	126	Ocean University of China	17
Top 2	Frontiers in Marine Science	21	Failler P	7	Bueger C, 2015 (What is mar.)	91	UK	80	University of British Columbia	17
Top 3	Journal of the Indian Ocean Region	20	Voyer M	7	Jobstvogt N, 2014 (Looking ble.)	65	Australia	53	Kenya Marine and Fisheries Research Institute	16
Top 4	Journal of Coastal Research	12	Bennett Nj	6	Morrissey K, 2013 (The role o.)	63	Japan	48	University of Washington	13
Top 5	Ocean and Coastal Management	10	Morrissey K	6	Winder GM, 207 (Assembling a.)	50	South Africa	36	University of Wollongong	11

(b) Coastal Tourism

Ranking	Sources		Authors		Documents		Countries		Institutions	
	Name	NP	Name	NP	Name	TC	Name	NP	Name	NP
Top 1	Frontiers in Marine Science	4	Cisneros M	2	Pinto H, 2015 (Cooperation an.)	39	UK	12	Nelson Mandela University	5
Top 2	Marine Policy	3	Kolesnikova M	2	Hadjimichael M, 2018 (A call fo.)	27	South Africa	5	Heriot Watt University	2
Top 3	Journal of Coastal Research	2	Na Na	2	Llewellyn LE, 2016 (A roadma.)	17	Australia	5	Independent Researcher	2
Top 4	Journal of the Indian Ocean Region	2	Potts T	2	Van Den Burg SWK, 2019 (Asses.)	16	Portugal	4	Kenya Marine and Fisheries Research Institute	2
Top 5	Ocean and Coastal Management	2	Aguilar-M	1	Bari A, 2017 (Our oceans an.)	13	Italy	4	Rhodes University	2

Note: NP: number of publications; TC: total citations. Source: researcher, derived from R Programming Language (bibliometrix package).

5. Limitations and Future Research

The main limitations in this study are due to the bibliometric analysis, which was the selected literature review method that the research relied on in analyzing the scientific production of BE and coastal tourism. Using Scopus as the main database for collected literature in this study is considered the first limitation. Although Scopus is one of the largest and most reliable global databases, combining Scopus with other databases such as Web of Science (WOS) may give an opportunity for a deeper bibliometric analysis and thus will lead to better and more reliable results. Furthermore, often in the bibliometric analysis, exclusion criteria are used to refine the collected publications (e.g., paper language; type of documents), and although this research did not address any of these exclusion criteria, determining the time period for the research from 2012 to 2020 may be one of the limitations of this study.

In the future, this research could be conducted by using different research queries, timespan, or bibliometric analysis parameters. Furthermore, this study can be followed with content analysis or any other qualitative analysis methods that can present deep and new information or findings related to BE and coastal tourism.

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Has the COVID-19 Pandemic Affected Maritime Connectivity? An Estimation for China and the Polar Silk Road Countries

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Abstract: In light of about 80% of international freight traffic carried by sea, maritime supply chains' stability is pivotal to global connectivity. For over a year now, the transboundary mobility of vessels and cargoes has been restricted by diverse forms of the COVID-19 containment measures applied by national governments, while the lockdowns of people, businesses, and economic activities have significantly affected the growth prospects of various maritime connectivity initiatives. This study investigates how the pandemic-related public health, trade, and market factors have shifted the connectivity patterns in the Polar Silk Road (PSR) transport corridor between China, South Korea, Japan, Russia, and four economies of Northern Europe. The causality links between the Shipping Connectivity Index (SCI) and the number of COVID-19 cases and deaths, trade volumes with China and the rest of the world, and price indexes of minerals, fuels, food, and agricultural products are revealed separately for eight countries and thirty-five ports. The study algorithm is built on the consecutive application of the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) stationarity tests, the Autoregressive Distributed Lag (ARDL) method, the Fully-Modified Ordinary Least Squares (FMOLS) and the Dynamic Ordinary Least Squares (DOLS) robustness checks, and the Toda-Yamamoto causality test. Tight trade-connectivity links are recorded in all locations along the China-PSR transport corridor in 2015–2019, but in 2020, the relationships weakened. Bidirectional influences between the number of COVID-19 cases and connectivity parameters demonstrate the maritime sector's sensitivity to safety regulations and bring into focus the role of cargo shipping in the transboundary spread of the virus. The authors' four-stage approach contributes to the establishment of a methodology framework that may equip stakeholders with insights about potential risks to maritime connectivity in the China-PSR maritime trade in the course of the pandemic.

Keywords: China; connectivity; COVID-19 pandemic; maritime trade; Polar Silk Road; shipping

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1. Introduction

In just a few months, the COVID-19 outbreak has turned upside down nearly all kinds of economic activities and everyday interactions between people, businesses, and countries. By the first quarter of 2020, the disease had emerged from a health issue to a complex of economic and social problems, almost stopping travel and transboundary mobility and causing unprecedented lockdowns and other painful disruptions to supply chains and global trade [1]. According to the United Nations [2], by the second quarter of 2020, 90% of the world economy had suffered from various kinds of lockdowns. At about the same time, the International Energy Agency [3] reported that nearly 54% of the global population was affected by restrictions to mobility and other forms of social activities and mass gatherings [4]. To a greater or lesser extent, most countries closed their national borders—not only for tourists but also for various types of products [5–7]. Since the bulk of intercountry freight traffic is accounted for by maritime transport [1,8], the maritime community has particularly severely suffered from the pandemic. The United Nations Conference on Trade and Development (UNCTAD) [1] expects the volume of international maritime trade to decline by 4.1% in 2020 amid the projected fall of the world GDP from 2.5% (the best-case scenario from the Word Trade Organization (WTO) [9]) to 6.0% forecasted by the Organization for Economic Co-operation and Development (OECD) [10]. On the other hand, as emphasized by the UNCTAD [1], Notteboom et al. [11], Van Tatenhove [12], Kolesnikova [13], and many other scholars, the pandemic has brought to the fore the utmost significance of maritime transport as an essential mean for ensuring the stability of global supply chains, continuing the delivery of major products across continents, and supporting connectivity between disjointed markets.

The OECD [14] allows about 70% of international trade for global value chains, with China predominating in many of them as either a producer, exporter, or importer of resources, intermediate commodities, or final products. Today, China makes up 16% of global GDP and accounts for 20% of world imports by sea [1]. Since the early 2000s, the shipping sector's increase has been tightly linked to China's skyrocketing economic growth. Considering the fact that China has been hit by the COVID-19 outbreak longer than any other country and practiced the world's strictest virus containment measures (and even total lockdowns in the first half of 2020) it is conceivable that maritime trade has experienced a crushing loss [15]. The UNCTAD [1] records shockwaves across ports in China and worldwide in the forms of declined vessel movements, deployed port operations and warehousing capacities, and quarantine restrictions on vessels and crew [16].

These disruptions may cause shifts in the overall patterns of global maritime trade and value chains [17,18] and suspend China's initiatives in the sphere of maritime connectivity. In 2013, China's President Xi Jinping [19] proposed the Belt and Road Initiative (BRI) with the view to improve logistics, increase trade, and enhance market integration between participating countries [20]. The initial vision of the two constituent parts of the BRI (the Silk Road Economic Belt and the 21st Century Maritime Silk Road) was then expanded in the 2017 Vision for Maritime Cooperation under the Belt and Road Initiative [21] by designating three "blue economic passages"—the China-Indian Ocean-Africa-Mediterranean Sea Blue Economic Passage, the China-Oceania-South Pacific Blue Economic Passage, and the Polar Silk Road (PSR) via the Arctic Ocean [22].

Among the blue passages, the latter has remained the least explored in terms of its potential impact on changing the landscape of maritime trade and potential losses or gains for global maritime connectivity in the course of the pandemic. China's Arctic Policy states that the PSR "facilitates connectivity and sustainable economic and social development of the Arctic" [23] by opening up an economic passage between China and Europe through Russia's Northern Sea Route (NSR) [24,25]. Many scholars have studied the conditions and requirements for trans-Arctic shipping routes to be economically feasible [26–28], analyzed freight traffic between Europe, Russia, China, and other countries of Asia [29–31], and modeled future volumes of transit and cabotage cargo flows with account for climate change [32–36], exploration of mineral and hydrocarbon resources in the High North [37–42], and perspectives of bulk and container transport [35,43–46]. Before the COVID-19 outbreak hit the world, China had planned to redirect up to 1% of its maritime trade to the PSR by the early 2020s [47]. However, with the pandemic emerging into a global economic threat, there have emerged a number of new issues that could derail the PSR initiative [48]. The effects of these new contributing factors must be adequately studied. While the overall impact of the COVID-19 outbreak on maritime trade remains clouded, the PSR-related estimates have appeared to be particularly scarce and fragmented. The China-PSR maritime trade studies have not comprehensively broken trade flows down by categories of cargo. A breakdown by ports along the route from China to Europe (including Russia's NSR ports) is almost missing. Against this background, we attempted to fill the existing lacunas by revealing the pandemic's implications for maritime connectivity and trade in the High North.

2. Materials and Methods

2.1. Countries and Ports

This study includes China and seven countries of Northeast Asia and Northern Europe (in alphabetical order, Denmark (including Greenland), Iceland, Japan, Norway, Russia, South Korea, and Sweden). In each country, we selected major ports located along the potential PSR corridor (in China—largest ports in the northeastern coastal provinces) (Figure 1).

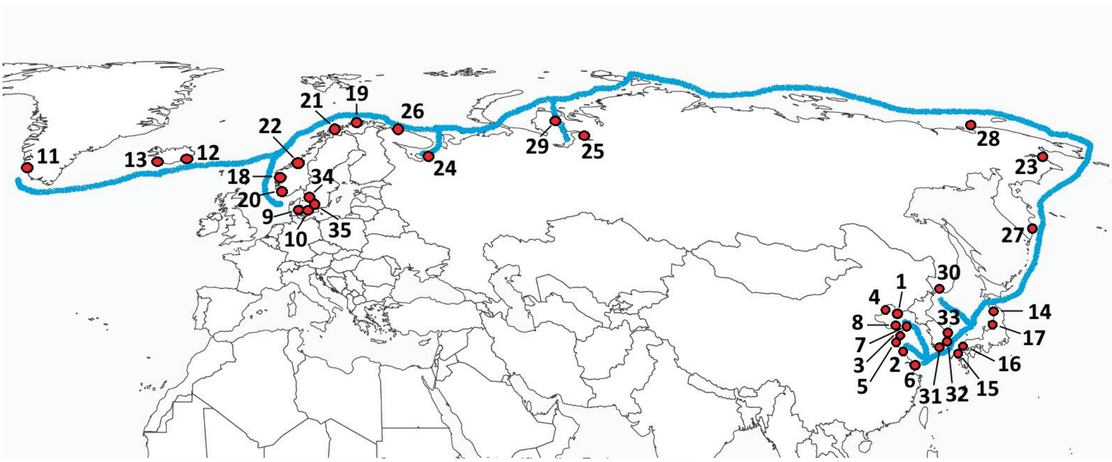

Figure 1. Countries and ports included in the study. Note: 1 = China: Dalian; 2= China: Lianyungang; 3 = China: Qingdao; 4 = China: Qinhuangdao; 5 = China: Rizhao; 6 = China: Shanghai; 7 = China: Weihai; 8 = China: Yantai; 9 = Denmark: Aarhus; 10 = Denmark: Copenhagen; 11 = Greenland: Nuuk; 12 = Iceland: Reydharfjordur; 13 = Iceland: Reykjavik; 14 = Japan: Akita; 15 = Japan: Hakata; 16 = Japan: Kitakyushu; 17 = Japan: Niigata; 18 = Norway: Bergen; 19 = Norway: Hammerfest; 20 = Norway: Stavanger; 21 = Norway: Tromso; 22 = Norway: Trondheim; 23 = Russia: Anadyr; 24 = Russia: Arkhangelsk; 25 = Russia: Dudinka; 26 = Russia: Murmansk; 27 = Russia: Petropavlovsk; 28 = Russia: Pevek; 29 = Russia: Sabetta; 30 = Russia: Vladivostok; 31 = South Korea: Gwangyang; 32 = South Korea: Pusan; 33 = South Korea: Ulsan; 34 = Sweden: Gothenburg; 35 = Sweden: Halmstad. Source: Authors' development.

2.2. Variables and Data

Across the established array of localities, we aim to estimate the possible economic effects of the COVID-19 pandemic on the integration of individual countries and ports into shipping networks with China (in the case of China—into the PSR shipping network). A country's integration level into global shipping networks is commonly measured by the shipping connectivity index (SCI). According to the UNCTAD [49] and the MDS Transmodal [50], the SCI captures the transport connectivity of a country with its counterparts through maritime trade. The index aggregates six parameters of a country's maritime connectivity, such as the number of ship calls per month, deployed capacity of transport vessels, the number of regular shipping services to and from the country, the number of shipping companies that provide such services, the average deadweight of the vessels deployed by shipping services, and the number of countries that are connected to the country through shipping. The SCI is set at 100 for the maximum value of a country's connectivity in the first quarter of 2006, which was China. Respectively, transport connectivity of individual ports is measured by the port shipping connectivity index (PSCI) [49]. Previously, neither the SCI nor the PSCI has been employed to study transport connectivity in the PSR. Still, both indexes have been extensively used as reliable reflections of maritime connectivity in many global-scale studies [17,51–53], as well as local estimations of maritime trade in Asia [54–56] and Europe [57–59].

To reflect the complexity of the pandemic-related factors and their possible influences on the SCI and the PSCI, we used three dimensions of independent variables: direct effects of the pandemic, effects of trade, and market effects (Table 1).

- As the pandemic is still progressing (at the time of this writing, January 2021), it is hardly possible to establish an unambiguous relationship between the spread of the disease, lockdown and containment measures, market fluctuations, economic slowdown, and trade activities. Nevertheless, many scholars, including Ding et al. [60], Baber [61], Erokhin and Gao [62], Ceylan et al. [63], and Mityakov [64], demonstrated the applicability of the number of registered COVID-19 cases in international comparisons of the economic effects of the pandemic. In earlier studies of other outbreaks (SARS, MERS, etc.), Bakalis et al. [65], Poudel et al. [66], and Bhargava et al. [67] also found that economic and trade activities could be associated with morbidity and mortality rates. The confirmed COVID-19 cases and death counts were employed by Nallon [16] to calculate the potential risk of COVID-19 spread related to individual ports. Therefore, we use the monthly number of new confirmed COVID-19 cases (X_1) and the monthly number of new confirmed COVID-19 deaths (X_2) to capture the pandemic's direct effects on the degree of maritime connectivity.
- Regarding the effects of trade on maritime connectivity, we avoid using UNCTAD's seaborne trade measure to ensure the cointegration between the variables. As reported by Liang and Liu [68], Hu et al. [69], Bertho et al. [70], and Chang et al. [56], seaborne trade directly relates to maritime connectivity, and thus it cannot be used as an independent variable in our study. Instead, the influences of trade activities on the SCI and the PSCI are reflected by the country's monthly total exports and imports. Apart from preventing the multicollinearity problem, taking total outbound and inbound trade flows as variables allows us to check whether the role of maritime trade in the total trade turnover of a country has changed during the pandemic. Expressly, we can assume that stronger relationships between shipping connectivity indexes from one side and export and imports from the other can mean a reorientation of total trade towards the maritime sector. To differentiate between the total trade with the world and intra-PSR trade flows, we employ the parameters of total exports to the world (X_3) and exports to China (X_5) (for China, X_5 designates exports to PSR countries) along with total imports from the world (X_4) and imports from China (X_6) (for China, X_6 specifies imports from PSR countries).
- The pandemic has dramatically affected daily economic activities and transportation worldwide [71–73]. Generally, as reported by Černikovaitė and Karazijienė [74], Leach et al. [75], Egger et al. [76], and other scholars, the COVID-driven transformations of the economic environment have been reflected in the behavior patterns of businesses and consumers, i.e., supply and demand shifts in the global market. The most common approach to tracking market volatilities is to monitor prices. That is why we employed the Commodity Price Index (CPI), an average of monthly quotations at a commodity's main marketplace. According to the UNCTAD [77], the CPI is a fixed-base Laspeyres index, where the weights are proportional to the individual commodities' shares in total merchandise exports of a country in the base period (2014–2016). Four independent variables are included in the study to capture the categories of cargo that dominate in the Asia-Russia-Europe transit via the Northern Sea Route (NSR), the so-far primary operating transport passage in the Arctic Ocean [78]: X_7–minerals, ores, and metals; X_8–fuels; X_9–food products; X_{10}–agricultural raw materials and oilseeds.

To reveal the pandemic-driven effects of the independent variables on maritime connectivity, the calculations are made separately for the two periods. First, we find the Y-$X_{3–10}$ relationships in 2015–2019 (January–September in each year, 45 observations in total). Then, we add variables X_1 and X_2 and calculate the Y-$X_{1–10}$ model for the period from January 2020 (when COVID-19 cases were first confirmed outside China) till the end of September 2020 (availability of data for all variables included in the study). In addition to differentiating between the pre-pandemic and pandemic periods, we make separate country-level (eight countries) and port-level (thirty-five ports) calculations, as described below.

Table 1. Variables included in the study.

Index	Variable	Unit of Measure	Definition	Source of Data
Y	Shipping Connectivity Index (SCI) or Port Shipping Connectivity Index (PSCI)	Points	A degree of a country's (port's) integration into global shipping networks	UNCTAD [49,79], MDS Transmodal [50]
X_1	Number of new confirmed COVID-19 cases	Number of cases	Monthly new confirmed COVID-19 cases in a country	Johns Hopkins University of Medicine [80], Our World in Data [81]
X_2	Number of new confirmed COVID-19 deaths	Number of deaths	Monthly new confirmed COVID-19 deaths in a country	Johns Hopkins University of Medicine [80], Our World in Data [81]
X_3	Exports to the world	$ million	Monthly total exports from a country to the world	UNCTAD [79]
X_4	Imports from the world	$ million	Monthly total imports to a country from the world	UNCTAD [79]
X_5	Exports to a country	$ million	Monthly total exports from a country to China (for China–monthly total exports to PSR countries)	UNCTAD [79]
X_6	Imports from a country	$ million	Monthly total imports to a country from China (for China–monthly total imports from PSR countries	UNCTAD [79]
X_7	Commodity Price Index: minerals	Points	Index of monthly prices of minerals, ores, and non-precious metals exported by a country (aluminum, copper, iron ore, lead, manganese ore, nickel, phosphate rock, tin, zinc)	UNCTAD [79]
X_8	Commodity Price Index: fuels	Points	Index of monthly prices of fuels exported by a country (coal, crude oil, natural gas, including liquefied natural gas)	UNCTAD [79]
X_9	Commodity Price Index: food	Points	Index of monthly prices of food products exported by a country (meat and meat products, milk and dairy products, fish and seafood products, sugar, wheat)	UNCTAD [79]
X_{10}	Commodity Price Index: agriculture	Points	Index of monthly prices of agricultural raw materials and oilseeds exported by a country (palm oil, soybean meal, soybean oil, soybeans, sunflower oil)	UNCTAD [79]

Source: Authors' development.

2.3. Methodology Framework

The study goes along the four stages as depicted in Figure 2. We start with checking a cointegration in the established datasets, then investigate short-run and long-run interactions between dependent and independent variables, test the robustness of the results, and complete the study by revealing the causality directions between Y and each of $X_{1–10}$ variables.

Before the dataset is used in the analysis, it is crucial to confirm the stationarity of the dataset and the cointegration between the selected variables [82,83]. At Stage 1, we check the dataset's stationarity by implementing two commonly used methods, the Augmented Dickey-Fuller (ADF) test [84] and the Phillips-Perron (PP) test [85]. The applicability of the combination of the two methods to the short-run and long-run inter-country comparisons of trade parameters and prices have been demonstrated by many scholars, including Chang et al. [82,86], Hoarau [87], Herwartz and Reimer [88], and Aliyev et al. [89].

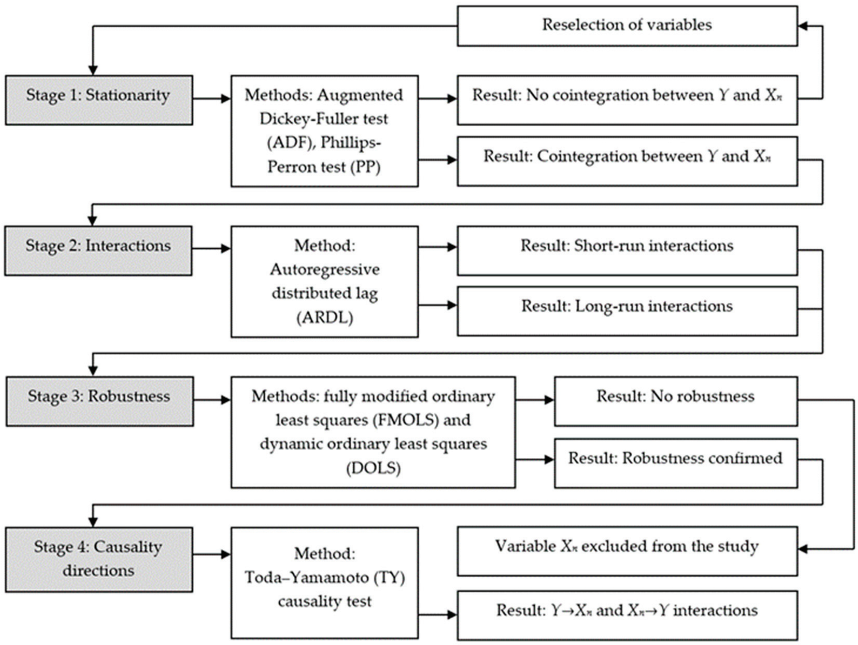

Figure 2. Study algorithm. Source: Authors' development.

Having confirmed the cointegration between Y and independent variables, we apply the autoregressive distributed lag (ARDL) method [90]. Since the early 2000s, this technique has been extensively used in revealing short- and long-run relationships between various macroeconomic parameters, including in trade-related studies [91–95], investigations of market volatilities [96–99], and, most recently, estimations of the economic effects of the COVID-19 pandemic and other outbreaks [62,100]. Two ARDL models are established for studying the Y-$X_{3\text{–}10}$ relationships in 2015–2019 (Equation (1)) and the Y-$X_{1\text{–}10}$ interactions in 2020 (Equation (2)). If F-statistics is larger than the upper critical bounds value [I(1)], the series are cointegrated. If it is below the lower critical bounds [I(0)], the variables are not cointegrated.

$$\begin{aligned}\Delta Y_t \; &= \delta_0 + \sum_{i=1}^{l} \delta_{1i}\Delta Y_{t-i} + \sum_{i=1}^{l} \delta_2 i\, \Delta X3_{t-i} + \sum_{i=1}^{l} \delta_3 i\Delta X4_{t-i} + \sum_{i=1}^{l} \delta_{4i}\, \Delta X5_{t-i} \\ &+ \sum_{i=1}^{l} \delta_{5i}\, \Delta X6_{t-i} + \sum_{i=1}^{l} \delta_{6i}\, \Delta X7_{t-i} + \sum_{i=1}^{l} \delta_{7i}\, \Delta X8_{t-i} + \sum_{i=1}^{l} \delta_{8i}\, \Delta X9_{t-i} \\ &+ \sum_{i=1}^{l} \delta_{9i}\, \Delta X10_{t-i} + \varpi ECT_{t-1} + \varepsilon_{t-i}\end{aligned} \quad (1)$$

$$\begin{aligned}\Delta Y_t \; &= \delta_0 + \sum_{i=1}^{l} \delta_{1i}\Delta Y_{t-i} + \sum_{i=1}^{l} \delta_2 i\, \Delta X1_{t-i} + \sum_{i=1}^{l} \delta_3 i\Delta X2_{t-i} + \sum_{i=1}^{l} \delta_{4i}\, \Delta X3_{t-i} \\ &+ \sum_{i=1}^{l} \delta_5 i\, \Delta X4_{t-i} + \sum_{i=1}^{l} \delta_6 i\, \Delta X5_{t-i} + \sum_{i=1}^{l} \delta_7 i\, \Delta X6_{t-i} + \sum_{i=1}^{l} \delta_8 i\, \Delta X7_{t-i} \\ &+ \sum_{i=1}^{l} \delta_9 i\, \Delta X8_{t-i} + \sum_{i=1}^{l} \delta_{10} i\, \Delta X9_{t-i} + \sum_{i=1}^{l} \delta_{11} i\, \Delta X10_{t-i} + \varpi ECT_{t-1} \\ &+ \varepsilon_{t-i}\end{aligned} \quad (2)$$

where $\mathbf{\Delta}$ = first difference operator; δ_0 = constant term; δ_{1-10} = short-run elasticities of the variables; i = ARDL model lag order; ϖECT_{t-1} = error correction term; ε_t = error disturbance; t = time.

At Stage 3, robustness checks of the short-run and long-run ARDL results are made by implementing a combination of the fully-modified ordinary least squares (FMOLS) and the dynamic ordinary least squares (DOLS) methods, which is an approach previously tested by Yuzbashkandi and Sadi [101], Pasha and Ramzan [102], Erokhin and Gao [62], Adebayo [95], and many other authors. The selection of the FMOLS is explained by the fact that the method allows one to receive consistent parameters even in the small samples in the short-run [62]. For the 2020 array with nine observations, it is a particularly valuable characteristic of the method. Furthermore, as evidenced by Priyankara [103] and Bashier and Siam [104], the FMOLS effectively addresses the problems of endogeneity and serial correlation, which ensures heterogeneity in the variables. The use of the DOLS in combination with the FMOLS helps to estimate the equilibrium that is corrected for potential simultaneity bias among explanatory variables [105]. The use of the DOLS is also advantageous in our study since it applies to small samples in the short term [106].

Stage 4 completes the study's calculation by finding the direction of causalities between Y and $X_{3–10}$ (2015–2019 model) and Y and $X_{1–10}$ (2020 model). The Toda-Yamamoto causality test [107] is used, as previously practiced in investigating causal linkages between economic parameters and non-economic influences of exogenous factors, including the COVID-19 pandemic, by Belaid et al. [108], Erokhin and Gao [62], Ben Amar et al. [109], Amiri and Ventelou [110], and Soytas et al. [111]. The TY value demonstrates a strong causality link between the variables in case of the significance at 1% level (5%—above average, 10%—average, all other cases–weak). In a $[Y \rightarrow X_n; X_n \rightarrow Y]$ pair, the causality can be unidirectional (direct or reverse), bidirectional, or neutral. Based on the parameters of strength and direction of the causality link, we compare the 2015–2019 and the 2020 models to reveal changes in the Y-X_n relationships that can be attributed to the influence of the COVID-19 pandemic on maritime connectivity.

3. Results

3.1. Stationarity of Data

The values of the SCI (eight countries) and the PSCI (35 ports) are calculated separately for the 2015–2019 model (45 observations) and the 2020 model (nine observations) (Appendix A, Table A1). The $X_{3–10}$ and $X_{1–10}$ arrays are established accordingly. The implementation of the ADF and the PP methods to the two arrays of data (2015–2019—see Appendix B, Table A2; 2020—see Appendix B, Table A3) allows us to confirm that all selected variables are stationary at a level of either I(0) or I(1). In both models, the parameter of F-statistics is above the upper bound (Table 2). Therefore, at Stage 1, we find that the preconditions for co-integration between Y and $X_{3–10}$ (2015–2019 dataset) and Y and $X_{1–10}$ (2020 dataset) exist in all countries and ports included in the study. The datasets' stationarity and the co-integration between the variables justify the appropriateness of the models for further analysis.

Table 2. Bound test results, countries.

Countries	F-Statistics	
	2015–2019	2020
China	13.5743	14.0719
Denmark	10.1720	9.1427
Iceland	11.4866	8.3820
Japan	20.0552	21.5932
Norway	9.4003	10.6315
Russia	7.1465	8.4988
South Korea	14.9028	13.1100
Sweden	8.4991	9.1451

Source: Authors' calculation.

3.2. Interactions between Variables

Since the study aims to reveal the fluctuations in Y-X_n relations caused by the pandemic in 2020, the ARDL analysis starts with estimating the short-run patterns. In 2015–2019, the strongest effect on the growth of Y is caused by an increase in trade volumes with the world. For both exports X_3 and imports X_4, this effect is the most significant in Japan, Iceland, and South Korea (Table 3), where the contribution of maritime transport to overall trade turnover was exceptionally high. In China, the influence on maritime connectivity of trade activities with PSR countries is statistically significant, especially in Shanghai, Qingdao, and Dalian (Appendix C, Table A4). When other variables remain constant, a growth of aggregate exports from China to the seven PSR countries by 5% results in the increase in the SCI by 0.25% (0.22% in the case of imports, respectively). Among PSR countries included in the study, maritime connectivity strongly depends on trade with China in Japan, South Korea, and Norway.

The influences of $X_{7–10}$ on Y in the 2015–2019 model are divergent. Thus, we see a relatively strong direct relationship between maritime connectivity and mineral prices in Iceland, Norway, and Russia (major exporters of ores and other minerals) and Japan and South Korea (importers of scarce mineral resources). The strongest Y-X_7 link is recorded in Nuuk (Greenland), Reydharfjordur (Iceland), and Niigata (Japan). The impact of oil prices on Y is weaker than that of mineral prices, along with a reverse relationship in China, Japan, and South Korea. In these countries, a decline in the fuels CPI is associated with more imports and, consequently, an increase in the SCI (the PSCI in Dalian, Lianyungang, Qingdao, Gwangyang, Pusan, and Ulsan). Similar negative relationships between prices and maritime connectivity are observed in [Y; X_9] and [Y; X_{10}] pairs in China, South Korea, and Japan, who are net importers of food and agricultural products.

In 2020, the strengths of many Y-X_n linkages declined. Weaker associations are recorded between maritime connectivity on one side and exports and imports on the other in China, Russia, and Nordic countries (Table 4). Smaller ports experience more considerable losses, for example, Rizhao, Lianyungang, Qinhuangdao, and Weihai in China, Hammerfest and Tromso in Norway, and most of Russia's ports in the Northern Sea Route (Appendix C, Table A5). In Japan and South Korea, whose foreign trade primarily relies on maritime transport, the Y-X_3 and Y-X_4 links became tighter in January–September 2020 compared to the average values in January–September 2015–2019. However, the strengthening of the trade-connectivity linkage is specific to bigger ports (Niigata and Pusan), while in smaller ones, the Y-$X_{3–4}$ association has been weakened (Hakata and Kitakyushu in Japan and Gwangyang and Ulsan in South Korea).

A downward trend is also observed for the influence of China-PSR trade on maritime connectivity. Across all seven countries, exports to China and imports from China contribute less to the SCI index in 2020 than in 2015–2019. In China, an increase in the value of exports to PSR countries by 5% is associated with a growth of maritime connectivity by 0.24%, a decline by 0.01 percentage point compared to the 2015–2019 model. An equal increase in imports results in a growth of the SCI value by 0.20%—a loss of 0.02 percentage points. The most profound drops occur in Shanghai (0.28 percentage points for X_5 and 0.36 percentage points for X_6), Qingdao (0.11 and 0.13 percentage points, respectively), and Yantai (0.10 and 0.08 percentage points, respectively).

The long-run ARDL models confirm the short-run estimates with very few exceptions. In 2015–2019, the long-run contribution of trade with PSR countries to the value of China's maritime connectivity is weaker compared to the short-run estimations (Table 5). In 2020, however, the relationship between China's SCI score and $X_{5–6}$ becomes tighter (Table 6). On the other hand, in some PSR countries, the role of either exports to China (Iceland, Sweden) or imports from China (South Korea) in 2020 increases compared to the average 2015–2019 values. Thus, the Y-X5 link becomes stronger in Reydharfjordur (Iceland), Kitakyushu (Japan), and Ulsan (South Korea), while the strength of the Y-X_6 relationship increases in Reykjavik and Reydharfjordur (Iceland), Gwangyang and Pusan (South Korea), Gothenburg (Sweden), Murmansk (Russia), and Dalian (China) (Appendix D, Tables A6 and A7).

Table 3. ARDL short-run estimates, countries, 2015–2019.

Country	Parameter	ΔX_3	ΔX_4	ΔX_5	ΔX_6	ΔX_7	ΔX_8	ΔX_9	ΔX_{10}	ECM
China	Coefficient	0.1311	0.1785	0.2524	0.2206	0.0411	−0.1552	−0.0207	−0.0561	0.2301
	t-stat	3.2059	−4.0693	2.9733	−3.5291	1.5634	2.0591	3.1298	3.8298	2.7428
	Prob	0.4052 **	0.2951 **	0.6021 **	0.4904 **	0.2830 **	0.2756 **	0.2885 ***	0.1407 ***	0.1082 **
Denmark	Coefficient	0.0820	0.1694	0.0846	0.0337	0.1029	−0.0147	0.0759	0.0934	−0.0503
	t-stat	2.4392	−2.2942	3.0920	−3.1108	1.1406	−4.8388	3.0746	4.5055	1.5509
	Prob	0.3501 **	0.2909 **	0.1701 **	0.2235 *	0.1773 **	0.0440 *	0.0005 **	0.0122 **	0.2182 *
Iceland	Coefficient	0.5100	0.4535	0.3335	0.1609	0.5002	−0.0609	0.0642	0.0316	0.0335
	t-stat	−2.4027	3.5400	−2.2852	2.5574	−1.0043	−3.6201	1.3866	2.0434	4.5820
	Prob	0.1823 ***	0.7512 **	0.3977 **	0.1000 **	0.1904 ***	0.0003 *	0.0013 **	0.0608 **	0.0444 **
Japan	Coefficient	0.7544	0.6524	0.3144	0.3207	0.5194	0.2451	−0.1018	−0.1527	−0.1607
	t-stat	1.4156	2.1003	−3.5023	−2.2909	1.3663	1.2945	2.4083	2.4091	−2.3076
	Prob	0.3723 ***	0.8201 ***	0.4141 ***	0.3410 ***	0.3065 ***	0.1777 **	0.3091 ***	0.4866 ***	0.6389 ***
Norway	Coefficient	0.0942	0.0805	0.1507	0.2154	0.2011	0.5519	0.0504	0.0238	0.2492
	t-stat	2.2709	2.2664	−1.1578	−1.2388	1.7747	3.0004	−2.4025	−2.0777	−1.4883
	Prob	0.1114 **	0.2005 **	0.1942 **	0.0000 **	0.3029 **	0.7035 ***	0.0412 **	0.0561 **	0.1994 **
Russia	Coefficient	0.0826	0.1904	0.0549	0.0662	0.1413	−0.0501	0.0152	0.0105	−0.3596
	t-stat	−2.1527	−1.5388	−2.0285	−2.4019	2.0285	−2.0483	3.7498	3.1023	3.8537
	Prob	0.3491 *	0.4021 **	0.0083 **	0.2898 *	0.2474 **	0.0015 **	0.1753 **	0.1591 *	0.4374 *
South Korea	Coefficient	0.2409	0.3502	0.3046	0.2326	0.4140	0.0930	−0.0502	−0.1287	0.1665
	t-stat	1.3000	1.5556	3.1774	1.5092	2.8287	−1.6282	3.0006	2.4272	1.6097
	Prob	0.3917 ***	0.4834 ***	0.2395 ***	0.3316 ***	0.5286 **	0.0101 **	0.1284 ***	0.1485 ***	0.1116 ***
Sweden	Coefficient	0.2003	0.2013	0.2090	0.1700	0.1104	−0.0674	0.0166	0.0903	−0.2208
	t-stat	−4.4627	−3.5508	−1.3286	−2.0446	2.0537	−2.1260	2.0845	1.5396	−2.2754
	Prob	0.2509 **	0.3627 **	0.1298 **	0.2679 *	0.2952 **	0.1305 *	0.0127 *	0.1877 *	0.1377 *

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

Table 4. ARDL short-run estimates, countries, 2020.

Country	Parameter	ΔX_1	ΔX_2	ΔX_3	ΔX_4	ΔX_5	ΔX_6	ΔX_7	ΔX_8	ΔX_9	ΔX_{10}	ECM
China	Coefficient	−0.0172	0.0029	0.1205	0.1693	0.2412	0.1984	0.0255	−0.1303	−0.0145	−0.0403	0.1977
	t-stat	1.1928	2.4802	4.2918	−5.4827	3.6980	−4.0015	1.1983	2.4550	3.0961	4.9522	3.9584
	Prob	0.0193 *	0.0337 **	0.5891 **	0.4094 **	0.2295 **	0.3791 **	0.0142 *	0.1876 **	0.0198 ***	0.0361 ***	0.2951 **
Denmark	Coefficient	−0.0040	−0.0101	0.0977	0.1185	0.0381	0.0270	0.1309	−0.0095	0.0842	0.0720	−0.0303
	t-stat	3.2801	2.1798	2.9063	−1.0391	3.8555	−4.0053	2.6178	−3.9487	4.4275	5.2973	2.4981
	Prob	0.1225 *	0.3415 *	0.2988 **	0.0794 **	0.1862 *	0.2062 *	0.0526 **	0.0293 *	0.0860 *	0.0056 *	0.0922 *
Iceland	Coefficient	0.0027	0.0064	0.4954	0.4286	0.3004	0.1487	0.4550	−0.0008	0.0555	0.0064	0.0193
	t-stat	2.9024	3.0540	−3.1171	4.6032	−3.0978	3.8684	−1.2095	−2.5365	1.4736	2.9021	3.6466
	Prob	0.2870 *	0.1996 *	0.2095 ***	0.3117 ***	0.2719 **	0.1396 **	0.0281 ***	0.0000 *	0.0001 **	0.0003 **	0.0295 **
Japan	Coefficient	−0.3015	−0.1855	0.7926	0.6860	0.2981	0.3106	0.5527	0.2117	−0.1204	−0.1835	−0.1320
	t-stat	−3.5523	−2.8473	1.5930	2.4877	−3.9615	−2.5493	1.4902	2.0836	3.9223	2.8504	−1.4955
	Prob	0.4984 ***	0.3861 ***	0.5983 ***	0.6994 ***	0.2755 ***	0.3987 ***	0.2653 ***	0.0584 **	0.1887 ***	0.2309 ***	0.3091 ***
Norway	Coefficient	−0.0452	−0.0384	0.0527	0.0695	0.1141	0.2095	0.1844	0.5763	0.0646	0.0053	0.2094
	t-stat	−1.0836	−2.3918	3.1951	2.7070	−1.0479	−1.1704	2.0596	3.4609	−1.2984	−2.5918	−1.0672
	Prob	0.1179 **	0.3251 **	0.0592 **	0.0486 **	0.0185 *	0.0278 *	0.1035 **	0.8848 ***	0.0390 **	0.0442 **	0.0333 **
Russia	Coefficient	0.0041	0.0292	0.0689	0.1274	0.0202	0.0385	0.1300	−0.0487	0.0053	0.0127	−0.3890
	t-stat	4.8560	3.6005	−2.0576	−1.7066	−2.2367	−1.5092	2.5982	−3.1052	1.5295	2.0004	4.1987
	Prob	0.2957 **	0.3146 **	0.2208 *	0.3517 *	0.1985 *	0.0188 *	0.2397 *	0.0006 *	0.0049 *	0.1156 *	0.4912 *
South Korea	Coefficient	0.0666	0.0718	0.2985	0.3020	0.2563	0.1900	0.4005	0.0825	−0.0415	−0.0923	0.1475
	t-stat	−2.1947	−2.0987	1.6096	1.8044	2.0054	1.4553	2.6360	−1.4044	2.4986	2.8921	1.8259
	Prob	0.3021 ***	0.2451 ***	0.1239 ***	0.2508 ***	0.1946 ***	0.3409 ***	0.6931 **	0.0036 **	0.0318 ***	0.0197 ***	0.0504 ***
Sweden	Coefficient	0.0003	0.0036	0.1753	0.2113	0.2291	0.1486	0.1054	−0.0592	0.0014	0.0965	−0.2095
	t-stat	1.6398	2.4019	−5.5094	−4.3005	−1.1982	−2.3075	1.9945	−3.0758	1.7095	2.0349	−3.1199
	Prob	0.0520 *	0.0481 *	0.1398 **	0.1864 **	0.0097 *	0.0392 *	0.1708 **	0.0505 *	0.0000 *	0.0038 *	0.0008 *

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

Table 5. ARDL long-run estimates, countries, 2015–2019.

Country	Parameter	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Constant
China	Coefficient	0.1523	0.1620	0.2208	0.2019	0.0506	−0.1713	−0.0499	−0.0668	3.2612
	t-stat	3.4128 **	−3.5982 **	2.5052 **	−3.0276 **	1.3049 **	2.1445 **	3.4091 ***	2.1367 ***	2.1553
Denmark	Coefficient	0.1859	0.1415	0.1100	0.0542	0.1233	−0.0285	0.0521	0.0840	−2.0788
	t-stat	2.0024 **	−2.1387 **	2.4719 **	−3.6528 *	1.5621 **	−4.2872 *	2.4865 **	4.1726 **	−1.7262
Iceland	Coefficient	0.5724	0.4736	0.3004	0.1811	0.6376	−0.0883	0.0404	0.0551	5.1285
	t-stat	−2.3182 ***	3.1671 **	−1.8638 **	2.9512 **	−1.8170 ***	−3.9166 *	1.6523 **	2.6600 **	3.4109
Japan	Coefficient	0.7169	0.6882	0.3230	0.3592	0.5441	0.2610	−0.1332	−0.1775	−3.2458
	t-stat	2.0584 ***	2.8509 ***	−3.2099 ***	−2.6091 ***	1.6730 ***	1.5094 **	2.9615 ***	1.3409 ***	−4.5091
Norway	Coefficient	0.1002	0.0995	0.1784	0.2592	0.2240	0.5607	0.0612	0.0309	2.2493
	t-stat	2.4081 **	2.1682 **	−1.2955 **	−1.4187 **	2.1483 **	3.3021 ***	−2.5443 **	−2.3183 **	2.6991
Russia	Coefficient	0.0995	0.2309	0.0707	0.0831	0.1715	−0.0773	0.0170	0.0148	−3.3399
	t-stat	−2.5023 *	−1.7192 **	−2.1973 **	−2.6886 *	2.3091 **	−2.4088 **	2.0493 **	4.8122 *	−3.2942
South Korea	Coefficient	0.2677	0.3069	0.3330	0.2045	0.4509	0.0847	−0.0742	−0.1309	5.2700
	t-stat	1.3920 ***	1.8491 ***	3.8186 ***	2.2353 ***	3.5412 **	−2.0596 **	4.1827 ***	2.5511 ***	2.3818
Sweden	Coefficient	0.2145	0.2346	0.2155	0.1764	0.1399	−0.0472	0.0334	0.0916	−5.0376
	t-stat	−4.8921 **	−3.0830 **	−1.9188 **	−2.5616 *	2.3984 **	−1.0001 *	3.5925 *	1.6810 *	−3.5922

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

Table 6. ARDL long-run estimates, countries, 2020.

Country	Parameter	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Constant
China	Coefficient	−0.0209	0.0045	0.1018	0.1576	0.2665	0.2301	0.0305	−0.1447	−0.0160	−0.0562	5.2815
	t-stat	1.5622 *	1.9832 **	3.3090 **	−5.8935 **	4.4587 **	−4.5634 **	1.4986 *	3.5981 **	3.2999 ***	3.6645 ***	3.1874
Denmark	Coefficient	−0.0113	−0.0222	0.0626	0.1409	0.0453	0.0465	0.1003	−0.0160	0.0764	0.0650	−6.2966
	t-stat	3.5620 *	2.6874 *	3.5527 **	−1.5412 **	3.3300 *	−4.1384 *	2.7056 **	−3.4885 *	4.6081 *	5.4817 *	−1.1383
Iceland	Coefficient	0.0098	0.0100	0.4215	0.4005	0.3196	0.1350	0.4084	−0.0023	0.0508	0.0053	4.2650
	t-stat	2.4091 *	3.3958 *	−3.7402 ***	3.7756 ***	−3.2091 **	3.4987 **	−2.6019 ***	−2.9044 *	1.7750 **	2.3601 **	2.5948
Japan	Coefficient	−0.3349	−0.1505	0.7414	0.6629	0.2448	0.3231	0.5367	0.2340	−0.1506	−0.2064	−3.4896
	t-stat	−3.0072 ***	−2.2061 ***	1.7750 ***	2.0026 ***	−3.5093 ***	−2.2297 ***	1.5873 ***	2.3851 **	4.6095 ***	2.3091 ***	−4.7750
Norway	Coefficient	−0.0506	−0.0512	0.0680	0.0804	0.1237	0.2095	0.2066	0.5391	0.0572	0.0088	3.2409
	t-stat	−1.2347 **	−2.1985 **	3.0221 **	2.5875 **	−1.2091 *	−1.1986 *	2.3914 **	3.0056 ***	−2.4095 **	−2.7093 **	2.1778
Russia	Coefficient	0.0059	0.0308	0.0735	0.1509	0.0334	0.0405	0.1276	−0.0627	0.0084	0.0103	−4.0516
	t-stat	4.0692 **	3.4813 **	−2.3918 *	−1.5601 *	−2.5963 *	−1.2761 *	2.1052 *	−3.6091 *	1.0016 *	2.3967 *	−3.0793
South Korea	Coefficient	−0.0987	−0.0570	0.3408	0.2694	0.2409	0.2063	0.4168	0.0705	−0.0506	−0.0848	2.5908
	t-stat	−2.4094 ***	−2.3091 ***	1.4915 ***	1.6021 ***	2.5710 ***	1.7092 ***	2.0594 **	−2.9776 **	2.1741 ***	2.3999 ***	2.0007
Sweden	Coefficient	0.0010	0.0052	0.1529	0.2073	0.2196	0.1500	0.1234	−0.0601	0.0025	0.0807	−4.0675
	t-stat	2.3881 *	2.0655 *	−4.1884 **	−3.8996 **	−1.3609 *	−2.4861 *	1.8602 **	−3.1498 *	1.4082 *	2.2061 *	−3.2981

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

In both short-run and long-run ARDL estimations for the 2020 model (Tables 4 and 6), we see how the values of the maritime connectivity at the country and port levels are affected by the number of confirmed COVID-19 cases and deaths (or rather lockdowns and restrictions imposed to maritime transportation due to the pandemic). It is safe to assume that the pandemic-related logistics constraints are reflected in the connectivity index body through a decrease in the number of ship calls at ports or a breakdown of shipping services between countries. Still, we identify associations between $X_{1–2}$ and Y in all eight countries, though of varying strength and direction. The strongest negative link between Y and X_1 (an increase in the number of COVID-19 cases is associated with a decrease in maritime connectivity) is observed in Japan and South Korea, the two countries that have been most severely hit by the COVID-19 outbreak among those included in the study. In China, where the number of COVID-19 cases has been much lower compared to that in the countries of Asia, Northern Europe, and Russia (while the spread of the virus was curbed in the first half of 2020), an adverse effect of X_1 on Y is negligible. In those countries where the lockdowns have been relatively mild (Sweden, Russia) or the number of COVID-19 cases has remained low (Iceland, Greenland), the Y-$X_{1–2}$ linkages are weak.

3.3. Robustness Test

The employment of the FMOLS and DOLS tests demonstrates the ARDL estimates' robustness in both the 2015–2019 and the 2020 models. The number of new confirmed COVID-19 cases is confirmed to result in lower maritime connectivity levels in Japan and South Korea (significance at 1% level) and, to a lesser extent, in Norway, Denmark, and China (Table 7).

The impact of the number of new confirmed COVID-19 deaths on the SCI is noticeably lower across all eight economies. This difference can be attributed to the fact that governments have been attempting to curb the transboundary spread of the virus by introducing restrictions based on the number of new cases. The number of deaths is an indicator of how national health care systems have coped with the pandemic, rather than a parameter of stringency of logistics and economic restrictions.

When comparing the 2020 estimations with the 2015–2019 FMOLS and DOLS test results (Table 8), we should emphasize tighter linkages between maritime connectivity and trade-related variables in the pre-pandemic period. The prevalence of statistically strong interplays between Y and $X_{3–4}$ is confirmed in Japan, South Korea, and Iceland. The China-PSR trade paradigm is particularly relevant for maritime connectivity in Japan and South Korea (significance at 1% level for both exports and imports), Norway and Iceland (significance at 5% level), and Denmark, Russia, and Sweden (significance at 5% level for exports to China). In the case of China, the robustness test does not show an essential strengthening of Y-$X_{5–6}$ linkages in 2020 compared to 2015–2019, but the interplays in [Y; X_5] and [Y; X_6] pairs remain statistically strong both before and during the pandemic.

Regarding prices of minerals, fuels, and food and agricultural products, the FMOLS-DOLS test confirms earlier revealed ARDL estimates. We see that in net importing economies, a decrease in prices exerts a reverse influence on the maritime connectivity. The strongest effects of this kind are observed in Japan, South Korea, and China for food and agricultural products, as well as in China, Denmark, Iceland, Sweden, and South Korea for oil, natural gas, and coal. In net exporting countries, the prices-connectivity relationship is commonly direct, for example, in Iceland, Russia, Norway, Sweden, and Denmark for minerals, Norway and Russia for fuels, and Denmark, Iceland, Norway, Sweden, and Russia for food and agricultural products.

3.4. Causality Directions

The TY test demonstrates the most significant causality flowing from the number of new confirmed COVID-19 cases to maritime connectivity in South Korea, Japan, and China. As revealed earlier, the number of COVID-19 deaths has no real impact on changes in the SCI score (Table 9).

Table 7. FMOLS and DOLS tests results, countries, 2020.

Country	Parameter	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Constant
China	FMOLS coefficient	−0.0187	0.0041	0.1156	0.1344	0.2406	0.2220	0.0243	−0.1316	−0.0153	−0.0504	5.1438
	FMOLS t-stat	1.4153 *	1.5385 **	3.0287 **	−5.6193 **	4.2857 **	−4.3451 **	1.0054 *	3.2852 **	3.1709 ***	3.3572 ***	4.2065
	DOLS coefficient	−0.0130	0.0054	0.0983	0.1197	0.2181	0.1956	0.0250	−0.1247	−0.0147	−0.0427	5.0032
	DOLS t-stat	1.6831 *	1.2042 **	2.4321 **	−4.3852 **	4.0729 **	−4.1328 **	1.0396 *	2.7953	3.0865 ***	3.1845 ***	4.1739
Denmark	FMOLS coefficient	−0.0105	−0.0016	0.0578	0.1354	0.0412	0.0424	0.0975	−0.0140	0.0723	0.0631	−6.3945
	FMOLS t-stat	3.1548 *	2.2000 *	3.3132 **	−1.3805 **	3.1844 *	−4.0538 *	2.5214 **	−3.2481 *	4.4808 *	5.1536 *	−3.0082
	DOLS coefficient	−0.0127	−0.0088	0.0615	0.1442	0.0383	0.0415	0.0827	−0.0125	0.639	0.0528	−5.2631
	DOLS t-stat	3.2740 *	2.3523 *	3.2057 **	−1.2790 **	3.2567 *	−4.1782 *	2.6064 **	−3.1225 *	4.2055 *	5.2552 *	−4.3994
Iceland	FMOLS coefficient	0.0084	0.0097	0.4153	0.3886	0.3093	0.1290	0.4158	−0.0014	0.0457	0.0049	4.1486
	FMOLS t-stat	2.1095 *	3.1684 *	−3.2584 ***	3.5940 ***	−3.1875 **	3.2368 **	−2.3362 ***	−2.0740 **	1.6521 **	2.0748 **	3.5509
	DOLS coefficient	0.0069	0.0080	0.3968	0.3732	0.3149	0.1321	0.3967	−0.0035	0.0553	0.0037	4.0043
	DOLS t-stat	2.3804 *	3.2515 *	0.4251 ***	3.2049 ***	−3.2648 **	3.3489 **	−2.1680 ***	−1.8589 **	1.4474 **	2.1485 **	3.2817
Japan	FMOLS coefficient	−0.3077	−0.0339	0.6826	0.6537	0.2234	0.3006	0.5163	−0.1144	−0.1361	−0.1750	−4.6700
	FMOLS t-stat	−2.4985 ***	−2.0376 ***	1.5485 ***	2.1940 ***	−3.1555 ***	−2.1348 ***	1.2850 ***	2.0379 **	4.2683 ***	2.1322 ***	−3.3574
	DOLS coefficient	−0.3150	−0.0532	0.7038	0.6218	0.2165	0.2872	0.4734	−0.1352	−0.1075	−0.1894	−4.2382
	DOLS t-stat	−3.0064 ***	−2.1011 ***	1.4624 ***	2.0741 ***	−3.2902 ***	−2.3641 ***	1.3258 ***	2.1567 **	4.1954 ***	2.2051 ***	−3.8595
Norway	FMOLS coefficient	−0.0487	−0.0094	0.0635	0.0746	0.1053	0.2140	0.1846	0.5250	0.0495	0.0082	3.1570
	FMOLS t-stat	−1.0039 **	−2.0830 **	3.0000 **	2.2566 **	−1.1845 *	−1.1283 *	2.2952 **	3.1227 ***	−2.2211 **	−2.3549 **	2.2064
	DOLS coefficient	−0.0406	−0.0113	0.0597	0.7212	0.1190	0.2036	0.1703	0.4942	0.0468	0.0074	3.1282
	DOLS t-stat	−1.0158 **	−2.1947 **	3.0516 **	2.1337 **	−1.0698 **	−1.2562 **	2.1784 **	3.1396 ***	−2.1690 **	−2.1513 **	2.3975
Russia	FMOLS coefficient	0.0047	0.0286	0.0744	0.1368	0.0312	0.0395	0.1069	0.0648	0.0076	0.0114	−4.0373
	FMOLS t-stat	4.0254 **	3.3485 **	−2.1586 *	−1.4195 *	−2.1877 *	−1.2136 *	2.0625 *	−3.5351 *	1.0350 *	2.1538 *	−3.2480
	DOLS coefficient	0.0039	0.0251	0.0600	0.1206	0.0290	0.0253	0.1123	−0.0774	0.0137	0.0152	−4.1488
	DOLS t-stat	4.0160 **	3.1492 **	−2.1173 **	−1.3017 **	−2.2184 *	−1.1545 *	1.9258 *	−3.1695 *	1.2594 *	2.2705 *	−3.3694
South Korea	FMOLS coefficient	−0.0916	−0.0134	0.3142	0.2355	0.2138	0.1850	0.3867	−0.1684	−0.0482	−0.0758	2.6212
	FMOLS t-stat	−2.2475 ***	−2.4872 ***	1.2676 ***	1.4772 ***	2.2754 ***	1.4431 ***	2.0258 **	−2.4376 **	2.0863 ***	2.1450 ***	2.3597
	DOLS coefficient	−0.0723	−0.0165	0.2890	0.2142	0.1849	0.1942	0.4250	−0.1593	−0.0490	−0.0649	2.5073
	DOLS t-stat	−2.0649 ***	−2.1840 ***	1.3574 ***	1.2095 ***	2.0687 ***	1.5185 ***	1.8637 **	−2.5499 **	1.9317 ***	2.2478 ***	2.4826
Sweden	FMOLS coefficient	0.0013	0.0048	0.1349	0.2146	0.1960	0.1414	0.1066	−0.0583	0.0021	0.0796	−4.0918
	FMOLS t-stat	2.2454 *	1.7487 *	−4.0268 **	−3.6384 **	−1.2694 *	−2.1342 *	1.5284 **	−3.0574 *	1.3780 *	2.1347 *	−3.4275
	DOLS coefficient	0.0017	0.0030	0.1253	0.1852	0.1775	0.1286	0.1127	−0.0439	0.0033	0.0625	−4.1207
	DOLS t-stat	2.1056 **	1.5389 **	−3.7995 **	−3.2591 **	−1.3038 **	−2.2963 *	1.6435 **	−2.5665 **	1.2684 *	2.0000 **	−3.3590

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

Table 8. FMOLS and DOLS tests results, countries, 2015–2019.

Country	Parameter	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Constant
China	FMOLS coefficient	0.1862	0.1527	0.2418	0.2135	0.0542	−0.1893	−0.0536	−0.0624	3.3891
	FMOLS t-stat	2.7265 **	−3.8184 **	2.4633 **	−3.1632 **	1.3490 **	2.2002 **	3.6289 ***	2.2016 ***	2.4400
	DOLS coefficient	0.1900	0.1301	0.2147	0.2470	0.0584	−0.1625	−0.0577	−0.0680	3.1576
	DOLS t-stat	3.5528 **	−2.3710 **	2.3592 **	−3.0083 **	1.5746 **	2.0371 **	3.5825 ***	2.4672 ***	2.5965
Denmark	FMOLS coefficient	0.1753	0.1569	0.1251	0.0536	0.1285	−0.0310	0.0531	0.0865	−2.1327
	FMOLS t-stat	1.9791 **	−2.1062 **	2.4604 **	−3.7518 *	1.5703 **	−4.2592 *	2.6094 **	4.1541 **	−1.6056
	DOLS coefficient	0.1684	0.1638	0.1309	0.0522	0.1052	−0.0286	0.0627	0.0970	−2.1594
	DOLS t-stat	2.1550 **	−2.0571 **	2.3700 **	−3.6295 *	1.6481 **	−4.0007 *	2.4862 **	3.8253 **	−1.7380
Iceland	FMOLS coefficient	0.5562	0.4506	0.3185	0.1900	0.6673	−0.0924	0.0458	0.0586	5.2462
	FMOLS t-stat	−2.3673 ***	3.0021 **	−1.7370 **	2.8725 **	−1.7241 ***	−3.8712 *	1.7004 **	2.5432 **	3.5117
	DOLS coefficient	0.5159	0.4425	0.3213	0.1747	0.6208	−0.0853	0.0573	0.0594	5.2085
	DOLS t-stat	−2.4851 ***	3.2174 **	−1.6536 **	2.7582 **	−1.6532 ***	−3.6905 *	1.6841 **	2.6709 **	3.2439
Japan	FMOLS coefficient	0.7083	0.6910	0.3057	0.3447	0.5613	−0.1342	−0.1463	−0.1800	−3.0557
	FMOLS t-stat	2.1360 ***	2.7382 ***	−3.1725 ***	−2.5184 ***	1.7481 ***	1.5397 ***	3.1205 ***	1.2941 ***	−4.4186
	DOLS coefficient	0.6749	0.6425	0.3158	0.3085	0.5357	−0.1308	−0.1738	−0.1752	−3.7305
	DOLS t-stat	2.5261 ***	2.6957 ***	−3.2621 ***	−2.4850 ***	1.6232 ***	1.4841 ***	3.3463 ***	1.5384 ***	−3.8419
Norway	FMOLS coefficient	0.1106	0.0844	0.1625	0.2492	0.2383	0.5325	0.0676	0.0375	2.3568
	FMOLS t-stat	2.4295 **	2.2598 **	−1.2463 **	−1.3051 **	2.3966 **	3.2692 ***	−2.3315 **	−2.1632 **	2.2571
	DOLS coefficient	0.0918	0.0793	0.1792	0.2174	0.2157	0.5046	0.0582	0.0491	2.4915
	DOLS t-stat	2.3704 ***	2.3201 ***	−1.3758 **	−1.2593 **	2.0582 **	3.0001 ***	−2.4071 **	−2.0586 **	2.0868
Russia	FMOLS coefficient	0.0937	0.2257	0.0759	0.0890	0.1693	0.0728	0.0185	0.0257	−3.4036
	FMOLS t-stat	−2.7251 *	−1.8942 **	−2.3682 **	−2.4173 *	2.5256 **	−2.2735 **	2.1263 **	4.6280 *	−3.0157
	DOLS coefficient	0.0863	0.2084	0.0483	0.0752	0.1508	−0.0594	0.0242	0.0199	−3.3885
	DOLS t-stat	−2.4009 **	−1.7511 **	−2.7500 **	−2.1845 *	2.4775 **	−2.5002 **	2.0736 **	3.2875 **	−2.8730
South Korea	FMOLS coefficient	0.2416	0.2897	0.3149	0.1746	0.4369	−0.1715	−0.0695	−0.1488	5.1404
	FMOLS t-stat	1.1875 ***	1.5096 ***	3.7490 ***	2.0289 ***	3.1830 **	−1.8154 **	4.0051 ***	2.3269 ***	3.9748
	DOLS coefficient	0.2193	0.2795	0.3287	0.1980	0.4068	−0.1729	−0.5704	−0.1267	4.2541
	DOLS t-stat	1.0632 ***	1.6006 ***	3.4211 ***	1.7176 ***	3.0127 **	−1.9952 **	3.9827 ***	2.0946 ***	3.8826
Sweden	FMOLS coefficient	0.1709	0.2053	0.1900	0.1538	0.1247	−0.0414	0.0285	0.0874	−5.0107
	FMOLS t-stat	−4.5286 **	−3.1602 **	−1.7396 **	−2.3871 *	2.0093 **	−1.1987 *	3.1994 *	1.3086 *	−3.2485
	DOLS coefficient	0.1047	0.1886	0.1794	0.1604	0.1309	−0.0355	0.0305	0.0500	−4.7526
	DOLS t-stat	−3.9405 ***	−3.2943 ***	−1.5708 **	−2.0175 *	1.8548 **	−1.2893 **	2.4685 **	1.4429 *	−3.5982

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

Table 9. TY causality test results, countries, 2015–2019 and 2020.

Causality Directions	Parameter	China		Denmark		Iceland		Japan		Norway		Russia		South Korea		Sweden	
		2015-19	2020	2015-19	2020	2015-19	2020	2015-19	2020	2015-19	2020	2015-19	2020	2015-19	2020	2015-19	2020
$Y \rightarrow X_1$	TS		3.05		4.66		0.85		7.31		0.46		3.02		6.11		1.06
	P		0.09 *		0.08 *		0.66		0.04 **		0.77		0.09 *		0.04 **		0.49
$X_1 \rightarrow Y$	TS		5.58		1.53		0.64		3.04		0.58		0.39		5.80		0.90
	P		0.08 *		0.27		0.79		0.08 *		0.69		0.50		0.04 **		0.53
$Y \rightarrow X_2$	TS		1.86		1.04		0.62		1.10		0.37		0.86		0.83		1.01
	P		0.45		0.35		0.80		0.26		0.80		0.44		0.37		0.50
$X_2 \rightarrow Y$	TS		0.72		0.90		0.55		1.39		0.51		0.30		3.25		0.86
	P		0.68		0.44		0.83		0.15		0.72		0.59		0.09 *		0.54
$Y \rightarrow X_3$	TS	13.07	15.46	3.65	1.75	2.18	1.94	9.15	16.22	7.37	9.70	0.85	0.98	12.69	10.26	0.77	4.05
	P	0.00 ***	0.00 ***	0.15	0.22	0.27	0.36	0.01 **	0.00 ***	0.05 *	0.03 **	0.44	0.40	0.02 **	0.01 **	0.37	0.06 *
$X_3 \rightarrow Y$	TS	8.88	6.84	6.46	7.15	9.09	9.95	13.56	13.25	5.29	5.83	0.63	3.21	19.67	7.42	3.88	2.23
	P	0.03 **	0.06 *	0.07 *	0.07 *	0.02 **	0.03 **	0.00 ***	0.00 ***	0.08 *	0.07 *	0.52	0.09 *	0.00 ***	0.03 **	0.06 *	0.12
$Y \rightarrow X_4$	TS	10.50	13.09	2.98	1.26	2.00	1.14	10.95	14.40	4.31	8.88	1.14	1.18	12.25	15.42	0.66	1.47
	P	0.02 **	0.00 ***	0.28	0.30	0.31	0.57	0.00 ***	0.00 ***	0.09 *	0.04 **	0.29	0.36	0.02 **	0.00 ***	0.42	0.30
$X_4 \rightarrow Y$	TS	10.98	7.25	6.12	7.00	8.16	8.52	12.04	13.13	7.02	7.69	1.66	3.90	17.50	6.84	2.79	3.79
	P	0.02 **	0.05 *	0.07 *	0.07 *	0.03 **	0.04 **	0.00 ***	0.00 ***	0.05 *	0.05 *	0.15	0.07 *	0.00 ***	0.04 **	0.08 *	0.07 *
$Y \rightarrow X_5$	TS	11.35	12.96	0.51	3.46	1.37	4.44	2.82	7.27	0.58	2.06	0.43	0.34	8.74	13.70	0.58	1.86
	P	0.00 ***	0.00 ***	0.76	0.08 *	0.40	0.09 *	0.08 *	0.04 **	0.79	0.22	0.62	0.52	0.05 *	0.00 ***	0.45	0.22
$X_5 \rightarrow Y$	TS	6.72	5.24	7.84	9.41	11.24	11.17	9.55	4.54	10.13	5.20	1.00	1.41	10.01	4.95	3.13	3.54
	P	0.04 **	0.08 *	0.03 **	0.02 **	0.01 **	0.01 **	0.01 **	0.06 *	0.01 **	0.07 *	0.35	0.27	0.03 **	0.07 *	0.07 *	0.08 *
$Y \rightarrow X_6$	TS	7.46	12.41	0.79	3.08	1.25	1.92	4.38	6.92	0.85	3.99	0.79	1.11	7.07	10.14	0.83	1.65
	P	0.03 **	0.00 ***	0.61	0.09 *	0.43	0.37	0.05 *	0.04 **	0.56	0.09 *	0.48	0.38	0.06 *	0.01 **	0.33	0.27
$X_6 \rightarrow Y$	TS	6.05	7.77	5.40	5.99	6.28	6.03	7.47	3.80	6.55	7.05	0.27	0.24	14.32	4.37	2.04	2.12
	P	0.04 **	0.04 **	0.08 *	0.07 *	0.06 *	0.07 *	0.02 **	0.07 *	0.06 *	0.05 *	0.80	0.66	0.01 **	0.07 *	0.09 *	0.15
$Y \rightarrow X_7$	TS	3.22	2.23	3.47	0.95	0.97	0.90	0.68	0.70	2.83	2.10	3.71	4.78	1.13	0.74	1.14	3.11
	P	0.09 *	0.25	0.23	0.42	0.51	0.63	0.49	0.54	0.14	0.21	0.08 *	0.05 *	0.60	0.43	0.19	0.09 *
$X_7 \rightarrow Y$	TS	5.13	2.41	8.55	6.53	1.14	1.20	1.04	0.96	4.90	2.16	6.58	4.22	1.93	0.48	3.00	2.05
	P	0.04 **	0.20	0.02 **	0.07 *	0.48	0.55	0.30	0.49	0.08 *	0.19	0.00 ***	0.06 *	0.41	0.52	0.07 *	0.16
$Y \rightarrow X_8$	TS	1.37	1.29	2.20	0.49	0.76	0.73	0.41	0.22	4.27	11.71	2.84	3.78	1.74	1.06	0.93	1.18
	P	0.43	0.51	0.37	0.68	0.59	0.71	0.62	0.83	0.09 *	0.02 **	0.09 *	0.07 *	0.46	0.20	0.26	0.45
$X_8 \rightarrow Y$	TS	5.90	4.97	3.14	0.82	1.27	0.88	2.24	5.37	21.40	18.48	5.97	6.16	9.84	9.99	1.07	0.97
	P	0.04 **	0.08 *	0.28	0.50	0.44	0.64	0.09 *	0.04 **	0.00 ***	0.00 ***	0.03 **	0.02 **	0.04 **	0.01 **	0.21	0.51
$Y \rightarrow X_9$	TS	2.98	8.47	0.84	1.93	4.25	5.47	1.45	2.71	1.22	8.25	3.02	5.85	2.59	4.60	0.85	5.28
	P	0.09 *	0.03 **	0.55	0.16	0.15	0.08 *	0.23	0.09 *	0.32	0.04 **	0.09 *	0.03 **	0.30	0.07 *	0.32	0.03 **
$X_9 \rightarrow Y$	TS	7.01	10.73	6.90	4.25	15.37	13.06	6.19	6.25	17.53	13.06	5.25	4.15	11.97	12.53	4.12	2.97
	P	0.03 **	0.02 **	0.04 **	0.08 *	0.00 ***	0.00 ***	0.03 **	0.04 **	0.00 ***	0.01 **	0.04 **	0.06 *	0.02 **	0.00 ***	0.04 **	0.09 *
$Y \rightarrow X_{10}$	TS	1.01	4.84	1.55	0.36	0.53	0.60	0.77	0.48	0.64	0.61	3.58	5.26	0.95	3.58	0.30	1.62
	P	0.56	0.08 *	0.47	0.70	0.68	0.81	0.45	0.77	0.71	0.64	0.08 *	0.04 **	0.64	0.09 *	0.59	0.28
$X_{10} \rightarrow Y$		9.67	11.86	5.02	1.61	0.82	0.66	4.30	9.96	0.73	0.42	5.01	3.69	5.33	7.27	0.69	0.50
	P	0.02 **	0.01 **	0.09 *	0.27	0.57	0.77	0.05 *	0.03 **	0.69	0.79	0.04 **	0.07 *	0.08 *	0.03 **	0.41	0.74

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively; TS = test statistics; P = *p* value. Source: Authors' calculation.

Among the ten X_n variables included in the study, the most decisive influence on Y is exerted by exports to and imports from the world, particularly in countries where maritime transport dominates as a means of freight traffic (Japan, South Korea, Iceland). In some [Y; X_3] and [Y; X_4] pairs, we see bidirectional interactions between the variables with a particularly strong influence of Y on either exports or imports in 2020. Reasoning from this finding, we can assume that the parameters that compose the SCI have gained significance amid the pandemic and have directly affected the value of foreign trade operations at ports (for example, through restrictions to some shipping services, quarantine requirements to vessels, cargo, and crew, or reduced number of ship calls). We should also stress the reverse $Y \rightarrow X_1$ causality link in Japan, South Korea, China, Russia, and Denmark, which could signify the role maritime transportation has played in the transboundary spread of the virus.

To a considerable degree, causality links in the [Y; X_5] and [Y; X_6] pairs iterate those between maritime connectivity and trade with the world—the impact of Y on the China-PSR trade grows, while the reverse causality flowing from trade to connectivity weakens. In 2020, trade with China still exerts a statistically strong influence on the SCI score in Northern Europe (Denmark, Iceland, Norway) and Russia. In Japan and South Korea, the impact of connectivity on trade with China surpasses that of trade on connectivity evidenced in 2015–2019. A similar trend is observed on China's side in trade with PSR countries, but both $X_5 \rightarrow Y$ and $X_6 \rightarrow Y$ causality links remain strong.

The causalities between prices and maritime connectivity become weaker in January–September 2020 compared to 2015–2019. Among $X_{7–10}$ variables, we see the weakest influence of minerals prices on the SCI across all eight countries. The $X_8 \rightarrow Y$ causality link strengthens in Japan, South Korea, and China, which could probably designate the increase in fuel purchases amid falling global prices to establish reserves. The reasons, directions, and strengths of particular causality links in 2020 compared to the pre-pandemic period are detailed and discussed in the next section.

4. Discussion

Possible consequences of the COVID-19 pandemic to maritime connectivity are addressed as changes in causality linkages between variables in the 2020 model compared to the 2015–2019 model. As the TY framework assumes, these changes can be reflected through either the direction of causality, the strength of causality, or both (Table 10).

Proceeding from breaking the array of independent variables down to the pandemic-related, trade, and market segments ($X_{1–2}$, $X_{3–6}$, and $X_{7–10}$, respectively), possible influences on maritime connectivity in the course of the COVID-19 outbreak are further addressed separately.

4.1. Pandemic Effects

Unsurprisingly, both the ARDL analysis and the TY causality test show that the COVID-19 outbreak can be associated with monthly changes in the SCI scores that have been observed by the UNCTAD [1], research and statistics entities [112–114], and many scholars worldwide [16,115–117]. However, in contrast to Samli [118], Koyuncu et al. [119], and some other authors who estimated the pandemic impacts on commerce at container ports, we do not observe strong linkages between the number of COVID-19 cases and the overall SCI score. Across the countries and ports included in the study, the causality flowing from the number of new COVID-19 cases to maritime connectivity is either weak or average (Japan and China). Only in South Korea, the strength of the causality is estimated as above average, but it is bidirectional at the same time. Bidirectional links are also observed in China and Japan, while in Denmark and Russia, connectivity parameters affect the spread of the virus, and not the other way around.

Table 10. Strengths and directions of the Y-X_n causality links in 2015–2019 and 2020.

Causality Directions	China		Denmark		Iceland		Japan		Norway		Russia		South Korea		Sweden	
	2015-19	2020	2015-19	2020	2015-19	2020	2015-19	2020	2015-19	2020	2015-19	2020	2015-19	2020	2015-19	2020
$Y \rightarrow X_1$		A/BC		A/UC		W/NC		AA/BC		W/NC		A/UC		AA/BC		W/NC
$X_1 \rightarrow Y$		A/BC		W/RC		W/NC		A/BC		W/NC		W/RC		AA/BC		W/NC
$Y \rightarrow X_2$		W/NC		W/NC		W/NC		W/NC		W/NC		W/NC		W/RC		W/NC
$X_2 \rightarrow Y$		W/NC		W/NC		W/NC		W/NC		W/NC		W/NC		A/UC		W/NC
$Y \rightarrow X_3$	S/BC	S/BC	W/RC	W/RC	W/RC	W/RC	AA/BC	S/BC	A/BC	AA/BC	W/NC	W/RC	AA/BC	AA/BC	W/RC	A/UC
$X_3 \rightarrow Y$	AA/BC	A/BC	A/UC	A/UC	AA/UC	AA/UC	S/BC	S/BC	A/BC	A/BC	W/NC	A/UC	S/BC	AA/BC	A/UC	W/RC
$Y \rightarrow X_4$	AA/BC	S/BC	W/RC	W/RC	W/RC	W/RC	S/BC	S/BC	A/BC	AA/BC	W/NC	W/RC	AA/BC	S/BC	W/RC	W/RC
$X_4 \rightarrow Y$	AA/BC	A/BC	A/UC	A/UC	AA/UC	AA/UC	S/BC	S/BC	A/BC	A/BC	W/NC	A/UC	S/BC	AA/BC	A/UC	A/UC
$Y \rightarrow X_5$	S/BC	S/BC	W/RC	A/BC	W/RC	A/BC	A/BC	AA/BC	W/RC	W/RC	W/NC	W/NC	A/BC	S/BC	W/RC	W/RC
$X_5 \rightarrow Y$	AA/BC	A/BC	AA/UC	AA/BC	AA/UC	AA/BC	AA/BC	A/BC	AA/UC	A/UC	W/NC	W/NC	AA/BC	A/BC	A/UC	A/UC
$Y \rightarrow X_6$	AA/BC	S/BC	W/RC	A/BC	W/RC	W/RC	A/BC	AA/BC	W/RC	A/BC	W/NC	W/NC	A/BC	AA/BC	W/RC	W/NC
$X_6 \rightarrow Y$	AA/BC	AA/BC	A/UC	A/BC	A/UC	A/UC	AA/BC	A/BC	A/UC	A/BC	W/NC	W/NC	AA/BC	A/BC	A/UC	W/NC
$Y \rightarrow X_7$	A/BC	W/NC	W/RC	W/RC	W/NC	W/NC	W/NC	W/NC	W/RC	W/NC	A/BC	A/BC	W/NC	W/NC	W/RC	A/UC
$X_7 \rightarrow Y$	AA/BC	W/NC	AA/UC	A/UC	W/NC	W/NC	W/NC	W/NC	A/UC	W/NC	S/BC	A/BC	W/NC	W/NC	A/UC	W/RC
$Y \rightarrow X_8$	W/RC	W/RC	W/NC	W/NC	W/NC	W/NC	W/RC	W/RC	A/BC	AA/BC	A/BC	A/BC	W/RC	W/RC	W/NC	W/NC
$X_8 \rightarrow Y$	AA/UC	A/UC	W/NC	W/NC	W/NC	W/NC	A/UC	AA/UC	S/BC	S/BC	AA/BC	AA/BC	AA/UC	AA/UC	W/NC	W/NC
$Y \rightarrow X_9$	A/BC	AA/BC	W/RC	W/RC	W/RC	A/BC	W/RC	A/BC	W/RC	AA/BC	A/BC	AA/BC	W/RC	A/BC	W/RC	AA/BC
$X_9 \rightarrow Y$	AA/BC	AA/BC	AA/UC	A/UC	S/UC	S/BC	AA/UC	AA/BC	S/UC	AA/BC	AA/BC	A/BC	AA/UC	S/BC	AA/UC	A/BC
$Y \rightarrow X_{10}$	W/RC	A/BC	W/RC	W/NC	W/NC	W/NC	W/RC	W/RC	W/NC	W/NC	A/BC	AA/BC	W/RC	A/BC	W/NC	W/NC
$X_{10} \rightarrow Y$	AA/UC	AA/BC	A/UC	W/NC	W/NC	W/NC	A/UC	AA/UC	W/NC	W/NC	AA/BC	A/BC	A/UC	AA/BC	W/NC	W/NC

Note: S = strong causality link; AA = above average strength of causality link; A = average strength of causality link; W = weak causality link; UC = unidirectional causality; BC = bidirectional causality; RC = reverse causality; NC = neutral causality. Source: Authors' calculation.

It is safe to assume that the reverse or bidirectional interactions between the number of COVID-19 cases in a country and the maritime connectivity are attributed to the roles that certain constituents of the SCI (the number of ship calls, the number of regular shipping services from and to the country, the number of countries that are connected to the country through shipping) could play in the transboundary spread of the virus. According to the UNCTAD [1], the pandemic led to fewer port calls for most vessel types during the first half of 2020, which contributed to a breaking of virus transmission chains, but resulted in significant drops in maritime connectivity scores in China, Norway, Iceland, Russia, South Korea, and Sweden in January–June 2020 (Appendix A, Table A1). As demonstrated by Hsiang et al. [7], Deb et al. [120], and Chinazzi et al. [121], travel restrictions, mandatory quarantines, and other containment measures applied to maritime transportation have had a decisive influence on the reduction of the rate of virus transmission. Nevertheless, in South Korea and Japan (to a lesser extent, in Denmark, Russia, and China), we observe a distinct causality flowing from the SCI parameters to the number of new confirmed COVID-19 cases.

A new concern has emerged as researchers confirmed that the virus could survive on frozen foods [122]. Since fall 2020, Chinese sanitary authorities have been tracing the presence of viral genetic material in meat, fish, and seafood cold chains across the country [123,124]. Most of the local outbreaks since then (Qingdao, Dalian, Shanghai) have been directly associated with imported cold-chain products at ports (fish and seafood products from Russia, Norway, Indonesia, and Ecuador and beef and chicken wings from Brazil) [123]. In September 2020, China introduced precautionary measures against aquatic products from Norway [125] and then closed all ports to fish imports from Russia in December 2020 [126] to prevent the spread of the virus. It should be expected that the SCI scores for Chinese, Russian, and other PSR ports will continue to be depressed until import bans and other COVID-19 containment measures are lifted.

4.2. Trade Effects

Some experts argue that such safety-related restrictions to maritime trade significantly add to the deglobalization shift that has accelerated in recent years amid trade tensions between China and the USA, and a new rise of protectionist policies across the world [127–131]. Minárik and Čiderová [54], Ibn-Mohammed et al. [132], and Qin et al. [133] demonstrate how trade has succumbed to regional loci in the course of the pandemic, while supply chains have been reshaped, fragmented, and geographically dispersed due to restrictions to transboundary transportation. The Flock Freight [134] provides a growing number of examples of shortened supply chains with elements of nearshoring, reshoring, and redundancy (maintaining excess inventory). The UNCTAD [1] even forecasts a shift away from single country-centric sourcing and China's weaker role in certain maritime supply chains that both could happen due to the disruptions brought by the COVID-19 outbreak.

In support of these estimations, our results show much weaker $X_3 \rightarrow Y$ and $X_4 \rightarrow Y$ causality links in 2020 compared to 2015–2019 in some countries and ports included in the study. In China (mainly in smaller ports like Rizhao, Lianyungang, Qinhuangdao, and Weihai), the impacts of exports and imports on the SCI score drop from above average to average. South Korea's Ulsan also goes down from strong to above average causality link between trade volumes and the maritime connectivity index. Simultaneously, we do not record substantial changes in trade-connectivity causality across Northern Europe, while in Russia, both exports and imports have strengthened their contribution to the overall national SCI score. This can be explained by the fact that supplies of minerals and fuels from Russia, Norway, and Nordic countries have not been so much disrupted in 2020 compared to South Korea's, Japan's, or China's hi-tech and manufacture exports [133]. In most of the NSR ports in Russia, as well as in Norway, Iceland, Denmark, and Sweden, we see the SCI rebounds in Q3 2020 compared to the first half of the year.

A good part of these exports go to China, which designates above average or average causalities flowing from both X_5 and X_6 to Y in all PSR countries except Russia—which extensively trades with China's northwestern provinces through land border crossing points in Siberia and the Far East. Our calculations thus allow us to support the findings of Vidya and Prabheesh [135], who conclude that in many maritime supply chains, China's central position has not been as affected by the pandemic. According to Qin et al. [133], even in the course of the COVID-19 outbreak, China has remained one of the major sources of foreign value-add in total gross exports in Japan, South Korea, Russia, and other countries. Although Che et al. [136] evidenced a decline in China's trade with countries that suffered the most from the pandemic, we see that in Japan and South Korea, a contribution of trade with China to maritime connectivity has remained strong. The UNCTAD [1] emphasizes that China's maritime supply chains have appeared to be more resilient throughout the pandemic experience than other locations. In this sense, tighter connectivity between China and PSR economies contradicts many of the pandemic-related deglobalization and fragmentation fears, and instead establishes a foundation for China to continue developing the PSR initiative in the post-COVID era.

4.3. Market Effects

Minerals, fuels, and agricultural products are major categories of cargo transported via the Asia-Russia-Europe maritime corridor, but their influences on maritime connectivity in PSR countries are markedly different. For minerals, we observe insignificant changes in the already weak causality linkages between prices and the SCI scores. This well agrees with UNCTAD's estimation [1] that the pandemic-related reductions in mining and industrial activity had a minor impact on dry bulk trade in iron ore (78% of transit shipping in the NSR in 2020 [78]). Sand [137] associated slumps in construction and steel manufacturing in 2020 with declines in bulk trade in steel products, cement, and scrap metal. However, since China-PSR maritime trade in these commodities is negligible, we do not record visible changes in the $X_7 \rightarrow Y$ causality link. The causality link's strength decreases down to average in Russia and Denmark and weak in Sweden and Norway.

Trade in fuels, on the contrary, has been severely affected by the pandemic, while oil prices have turned out to be far more perceptible to the slowdown of economic activities compared to mineral prices [138–140]. Global oil demand has been depressed with restrictions on travel and transport and industrial activity cuts across the world [1]. China's imports of coal declined due to weaker power demand and lower oil and gas prices that have reduced the competitiveness of coal power generation. Global demand for liquefied natural gas has also come under pressure during the first quarter of 2020, while simultaneously the UNCTAD [1] reported that liquefied natural gas and liquefied petroleum gas carriers and tankers continued to record increases in port calls. A surplus in fuel production has filled oil and gas inventories to such an extent that many vessels were used as floating storage [1]. The latter accords with strengthening the $X_8 \rightarrow Y$ causality link revealed in Japan and South Korea, which established reserves of oil and gas amid lower prices [141,142]. For instance, in Pusan, South Korea, the SCI score lost only two points in Q2 2020 and then restored in Q3 2020 amid the increase in port and terminal utilization due to a rise in demand for storage capacities.

This trend is clearly traced in the case of the relationship between maritime connectivity and prices of food and agricultural products. The causality links between Y and X_9 and X_{10} become more assertive in 2020 compared to 2015–2019, with causalities flowing in both directions from prices to connectivity and backward. The most significant gains are observed in South Korea and Japan, the net importers of food products and agricultural raw materials. As reported by the UNCTAD [1], many shippers used advance yard storage in South Korea's, Japan's, and China's ports not only for fuels, but consumer commodities, food products, and grains. They then started moving goods early in spring and summer 2020, in anticipation of a resumption in demand and future commodity price developments. Large transit hubs like Pusan, Shanghai, Qingdao, Gothenburg, and Hakata have even benefited from lockdowns when storage space at ports has been used in cases where transit shipping has been suspended. Many studies have demonstrated emerging threats to global food security [62,143] and tremendous disruptions in agricultural supply chains [144,145] due to the pandemic. Notwithstanding that Wang et al. [146] and Cao et al. [147] expect that the impacts of supply disruption would be short-lived, development of warehousing and storage capacities at ports along the PSR should be considered a fundamental issue to ensure the sufficiency of safety stocks and inventories. The improvement of port infrastructure connectivity, logistics performance [68], and diversification in maritime routes [1] will allow China and its counterparts to avoid localized disruptions, establish a multiple-location trade network in the High North, and enhance the resilience of supply chains globally.

5. Conclusions

The COVID-19 outbreak has caused unprecedented disruption to global supply chains. Lockdowns of people and businesses along with restrictions on transboundary mobility and transport have resulted in a significant loss in international trade, much of which has manifested itself in the maritime sector. Assessing the pandemic's influence on maritime connectivity entails a great deal of uncertainty due to a variety of public health, economic, social, logistics, political, and other factors that take on new significance. This is why segmentation of maritime trade landscape and modeling causality links between maritime connectivity and smaller arrays of contributing factors could become viable analysis options.

In the case of the China-PSR trade corridor, we attempted to investigate how different maritime connectivity parameters have been affected in January–September 2020 compared to the respective periods in 2015–2019. The study was performed at two levels in eight countries and thirty-five ports. The changes in the SCI (national level) and the PSCI (port level) were studied against ten independent variables, including the number of COVID-19 cases and deaths, trade volumes with China and the rest of the world, and price indexes of major categories of products transported via the NSR as the major throughway in the Arctic (minerals, fuels, and food and agricultural products). The consecutive application of the ADF and the PP tests, the ARDL method, the FMOLS and the DOLS robustness checks, and the TY causality test in 2015–2019 and 2020 allowed us to investigate differences in the short-run and long-run interactions and reveal the pandemic-related transformations in the causality directions between the variables. Major findings flowing from this study can be summarized as follows.

- The number of COVID-19 cases is found to exert a more decisive influence on the maritime connectivity in South Korea, Japan, and China, which experienced the outbreak earlier compared to Nordic countries and Russia, as well as introduced stricter containment measures. The bidirectional relationship between the number of cases and the SCI allows us to assume the contribution of maritime connectivity factors to the transboundary spread of the virus.
- The number of COVID-19 deaths has a negligible impact on the maritime connectivity that can be explained by the fact that governments have been introducing restrictions based on the number of new cases rather than deaths.
- Tight links between the value of trade with the world and the SCI index are revealed across all locations included in the study in the pre-pandemic period, but in 2020, the relationships become weaker amid the influence of non-economic factors.
- The China-PSR trade patterns significantly affect the maritime connectivity in all countries except Russia, where a bulk of trade with China is carried by rail through the land border. Similar to trade with the world, the influence of trade with China on maritime connectivity has weakened in the course of the pandemic.
- While the trade-SCI linkages have become less noticeable, the reverse causality flowing from the connectivity parameters to trade value has intensified with a reduced number of ship calls at ports, quarantine requirements to vessels and crew, and other virus containment measures applied to shipping services.

- Bigger hubs have been able to rebound sooner in their PSCI scores, rising in demand for storage capacity during shipping suspension, while smaller ports continue experiencing depressing effects of restrictions to transit shipping even in the third quarter of 2020. Therefore, we can assume that in times of sudden disruptions in logistics chains, ports with scarcer connections suffer more compared to diversified hubs. However, that depends on how the market situation matches the specialization of a particular port. For instance, in most of the NSR ports, the PSCI has not been much affected due to their narrow specialization on outbound freights (minerals and fuels, for which trade has declined to a lesser degree compared to manufacture and consumer products).
- Prices have exerted divergent influence on maritime connectivity for exporters and importers. In net importers, the SCI score has been supported by more intensive imports amid falling global prices, while net exporters have experienced a negative influence of consumption slowdown on their maritime connectivity indexes.

It is tough to tell when exactly the pandemic will be curbed, restrictions on transboundary travels and transportation will be lifted, and the global economy will recover. Nevertheless, we see that the China-PSR trade pattern has a substantial potential in terms of the maritime connectivity between countries and ports and the reliance of counterparts on trade with each other. In the 2020 model, the calculation was made for a short array of data covering only three quarters of the year, but the COVID-19 pandemic will obviously have a lasting impact on freight shipping. With the updates of the data on the number of COVID-19 cases, market information, and dynamics of maritime trade between China, Russia, Northern Europe, and Asia, the estimations could become more precise. The adjustments of calculations along with the continuous monitoring of causal interactions between variables will equip stakeholders with insights about the status of maritime connectivity in the China-PSR trade, potential risks, and implications on trade and commerce.

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Appendix A

Table A1. Shipping connectivity and Port shipping connectivity indexes, 2015–2019 and 2020.

Countries/Ports	2015–2019, Average			2020		
	January–March	April–June	July–September	January–March	April–June	July–September
China	144.25600	146.40976	147.93279	158.37064	156.22624	160.29146
China: Dalian	60.93514	61.86997	61.57053	62.50721	62.87025	62.95251
China: Lianyungang	33.31145	35.07333	34.77936	41.43848	46.19355	41.28514
China: Qingdao	86.18790	87.76649	90.39664	97.98079	95.50218	96.02562
China: Qinhuangdao	6.99576	7.58951	8.90611	8.11250	8.11250	8.11250
China: Rizhao	11.56061	11.86857	12.41058	14.76849	14.66254	13.20044
China: Shanghai	127.02952	129.25465	130.75849	136.85170	134.51027	138.91384
China: Weihai	2.41896	2.43323	2.05983	2.00949	2.00949	2.00949
China: Yantai	14.92416	14.10571	13.91985	13.04158	13.04158	12.51689
Denmark	45.09137	45.06750	45.65967	46.58867	46.23473	46.33711
Denmark: Aarhus	42.61198	42.66091	43.46878	44.91011	44.92916	44.83680
Denmark: Copenhagen	5.19696	4.73303	4.56877	4.33206	4.52781	4.72332
Denmark, Greenland: Nuuk	2.00112	2.00106	2.01526	2.02933	2.02933	5.08021
Iceland	5.31360	5.29465	5.31737	6.13933	6.01947	6.96187
Iceland: Reydharfjordur	3.79390	3.66378	3.91174	3.82918	4.62143	4.62143
Iceland: Reykjavik	5.20064	5.21542	5.17170	5.80252	5.53034	6.47786
Japan	75.34626	72.88415	71.77790	78.78389	88.64641	88.70137
Japan: Akita	3.34431	3.32231	3.67081	3.81099	4.02925	4.46471
Japan: Hakata	19.33510	19.04703	19.40562	18.41141	17.49040	17.45937
Japan: Kitakyushu	3.60891	3.94439	3.84279	7.40050	5.79934	3.64653
Japan: Niigata	5.75781	5.66677	5.77444	5.79424	5.60332	5.61266
Norway	9.71469	9.86324	10.22606	10.63827	9.63687	10.16871
Norway: Bergen	5.04260	5.16227	5.21057	5.87044	4.87413	5.05370
Norway: Hammerfest	1.57109	1.57109	1.57109	1.51746	1.17813	1.17813
Norway: Stavanger	2.32561	2.31488	2.29814	2.55296	2.55296	3.07447
Norway: Tromso	1.96436	1.96436	1.96436	1.91074	1.17813	1.17813
Norway: Trondheim	1.75531	1.79821	1.79821	1.17973	1.17813	2.06056
Russia	46.07389	43.19898	42.36271	35.98139	33.90037	33.46525
Russia: Anadyr	0.96594	0.96594	0.96633	0.73057	0.73056	0.73054
Russia: Arkhangelsk	0.56784	0.55588	0.55588	0.55586	0.55583	0.55580
Russia: Dudinka	1.63985	1.63982	1.63979	1.63980	1.63982	1.62975
Russia: Murmansk	3.17882	3.18298	3.17740	3.16982	3.17005	3.17249
Russia: Petropavlovsk	2.13561	2.14458	2.07056	1.78557	1.78504	1.78592
Russia: Pevek	1.13678	1.13679	1.13672	1.13668	1.13670	1.13674
Russia: Sabetta	0.49093	0.50922	0.50593	0.51891	0.50478	0.51293
Russia: Vladivostok	16.14067	14.07223	14.00720	13.93689	13.45200	13.78345
South Korea	98.44056	99.90325	101.46473	108.39640	106.95343	107.55277
South Korea: Gwangyang	60.50077	60.79394	61.83644	66.80079	65.30716	60.35533
South Korea: Pusan	108.68804	110.22309	111.70417	118.73122	116.39475	117.09869
South Korea: Ulsan	18.87085	18.95059	19.09108	23.73320	20.69843	19.27688
Sweden	46.62914	46.01937	47.93833	48.59986	47.64887	48.41985
Sweden: Gothenburg	41.34901	40.80150	42.72292	42.28518	42.34241	41.79951
Sweden: Halmstad	2.93740	3.58594	3.27535	3.16433	1.99846	2.72541

Source: Authors' development based on [79].

Appendix B

Table A2. ADF and PP results, countries, 2015–2019.

Country	Parameter	Y	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
China	ADF level	−1.46 **	−4.18 **	−2.43 ***	−0.28 **	−1.36 *	−2.40 **	−3.12 ***	−0.97 *	−2.57 ***
	ADF first difference	−3.17 **	−2.64 ***	−3.29 **	−1.27 *	−3.18	−1.97 ***	−1.80 **	−1.23 *	−3.60 **
	PP level	−4.20 *	−3.80 **	−2.15 ***	−0.94 **	−1.15 *	−2.86 **	−4.23 ***	−1.74	−2.08 ***
	PP first difference	−3.88 **	−2.95 ***	−3.50 **	−2.23 *	−2.94	−1.05 ***	−2.95 **	−0.60 **	−3.15 **
Denmark	ADF level	−2.47	−3.43 *	−1.26 *	−1.48 ***	−0.62 **	−3.48 ***	−0.19 *	−2.15 *	−2.42 *
	ADF first difference	−1.63 *	−2.19 **	−0.80 **	−2.03 **	−1.23 *	−4.62 ***	−1.28	−1.96 *	−1.69 **
	PP level	−1.94 **	−3.51 **	−1.38 *	−1.93 ***	−0.80 **	−3.23 **	−0.56 *	−0.48 **	−2.81 *
	PP first difference	−1.05 *	−2.58 *	−0.57 **	−2.66 **	−1.75 *	−4.19 ***	−1.44	−1.57 *	−1.85 **
Iceland	ADF level	−0.56 ***	−1.33 **	−2.00 ***	−0.49 ***	−0.55 ***	−2.48 ***	−0.75 *	−0.73 *	−1.33
	ADF first difference	−1.18 **	−0.87 ***	−1.69 **	−1.11 **	−2.17 *	−3.70 ***	−2.52	−0.95 *	−2.02 *
	PP level	−0.97 ***	−2.46 **	−2.93 ***	−0.85 ***	−1.36 **	−2.57 **	−0.48 *	−0.22 *	−1.94
	PP first difference	−1.42 **	−1.39 **	−1.02 **	−2.34 **	−2.19 *	−4.64 **	−1.76	−1.08	−0.76 **
Japan	ADF level	−2.14 *	−4.40 **	−3.42 **	−2.30 ***	−3.03 **	−0.86 *	−0.41 **	−2.16 **	−0.30
	ADF first difference	−2.71 **	−3.81 ***	−2.91 ***	−4.18 **	−2.48 *	−1.43 **	−1.03 *	−1.94 *	−1.00 *
	PP level	−1.85 **	−4.28 **	−1.48 **	−2.45 ***	−2.22 **	−0.90 *	−0.69 **	−2.37 **	−0.95
	PP first difference	−2.06 **	−2.65 ***	−2.05 ***	−3.13 **	−1.40 *	−2.16	−2.17	−0.66 ***	−1.38 *
Norway	ADF level	−0.97	−1.94 *	−0.73 **	−1.76 **	−1.14	−3.25 ***	−4.90 ***	−2.05 ***	−2.73 **
	ADF first difference	−1.23	−3.12 **	−1.34 *	−2.39 ***	−2.37 *	−2.98 **	−2.38 **	−4.78 ***	−1.49 ***
	PP level	−1.01 *	−2.83 *	−0.49 ***	−1.97 **	−1.28 *	−4.42 ***	−3.45 ***	−2.64 ***	−2.04 **
	PP first difference	−1.30 *	−1.47 **	−1.05 *	−3.00 ***	−1.63 **	−3.11 **	−2.06 **	−3.19 ***	−1.12 ***
Russia	ADF level	−3.58 **	−2.20 ***	−3.10 ***	−4.01 *	−2.35 *	−4.66 ***	−4.77 ***	−2.57 **	−3.46 **
	ADF first difference	−2.74 **	−1.95 **	−2.53 **	−3.22 **	−1.46 **	−3.85 ***	−3.83 ***	−3.33 *	−2.98 **
	PP level	−3.99 **	−2.41 ***	−4.24 ***	−4.29 *	−2.97 *	−3.79 ***	−4.50 ***	−2.41 **	−2.35 **
	PP first difference	−1.16 *	−1.53 **	−2.17 **	−3.06 **	−1.09 **	−4.52 **	−4.91 ***	−2.84 ***	−3.81 ***
South Korea	ADF level	−2.86 ***	−4.46 *	−2.03 *	−1.21 ***	−3.14 *	−0.78 *	−1.25 *	−4.12 *	−1.06 ***
	ADF first difference	−3.42 ***	−3.82 *	−1.75 **	−2.35 **	−2.22 **	−0.97 **	−2.42 **	−3.90 *	−2.93 **
	PP level	−3.11 **	−2.17	−2.84 *	−1.94 ***	−3.85 *	−1.49	−1.38 *	−3.65 **	−1.17 ***
	PP first difference	−2.95 ***	−3.04	−1.15 **	−2.70 **	−2.37 **	−1.05	−0.57 ***	−4.08 *	−2.36 **
Sweden	ADF level	−0.87 ***	−2.43 **	−0.99 **	−1.27	−1.79 ***	−2.30 **	−1.12 **	−1.40 ***	−1.68 *
	ADF first difference	−1.59 ***	−1.95 **	−2.53 *	−3.15	−0.96 **	−3.21 **	−2.09 *	−0.73 ***	−2.00 **
	PP level	−1.28 **	−1.37 ***	−1.74 **	−0.44 *	−1.45 ***	−2.58 *	−1.50 **	−1.99 **	−1.55 *
	PP first difference	−0.94 **	−2.18 ***	−2.06 *	−2.96	−2.13 **	−3.42	−2.86 *	−1.54 **	−2.42 **

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

Table A3. ADF and PP results, countries, 2020.

Country	Parameter	Y	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
China	ADF level	−1.20 **	−1.54 ***	−1.05 ***	−3.14 **	−2.95 **	−0.47 **	−1.55 *	−2.14 **	−3.43 **	−1.12 **	−2.93 ***
	ADF first difference	−2.78 *	−1.09 **	−1.36 **	−3.03 ***	−2.03 **	−1.51 *	−4.20	−2.01 ***	−2.74 ***	−1.48 *	−3.00 **
	PP level	−3.35 *	−2.42 **	−2.28 ***	−2.50 ***	−1.90 ***	−1.90 **	−1.26 *	−1.70 ***	−3.05 **	−1.07	−2.21 ***
	PP first difference	−2.36 **	−1.76 **	−1.25 **	−3.27 **	−2.86 **	−2.02 *	−2.81	−1.97 **	−3.19 **	−0.83 **	−3.44 **
Denmark	ADF level	−2.12	−0.98 *	−1.37 *	−2.98 **	−1.12 *	−1.37 ***	−0.78 **	−3.18 ***	−0.88 *	−2.36 *	−2.58 *
	ADF first difference	−1.28 *	−1.41 *	−1.29	−1.43 **	−0.73 **	−2.34 **	−1.05 *	−4.04 **	−1.51	−1.45 *	−1.92 **
	PP level	−1.51 **	−0.72 *	−1.94 *	−2.04 **	−1.84 *	−1.85 ***	−0.92 **	−3.22 **	−0.62 *	−0.55 ***	−2.04 *
	PP first difference	−1.23 *	−1.15	−0.38 **	−3.19 *	−0.91 **	−2.04 **	−1.64 *	−4.85 **	−1.75	−1.76 *	−1.71 **
Iceland	ADF level	−1.17 **	−0.57	−1.44 *	−1.95 **	−1.66 **	−0.99 ***	−0.88 ***	−2.13 ***	−0.93 *	−0.94 *	−1.03
	ADF first difference	−1.32 **	−2.28	−0.80 **	−1.01 **	−1.09 **	−1.26 **	−2.53 *	−3.54 ***	−2.71 *	−0.82 *	−2.35 *
	PP level	−1.58 **	−0.46 *	−0.95	−2.30 **	−2.17 ***	−1.80 **	−1.70 **	−2.02 **	−0.80 *	−0.35 *	−1.74
	PP first difference	−1.67 **	−1.30	−0.46 *	−1.26 **	−1.40 **	−2.25 **	−2.01 *	−4.36 **	−1.44	−1.14 *	−0.65 **
Japan	ADF level	−2.40 **	−2.43 **	−1.82 **	−3.72 **	−3.19 **	−2.00 ***	−3.34 **	−1.18 *	−0.39 **	−2.42 **	−0.86
	ADF first difference	−2.05 **	−3.58 **	−2.13 *	−3.29 ***	−2.22 ***	−4.44 **	−2.27 *	−1.27 **	−1.27 *	−1.83 *	−1.12 *
	PP level	−1.62 **	−2.94 ***	−1.50 **	−2.14 ***	−1.00 **	−2.51 ***	−2.18 **	−1.22 *	−0.95 **	−2.04 **	−0.90
	PP first difference	−1.98 **	−1.56 ***	−2.74 *	−3.00 **	−1.49 ***	−3.01 **	−2.00 *	−2.39	−1.91 *	−0.97 ***	−1.27 *
Norway	ADF level	−0.85	−1.16 *	−0.66 **	−2.23 *	−0.86 **	−1.86 **	−1.55	−3.00 ***	−4.82 ***	−1.16 ***	−2.58 **
	ADF first difference	−1.51	−2.05	−1.37 *	−2.95 **	−1.28 *	−2.27 ***	−2.36 *	−2.54 **	−2.83 **	−4.72 **	−2.17 **
	PP level	−1.23 *	−1.77 *	−1.01 **	−2.41 *	−0.74 ***	−1.73 **	−1.39 *	−3.08 ***	−3.27 **	−3.30 ***	−1.84 **
	PP first difference	−1.47 *	−2.22	−2.00	−1.09 **	−1.37 *	−2.92 ***	−1.05 **	−2.47 **	−2.65 **	−3.64 ***	−1.75 ***
Russia	ADF level	−2.99 **	−2.58 **	−2.45 **	−2.43 **	−2.83 ***	−4.19 *	−2.74 *	−4.25 ***	−4.18 ***	−2.09 **	−3.03 **
	ADF first difference	−2.70 **	−3.14 **	−3.58 **	−1.55 **	−2.06 **	−3.40 **	−1.16 **	−3.13 ***	−3.04 ***	−3.48 *	−2.64 **
	PP level	−3.58 **	−2.35 *	−2.10 *	−1.86 ***	−3.90 ***	−4.04 *	−2.38 *	−3.29 **	−4.29 ***	−2.26 **	−2.22 **
	PP first difference	−1.03 *	−2.73 **	−3.34 **	−2.01 **	−2.44 **	−3.29 **	−1.25 **	−4.21 **	−4.37 ***	−2.55 ***	−3.75 ***
South Korea	ADF level	−2.75 ***	−4.40 **	−4.22 **	−4.17 *	−1.92 *	−1.58 ***	−2.59 **	−0.80 *	−1.46 *	−4.00 *	−1.39 ***
	ADF first difference	−3.14 ***	−3.27 ***	−4.71 **	−3.33 *	−2.85 **	−2.25 **	−2.30 **	−0.75 **	−1.95 **	−3.59 *	−2.18 **
	PP level	−2.89 **	−2.05 ***	−3.18 ***	−2.80	−2.25 *	−1.71 ***	−3.67 *	−1.06	−1.57 **	−3.47 **	−1.42 ***
	PP first difference	−2.43 **	−3.49 **	−3.62 **	−2.74 *	−1.04 **	−2.53 **	−2.41 **	−1.77	−0.86 ***	−4.23 *	−2.30 **
Sweden	ADF level	−1.32 **	−1.98	−2.04 *	−2.05 **	−0.62 **	−1.34	−1.66 ***	−1.43 **	−1.00 **	−1.74 ***	−1.51 *
	ADF first difference	−1.13 ***	−0.46 *	−1.28 *	−1.48 **	−2.37 *	−3.00 *	−1.23 **	−2.59 **	−1.34 *	−0.88 ***	−1.45 ***
	PP level	−1.40 **	−1.13	−0.55 **	−1.51 ***	−1.50 **	−0.59 *	−1.50 ***	−1.40 **	−1.82 **	−1.51 **	−1.68 *
	PP first difference	−1.25 **	−0.80 *	−1.11 *	−2.16 ***	−1.33 *	−2.85	−2.28 **	−2.88	−2.40 *	−1.65 **	−2.11 **

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

Appendix C

Table A4. ARDL short-run estimates, ports, 2015–2019.

Port	Parameter	ΔX_3	ΔX_4	ΔX_5	ΔX_6	ΔX_7	ΔX_8	ΔX_9	ΔX_{10}	ECM
China: Dalian	Coefficient	0.0994	0.2093	0.2187	0.2045	0.0594	−0.1238	−0.0457	−0.1309	0.1566
	t-stat	1.0298	−3.1550	−1.4885	−2.0882	4.6982	−2.0997	1.4409	2.1170	2.0297
	Prob	0.0827 ***	0.4146 ***	0.7209 **	0.5009 **	0.1597 *	0.5505 **	0.1287 ***	0.4691 ***	0.1502 **
China: Lianyungang	Coefficient	0.1725	0.2007	0.1044	0.1236	0.1809	−0.0562	0.0662	−0.0987	0.1419
	t-stat	−2.6009	3.4482	−2.0841	−2.9503	−3.8751	1.7793	2.4091	−3.6092	−2.5446
	Prob	0.1388 **	0.3091 **	0.0529 *	0.0987 *	0.3350 *	0.6720 *	0.6348 **	0.0505 **	0.4091 *
China: Qingdao	Coefficient	0.2476	0.2453	0.3112	0.3598	0.0983	−0.0186	−0.3007	−0.1559	−0.3008
	t-stat	1.5098	2.4458	−4.2678	−1.9942	2.0759	1.5631	3.6298	−1.5774	1.7832
	Prob	0.4033 **	0.7346 **	0.0039 ***	0.9387 ***	0.3391 *	0.8599 **	0.1127 ***	0.2386 ***	0.2557 **
China: Qinhuangdao	Coefficient	0.2092	0.1900	0.1251	0.1409	0.0985	0.0134	0.0263	−0.0112	0.0103
	t-stat	2.6071	3.1462	1.0093	2.0000	−2.5983	1.6673	2.6995	5.0064	3.6084
	Prob	0.2395 **	0.5884 **	0.0076 *	0.7503 *	0.4774 *	0.5887 *	0.2409 **	0.3081 **	0.1536 *
China: Rizhao	Coefficient	0.3993	0.3588	0.1092	0.1725	0.0070	0.1490	0.0135	0.0146	0.1597
	t-stat	4.0075	2.4902	−2.5557	−1.4647	3.5371	−2.5556	−2.6734	2.7795	1.2285
	Prob	0.5982 **	0.5395 **	0.4998 *	0.9098 *	0.5893 *	0.6729 *	0.8995 *	0.9806 **	0.2456 *
China: Shanghai	Coefficient	0.7300	0.7936	0.5781	0.6045	0.1400	0.2304	0.2289	−0.2037	−0.1877
	t-stat	5.1486	−1.2980	1.0008	2.6551	−3.7735	2.6780	−1.3485	2.1285	−3.5832
	Prob	0.4995 ***	0.0075 ***	0.4790 ***	0.8840 ***	0.3809 **	0.7713 **	0.6737 ***	0.7900 ***	0.1709 ***
China: Weihai	Coefficient	0.3215	0.4098	0.1452	0.1793	0.0673	0.1694	0.1891	0.0476	0.1558
	t-stat	4.6617	1.8403	−4.7937	−2.0041	3.7098	2.4843	2.1594	−1.5285	3.3790
	Prob	0.4592 **	0.3704 **	0.1364 **	0.2055 **	0.7149 *	0.7091 *	0.0005 **	0.9287 **	0.4421 *
China: Yantai	Coefficient	0.2498	0.2591	0.1990	0.2286	0.1303	0.2002	0.0309	−0.1098	0.0547
	t-stat	3.6895	−2.8390	2.5558	1.8930	−2.5681	3.4673	2.1587	−1.5556	2.0965
	Prob	0.0982 ***	0.3498 ***	0.4091 **	0.0089 **	0.3899 **	0.5508 **	0.3985 **	0.2018 **	0.2490 **
Denmark: Aarhus	Coefficient	0.1506	0.1183	0.0552	0.0344	0.0710	−0.0305	0.1335	0.0784	−0.1257
	t-stat	3.1377	2.2407	1.1147	−2.0728	1.2745	−3.4122	1.1784	2.1995	1.1346
	Prob	0.0793 ***	0.9874 ***	0.0005 *	0.1482 *	0.2993 *	0.4355 *	0.3985 **	0.3993 *	0.2066 *
Denmark: Copenhagen	Coefficient	0.1285	0.1596	0.0134	0.0637	0.0226	0.0490	0.0621	0.1006	−0.0557
	t-stat	−1.2759	2.8837	−2.2861	−4.0053	2.6298	4.8794	3.1784	−1.5975	−1.0086
	Prob	0.4102 ***	0.5884 ***	0.6390 *	0.0394 *	0.5094 *	0.2609 *	0.7985 *	0.8585 *	0.7723 *
Denmark, Greenland: Nuuk	Coefficient	0.7512	0.7056	0.1258	0.0115	0.5035	−0.1223	−0.0556	−0.0144	0.1609
	t-stat	3.5008	4.2224	−1.0677	2.3379	−1.7772	2.4000	−1.4700	−1.1863	2.2866
	Prob	0.5954 ***	0.3983 ***	0.2851 *	0.2807 *	0.3683 **	0.3875 *	0.3653 *	0.0005 *	0.4124 *
Iceland: Reydharfjordur	Coefficient	0.4872	0.4085	0.2338	0.2561	0.5506	−0.0206	0.0725	0.0236	0.0446
	t-stat	3.1676	2.1674	−1.0365	2.5974	−1.4287	2.0565	2.1277	1.6905	1.3378
	Prob	0.2805 ***	0.0875 ***	0.2870 *	0.3885 *	0.1209 ***	0.1274 *	0.1443 *	0.2553 *	0.2785 **
Iceland: Reykjavik	Coefficient	0.6609	0.6077	0.4924	0.2567	0.1558	−0.0258	0.1408	0.0784	0.1309
	t-stat	1.8642	−2.4365	−2.7385	2.3798	−2.4097	1.4596	2.2895	−2.0055	2.0554
	Prob	0.4900 ***	0.5836 ***	0.2294 **	0.5275 **	0.0050 **	0.4927 *	0.2093 **	0.7053 **	0.2378 **

Table A4. *Cont.*

Port	Parameter	ΔX_3	ΔX_4	ΔX_5	ΔX_6	ΔX_7	ΔX_8	ΔX_9	ΔX_{10}	ECM
Japan: Akita	Coefficient	0.5064	0.6235	0.2346	0.1999	0.1667	0.0238	−0.0606	−0.0437	−0.1345
	t-stat	2.0832	1.8509	−3.1459	−2.4875	2.2245	−1.2977	2.5498	1.3865	−1.6299
	Prob	0.0385 **	0.1274 **	0.3240 **	0.5083 **	0.0000 *	0.2769 *	0.0627 *	0.2790 *	0.4904 **
Japan: Hakata	Coefficient	0.4226	0.4800	0.1665	0.2664	0.3239	0.0304	0.0524	0.0654	0.1297
	t-stat	1.3094	2.5821	1.9974	2.5093	1.6008	4.6831	2.5563	−2.6003	1.5556
	Prob	0.1317 **	0.2650 **	0.6339 **	0.3837 **	0.0236 *	0.5583 *	0.2741 *	0.5995 *	0.2804 **
Japan: Kitakyushu	Coefficient	0.3735	0.4407	0.1509	0.1880	0.2013	0.1579	0.0337	0.0597	−0.2579
	t-stat	1.6220	2.6883	−2.0096	−2.4985	4.1794	−1.6282	2.0084	1.4083	2.5458
	Prob	0.4087 **	0.0005 **	0.5584 **	0.3077 **	0.6231 **	0.4595 *	0.2863 *	0.2129 *	0.4267 *
Japan: Niigata	Coefficient	0.2336	0.2551	0.2335	0.3134	0.0349	0.1543	−0.1245	−0.0450	0.0605
	t-stat	−2.5543	−2.9835	3.9598	2.0075	1.8444	2.1886	1.3062	3.1582	1.3490
	Prob	0.0985 ***	0.2987 ***	0.7401 ***	0.4982 ***	0.3986 ***	0.2583 *	0.2750 **	0.2086 **	0.4558 **
Norway: Bergen	Coefficient	0.2308	0.1347	0.2134	0.2086	0.1674	0.2996	0.1124	0.2057	0.4007
	t-stat	2.1894	−1.9845	−2.6755	−1.1455	−2.6281	1.3285	−1.8655	−2.3348	−3.3285
	Prob	0.1307 **	0.4808 **	0.5897 *	0.8743 *	0.3309 **	0.5281 **	0.2349 **	0.0293 **	0.5380 **
Norway: Hammerfest	Coefficient	0.0565	0.0655	0.0775	0.0776	0.2496	0.2457	0.0985	0.3615	0.2236
	t-stat	2.0296	3.2941	−3.1709	−2.3589	2.5414	−2.3987	−2.1294	3.0006	−2.1137
	Prob	0.5991 **	0.9836 **	0.4386 *	0.3034 *	0.6083 *	0.4446 **	0.0013 **	0.1257 **	0.2768 *
Norway: Stavanger	Coefficient	0.2783	0.2997	0.0688	0.0676	0.2379	0.2008	0.3872	0.2027	0.3566
	t-stat	5.0046	2.0953	4.1763	1.5583	−2.5245	1.5125	2.3409	1.1498	1.7495
	Prob	0.2098 ***	0.4827 ***	0.5266 **	0.4127 **	0.0488 **	0.2309 **	0.3874 **	0.1874 **	0.5574 **
Norway: Tromso	Coefficient	0.2449	0.2690	0.1295	0.0985	0.1794	0.0738	0.0228	0.0500	0.2323
	t-stat	2.6928	−4.9007	1.5693	2.2187	1.8609	−1.7995	3.1264	1.2046	−2.8476
	Prob	0.3582 ***	0.0006 ***	0.3475 *	0.3126 *	0.3453 **	0.6297 *	0.0996 *	0.4529 *	0.2001 **
Norway: Trondheim	Coefficient	0.1308	0.2564	0.3290	0.2997	0.0775	0.1555	0.4003	0.1654	0.3829
	t-stat	−1.9387	1.5981	2.1138	1.3854	−2.5498	3.6694	2.6595	−3.5521	2.5444
	Prob	0.2006 ***	0.4800 ***	0.3685 **	0.1237 **	0.2846 **	0.3712 **	0.0054 **	0.4670 **	0.0657 ***
Russia: Anadyr	Coefficient	0.0745	0.0011	0.0054	0.0060	0.0664	−0.0074	−0.0011	0.0014	−0.0565
	t-stat	−1.0043	−2.8749	−1.4976	−2.2381	1.7539	−2.0386	2.1554	3.4299	2.0657
	Prob	0.0428 *	0.6066 *	0.3453 *	0.5199 *	0.5665 **	0.2525 *	0.6877 *	0.5434 *	0.6225 *
Russia: Arkhangelsk	Coefficient	0.0314	0.0258	0.0069	0.0234	0.1221	−0.0066	0.2023	0.1285	0.0778
	t-stat	−2.5638	−2.3987	−2.9744	3.0445	2.8867	2.3854	−1.6684	−2.3254	2.0444
	Prob	0.5174 **	0.2216 **	0.0032 *	0.6256 *	0.4543 *	0.2850 *	0.0675 *	0.6193 *	0.3095 **
Russia: Dudinka	Coefficient	0.0067	0.0011	0.0050	0.0013	0.1138	0.0157	0.0098	0.0069	0.0352
	t-stat	−3.1286	1.6598	−2.4873	−2.4736	−1.4455	2.5180	1.5784	2.0575	−1.5476
	Prob	0.0000 *	0.4144 *	0.3864 *	0.5179 *	0.0098 **	0.1442 *	0.3591 *	0.3443 *	0.6564 *
Russia: Murmansk	Coefficient	0.1056	0.1316	0.0423	0.0122	0.1553	0.0205	0.1843	0.2114	0.2573
	t-stat	−2.5239	−1.5830	−1.6495	2.1540	−2.2376	−1.1222	2.1487	−2.4986	−2.0554
	Prob	0.6928 ***	0.7455 ***	0.2442 *	0.0085 *	0.4232 **	0.0000 **	0.6650 **	0.3000 **	0.1672 ***
Russia: Petropavlovsk	Coefficient	0.1392	0.1609	0.0219	0.0124	0.0664	0.0597	0.0045	0.0067	0.2012
	t-stat	−4.5667	−2.1423	1.1113	2.5548	−1.7459	2.6566	2.0027	−2.5068	3.1478
	Prob	0.6400 *	0.6998 *	0.1854 *	0.6512 *	0.0051 **	0.2875 *	0.1556 *	0.4366 *	0.5465 **

Table A4. *Cont.*

Port	Parameter	ΔX_3	ΔX_4	ΔX_5	ΔX_6	ΔX_7	ΔX_8	ΔX_9	ΔX_{10}	ECM
Russia: Pevek	Coefficient	0.1614	0.0087	0.0107	0.0053	0.0234	0.0124	0.0064	0.0078	0.1504
	t-stat	1.7958	1.3422	2.9876	1.4998	−3.1343	2.6579	−3.5538	−1.4657	−1.3227
	Prob	0.4123 *	0.5673 *	0.2333 *	0.0413 *	0.2265 **	0.4386 *	0.2656 *	0.5388 *	0.5980 *
Russia: Sabetta	Coefficient	0.0501	0.0015	0.1254	0.0015	0.0076	0.2235	0.0012	0.0043	0.3670
	t-stat	2.3472	−2.3762	1.2775	2.5234	2.1121	−4.2534	−2.7754	−3.0987	1.1231
	Prob	0.4653 **	0.6909 *	0.5634 **	0.6498 *	0.5398 *	0.5767 **	0.4486 *	0.6055 *	0.3875 **
Russia: Vladivostok	Coefficient	0.0638	0.2155	0.1552	0.2237	0.0423	0.0996	0.2667	0.2442	0.5234
	t-stat	4.7754	2.0007	−2.6578	3.3456	−2.1364	−2.3687	1.2355	1.0936	2.0669
	Prob	0.1906 ***	0.3908 **	0.5234 ***	0.3002 ***	0.3172 *	0.4522 **	0.2136 ***	0.2573 ***	0.4987 ***
South Korea: Gwangyang	Coefficient	0.4287	0.4065	0.3286	0.3314	−0.0965	−0.0940	−0.0025	−0.0074	0.4906
	t-stat	2.5005	1.1749	−2.0517	−1.5000	3.9187	−2.6053	1.8247	−2.6819	2.4022
	Prob	0.9276 ***	0.7378 **	0.4005 ***	0.6249 ***	0.0005 *	0.1547 *	0.1496 *	0.2760 **	0.3795 **
South Korea: Pusan	Coefficient	0.8340	0.8150	0.7349	0.6538	−0.1396	−0.1548	−0.0102	−0.0351	0.7007
	t-stat	−1.8733	−2.1244	−1.4380	−2.5356	1.1487	2.5952	−3.4783	−1.4958	−3.6541
	Prob	0.7612 ***	0.6626 ***	0.0095 ***	0.0298 ***	0.7395 **	0.3813 **	0.5849 **	0.0006 **	0.5328 ***
South Korea: Ulsan	Coefficient	0.6195	0.5892	0.5052	0.4872	0.0056	−0.0865	−0.0912	−0.0873	0.5045
	t-stat	4.0557	3.1505	−1.9347	−2.5360	−3.9841	−3.1260	−2.0375	−4.5941	−1.3968
	Prob	0.3941 ***	0.7984 ***	0.0498 ***	0.8375 ***	0.1203 *	0.4891 *	0.2096 *	0.7500 **	0.4093 **
Sweden: Gothenburg	Coefficient	0.6827	0.7023	0.1854	0.1733	0.1660	−0.0097	0.0150	0.0964	−0.3264
	t-stat	−2.1793	−1.0065	−2.0057	−3.4281	2.5377	−1.3761	2.5891	−1.3681	−2.7813
	Prob	0.5482 ***	0.6398 ***	0.2941 **	0.0054 **	0.2198 **	0.3405 *	0.0614 *	0.2592 *	0.8867 ***
Sweden: Halmstad	Coefficient	0.3864	0.4290	0.1519	0.1625	0.0634	−0.0143	0.0523	0.0775	0.0810
	t-stat	−1.0709	−3.5836	−3.4015	−1.3096	3.8765	2.0567	3.4175	1.8131	−1.3986
	Prob	0.5298 ***	0.4211 ***	0.2366 **	0.4231 **	0.3891 **	0.1831 *	0.0022 *	0.4973 *	0.5715 **

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

Table A5. ARDL short-run estimates, ports, 2020.

Port	Parameter	ΔX_1	ΔX_2	ΔX_3	ΔX_4	ΔX_5	ΔX_6	ΔX_7	ΔX_8	ΔX_9	ΔX_{10}	ECM
China: Dalian	Coefficient	−0.0108	−0.0182	0.1113	0.1290	0.1528	0.1670	0.0342	−0.1061	−0.0100	−0.1544	0.1305
	t-stat	2.0817	3.1175	2.1865	−4.4598	2.0483	−3.2391	2.5378	1.3728	2.3597	3.0580	2.5988
	Prob	0.1982 **	0.0255 **	0.3034 **	0.3600 **	0.3015 *	0.0045 **	0.3066 *	0.3762 **	0.0198 ***	0.1853 ***	0.1264 **
China: Lianyungang	Coefficient	−0.0271	−0.0390	0.0298	0.0357	0.0466	0.0322	0.1485	−0.0394	0.0514	−0.1098	0.1692
	t-stat	−3.4918	−2.8776	3.1765	2.6873	−1.7671	−2.5094	−2.0039	4.6380	2.5010	−1.4511	−3.9830
	Prob	0.3870 **	0.2871 **	0.0387 *	0.0294 *	0.0529 *	0.1298 *	0.2450 *	0.0045 *	0.4902 **	0.0387 **	0.2506 *
China: Qingdao	Coefficient	0.0189	0.0040	0.1011	0.1245	0.2067	0.2217	0.0551	−0.0041	−0.2697	−0.1673	−0.3567
	t-stat	2.9876	2.0586	3.0284	3.1257	−2.5083	−3.0083	4.6348	3.5026	2.5553	3.0856	2.0854
	Prob	0.0281 *	0.2877 *	0.2975 *	0.1654 *	0.0005 **	0.0491 **	0.0000 *	0.4817 **	0.0976 ***	0.1299 ***	0.2078 **
China: Qinhuangdao	Coefficient	−0.0677	−0.0562	0.1876	0.1522	0.0742	0.0504	0.0723	0.0038	0.0144	−0.0030	0.0035
	t-stat	−2.4980	−3.5991	1.9550	3.0973	4.3311	3.6566	−2.4475	1.5411	3.5095	4.7109	2.6419
	Prob	0.0485 *	0.0593 *	0.1183 **	0.3070 **	0.0760 *	0.0872 *	0.2559 *	0.3904 *	0.1567 **	0.2054 **	0.0754 *

Table A5. *Cont.*

Port	Parameter	ΔX_1	ΔX_2	ΔX_3	ΔX_4	ΔX_5	ΔX_6	ΔX_7	ΔX_8	ΔX_9	ΔX_{10}	ECM
China: Rizhao	Coefficient	−0.1096	−0.0987	0.1542	0.1276	0.0493	0.0910	0.0046	0.1053	0.0059	0.0102	0.1200
	t-stat	−4.8561	−3.4982	2.7091	3.0188	2.0452	2.6413	1.9550	−3.5085	−2.4832	1.6598	3.1675
	Prob	0.5875 **	0.1824 **	0.2587 **	0.4900 **	0.0500 *	0.1287 *	0.1677 *	0.0044 *	0.6910 *	0.0371 **	0.0444 *
China: Shanghai	Coefficient	0.1203	0.1186	0.3876	0.3497	0.2988	0.2462	0.1011	0.1876	0.1954	−0.2459	−0.2037
	t-stat	2.8762	2.0590	4.6003	3.6065	1.5974	1.8005	−4.7492	5.3009	3.0766	2.0076	−4.1002
	Prob	0.3094 *	0.5871 *	0.3760 ***	0.4012 ***	0.2867 ***	0.3041 ***	0.0083 **	0.0487 **	0.2598 ***	0.0834 ***	0.1885 ***
China: Weihai	Coefficient	−0.0087	−0.0124	0.1165	0.1411	0.0313	0.0456	0.0544	0.1250	0.1608	0.0325	0.1341
	t-stat	−1.3905	−2.4870	3.9841	3.0676	−4.0606	−3.3407	2.6715	3.5734	1.0075	−3.4472	2.1765
	Prob	0.0094 **	0.0288 **	0.3690 **	0.4059 **	0.0512 **	0.2888 **	0.0817 *	0.2986 *	0.1842 **	0.0000 **	0.9874 *
China: Yantai	Coefficient	−0.0582	−0.0444	0.1033	0.0962	0.1003	0.1516	0.1249	0.1378	0.0411	−0.1126	0.0368
	t-stat	3.8654	2.5109	4.0845	3.7764	2.5764	3.0693	−2.7308	4.1540	3.0697	−1.6093	2.1677
	Prob	0.3751 **	0.4225 **	0.2870 **	0.0061 **	0.3986 **	0.2100 **	0.0031 **	0.3991 **	0.2134 **	0.0421 **	0.1295 **
Denmark: Aarhus	Coefficient	−0.0125	−0.0056	0.3286	0.3064	0.0275	0.0186	0.0518	−0.0186	0.1046	0.0587	−0.1079
	t-stat	−4.3890	−3.8271	5.0400	3.1286	1.3884	−2.6931	1.4553	−2.5583	3.0035	3.0683	2.5872
	Prob	0.2362 *	0.3053 *	0.5156 **	0.2791 **	0.2380 *	0.3815 *	0.1609 *	0.3990 *	0.2377 **	0.2609 *	0.1884 *
Denmark: Copenhagen	Coefficient	−0.1274	−0.1040	0.2467	0.2075	0.0052	0.0457	0.0071	0.0155	0.0391	0.0846	−0.0385
	t-stat	2.0071	4.8638	−1.1865	2.9666	−3.1409	−4.9062	2.3645	1.6984	2.5986	−2.6122	−1.4096
	Prob	0.0385 **	0.1787 **	0.4003 **	0.3781 **	0.8726 *	0.0498 *	0.3096 *	0.0682 *	0.3352 *	0.4823 *	0.3193 *
Denmark, Greenland: Nuuk	Coefficient	0.0383	0.0446	0.7199	0.6483	0.0954	0.0073	0.4338	−0.0870	−0.0275	−0.0081	0.1487
	t-stat	−1.4984	−2.0095	4.2311	3.9750	2.8600	3.9846	−2.6094	3.5941	−1.5900	−3.1977	4.1550
	Prob	0.8780 *	0.3967 *	0.7820 ***	0.5301 ***	0.0016 *	0.6019 *	0.4487 **	0.1110 *	0.4692 *	0.5239 *	0.3819 *
Iceland: Reydharfjordur	Coefficient	0.0298	0.0202	0.5083	0.3716	0.2609	0.2317	0.5790	−0.0142	0.0613	0.0103	0.0204
	t-stat	−2.9334	−2.0651	4.5800	3.0825	−2.4485	4.0883	−2.0554	1.4496	2.8088	1.3585	2.5985
	Prob	0.5912 *	0.3894 *	0.3109 ***	0.2904 ***	0.5886 *	0.2076 *	0.1195 ***	0.0065 *	0.0301 *	0.2780 *	0.1920 **
Iceland: Reykjavik	Coefficient	−0.0155	−0.0097	0.6214	0.5575	0.3173	0.2800	0.1677	−0.0097	0.1005	0.0497	0.1106
	t-stat	−3.5506	4.6090	3.1798	−2.4900	−1.6960	1.9964	−3.1385	2.2853	3.8974	−2.6982	3.6899
	Prob	0.1483 *	0.3698 *	0.7926 ***	0.0187 ***	0.1678 **	0.4209 **	0.2509 **	0.3880 *	0.1296 **	0.3485 **	0.3871 **
Japan: Akita	Coefficient	−0.1047	−0.0964	0.5388	0.6011	0.1855	0.2076	0.1240	0.0047	−0.0371	−0.0222	−0.1102
	t-stat	−2.0739	−1.3009	2.4150	3.0653	−2.3920	−3.5391	4.7921	−2.1494	1.1986	2.1043	−2.7198
	Prob	0.3017 **	0.4755 **	0.5237 **	0.0517 **	0.1904 **	0.4864 **	0.3417 *	0.1000 *	0.0412 *	0.1498 *	0.5931 **
Japan: Hakata	Coefficient	−0.0341	−0.0865	0.4021	0.3500	0.1472	0.1558	0.3572	0.0155	0.0394	0.0417	0.1034
	t-stat	4.2880	3.6901	1.9733	2.8499	3.0593	2.6312	1.5996	2.9709	1.4980	−1.4020	1.8765
	Prob	0.4494 **	0.0007 **	0.0598 **	0.1784 **	0.5700 **	0.2909 **	0.0038 *	0.4882 *	0.2653 *	0.4883 *	0.0029 **
Japan: Kitakyushu	Coefficient	−0.2082	−0.2136	0.3424	0.4065	0.1975	0.1607	0.2005	0.1003	0.0167	0.0269	−0.2690
	t-stat	3.5685	−2.0071	1.5076	4.7702	−1.4767	−2.0041	3.5877	−1.5987	3.2992	2.8840	3.3851
	Prob	0.1376 **	0.2500 **	0.8927 **	0.8534 **	0.3092 **	0.2868 **	0.4982 **	0.0781 *	0.1558 *	0.2641 *	0.5980 *
Japan: Niigata	Coefficient	0.1595	0.1243	0.1980	0.2371	0.2206	0.2547	0.0523	0.1204	−0.0861	−0.0293	0.0416
	t-stat	4.1284	2.0009	−1.2956	−2.0046	4.1475	1.5083	2.9084	4.0880	3.1822	4.1000	2.1950
	Prob	0.3002 **	0.2764 **	0.0045 ***	0.0498 ***	0.0016 ***	0.1696 ***	0.5081 ***	0.3905 *	0.0015 **	0.1729 **	0.2407 **
Norway: Bergen	Coefficient	−0.0103	−0.0225	0.1286	0.1085	0.1690	0.1773	0.1503	0.2566	0.1408	0.1774	0.3718
	t-stat	−4.1852	−3.0741	2.0954	3.1264	−1.5821	−2.2045	−1.5938	2.0548	−1.3056	−2.0063	−2.2595
	Prob	0.1084 **	0.4827 **	0.1008 **	0.3851 **	0.4593 *	0.3841 *	0.2855 **	0.7109 **	0.1297 **	0.5028 **	0.2091 **

Table A5. *Cont.*

Port	Parameter	ΔX_1	ΔX_2	ΔX_3	ΔX_4	ΔX_5	ΔX_6	ΔX_7	ΔX_8	ΔX_9	ΔX_{10}	ECM
Norway: Hammerfest	Coefficient	−0.0287	−0.0113	0.0392	0.0506	0.0452	0.0587	0.2014	0.2065	0.0495	0.3125	0.2046
	t-stat	−3.7918	−1.0584	2.9805	3.8562	−4.0127	−2.1084	1.5039	−1.5003	−3.0882	1.4995	−3.0067
	Prob	0.3866 **	0.2095 **	0.6733 *	0.3500 *	0.2986 *	0.3762 *	0.5877 *	0.4201 **	0.0000 **	0.0982 **	0.0038 *
Norway: Stavanger	Coefficient	0.0110	0.0273	0.2409	0.2307	0.0175	0.0385	0.1805	0.1699	0.3019	0.2543	0.3102
	t-stat	2.1084	1.9820	4.9864	1.3986	3.0386	2.4761	−1.4082	2.4056	4.2066	3.0051	2.9047
	Prob	0.3872 *	0.2574 *	0.5001 **	0.3403 **	0.4501 **	0.5720 **	0.0060 **	0.1785 **	0.3874 **	0.5052 **	0.3855 **
Norway: Tromso	Coefficient	−0.0490	−0.0502	0.2288	0.1954	0.0787	0.0644	0.1513	0.0284	0.0135	0.0498	0.1984
	t-stat	1.8723	3.0001	2.6505	3.0843	2.0004	4.3965	3.8601	−2.6097	1.0741	3.1110	−2.4091
	Prob	0.0986 **	0.4985 **	0.0041 **	0.2671 **	0.3096 *	0.4861 *	0.2312 **	0.3550 *	0.2864 *	0.3509 *	0.4986 **
Norway: Trondheim	Coefficient	0.0564	0.0632	0.1152	0.1605	0.2851	0.2550	0.0397	0.1296	0.3750	0.2076	0.4097
	t-stat	3.2951	2.4077	3.4096	2.2472	3.0448	2.1977	−1.5085	4.5402	1.8563	−2.0985	3.0950
	Prob	0.0007 **	0.0134 **	0.2509 ***	0.4854 ***	0.2099 **	0.3296 **	0.4994 **	0.3347 **	0.5097 **	0.1209 **	0.0036 ***
Russia: Anadyr	Coefficient	0.0015	0.0019	0.0553	0.0002	0.0038	0.0005	0.0408	−0.0003	−0.0002	0.0005	−0.0481
	t-stat	3.1408	2.4801	−2.1984	−1.8508	−2.0045	−1.0672	3.7055	−4.1834	3.8591	2.5281	1.0833
	Prob	0.2981 *	0.0975 *	0.3061 *	0.4009 *	0.3072 *	0.6820 *	0.3097 **	0.2751 *	0.6953 *	0.6509 *	0.5802 *
Russia: Arkhangelsk	Coefficient	−0.0196	−0.0207	0.0187	0.0206	0.0054	0.0098	0.0829	−0.0040	0.1497	0.1025	0.0496
	t-stat	2.0507	3.8502	−1.3955	−2.0412	−4.9287	5.0945	2.7756	3.9852	−1.5054	−2.0064	3.1247
	Prob	0.0829 **	0.3813 **	0.4409 **	0.0389 **	0.5845 *	0.5699 *	0.7281 *	0.8555 *	0.0582 *	0.7177 *	0.2986 **
Russia: Dudinka	Coefficient	0.0062	0.0108	0.0052	0.0005	0.0059	0.0002	0.0665	0.0104	0.0051	0.0040	0.0182
	t-stat	−1.4078	−2.5095	4.0581	2.9770	3.9006	−4.5281	−1.9664	3.8911	2.6096	4.9873	−1.9503
	Prob	0.3769 *	0.4401 *	0.7200 *	0.3086 *	0.4071 *	0.5069 *	0.0052 **	0.0837 *	0.2223 *	0.5019 *	0.0849 *
Russia: Murmansk	Coefficient	−0.0295	−0.0180	0.1149	0.1509	0.0297	0.0104	0.1147	0.0124	0.1614	0.1808	0.2580
	t-stat	4.5096	2.5985	−1.4085	−3.0955	−1.0583	2.0588	1.0095	2.0985	3.0009	−2.4621	−4.9076
	Prob	0.4507 **	0.3811 **	0.3222 ***	0.4086 ***	0.5929 *	0.0061 *	0.3376 **	0.5902 *	0.6871 **	0.2984 **	0.0791 ***
Russia: Petropavlovsk	Coefficient	0.0663	0.0504	0.1146	0.1532	0.0135	0.0067	0.0508	0.0396	0.0023	0.0040	0.1573
	t-stat	2.0000	2.3856	−3.5041	−2.0698	1.0532	4.9433	−2.9870	1.6084	2.6830	−3.8045	2.0005
	Prob	0.5288 *	0.6902 *	0.0057 *	0.1904 *	0.0994 *	0.7502 *	0.3099 **	0.0087 *	0.1481 *	0.5409 *	0.4873 **
Russia: Pevek	Coefficient	0.0075	0.0104	0.2094	0.0066	0.0061	0.0013	0.0114	0.0058	0.0014	0.0023	0.1106
	t-stat	−1.9409	−3.8700	2.8895	1.0587	3.0855	2.9555	−2.0065	3.1335	−4.9722	−2.5561	−3.6091
	Prob	0.0663 *	0.4426 *	0.5873 *	0.4200 *	0.0000 *	0.0000 *	0.1982 **	0.5987 *	0.0003 *	0.4093 *	0.3863 *
Russia: Sabetta	Coefficient	0.0207	0.0195	0.0396	0.0008	0.0897	0.0002	0.0058	0.1804	0.0004	0.0002	0.3472
	t-stat	−2.2060	−1.4809	2.9487	4.0596	3.1774	2.1247	3.0871	−5.0822	−3.8961	−4.2247	3.6053
	Prob	0.4791 *	0.2853 *	0.0035 **	0.7091 *	0.6908 **	0.7883 *	0.0039 *	0.9431 **	0.2907 *	0.6148 *	0.5686 **
Russia: Vladivostok	Coefficient	−0.0593	−0.0355	0.0340	0.1985	0.1345	0.1590	0.0292	0.0853	0.2480	0.2175	0.4112
	t-stat	3.1134	1.4094	2.0556	3.5444	1.9800	4.9801	−2.0440	−3.5104	4.1564	3.9962	2.2275
	Prob	0.0988 **	0.0527 **	0.0974 ***	0.1307 **	0.4877 ***	0.2874 ***	0.0598 *	0.1365 *	0.3902 ***	0.8271 ***	0.3609 ***
South Korea: Gwangyang	Coefficient	−0.0570	−0.0651	0.3406	0.3053	0.3415	0.3076	−0.0817	−0.0993	−0.0018	−0.0036	0.2808
	t-stat	−3.5442	−2.2309	4.1158	3.4724	−1.5982	−2.7951	2.0041	−1.5081	2.5814	3.4140	1.7377
	Prob	0.8691 **	0.4255 **	0.3754 **	0.5160 **	0.4773 ***	0.5870 ***	0.0482 *	0.5802 *	0.1263 *	0.0006 **	0.1283 **
South Korea: Pusan	Coefficient	0.0814	0.0642	0.8115	0.8359	0.6776	0.6015	−0.1405	−0.1620	−0.0057	−0.0114	0.6217
	t-stat	1.8693	2.7993	4.6346	3.0045	−3.6871	−1.9865	2.0481	3.6111	−1.5548	−2.6932	−4.8994
	Prob	0.0809 **	0.5581 **	0.9500 ***	0.8198 ***	0.6900 ***	0.5824 ***	0.3870 **	0.4816 **	0.8347 **	0.5918 **	0.6000 ***

Table A5. *Cont.*

Port	Parameter	ΔX_1	ΔX_2	ΔX_3	ΔX_4	ΔX_5	ΔX_6	ΔX_7	ΔX_8	ΔX_9	ΔX_{10}	ECM
South Korea: Ulsan	Coefficient	−0.0474	−0.0576	0.5209	0.5573	0.5116	0.4370	0.0045	−0.0954	−0.0664	−0.0407	0.5836
	t-stat	3.5500	1.4732	3.5664	4.0560	−2.8095	−1.4567	−3.9582	−2.0585	−3.4493	−2.3763	−3.1371
	Prob	0.3571 **	0.5918 **	0.6816 ***	0.4176 ***	0.5983 ***	0.4442 ***	0.9185 *	0.7203 *	0.0037 *	0.0448 **	0.2795 **
Sweden: Gothenburg	Coefficient	0.0045	0.0037	0.7054	0.7650	0.1619	0.1890	0.1581	−0.0018	0.0136	0.0744	−0.3028
	t-stat	1.5828	2.5336	−4.9007	−3.1974	−1.8592	−2.2971	1.8429	−3.0284	1.7083	2.1286	−3.1401
	Prob	0.3752 *	0.4975 *	0.8162 ***	0.7005 ***	0.6866 **	0.2309 **	0.4105 **	0.1562 *	0.0000 *	0.0287 *	0.5982 ***
Sweden: Halmstad	Coefficient	0.0006	0.0004	0.3569	0.4021	0.1047	0.1456	0.0368	−0.0035	0.0275	0.0805	0.0485
	t-stat	3.7099	2.8671	−3.0988	−2.6810	−4.6438	−2.0974	2.0815	4.4911	2.6092	3.8881	−2.7002
	Prob	0.3812 *	0.4502 *	0.4713 ***	0.5658 ***	0.1870 **	0.2619 **	0.5092 **	0.2976 *	0.4983 *	0.2550 *	0.2976 **

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

Appendix D

Table A6. ARDL long-run estimates, ports, 2015–2019.

Port	Parameter	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Constant
China: Dalian	Coefficient	0.1235	0.2248	0.2035	0.1944	0.0720	−0.1424	−0.0565	−0.1527	3.2765
	t-stat	1.2741 ***	−3.4297 ***	−1.9264 **	−2.3273 **	3.8319 *	−1.8300 **	1.7347 ***	2.3091 ***	2.2281
China: Lianyungang	Coefficient	0.1638	0.2134	0.1386	0.1307	0.2015	−0.0748	0.0548	−0.1132	2.4523
	t-stat	−2.4371 **	2.9999 **	−2.3982 *	−3.2591 *	−3.4778 *	1.9756 *	2.7232 **	−3.4544 **	3.1742
China: Qingdao	Coefficient	0.2655	0.2318	0.3445	0.3616	0.1232	−0.0375	−0.3111	−0.1459	−4.1376
	t-stat	1.4967 **	2.6805 **	−4.5940 ***	−1.8367 ***	2.3719 *	1.7622 **	3.4780 ***	−1.3254 ***	−1.5005
China: Qinhuangdao	Coefficient	0.2352	0.2002	0.1453	0.1542	0.0863	0.0283	0.0387	−0.0371	5.1893
	t-stat	2.8307 **	3.1531 **	1.2763 *	2.5395 *	−2.1279 *	1.4721 *	1.0724 **	4.3864 **	3.4722
China: Rizhao	Coefficient	0.4176	0.3726	0.1280	0.1666	0.0084	0.1637	0.0255	0.0169	4.8531
	t-stat	4.3809 **	2.0827 **	−2.3195 *	−2.0874 *	3.4807 *	−2.1489 *	−2.2987 *	2.3206 **	3.3678 *
China: Shanghai	Coefficient	0.7254	0.7742	0.5683	0.5967	0.1798	0.2483	0.2659	−0.3215	−5.2730
	t-stat	4.9512 ***	−2.3945 ***	1.1700 ***	2.4843 ***	−3.4615 **	2.3311 **	−1.0315 ***	3.8843 ***	−3.1662
China: Weihai	Coefficient	0.3017	0.4276	0.1635	0.1955	0.0564	0.1829	0.1946	0.0636	2.2113
	t-stat	4.5200 **	1.6991 **	−4.2046 **	−2.2316 **	3.2851 *	2.1272 *	3.0271 **	−1.8200 **	3.6585
China: Yantai	Coefficient	0.2784	0.2465	0.1739	0.2341	0.1529	0.2585	0.0555	−0.1478	4.3971
	t-stat	3.0773 ***	−2.5710 ***	3.2285 **	1.7275 **	−2.3004 **	3.1964 **	2.7232 **	−2.7193 **	2.2276
Denmark: Aarhus	Coefficient	0.1845	0.1344	0.0722	0.0624	0.0965	−0.0421	0.1617	0.0995	−3.5323
	t-stat	2.3808 ***	2.5956 ***	1.5310 *	−2.2937 *	1.5312 *	−3.1375 *	1.2534 **	2.3852 *	1.5905
Denmark: Copenhagen	Coefficient	0.1402	0.1732	0.0255	0.0813	0.0400	0.0667	0.0511	0.1267	−4.6628
	t-stat	−1.5213 ***	3.1648 ***	−2.0176 *	−4.2565 *	2.1406 *	4.5489 *	2.7042 *	−1.8553 *	−2.7390
Denmark, Greenland: Nuuk	Coefficient	0.7235	0.6857	0.1523	0.0246	0.5275	−0.1382	−0.0756	−0.0250	5.2034
	t-stat	3.0804 ***	4.1621 ***	−1.4592 *	2.4521 *	−1.9221 **	2.3176 *	−1.3413 *	−1.5126 *	3.5615
Iceland: Reydharfjordur	Coefficient	0.5156	0.4275	0.2551	0.2472	0.5384	−0.0347	0.0614	0.0411	2.3587
	t-stat	2.7443 ***	2.6310 ***	−1.2964 *	2.8333 *	−1.6565 ***	2.4251 *	2.7256 *	1.8324 *	2.0671

Table A6. *Cont.*

Port	Parameter	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Constant
Iceland: Reykjavik	Coefficient	0.6842	0.6198	0.4823	0.2755	0.1716	−0.0423	0.1399	0.0638	4.2592
	t-stat	2.1763 ***	−2.5334 ***	−2.5562 **	2.6216 **	−2.6288 **	1.7262 *	3.1762 **	−1.8230 **	3.7460
Japan: Akita	Coefficient	0.5111	0.6087	0.2431	0.2284	0.1803	0.0479	−0.0843	−0.0655	−4.5829
	t-stat	2.2875 **	2.7918 **	−3.3827 **	−2.5197 **	2.6951 *	−1.6035 *	2.4114 *	1.5314 *	−2.7044
Japan: Hakata	Coefficient	0.4584	0.4975	0.1963	0.2512	0.3560	0.0671	0.0782	0.0821	4.8276
	t-stat	1.7721 **	2.8512 **	3.0008 **	2.4908 **	1.9542 *	3.2556 *	2.3907 *	−2.6630 *	2.7921
Japan: Kitakyushu	Coefficient	0.3927	0.4584	0.1746	0.2165	0.2294	0.1777	0.0653	0.0882	−5.6415
	t-stat	1.8409 **	2.9116 **	−2.3875 **	−2.1840 **	4.5517 **	−1.8623 *	2.7621 *	1.7313 *	−4.5526
Japan: Niigata	Coefficient	0.2752	0.2460	0.2861	0.3485	0.0514	0.1405	−0.1584	−0.0621	3.3840
	t-stat	−2.8150 ***	−2.3854 ***	3.3705 ***	2.6832 ***	1.7280 ***	2.7334 *	1.7335 **	3.5992 **	2.0052
Norway: Bergen	Coefficient	0.2516	0.1563	0.2440	0.2186	0.1843	0.3247	0.1360	0.2239	3.5287
	t-stat	2.3543 **	−2.1885 **	−2.2598 *	−1.4934 *	−3.7609 **	1.6111 **	−2.3952 **	−2.5251 **	2.1645
Norway: Hammerfest	Coefficient	0.0744	0.0800	0.0961	0.0709	0.2665	0.2330	0.0941	0.3883	5.3054
	t-stat	2.3187 **	3.5816 **	−3.0335 *	−2.5882 *	2.9174 *	−3.5792 **	−2.5304 **	3.4737 **	3.5287
Norway: Stavanger	Coefficient	0.2995	0.3447	0.0927	0.0731	0.2652	0.1755	0.4265	0.2385	4.2556
	t-stat	4.1850 ***	2.5643 ***	4.4436 **	1.8520 **	−3.0186 **	1.7234 **	2.8667 **	1.7114 **	2.0081
Norway: Tromso	Coefficient	0.2713	0.2862	0.1543	0.1256	0.1913	0.0996	0.0309	0.0622	3.4619
	t-stat	2.2246 ***	−4.5505 ***	2.6285 *	2.7095 *	1.7200 **	−2.2838 *	3.5176 *	2.3787 *	2.0387
Norway: Trondheim	Coefficient	0.1637	0.2739	0.3612	0.3330	0.0908	0.1831	0.4274	0.1916	5.1862
	t-stat	−2.3062 ***	1.8174 ***	2.7556 **	1.8621 **	−3.1634 **	4.2559 **	2.2965 **	−3.0001 **	4.6559
Russia: Anadyr	Coefficient	0.0706	0.0032	0.00109	0.0075	0.0837	−0.0112	−0.0030	0.0028	−3.1780
	t-stat	−2.5873 *	−3.5985 *	−1.3917 *	−2.6173 *	1.4095 **	−2.3887 *	2.6774 *	2.1795 *	−2.5545
Russia: Arkhangelsk	Coefficient	0.0581	0.0374	0.0095	0.0457	0.1520	−0.0135	0.2487	0.1553	5.2761
	t-stat	−2.3995 **	−2.0456 **	−3.5286 *	3.6812 *	3.2293 *	2.7697 *	−1.9990 *	−2.0046 *	4.6882
Russia: Dudinka	Coefficient	0.0089	0.0037	0.0077	0.0065	0.1671	0.0202	0.00116	0.0122	3.4550
	t-stat	−3.3553 *	1.8820 *	−2.8148 *	−2.9153 *	−1.8729 **	2.8151 *	1.5370 *	2.7609 *	2.7166
Russia: Murmansk	Coefficient	0.1417	0.1815	0.0621	0.0120	0.1773	0.0266	0.11744	0.2751	6.3375
	t-stat	−3.0815 ***	−2.0058 ***	−1.8130 *	2.4839 *	−2.0194 **	−1.7810 **	2.7151 **	−2.0365 **	5.0949
Russia: Petropavlovsk	Coefficient	0.1550	0.1732	0.0445	0.0278	0.0709	0.0628	0.0076	0.0090	3.5812
	t-stat	−4.2656 *	−2.8954 *	1.8182 *	3.3365 *	−1.6845 **	3.1475 *	2.6187 *	−2.1154 *	3.2980
Russia: Pevek	Coefficient	0.1822	0.00135	0.0163	0.0189	0.0200	0.0447	0.0103	0.0067	4.3167
	t-stat	1.9457 *	1.6089 *	3.8265 *	1.7704 *	−3.5287 **	2.1860 *	−3.1498 *	−1.5980 *	2.0095
Russia: Sabetta	Coefficient	0.0663	0.0043	0.1664	0.0091	0.0084	0.2788	0.0060	0.0069	3.7599
	t-stat	2.5055 **	−2.0787 *	1.9875 **	2.4980 *	2.5112 *	−4.5909 **	−3.1693 *	−3.4897 *	2.4631
Russia: Vladivostok	Coefficient	0.0884	0.2352	0.1713	0.2054	0.0535	0.1275	0.2926	0.2112	6.2680
	t-stat	4.4591 ***	2.3716 **	−2.5361 ***	3.8276 ***	−2.6289 *	−2.5804 **	1.2017 ***	1.7975 ***	5.3799
South Korea: Gwangyang	Coefficient	0.4516	0.4285	0.3590	0.3082	−0.0904	−0.1126	−0.0132	−0.0089	3.2795
	t-stat	2.8029 ***	1.5296 **	−2.3983 ***	−1.6396 ***	4.8275 *	−2.8227 *	1.5541 *	−2.4002 **	2.7891
South Korea: Pusan	Coefficient	0.8217	0.7814	0.7093	0.6619	−0.1541	−0.1773	−0.0158	−0.0594	5.3987
	t-stat	−2.0039 ***	−2.5870 ***	−1.4069 ***	−2.9276 ***	1.8266 **	2.0095 **	−4.5203 **	−1.8886 **	3.1963

Table A6. *Cont.*

Port	Parameter	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Constant
South Korea: Ulsan	Coefficient	0.6573	0.5718	0.5608	0.4767	0.0134	−0.0874	−0.1227	−0.0995	4.0440
	t-stat	4.1280 ***	3.0052 ***	−2.4816 ***	−2.0086 ***	−4.5598 *	−3.2790 *	−2.4986 *	−4.2644 **	3.8215
Sweden: Gothenburg	Coefficient	0.7031	0.7394	0.2001	0.1670	0.1783	−0.0144	0.0169	0.0931	6.4778
	t-stat	−2.3827 ***	−1.6590 ***	−2.3857 **	−3.5281 **	3.5990 **	−1.8976 *	2.1024 *	−1.5509 *	4.6380
Sweden: Halmstad	Coefficient	0.4136	0.4322	0.1760	0.1574	0.0775	−0.0353	0.0665	0.0963	5.1385
	t-stat	−1.4789 ***	−3.2971 ***	−3.9178 **	−1.6660 **	4.9836 **	2.4812 *	3.0009 *	1.5987 *	3.0041

Note: *, **, *** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

Table A7. ARDL long-run estimates, ports, 2020.

Port	Parameter	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Constant
China: Dalian	Coefficient	−0.0157	−0.0245	0.1470	0.1568	0.1773	0.1982	0.0561	−0.1450	−0.0239	−0.1725	3.7612
	t-stat	2.2249 **	3.0019 **	2.9387 **	−4.0012 **	2.6981 *	−3.5099 **	2.8512 *	1.9563 **	2.0045 ***	3.2986 ***	2.6546
China: Lianyungang	Coefficient	−0.0358	−0.0442	0.0528	0.0647	0.0425	0.0513	0.1630	−0.0672	0.0730	−0.1379	6.3715
	t-stat	−3.2905 **	−2.5990 **	3.6111 *	2.1295 *	−1.6056 *	−2.6276 *	−2.4389 *	4.1508 *	2.6884 **	−1.5203 **	4.2100
China: Qingdao	Coefficient	0.0312	0.0054	0.1452	0.1555	0.2234	0.2521	0.0618	−0.0083	−0.2953	−0.1476	−5.8761
	t-stat	3.1649 *	2.5189 *	3.3765 *	3.6186 *	−2.6701 **	−3.3478 **	4.7165 *	3.4514 **	2.6197 ***	3.2421 ***	−3.3409
China: Qinhuangdao	Coefficient	−0.0754	−0.0548	0.2387	0.1752	0.0733	0.0567	0.0831	0.0097	0.0205	−0.0044	5.1285
	t-stat	−2.6285 *	−3.7153 *	1.7440 **	3.1508 **	4.5172 *	3.3196 *	−2.2590 *	1.3896 *	4.0089 **	3.5217 **	4.0006
China: Rizhao	Coefficient	−0.1340	−0.1195	0.1297	0.1201	0.0376	0.0935	0.0097	0.1582	0.0094	0.0190	4.1138
	t-stat	−4.2759 **	−3.0164 **	2.2256 **	3.2378 **	2.1390 *	2.8527 *	1.8361 *	−3.4800 *	−2.7182 *	1.3114 **	3.5706
China: Shanghai	Coefficient	0.1304	0.1256	0.4150	0.3628	0.4209	0.2514	0.1523	0.2195	0.2156	−0.2230	−6.1713
	t-stat	2.5981 *	2.1294 *	3.7598 ***	3.4519 ***	1.3871 ***	1.5662 ***	−4.5299 **	5.3298 **	3.1590 ***	2.1308 ***	−4.2992
China: Weihai	Coefficient	−0.0122	−0.0237	0.1442	0.1753	0.0674	0.0751	0.0640	0.1483	0.1815	0.0427	5.7634
	t-stat	−1.5380 **	−2.6908 **	4.5700 **	3.4729 **	−4.2568 **	−3.6225 **	2.8321 *	3.2648 *	1.2930 **	−3.5113 **	2.5310
China: Yantai	Coefficient	−0.0503	−0.0531	0.1256	0.0950	0.1241	0.1553	0.1452	0.1527	0.0505	−0.1486	4.4456
	t-stat	3.6125 **	2.7142 **	4.4003 **	3.6128 **	2.3987 **	3.1786 **	−2.5009 **	4.7996 **	3.2913 **	−2.7962 **	3.5897
Denmark: Aarhus	Coefficient	−0.0246	−0.0097	0.3419	0.2915	0.0347	0.0224	0.0575	−0.0192	0.1164	0.0740	−5.1362
	t-stat	−4.4085 *	−3.7736 *	5.3600 **	3.6262 **	1.5503 *	−2.2843 *	1.6448 *	−2.4861 *	3.7080 **	3.5123 *	−4.6251
Denmark: Copenhagen	Coefficient	−0.1566	−0.1454	0.2503	0.2264	0.0060	0.0554	0.0083	0.0164	0.0435	0.0777	−3.2587
	t-stat	2.3051 **	4.7238 **	−1.4967 **	2.7481 **	−3.3714 *	−4.7006 *	2.5091 *	1.5226 *	2.6172 *	−2.4553 *	−2.3521
Denmark, Greenland: Nuuk	Coefficient	0.0366	0.0473	0.7351	0.6775	0.0921	0.0070	0.4516	−0.0832	−0.0299	−0.0134	4.5600
	t-stat	−1.5827 *	−2.2518 *	4.2879 ***	3.8163 ***	2.7265 *	3.6198 *	−2.6315 **	3.4440 *	−1.7451 *	−3.5819 *	4.2187
Iceland: Reydharfjordur	Coefficient	0.0342	0.0215	0.5274	0.3969	0.2830	0.2697	0.5930	−0.0156	0.0715	0.0147	5.0232
	t-stat	−2.4054 *	−2.7916 *	4.2613 ***	3.3514 ***	−2.5326 *	4.4625 *	−2.4811 ***	1.6822 *	2.6380 *	1.0000 *	3.5714
Iceland: Reykjavik	Coefficient	−0.0236	−0.0174	0.6532	0.5731	0.3003	0.2954	0.1850	−0.0123	0.1486	0.0638	6.3522
	t-stat	−3.7198 *	4.5261 *	3.3899 ***	−2.5247 ***	−1.8345 **	1.9685 **	−3.2747 **	2.4981 *	3.5344 **	−2.8625 **	5.4910
Japan: Akita	Coefficient	−0.1123	−0.0909	0.5563	0.6215	0.1964	0.2240	0.1498	0.0086	−0.0465	−0.0341	−3.5213
	t-stat	−2.5934 **	−1.5487 **	2.5712 **	3.3408 **	−2.5370 **	−3.0567 **	4.4665 *	−2.4565 *	1.3173 *	2.4226 *	−2.3999
Japan: Hakata	Coefficient	−0.0405	−0.0864	0.4340	0.3422	0.1635	0.1754	0.3613	0.0170	0.0381	0.0654	3.6280
	t-stat	4.2984 **	3.7282 **	1.8651 **	2.8537 **	3.2049 **	2.6210 **	1.7506 *	2.8418 *	1.7399 *	−1.5980 *	2.1341

Table A7. *Cont.*

Port	Parameter	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Constant
Japan: Kitakyushu	Coefficient	−0.2316	−0.2300	0.3145	0.4928	0.2250	0.1549	0.2407	0.1255	0.0182	0.0333	−5.3826
	t-stat	3.7388 **	−2.2738 **	1.7507 **	4.5755 **	−1.6131 **	−2.1213 **	2.6628 **	−1.5673 *	3.1996 *	2.0276 *	−3.0024
Japan: Niigata	Coefficient	0.1775	0.1104	0.2158	0.2470	0.2015	0.2824	0.0600	0.1364	−0.0975	−0.0409	6.2345
	t-stat	3.5172 **	1.7396 **	−2.5573 ***	−3.6369 ***	4.3862 ***	2.5731 ***	1.5382 ***	4.7211 *	2.7523 **	3.3278 **	4.6117
Norway: Bergen	Coefficient	−0.0164	−0.0331	0.1485	0.1001	0.1884	0.1569	0.1754	0.2362	0.1565	0.1831	3.5220
	t-stat	−3.8526 **	−3.5920 **	2.1567 **	2.8332 **	−1.7210 *	−2.4352 *	−2.3709 **	2.5863 **	−2.4207 **	−2.7456 **	2.3476
Norway: Hammerfest	Coefficient	−0.0265	−0.0326	0.0472	0.0743	0.0399	0.0545	0.2356	0.2134	0.0612	0.3007	5.9992
	t-stat	−3.4387 **	−2.4187 **	3.4206 *	2.6938 *	−3.4251 *	−2.5710 *	2.4884 *	−1.6307 **	−3.2655 **	1.6284 **	3.5475
Norway: Stavanger	Coefficient	0.0153	0.0242	0.2580	0.2421	0.0166	0.0532	0.1775	0.1863	0.3350	0.2675	6.6820
	t-stat	3.2854 *	2.4966 *	4.7364 **	1.6408 **	3.2489 **	2.3005 **	−1.5113 **	2.5981 **	4.1673 **	3.2151 **	4.7532
Norway: Tromso	Coefficient	−0.0483	−0.0574	0.2341	0.1752	0.0785	0.0519	0.1670	0.0445	0.0256	0.0662	5.5311
	t-stat	2.5800 **	3.2856 **	2.7209 **	3.1954 **	2.3661 *	3.5998 *	3.4839 **	−2.9113 *	1.2749 *	3.4806 *	3.8006
Norway: Trondheim	Coefficient	0.0677	0.0585	0.1217	0.1751	0.2630	0.2652	0.0523	0.1400	0.3675	0.2138	4.3717
	t-stat	2.3692 **	3.6401 **	2.5962 ***	2.3760 ***	3.2624 **	2.2471 **	−1.6296 **	4.1625 **	2.8841 **	−2.1532 **	3.9552
Russia: Anadyr	Coefficient	0.0018	0.0023	0.0562	0.0009	0.0065	0.0012	0.0550	−0.0031	−0.0042	0.0013	−5.3276
	t-stat	2.1535 *	2.5184 *	−1.2396 *	−1.2536 *	−2.1427 *	−1.3074 *	2.6186 **	−3.5283 *	4.0635 *	2.1467 *	−4.4884
Russia: Arkhangelsk	Coefficient	−0.0332	−0.0411	0.0357	0.0448	0.0125	0.0231	0.0824	−0.0057	0.1621	0.1274	4.1235
	t-stat	2.1574 **	3.6275 **	−2.5583 **	−3.5751 **	−4.8266 *	5.2408 *	1.6200 *	4.8652 *	−2.6333 *	−3.6755 *	3.0053
Russia: Dudinka	Coefficient	0.0095	0.0127	0.0234	0.0032	0.0070	0.0035	0.0844	0.0159	0.0167	0.0281	3.2344
	t-stat	−2.3746 *	−2.4993 *	4.3857 *	2.6350 *	3.5416 *	−4.3683 *	−1.7268 **	3.7004 *	2.5758 *	4.5006 *	2.1206
Russia: Murmansk	Coefficient	−0.0443	−0.0325	0.1342	0.1781	0.0453	0.0328	0.1367	0.0335	0.1862	0.1775	6.1731
	t-stat	4.1986 **	3.6174 **	−2.6315 ***	−3.4277 ***	−2.2200 *	2.3990 *	1.2708 **	2.2847 *	3.4721 **	−2.2740 **	4.5255
Russia: Petropavlovsk	Coefficient	0.0857	0.0546	0.1473	0.1624	0.0366	0.0247	0.0612	0.0554	0.0135	0.0076	3.2346
	t-stat	2.2249 *	2.3358 *	−3.8821 *	−2.5290 *	1.2987 *	4.5224 *	−2.2775 **	1.7189 *	2.5000 *	−3.5227 *	2.9672
Russia: Pevek	Coefficient	0.0070	0.0122	0.2425	0.0258	0.0021	0.0046	0.0230	0.0337	0.0255	0.0088	5.3381
	t-stat	−1.8421 *	−3.4339 *	2.5190 *	1.3912 *	3.3059 *	2.4483 *	−2.3995 **	3.2694 *	−4.7141 *	−2.1945 *	4.0053
Russia: Sabetta	Coefficient	0.0243	0.0330	0.0527	0.0035	0.1232	0.0024	0.0113	0.2055	0.0013	0.0005	4.1225
	t-stat	−2.5992 *	−1.7268 *	2.3981 **	4.2664 *	3.0676 **	2.8495 *	3.4887 *	−5.1837 **	−3.4416 *	−4.3663 *	3.3406
Russia: Vladivostok	Coefficient	−0.0884	−0.0561	0.0402	0.2145	0.1567	0.1783	0.0285	0.0996	0.2743	0.2284	6.5893
	t-stat	3.2056 **	1.5725 **	2.6843 ***	3.3003 **	1.3280 ***	4.5871 ***	−2.1264 *	−3.4720 *	4.0065 ***	3.4071 ***	5.2444
South Korea: Gwangyang	Coefficient	−0.0664	−0.0852	0.3643	0.3315	0.3364	0.3142	−0.1398	−0.1145	−0.0020	−0.0074	4.3718
	t-stat	−3.2817 **	−2.5006 **	4.1509 **	3.4782 **	−1.7016 ***	−3.5290 ***	2.2750 *	−2.4988 *	3.4285 *	3.5311 **	2.2269
South Korea: Pusan	Coefficient	0.0953	0.0714	0.8165	0.8554	0.6571	0.6794	−0.1562	−0.1724	−0.0055	−0.0247	6.1378
	t-stat	1.7136 **	2.2485 **	4.9127 ***	4.2942 ***	−3.2704 ***	−1.6228 ***	2.3007 **	3.7506 **	−1.4682 **	−2.8156 **	4.4093
South Korea: Ulsan	Coefficient	−0.0676	−0.0608	0.5153	0.5429	0.5620	0.4475	0.0063	−0.1164	−0.0725	−0.0637	5.7107
	t-stat	3.3175 **	1.2601 **	3.4274 ***	4.1212 ***	−2.0053 ***	−1.7312 ***	−3.9279 *	−2.1505 *	−3.1000 *	−2.4861 **	3.2123
Sweden: Gothenburg	Coefficient	0.0068	0.0052	0.6987	0.7425	0.1850	0.1874	0.1637	−0.0032	0.0145	0.0957	−4.1752
	t-stat	1.3791 *	2.4720 *	−4.2405 ***	−3.6029 ***	−1.7442 **	−2.4933 **	1.7446 **	−3.1268 *	1.5286 *	2.3864 *	−3.6973
Sweden: Halmstad	Coefficient	0.0005	0.0007	0.3316	0.4254	0.1261	0.1100	0.0432	−0.0047	0.0530	0.0813	2.2097
	t-stat	3.3796 *	2.4305 *	−3.2777 ***	−2.7315 ***	−4.5985 **	−2.6013 **	2.3615 **	4.5841 *	2.7998 *	3.7286 *	2.0585

Note: *, **,*** = significance at 10% level, 5% level, and 1% level, respectively. Source: Authors' calculation.

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Cross-Country Potentials and Advantages in Trade in Fish and Seafood Products in the RCEP Member States

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Abstract: Fisheries has always played a vital role in supporting livelihoods and ensuring food security and sustainable economic and social development in Southeast Asia. Historically, rural and coastal communities across the region have heavily relied on the fish trade as an indispensable source of income and employment. With the establishment of the Regional Comprehensive Economic Partnership (RCEP) between Association of Southeast Asian Nations (ASEAN) economies and large fish traders like China, Japan, South Korea, Australia, and New Zealand, there is a threat for smaller countries to lose competitive advantages in the regional market. By studying bilateral trade flows between fifteen RCEP members in 2010–2019 and matching indicative untapped trade potentials (ITP method) with revealed comparative (RCA method), relative trade (RTA method), and competitive (Lafay index) advantages across 210 pairs of countries, the authors found substantial misbalances between potential values of country-to-country trade and actual advantages of RCEP economies. To optimize gains from intraregional trade for both smaller and larger RCEP members, this study identified advantageous and disadvantageous trading destinations and product categories for individual countries. The recommendations were then generalized along the four groups of economies based on their level of income, contribution to overall RCEP trade in fish, and the share of fishery products in the national trade turnover. From a practical side, the study adds to the knowledge about the fish trade in Asia by detailing how countries can better utilize individual combinations of advantages. From a methodological side, the approach can be employed widely outside the RCEP to establish a reliable picture of potential gains or losses of a particular country in trade with its counterparts across varied sets of competitive advantages.

Keywords: ASEAN; comparative advantage; fish; fishery products; RCEP; seafood; trade

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1. Introduction

For centuries, fish and fishery products have played a crucial role in establishing food security [1], particularly in poor coastal communities [2,3], and contributed to the economic development of many nations around the world [4,5]. With the huge emergence of an international exchange over the last decades, globalization has converged consumption patterns worldwide [6,7] and inextricably linked fish-abundant coastal areas to fish-deficit distant markets, hence affecting the sustainability of fish supply and global food security [8,9]. According to the most recent estimation of the Food and Agriculture Organization (FAO) [10], from 1976 to 2018, the value of global fish exports increased at an annual rate of 8% in nominal terms and 4% in real terms. Fishery products have become one of the world's most heavily traded food commodities [11], with over half of exports to developed countries originating from developing economies of Asia, Latin America, and Africa (compared to 39% in the 1970s) [12]. The share of developing countries of the total quantity of fish production increased from 39% in 1976 to 60% in 2018, supported by the rapid development of aquaculture and investment in export market facilities and infrastructure, particularly in China and Southeast Asia [12].

To a considerable degree, the growth of fish production and trade in Asia has been facilitated by a steady liberalization of global agricultural trade [13,14] and an increase in the number of regional trade agreements [12,15]. The reduction of import tariffs on fish products, which has become an issue in the international trade negotiations after the Doha Ministerial Meeting in 2001 [16], has been a major driver of fish trade since then [12]. Most countries that have exhausted their gains within national boundaries use trade measures on fish products to secure new markets [17–19]. The growth of intraregional networks in Asia started in 1967 with the establishment of the Association of Southeast Asian Nations (ASEAN) with Indonesia, Malaysia, Philippines, Singapore, and Thailand as founding members [20]. In 1992, ASEAN countries launched the ASEAN Free Trade Area (AFTA), which membership had further expanded by 1999 to ten countries with the accession of Brunei Darussalam, Vietnam, Lao PDR, Myanmar, and Cambodia. By entering into separate trade agreements with other countries of Asia and Oceania, the ASEAN had established a foundation for launching multilateral trade negotiations in 2012 in order to strengthen economic linkages and enhance trade activities among the parties [21]. In November 2020, the resulting Regional Comprehensive Economic Partnership (RCEP) agreement between the ten ASEAN states, Australia, China, Japan, New Zealand, and South Korea established the world's largest free trade area [22] covering a market of 2.2 billion people with a combined size of 30% of the world's GDP [23].

RCEP countries now play a crucial role in global fisheries production and exports with over 80% of the world's farmed seafood output and 85% of 60 million people around the world directly involved in the seafood sector [10]. The region has emerged as a global fish producer, owing to the growth of aquaculture and the large offshore fishing fleet [24]. The Mekong River Basin (Myanmar, Lao PDR, Thailand, Cambodia, and Vietnam) along with huge freshwater areas available in China allow for the production of several million tons of freshwater fish annually [25–27]. The fishery sector is an important contributor to the economic growth of RECP countries and an indispensable source of export revenue for national budgets, as well as a provider of employment [28] and a source of living [29,30], poverty alleviation [31], and food security [32] in coastal communities [10,33,34].

The relevance of fisheries and aquaculture to food security and sustainable development is highlighted by the targets of the United Nations Sustainable Development Goals [35]—the increase in agricultural productivity of fisheries [36], the regulation of fish harvesting and the fight against illegal, unreported, and unregulated fishing [37] and destructive fishing practices [38], and the prevention of trade restrictions and distortions in world agricultural markets [36]. Simplifying trade procedures and lowering import tariffs aims at making fishery products more competitive in the intraregional market [39,40], but current trade in fish in RCEP countries is characterized by three asymmetries.

First is that while bigger traders (China, Japan, Vietnam, Thailand) diversify their trade with the rest of the world, smaller economies critically depend on intraregional trade. China alone accounts for nearly 15% of the value of the world's total exports of fish and fishery products [41] with nearly two-thirds of the total trade turnover exported to or imported from outside the RCEP. On the other hand, for Cambodia, Lao PDR and Myanmar, where fisheries represent a critical source of export earnings [42], employment of the poor people, and income generation in coastal areas [24], fish trade is mainly generated within the RCEP (Figure 1).

Second, the intra-RCEP trade follows general globalized income inequality pattern demonstrated in earlier studies by Delgado et al. [43], Bene [28], and Mossler [44] when more developed countries act like net importers of low-value fish and seafood from less developed economies and specialize in exporting high-value processed fishery products. Vietnam, Thailand, Myanmar, and Indonesia enjoy a surplus in the intra-RCEP trade in fish with Japan, Australia, South Korea, and Singapore being the top net importers of fish in the region (Figure 2).

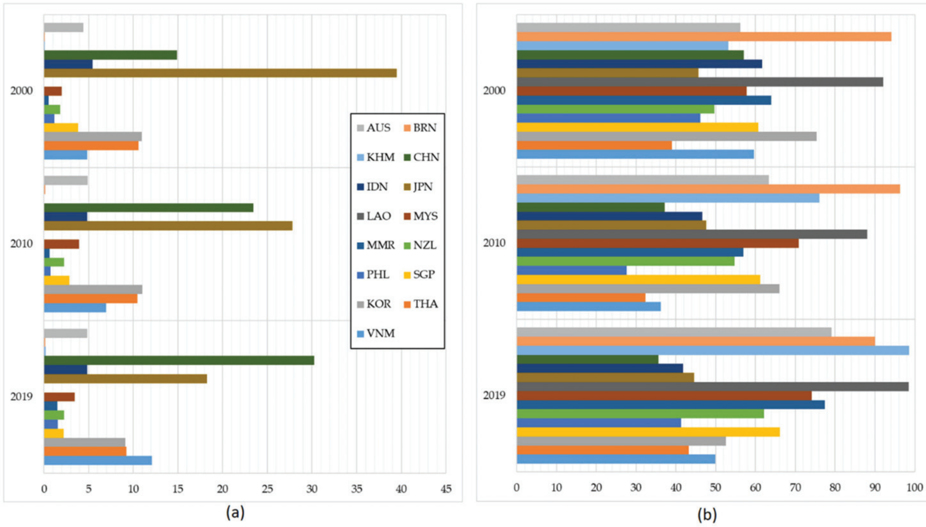

Figure 1. Regional Comprehensive Economic Partnership (RCEP) trade in fish and seafood products in 2000–2019: (**a**) share in RCEP trade, (**b**) RCEP/World trade, %. Note: country's contribution to the intraregional trade turnover of fish and seafood products; share of the intra-RCEP trade in the country's total trade turnover of fish and seafood products; country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam). Source: Authors' development based on [45].

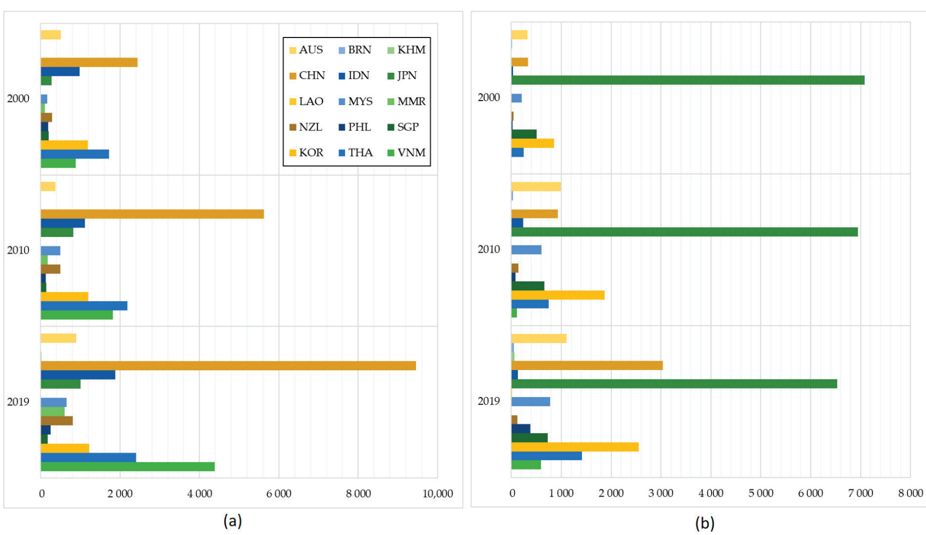

Figure 2. Intra-RCEP trade in fish and seafood products in 2000–2019: (**a**) exports to RCEP, (**b**) imports from RCEP, $ million. Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam). Source: Authors' development based on [45].

The third asymmetry is that the concentration of intraregional trade in fish and seafood products between RCEP members is highly skewed towards higher-income countries, mainly China, Japan, and South Korea, as well as large traders like Vietnam and Thailand, while fishing-dependent lower-income economies make a minor contribution to the intra-RCEP trade. Within the RCEP free trade area format, the reductions in import tariffs could further widen this gap by favoring producers in more developed countries at the expense of other exporters, reducing the margins of tariff preferences for less developed economies [46], affecting their competitiveness in the regional market, decreasing their contribution to the intraregional trade, and thus endangering overall stability of economic and social development in smaller RCEP states.

As evidenced by many ASEAN-related and then RCEP-related studies, including Park et al. [47], Prabhakar et al. [48], Yue [49], Erokhin [50], and Menon [51], to achieve stability and improve overall performance, an optimal free trade regime between Asian countries must ensure avoiding misbalances and provide the highest possible gains for all involved parties. From a trade-economic standpoint, the question of optimizing bilateral trade flows is not particularly widely studied. Rather, trade flows in their institutional/regulatory context are frequently estimated with respect to expectations of utility improvements (welfare gains). With this uneven distribution of fish trade in the newly established RCEP, revealing of trade gaps and untapped capacities of individual countries becomes an important knowledge to optimize contributions to and gains from the intraregional trade for a diverse community of higher-income economies (Japan, South Korea, Australia, New Zealand), bigger traders (China, Vietnam, Thailand, Indonesia, Malaysia), smaller countries (Singapore, Brunei Darussalam), less developed economies (Cambodia, Myanmar, Philippines), and even land-locked states (Lao PDR). Capacities and comparative advantages in fish trade of individual countries of Asia and Oceania have been widely investigated, but RCEP-wide studies are very scarce. No study has ever addressed potential trade losses of the RCEP community from the inadequate utilization of advantages of particular countries in the fishery sector. Therefore, in this paper, we aim at revealing potential values of trade in various categories of fish and seafood products between individual RCEP members, studying comparative, trade, and competitive advantages of the fifteen states in country-to-country and country-to region trade, and identifying possible matches between untapped trade potentials and existing advantages in order to optimize gains from the intra-RCEP trade and improve the overall performance of the trade block in the fish trade.

2. Materials and Methods

2.1. Countries, Products, and Data

The study is performed in the cases of the fifteen RCEP countries (Australia, Brunei Darussalam, Cambodia, China, Indonesia, Japan, Lao PDR, Malaysia, Myanmar, New Zealand, Philippines, Singapore, South Korea, Thailand, and Vietnam) in 2000–2019. According to the SITC Commodity classification of the United Nations Conference on Trade and Development [45], the array of fish and marine food products is established along five p_n positions (p_1 = fish, crustaceans, mollusks, and preparations thereof, total; p_2 = fresh, chilled, and frozen fish; p_3 = dried, salted, and smoked fish; p_4 = crustaceans, mollusks, and aquatic invertebrates; p_5 = prepared and preserved fish and aquatic invertebrates). Parameters of trade in p_n products (exports; imports, trade turnover, etc.) are calculated individually in 210 pairs of countries [$i;j$], where a country i exports a product p_n to a country j or a combined set of RCEP countries (r) (or imports a product p_n, respectively).

2.2. Study Flow Algorithm

To assess the potentials of individual RCEP countries in the intraregional trade in fish and fishery products, we used the five-stage approach (Table 1).

Table 1. Study stages.

Stage	Method	Results
Trade potential	Indicative Trade Potential (ITP)	For each pair of *i* and *j* countries, a comparison of the current trade turnover in products p_n with a potential value of trade. The four-level scale to measure trade potential.
Comparative advantage	Revealed Comparative Advantage (RCA)	Identification of comparative advantages in trade in products p_n within pairs of countries *i* and *j*.
Trade advantage	Relative Trade Advantage (RTA)	Identification of trade advantages in trade in products p_n within pairs of countries *i* and *j*. Detection of matches between comparative and trade advantages.
Overwriting advantages	Lafay Index (LI)	Identification of LI values for products p_n traded within pairs of countries *i* and *j*. Detection of matches between comparative and trade advantages and LI values.
Matching advantages and potentials	Trade potential scale, RCA, RTA, and LI	The four-level scale to measure advantages. Detection of countries *i* with high potential and advantages in trade in products p_n in [*i;j*] and [*i;r*] pairs.

Source: Authors' development.

At Stage 1, we aggregate parameters of the intraregional trade of the fifteen countries, average the values of exports, imports, and trade turnover (both total trade and p_n products) in 2000–2019, calculate indicative trade potentials based on the averaged data, and reveal the degree of fulfillment of trade potential in [*i;j*] pairs. At Stages 2–4, we sequentially calculate the Revealed Comparative Advantage (RCA), the Relative Trade Advantage (RTA), and the Lafay Index (LI) indexes based on averaged data for 2000–2019 for five p_n products and 210 pairs of countries and identify countries that demonstrate advantages in the three parameters. Finally, at Stage 5, we match trade potentials with advantages to find intersections and identify the most promising p_n products for trade in [*i;j*] and [*i;r*] pairs. Sections 2.3–2.7 explain the methods and approaches in more detail.

2.3. Trade Potential

In light of the existing asymmetries in the RCEP intraregional trade in fish and seafood products (which could probably emerge with the accession of large seafood traders like China, Japan, and South Korea to the agreement), it is crucial to estimate how free trade could help RCEP economies maximize their mutual gains and better utilize their advantages. Therefore, the study starts with examining whether there is an untapped trade potential between particular countries in the block.

A common approach to calculating trade potentials between the two countries or potential value of trade within a free trade area or any other set of countries is to find how far a country-to-country trade deviates from a country-to-region trade. Potential trade can be estimated by matching the total exports of a commodity from one country with the total imports of that commodity to another country [20]. As elaborated by Mukherji [52,53], when comparing exports and imports in such a way, a potential expansion of trade under free trade conditions can be estimated after subtracting existing trade–a technique known as indicative trade potential, or ITP (Equation (1)):

$$ITP_{ij}^{p} = \min\left(X_{ir}^{p}; M_{jr}^{p}\right) - X_{ij}^{p}, \quad (1)$$

where ITP_{ij}^{p} = indicative trade potential of a country i in trade in a product p with a country j; X_{ir}^{p}.= exports of a product p from a country i to all countries of the region r; M_{jr}^{p} = imports of a product p to a country j from all countries of the region r; X_{ij}^{p} = exports of a product p from a country i to a country j.

The Indicative Trade Potential (ITP) method has been widely used in assessing trade in food and other products both within ASEAN and between ASEAN and the countries of Asia and Oceania [20,54–57]. Compared to estimation trade models and gravity equations [58–60], the use of the ITP method is particularly beneficial in studying bilateral trade flows in the intra-region trade. A gravity model is effective when in addition to the intra-region trade, extra-area countries are considered to capture traded diversion effects and asymmetric shocks coming from other regions. In measuring intra-region trade, gravity model results could be distorted by the distance variable. The ITP approach allows one to identify products for which trade complementarity between the two countries is the highest irrespective of a distance between them or other extra-area parameters [61]. According to Helmers and Pasteels [62], the indicative trade potential in the [*i;j*] pair of countries shows the degree to which a country i could in principle direct all of its exports of a product p to a country j, or, respectively, a degree to which a country j could potentially absorb all imports of a product p from a country i. Another rationale for using trade potential as a baseline in our study is that the index has been widely applied in the literature in conjunction with the RCA, the RTA, and other trade-related indicators to test the complementarity or competitiveness in agricultural products between the two trading partners. The successful demonstrations of combined use of trade indexes can be found in Qayyum and Nigar [56], Li and Li [63], Bano [54], Kapuya et al. [64], Kaur et al. [65], and other studies of bilateral food trade flows in Asia.

Having calculated the ITPs for [*i;j*] pairs of RCEP countries, we then compare potentials with actual trade turnover (TT) between countries (average for 2000–2019) by finding the TT/ITP ratio (R_{ij}). We proceed from the assumption that the higher R_{ij}, the closer the ITP to the TT (which means less room for untapped potential, potential trade is close to actual trade (R_{ij} tends to 1) or even exceeds it ($R_{ij} > 1$)). Conversely, the closer R_{ij} to 0 the higher the degree of untapped potential of a country i in trade with a country j. To be able to differentiate R_{ij} values in terms of the gap between actual and potential trade, we introduce a four-level scale. Simple averaging of all R_{ij} values in the set results in the average value ($\overline{R_{ij}}$). The upper and the lower limits of $\overline{R_{ij}}$ are derived by averaging of R_{ijmax} and $\overline{R_{ij}}$ and R_{ijmin} and $\overline{R_{ij}}$, respectively. The degree of trade potential across [*i;j*] pairs of countries is identified by the falling of R_{ij} into one of the categories: high, above average, below average, and low (Table 2).

Table 2. Scale to measure the degree of trade potential.

Type of Trade Potential	Scale
Type 1: high	$\frac{R_{ijmin}+\overline{R_{ij}}}{2} > R_{ij} \geq R_{ijmin}$
Type 2: above average	$\overline{R_{ij}} > R_{ij} \geq \frac{R_{ijmin}+\overline{R_{ij}}}{2}$
Type 3: below average	$\frac{R_{ijmax}+\overline{R_{ij}}}{2} > R_{ij} \geq \overline{R_{ij}}$
Type 4: low	$\frac{R_{ijmax}+\overline{R_{ij}}}{2} \leq R_{ij} \leq R_{ijmax}$

Source: Authors' development.

2.4. Comparative Advantage

It is commonly accepted that the value of trade between the countries is affected by their comparative advantages [66,67] which can be measured by the Balassa index of revealed comparative advantage (RCA) [68] (Equation (2)):

$$RCA_{ij}^{p} = \frac{\frac{X_{ij}^{p}}{X_{ij}}}{\frac{X_{r}^{p}}{X_{r}}}, \tag{2}$$

where RCA_{ij}^{p} = revealed comparative advantage of a country i in trade in a product p with a country j; X_{ij}^{p}= exports of a product p from a country i to a country j; X_{ij} = total exports from a country i to a country j; X_{r}^{p} = exports of a product p within the region r; X_r = total intraregional exports.

This method has been employed by many scholars to identify comparative advantages in food and agricultural trade (including fish and seafood) within the RCEP [69], the ASEAN [59,70,71], and between ASEAN countries and China [72,73], Japan [74], South Korea [75], and other economies of Asia [76–79]. $RCA_{ij}^{p} > 1$ denotes a comparative advantage of a country i in trade in a product p with a country j, while $RCA_{ij}^{p} < 1$ means a comparative disadvantage, respectively. This means that a country i specializes in the export of a product p to a country j if the market share of this product in trade in [i;j] pair is above average or if the weight of a product p in the total export of a country i to a county j is higher than the weight of a product p in the aggregated RCEP exports [80].

Despite its wide use in studies of trade flows between countries, in some cases, the utilization of the RCA approach can result in rather rough or even misleading estimations [81]. According to many authors, including Balance et al. [82], Coniglio et al. [83], Tampubolon [73], and Gnidchenko and Salnikov [84], the comparative advantage measure must express the ratio of actual trade and reflect net trade rather than exports only. Moreover, due to its static nature, the RCA does not account for market volatilities in the long run, which limits its application in studying new free trade areas and multilateral trade agreements in their dynamics. Also, as emphasized by Yeats [85] and Hoen and Oosterhaven [86], the application of the RCA to a set of countries significantly different in size (the case of smaller ASEAN countries and large fish traders like China or Japan) can misleadingly result in excessively strong advantages for smaller economies.

2.5. Relative Trade Advantage

To avoid possible inaccuracies in measurement, we test revealed comparative advantages by the Vollrath index of relative trade advantage (RTA). So far, such a two-index technique has been rarely used in assessing advantages in fish trade in Asia (except by Khai et al. [87] when measuring comparative advantages of shrimp trade in Malaysia), but it has proven itself in the studies of agricultural trade in Europe [88–90], Latin America [91], and the Middle East [92]. In contrast to the RCA, the RTA accounts for both exports and imports and thus demonstrates net trade advantages (Equation (3)):

$$RTA_{ij}^{p} = \frac{\frac{X_{ij}^{p}}{X_{ij}}}{\frac{X_{r}^{p}}{X_{r}}} - \frac{\frac{M_{ij}^{p}}{M_{ij}}}{\frac{M_{r}^{p}}{M_{r}}}, \tag{3}$$

where RTA_{ij}^{p} = relative trade advantage of a country i in trade in a product p with a country j; X_{ij}^{p} = exports of a product p from a country i to a country j; X_{ij} = total exports from a country i to a country j; X_{r}^{p} = exports of a product p within the region r; X_r = total intraregional exports; M_{ij}^{p}= imports of a product p to a country i from a country j; M_{ij} = total imports to a country i from a country j; M_{r}^{p} = imports of a product p within the region r; M_r = total intraregional imports.

$RTA_{ij}^{p} > 0$ demonstrates that a country i enjoys a relative advantage in trade in a product p with a country j, while $RTA_{ij}^{p} < 0$ shows a comparative disadvantage, respectively.

2.6. Overwriting Advantages

Having identified products p in [i;j] pairs for which $RTA_{ij}^{p} > 0$, we then applied those results upon previously calculated RCAs, compared the sets, and revealed the matches between the two advantages. However, since both the RCA and the RTA are structural parameters of advantages [93] and are not always consistent in cardinal and ordinal measures [82,87,94], it is important to eliminate the influence of cyclical factors by using an alternative measure [95]. In cases of ASEAN countries, Karimi and Malekshahian [96] and Oberoi [97] tested revealed advantages by Lafay index (LI) (Equation (4)). This measure allows one to test both comparative and trade advantages by considering the difference between the normalized trade balance of a product and the overall normalized trade balance of a country [98,99].

$$LI_{ij}^{p} = 100 \times \left[\frac{X_{ij}^{p} - M_{ij}^{p}}{X_{ij}^{p} + M_{ij}^{p}} - \frac{X_{ir}^{p} - M_{ir}^{p}}{X_{ir}^{p} + M_{ir}^{p}} \right] \times \frac{X_{ij}^{p} + M_{ij}^{p}}{X_{ir}^{p} + M_{ir}^{p}}, \quad (4)$$

where LI_{ij}^{p} = Lafay index of a country i in trade in a product p with a country j; X_{ij}^{p} = exports of a product p from a country i to a country j; X_{ir}^{p} = exports of a product p from a country i to the region r; M_{ij}^{p} = imports of a product p to a country i from a country j; M_{ir}^{p} = imports of a product p to a country i from the region r.

To the best of the authors' knowledge, the LI has never been applied to testing the comparative and trade advantages of RCEP countries in the fishery sector. However, based on several successful evidences of earlier use of the three-indexes approach in various segments of food markets and supply chains in Europe [100–105], Asia [80,95,106,107], and Africa [108,109], we applied the Lafay index for testing the RCA and the RTA datasets across [i;j] pairs of RCEP countries and p_n product categories. If $LI_{ij}^{p} > 0$, a country i possesses a competitive advantage in trade in a product p with a country j, otherwise, there is a disadvantage. The particular value of the LI is that it captures intraregional trade flows by employing both the exports and imports variables [110]. For the purpose of this study, it is also beneficial that the LI does not take into account world variables [66], which is important in building reliable estimates of trade advantages of individual countries within the RCEP.

2.7. Matching Advantages and Potentials

The consecutive calculation of the RCA, the RTA, and the LI indexes for the same array of trade data results in a varied presentation of comparative, trade, and competitive advantages in the fish trade. To measure the degree of advantages of countries i in trade in certain products p_n in [i;j] pairs, we differentiate the values of the three indexes in the following way (Table 3):

Table 3. Scale to measure the degree of advantages.

Type of Advantage	Criteria
Strong advantage (S)	RCA > 1, RTA > 0, and LI > 0
Average advantage (A)	RTA > 0 and LI > 0
Weak advantage (W)	RCA > 1, or RTA > 0, or LI > 0
Disadvantage (D)	RCA < 1, RTA < 0, and LI < 0

Source: Authors' development.

The scale is based on previous theoretical insights into establishing the aggregate measure of trade competitiveness on the three-indexes basis (for instance, in Maitah et al. [99], Alessandrini et al. [110], Sanidas and Shin [66], Benesova et al. [101], and Szczepaniak [102]), as well as empirical applications of similar three-indexes measures made by Ishchukova [111], Benesova et al. [100], Smutka et al. [105], Erokhin et al. [80], Erokhin and Gao [95], and Verter et al. [108]. Proceeding from the findings of these studies, we assume that when $RCA > 1$, $RTA > 0$, $LI > 0$, a country i possesses strong comparative, trade, and competitive advantages (S type) in trade in a product p with a country j. If a country i demonstrates an advantage in both RTA and LI indexes, its advantage is defined as average (A type). In any other case, a country i is recognized as either having a weak advantage (W type) or a disadvantage (D type). Due to previously addressed (Section 2.4) possible inaccuracies in the measurement of comparative advantages, the [i;j] pairs, where the RCA advantage matches either the RTA or the LI (RCA > 1 and LI > 0 or RCA > 1 and RTA > 0) are not considered as A type. Moreover, as of Dunmore [112], Balance et al. [82], Tampubolon [73], and Leromain and Orefice [81], the RCA index is insufficient for describing the competitive positions of counterparts in bilateral trade, since it allows identifying comparative advantages rather than determining the underlying sources of such advantages. Also, according to Siggel [113], Costinot et al. [114], and Hinloopen and van Marrewijk [115], the RCA index fails to reveal the reasons of advantages and does not allow one to differentiate between natural and acquired advantages (which is crucial for any food production industry, including fisheries). Therefore, a competitive advantage in trade shall be regarded as confirmed only when the RCA is supported by both competitive (LI) and trade (RTA) parameters. To determine whether a country goes to W or D category, we compare matches between indexes. Those countries i for which $RCA < 1$, $RTA < 0$, and $LI < 0$ are recognized as having a disadvantage (D type). Countries i for which at least one of the indexes demonstrates an advantage are considered as having a weak advantage (W type) in trade in a product p within [i;j] pairs. Finally, we match the four-level trade advantages scale (Table 3) with the four-level trade potentials scale (Table 2) to detect how untapped trade potentials of individual RCEP countries can be improved by increasing or decreasing trade flows in particular fishery products.

3. Results

3.1. Actual and Potential Trade

We started with revealing how actual values of trade turnover of p_n products within [i;j] pairs of countries coincide with indicative trade potentials. In general, most of the countries have the potential to increase exports of fish and seafood products to their RCEP counterparts. Among fifteen RCEP member states, only China, Indonesia, Brunei Darussalam, and Lao PDR fulfill their trade potentials in the overall intraregional trade in fish (Appendix A, Table A1). Bilateral trade in fish in the RCEP is asymmetrical. The trade-to-potential ratio demonstrates a significant gap between actual and possible trade in all kinds of fishery products in Myanmar, New Zealand, and Philippines. China, the largest intra-RCEP fish trader, performs rather well in trade with Indonesia, Myanmar, New Zealand, Philippines, and South Korea (actual trade turnover exceeds indicative trade potential), while there is room for expansion of exports from China to Brunei Darussalam, Cambodia, Australia, Lao PDR, and Singapore (high trade potential in [China;j] pairs). Smaller traders like Myanmar, Philippines, New Zealand, and Cambodia experience wider TT/ITP gaps compared with China, Japan, South Korea, and Thailand. This tendency is observed across all four sub-categories of fishery products included in the study. The highest untapped trade potentials are revealed for Cambodia, Myanmar, and Philippines in trade in fresh, chilled, and frozen fish (p_2) (Appendix A, Table A2) and dried, salted, and smoked fish (p_3) (Appendix A, Table A3) and New Zealand and Australia in trade in crustaceans and mollusks (p_4) (Appendix A, Table A4) and prepared and preserved fish and aquatic invertebrates (p_5) (Appendix A, Table A5).

3.2. Three Types of Advantages

Having evidenced the asymmetries between larger and smaller traders in both [i;j] and [i;r] pairs, we then aim to find out how these differences can be stipulated by comparative advantages of particular i countries in trade in certain p_n products. Based on the average RCA values in 2000–2019, the strongest comparative advantages in overall trade in fish and seafood products (p_1) are revealed for Myanmar in its trade with Australia, Brunei

Darussalam, Malaysia, and Japan, for Vietnam in trade with Japan, South Korea, and Thailand, for New Zealand in trade with Cambodia, Brunei Darussalam, and Japan, and for Thailand in trade with Japan, Australia, and South Korea (Table 4).

Table 4. Comparative, trade, and competitive advantages of RCEP countries in total trade in fish, crustaceans, and mollusks (p_1).

Countries	Indexes	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS	RCA		−	−	−	−	−	−	−	−	−	−	−	−	−	+	−
	RTA		+	−	−	−	+	+	−	−	−	−	+	−	−	+	−
	LI		−	−	+	−	+	+	−	−	−	−	+	−	−	+	−
BRN	RCA	−		−	−	−	−	−	−	−	−	−	−	−	−	−	−
	RTA	−		−	−	−	−	+	−	−	−	−	−	−	−	−	−
	LI	+		−	+	+	+	+	−	−	−	−	−	+	+	−	−
KHM	RCA	+	−		−	−	−	+	−	−	−	−	−	−	+	−	−
	RTA	+	+		+	−	−	+	+	−	−	−	+	+	+	−	−
	LI	+	+		+	−	+	+	+	+	−	−	+	+	−	−	−
CHN	RCA	−	−	−		−	+	−	+	−	−	+	−	+	+	−	+
	RTA	+	−	−		−	+	+	+	−	−	+	+	+	+	−	+
	LI	−	−	−		−	+	+	+	−	−	−	+	+	−	−	+
IDN	RCA	+	−	−	+		+	−	+	−	−	−	−	−	+	+	+
	RTA	+	+	+	+		+	+	+	−	+	−	+	+	+	+	+
	LI	−	+	+	−		+	+	−	−	−	−	−	+	+	+	+
JPN	RCA	−	−	−	−	−		−	−	−	−	−	−	−	−	−	−
	RTA	−	+	+	−	−		+	−	−	−	−	−	−	−	−	−
	LI	−	+	+	−	−		+	+	−	+	−	+	+	+	−	−
LAO	RCA	−	−	−	−	−	−		−	−	−	−	−	−	−	−	−
	RTA	−	+	−	−	−	−		−	+	−	+	−	+	−	−	−
	LI	−	+	−	−	−	−		+	+	−	−	+	+	−	−	−
MYS	RCA	−	+	−	−	−	−	−		−	−	−	−	−	−	+	−
	RTA	+	+	−	−	−	+	+		−	−	−	+	+	−	−	−
	LI	+	+	+	−	−	+	+		−	−	−	+	+	−	+	−
MMR	RCA	+	+	−	+	+	+	−	+		+	−	+	+	+	+	+
	RTA	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+
	LI	+	+	+	+	−	+	+	+		−	+	+	+	−	+	+
NZL	RCA	+	+	+	+	−	+	+	+	−		−	+	+	+	+	+
	RTA	+	+	+	+	−	+	+	+	−		−	+	−	−	−	+
	LI	+	+	+	+	−	+	+	−	−		−	+	−	−	−	+
PHL	RCA	−	+	−	−	−	+	−	−	−	−		−	−	−	−	−
	RTA	+	+	+	−	+	+	+	+	−	+		+	+	+	−	+
	LI	+	+	+	−	−	+	+	+	−	−		+	+	+	−	+
SGP	RCA	−	−	−	−	−	−	−	−	−	−	−		−	−	−	−
	RTA	−	+	−	−	−	−	+	−	−	−	−		−	−	−	−
	LI	−	+	+	−	−	+	+	+	−	−	−		+	−	−	−
KOR	RCA	−	−	−	−	−	+	−	−	−	+	−	−		+	−	−
	RTA	+	+	−	−	−	+	−	−	−	+	−	−		−	−	−
	LI	+	+	−	−	−	+	+	−	−	+	−	+		+	−	−
THA	RCA	+	+	−	−	−	+	−	−	−	+	−	−	+		+	+
	RTA	+	+	−	−	−	+	+	+	−	−	−	+	+		−	+
	LI	+	+	+	−	−	+	+	+	−	−	−	+	−		−	+
VNM	RCA	+	+	−	+	−	+	−	+	−	+	+	+	+	+		+
	RTA	+	+	+	+	−	+	+	+	−	+	+	+	+	+		+
	LI	+	+	+	−	−	+	+	−	−	−	−	+	+	−		+

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); "+" = advantage; "−" = disadvantage. Source: Authors' development.

The RCA results show that smaller intraregional traders tend to enjoy higher comparative advantages in trade in p_1 product category than the largest economies of the block (China, Japan, and South Korea). Comparative advantages in trade in $p_{2–5}$ product categories are significant for Myanmar (p_2, p_3, and p_4), New Zealand (p_2, p_4, and p_5), Vietnam (p_2, p_3, p_4, and p_5), and Thailand ($p5$) (Appendix B, Tables A6–A10). Thus, we can say that in most [i;j] pairs, lower R_{ij} values correspond with higher RCA_{ij}, that is, larger untapped trade potentials coincide with stronger comparative advantages. However, when this relation is measured in [i;r] pairs, it is contradictory in Philippines and Cambodia (low R_{ir} and low RCA_{ir}) and Brunei Darussalam and Lao PDR (high R_{ir} and low RCA_{ir}). For bigger traders, lower values of TT/ITP ratio are generally associated with lower comparative advantages. Exceptions are China, in cases of trade in prepared and preserved fish and aquatic invertebrates (p_5) and fresh, chilled, and frozen fish (p_2), and Indonesia in the cases of trade in dried, salted, and smoked fish (p_3) and crustaceans, mollusks, and aquatic invertebrates (p_4).

The RTA values confirm the relationship between trade potentials and advantages, but with several exceptions. The same six countries (Myanmar, Vietnam, New Zealand, Thailand, Indonesia, and China) enjoy both types of advantages in the overall country-to-region trade in fish and seafood products (p_1) but Thailand's trade advantage is substantially weaker compared to its comparative advantage. Bigger traders, such as China and Indonesia, possess weaker advantages compared to smaller countries (Vietnam, New Zealand, and Myanmar). For the former, the most promising trading destinations are higher-income markets like Japan (high RTAs match with RCAs in p_3 and p_5) and South Korea (p_2 and p_4). For smaller traders, both comparative and trade advantages are the strongest in the array (all types of fish (p_2 and p_3) for Myanmar and New Zealand and $p_{2–5}$ for Vietnam).

However, in many [*i;j*] pairs, countries trade in p_n products in which they possess only relative trade advantages and no comparative ones. Thereby, we applied the Lafay index to test advantages by identifying the difference between the normalized trade balance of a product p_n and the overall normalized trade balance of a country *i* in trade with a country *j*. In most pairs of countries, the LI confirms previously identified relative trade or revealed comparative advantages. In those cases, where the LI does not match the RTA (a criterion for an advantage to be recognized as either average or weak), we distinctly observe two tendencies–depending on whether the LI cancels relative trade advantage or establishes a competitive advantage in the RTA-disadvantageous pairs.

Three types of advantages in the country-to-region overall trade in fish, crustaceans, and mollusks (p_1) are confirmed for the same array of six countries, but the strength of competitive advantages is different from that in the cases of comparative and trade advantages. The highest values of the LI are recorded for Myanmar and Vietnam (first and second ranks in all three indexes, respectively), then follow Thailand (fourth in the RCA and sixth in the RTA), New Zealand (third in the RCA and the RTA), China (sixth in the RCA and fifth in the RTA), and Indonesia (fifth in the RCA and fourth in the RTA). Philippines possess a weak competitive advantage in trade with RCEP countries which matches with earlier revealed relative trade advantage.

Overall, for major traders, the LI demonstrates competitive disadvantages more often than for smaller countries. In many [VNM;*j*] and [IDN;*j*] pairs, as well as in several [CHN;*j*], [THA;*j*], and [NZL;*j*] pairs, a potential strong or average advantage turns to a weak one. Conversely, most of smaller economies (Cambodia, Singapore, Brunei Darussalam), as well as large fish trading nations where RTAs were not detected previously (Japan, South Korea, Malaysia, and Australia), now show competitive advantages. Brunei Darussalam, Cambodia, and Lao PDR, for which the RTA previously showed a disadvantage across most of [*i;j*] pairs, could obtain potential competitiveness in trade with Australia (p_4, p_5), China (p_2, p_3, p_5), Indonesia (p_2), Malaysia (p_5), Vietnam (p_3, p_5), and Singapore (p_2, p_3). Bigger traders like Japan, South Korea, and Australia demonstrate competitive advantages in trade between themselves (Japan and South Korea in all categories $p_{2–5}$, Australia and Japan in p_3 and p_5), as well as in trade in value-added prepared and preserved fish and aquatic invertebrates (p_5) with China and Vietnam (Australia), crustaceans and mollusks (p_4) with China and New Zealand (Japan), salted and smoked fish (p_3) with Singapore (South Korea), and fresh fish (p_2) with Cambodia, Philippines, and Malaysia (Australia and Japan).

3.3. Advantages and Potentials

Therefore, we receive a picture of diverse relationships between higher and lower potentials and stronger and weaker advantages across 210 pairs of countries. By merging potentials and advantages into one matrix, we detect [*i;j*] and [*i;r*] pairs in which untapped trade potentials coincide with competitive advantages (Table 5).

Table 5. Degrees of trade potentials and advantages of RCEP countries in trade in fish, crustaceans, and mollusks (p_1) in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS		W	D	W	D	A	A	D	D	D	D	A	D	D	S	D
BRN	W		D	W	W	W	A	D	D	D	D	D	W	W	D	D
KHM	S	A		A	D	W	S	A	W	D	D	A	A	W	D	D
CHN	W	D	D		D	S	A	S	D	D	W	A	S	W	D	S
IDN	W	A	A	W		S	A	W	D	W	D	A	A	S	S	S
JPN	D	A	A	D	D		A	W	D	W	D	W	W	W	D	D
LAO	D	A	D	D	D	D		D	A	D	W	W	A	D	D	D
MYS	A	S	W	D	D	A	A		D	D	D	A	A	D	W	D
MMR	S	S	A	S	W	S	A	S		W	S	S	S	W	S	S
NZL	S	S	S	S	D	S	S	W	D		D	S	W	W	W	S
PHL	A	S	A	D	W	S	A	A	D	W		A	A	A	D	A
SGP	D	A	W	D	D	D	A	D	D	D	D		W	D	D	D
KOR	A	A	D	D	D	A	W	D	D	S	D	W		W	D	D
THA	S	S	W	D	D	S	A	A	D	W	D	A	W		W	S
VNM	S	S	A	W	D	S	A	W	D	W	W	S	S	W		S

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); green cells = high trade potential; blue cells = trade potential above average; yellow cells = trade potential below average; red cells = low trade potential; S = strong advantage; A = average advantage; W = weak advantage; D = disadvantage. Source: Authors' development.

Despite the fact that most of [*i;j*] pairs demonstrate high potentials for an increase in bilateral trade in fish, crustaceans, and mollusks (p_1), we see that in many cases, indicative potentials are not backed up by competitive, trade, or even comparative advantages. Conversely, either strong or average competitive advantages are identified in pairs where the indicative potential is below average (for example, [NZL;CHN], [KOR;NZL], and [VNM;JPN] pairs) or even low ([THA;LAO] pair). Similar discrepancies between the degrees of trade potentials and strengths of competitive advantages are observed in trade in fresh, chilled, and frozen fish (p_2) (Appendix C, Table A11), dried, salted, and smoked fish (p_3) (Appendix C, Table A12), crustaceans and mollusks (p_4) (Appendix C, Table A13), and prepared and preserved aquatic invertebrates (p_5) (Appendix C, Table A14). The per-country results and implications of these findings are further detailed in the Section 4.

4. Discussion

4.1. Optimization of Trade Potentials and Advantages

In light of the revealed diverse relationships between indicative trade potentials and the three types of advantages that differentiate between bigger and smaller RCEP countries, we discuss the findings separately for major trading nations (the high portion in the overall intraregional trade turnover of fish and seafood products), countries that specialize in trade in fish and fishery products (high share of fish products in the total national trade turnover with RCEP countries), smaller economies (low contribution to the intraregional trade in fish and seafood products), and other economies of the region (average parameters of both the share in the intraregional trade in fish and the share of fish products in foreign trade with RCEP countries).

Across these four groups of countries and individual economies, we established recommendations for prospective (trade should be increased), disadvantageous (trade should be decreased), and neutral (no changes in actual trade required) trading destinations and products (Table 6). The grouping is based on different combinations of trade potentials and advantages:

- Advantageous destinations/products: high trade potential + strong, or average, or weak advantage; trade potential above average + strong, or average, or weak advantage.

- Disadvantageous destinations/products: trade potential above average + disadvantage; trade potential below average + weak advantage or disadvantage; low trade potential + weak advantage or disadvantage.
- Neutral destinations/products: high trade potential + disadvantage; trade potential below average + strong or average advantage; low trade potential + strong or average advantage.

Table 6. Optimization of trade potentials and advantages in the intra-RCEP trade: destinations and products.

Groups/ Countries	Advantage, Destinations (Products) *	Disadvantage, Destinations (Products) **	Neutral, Destinations (Products) ***
Group 1			
CHN	AUS ($p_{2–5}$), BRN (p_5), KHM (p_3, p_5), JPN (p_4), LAO ($p_{2–5}$), MYS (p_2, p_3), NZL (p_5), SGP (p_2, p_4, p_5), THA (p_2, p_3)	IDN (p_2, p_4, p_5), MMR ($p_{2–5}$), NZL (p_2, p_4), PHL (p_3, p_5), THA (p_4, p_5), VNM ($p_{2–5}$)	BRN ($p_{2–4}$), KHM (p_2, p_4), IDN (p_3), JPN (p_2, p_3, p_5), MYS (p_4, p_5), NZL (p_3), PHL (p_2, p_4), SGP (p_3), KOR ($p_{2–5}$)
JPN	AUS (p_5), BRN (p_2, p_3, p_5), KHM ($p_{2–5}$), LAO ($p_{2–5}$), MYS (p_2, p_3, p_5), NZL (p_4, p_5), SGP ($p_{2–5}$)	AUS (p_2, p_4), CHN ($p_{2–5}$), IDN ($p_{2–5}$), MMR ($p_{2–5}$), NZL (p_2, p_3), PHL ($p_{2–5}$), KOR ($p_{2–5}$), THA ($p_{2–5}$), VNM ($p_{2–5}$)	AUS (p_3), BRN (p_4), MYS (p_4)
KOR	AUS ($p_{3–5}$), BRN (p_2, p_3, p_5), KHM (p_3, p_5), LAO ($p_{2–5}$), MYS (p_3), MMR (p_3), NZL (p_3, p_4), PHL (p_2), SGP ($p_{3–5}$), THA (p_2)	CHN ($p_{2–5}$), IDN (p_4), JPN (p_3), MMR (p_2, p_4), PHL ($p_{3–5}$), THA (p_4), VNM ($p_{2–5}$)	AUS (p_2), BRN (p_4), KHM (p_2, p_4), IDN (p_2, p_3, p_5), JPN (p_2, p_4, p_5), MYS (p_2, p_4, p_5), MMR (p_5), NZL (p_2, p_5), SGP (p_2), THA (p_3, p_5)
Group 2			
MMR	AUS ($p_{2–5}$), BRN ($p_{2–5}$), KHM ($p_{3–5}$), CHN ($p_{2–5}$), IDN ($p_{2–4}$), JPN (p_2, p_3, p_5), LAO ($p_{2–5}$), MYS ($p_{2–5}$), NZL (p_2, p_4, p_5), PHL ($p_{2–5}$), SGP ($p_{2–5}$), KOR ($p_{2–5}$), THA ($p_{2–4}$), VNM ($p_{2–5}$)		KHM (p_2), IDN (p_5), JPN (p_4), NZL (p_3), THA (p_5)
THA	AUS ($p_{2–5}$), BRN ($p_{2–5}$), CHN (p_3, p_4), IDN (p_3), JPN (p_3, p_5), MYS (p_2, p_3, p_5), NZL (p_3, p_4), SGP ($p_{2–5}$), KOR ($p_{3–5}$)	KHM ($p_{2–4}$), CHN (p_2), IDN (p_2, p_4, p_5), MMR ($p_{2–5}$), NZL (p_2, p_5), PHL (p_3, p_5), VNM ($p_{2–5}$)	KHM (p_5), CHN (p_5), JPN (p_2, p_4), LAO ($p_{2–5}$), MYS (p_4), PHL (p_2, p_4), KOR (p_2)
VNM	AUS ($p_{2–5}$), BRN ($p_{2–5}$), KHM (p_3, p_5), CHN (p_2, p_5), IDN (p_3, p_5), JPN (p_2, p_3, p_5), LAO ($p_{2–5}$), MYS ($p_{2–5}$), NZL ($p_{2–5}$), PHL ($p_{2–4}$), SGP ($p_{2–5}$), KOR ($p_{2–5}$), THA ($p_{2–5}$)	KHM (p_4), IDN (p_4), MMR (p_3, p_4)	KHM (p_2), CHN (p_3, p_4), IDN (p_2), JPN (p_4), MMR (p_2, p_5), PHL (p_5)
Group 3			
AUS	BRN ($p_{2–5}$), KHM (p_5), CHN (p_2), JPN (p_4, p_5), LAO ($p_{2–5}$), PHL (p_2), SGP ($p_{2–5}$), KOR (p_2)	KHM (p_3), CHN (p_4, p_5), IDN (p_4), JPN (p_3), MMR (p_4, p_5), NZL ($p_{2–4}$), PHL (p_3), THA (p_4, p_5), VNM (p_2, p_5)	KHM (p_2, p_4), CHN (p_3), IDN (p_2, p_3, p_5), JPN (p_2), MYS ($p_{2–5}$), MMR (p_3), NZL (p_5), PHL (p_4, p_5), KOR ($p_{3–5}$), THA (p_2, p_3), VNM (p_3, p_4)
IDN	AUS ($p_{2–5}$), BRN ($p_{2–5}$), KHM ($p_{2–5}$), CHN ($p_{2–4}$), JPN (p_2), LAO ($p_{2–5}$), MYS (p_2, p_4), MMR (p_5), NZL ($p_{3–5}$), SGP($p_{2–5}$), KOR ($p_{2–5}$), THA (p_2, p_4, p_5), VNM (p_2, p_5)	MMR (p_3, p_4), THA (p_3), VNM (p_3, p_4)	CHN (p_5), JPN ($p_{3–5}$), MYS (p_3, p_5), MMR (p_2), NZL (p_2), PHL ($p_{2–5}$)
MYS	AUS ($p_{2–5}$), BRN ($p_{2–5}$), KHM ($p_{3–5}$), IDN (p_3), JPN (p_2, p_4, p_5), LAO ($p_{2–5}$), NZL (p_5), PHL (p_2), SGP ($p_{2–5}$), KOR ($p_{2–5}$)	CHN (p_2, p_4), IDN (p_2, p_4), MMR ($p_{2–5}$), THA (p_2, p_3), VNM (p_2, p_3, p_5)	KHM (p_2), CHN (p_3, p_5), IDN (p_5), JPN (p_3), NZL ($p_{2–4}$), PHL ($p_{3–5}$), THA (p_4, p_5), VNM (p_4)

Table 6. *Cont.*

Groups/ Countries	Advantage, Destinations (Products) *	Disadvantage, Destinations (Products) **	Neutral, Destinations (Products) ***
NZL	AUS ($p_{3–5}$), BRN ($p_{2–5}$), KHM ($p_{2–5}$), CHN (p_2, p_5), JPN ($p_{2–5}$), LAO ($p_{2–5}$), MYS ($p_{2–5}$), MMR (p_3), PHL (p_2, p_4), SGP ($p_{2–5}$), KOR ($p_{2–5}$), THA (p_2, p_4, p_5), VNM (p_2)	PHL (p_3)	AUS (p_2), CHN (p_3, p_4), IDN ($p_{2–5}$), MMR (p_2, p_4, p_5), PHL (p_5), THA (p_3), VNM ($p_{3–5}$)
SGP	AUS (p_3, p_5), BRN ($p_{2–5}$), KHM ($p_{3–5}$), CHN (p_3), IDN (p_5), JPN (p_2, p_3), LAO ($p_{2–5}$), MYS (p_3), MMR (p_5), PHL (p_2, p_5), KOR ($p_{2–5}$), THA (p_2, p_3), VNM (p_2)	AUS (p_4), CHN (p_2, p_4, p_5), IDN ($p_{2–4}$), JPN (p_4), MYS (p_2, p_4, p_5), MMR ($p_{2–4}$), NZL (p_3), PHL (p_3), THA (p_4, p_5), VNM ($p_{3–5}$)	AUS (p_2), KHM (p_2), JPN (p_5), NZL (p_2, p_4, p_5), PHL (p_4)
Group 4			
BRN	AUS (p_4, p_5), KHM ($p_{3–5}$), IDN (p_2), JPN (p_2, p_4), LAO ($p_{2–5}$), MMR (p_3, p_5), PHL (p_3), KOR (p_3, p_4), THA (p_2), VNM (p_4)	AUS (p_3), CHN (p_2, p_3, p_5), IDN (p_5), JPN (p_5), MYS ($p_{2–5}$), MMR (p_4), NZL (p_2, p_5), PHL (p_5), SGP ($p_{2–5}$), KOR (p_5), THA (p_3, p_5), VNM (p_2, p_3, p_5)	AUS (p_2), KHM (p_2), CHN (p_4), IDN (p_3, p_4), JPN (p_3), MMR (p_2), NZL (p_3, p_4), PHL (p_2, p_4), KOR (p_2), THA (p_4)
KHM	AUS ($p_{2–5}$), BRN ($p_{2–5}$), CHN (p_2, p_3), IDN (p_2), JPN (p_2, p_4), LAO ($p_{2–5}$), MYS (p_2, p_3, p_5), MMR ($p_{3–5}$), NZL (p_2), PHL (p_2), SGP ($p_{2–4}$), KOR (p_2, p_4)	CHN (p_5), JPN (p_5), THA (p_4, p_5), VNM (p_2, p_4, p_5)	CHN (p_4), IDN ($p_{3–5}$), JPN (p_3), MYS (p_4), MMR (p_2), NZL ($p_{3–5}$), PHL ($p_{3–5}$), SGP (p_5), KOR (p_3, p_5), THA (p_2, p_3), VNM (p_3)
LAO	AUS (p_2, p_3), BRN ($p_{2–4}$), KHM (p_3, p_4), CHN (p_2), IDN (p_3), JPN (p_3), MYS (p_2, p_3), MMR ($p_{2–4}$), NZL (p_2, p_3), PHL ($p_{2–4}$), SGP (p_2), KOR (p_4)	AUS (p_4), KHM (p_2), CHN (p_3, p_5), IDN (p_4), JPN (p_5), NZL (p_4), SGP (p_3), KOR (p_3), THA ($p_{2–5}$), VNM ($p_{2–5}$)	AUS (p_5), BRN (p_5), KHM (p_5), CHN (p_4), IDN (p_5), JPN (p_2, p_4), MYS (p_4, p_5), MMR (p_5), NZL (p_5), PHL (p_5), SGP (p_4, p_5), KOR (p_2, p_5)
PHL	AUS ($p_{2–5}$), BRN ($p_{2–5}$), KHM ($p_{2–5}$), CHN (p_3), IDN ($p_{3–5}$), JPN (p_5), LAO ($p_{2–5}$), MYS ($p_{3–5}$), MMR (p_3), NZL (p_3, p_5), SGP (p_2, p_4, p_5), KOR ($p_{3–5}$), THA ($p_{2–5}$), VNM (p_4, p_5)	CHN (p_2), VNM (p_2)	CHN (p_4, p_5), IDN (p_2), JPN ($p_{2–4}$), MYS (p_2), MMR (p_2, p_4, p_5), NZL (p_4), SGP (p_3), KOR (p_2), VNM (p_3)

Note: Groups (1 = large contribution to the total intra-RCEP trade turnover of fish and seafood products; 2 = high share of fish products in the total national trade turnover with RCEP countries; 3 = low contribution to the intra-RCEP trade turnover of fish and seafood products; 4 = other countries); country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); * = trade in p_n products with j destinations can be increased; ** = trade in p_n products with j destinations should be decreased; *** = no need for substantial changes in current trade in p_n products with j destinations. Source: Authors' development.

The key takeaways from Table 6 can be summarized as follows:

- Major traders have made good use of their potentials and advantages in trade with other countries of the region, as well as between themselves. There are untapped advantages in trade in high-priced fishery products with smaller economies (bivalves and fresh and frozen fish (p_2) and prepared and preserved fishery products (p_5) (further discussed in Section 4.2).
- Countries that specialize in fishery obtain the strongest advantages in trade with higher-income RCEP economies to the extent that they have become overdependent on Chinese, Japanese, and Korean markets. Group 2 economies can gain from the diversification of the intra-RCEP trade by increasing exports of fresh, chilled, and frozen fish (p_2) and crustaceans, mollusks, and aquatic invertebrates (p_4) all over the region (further discussed in Section 4.3).

- Countries that make a minor contribution to the intra-RCEP trade in fish possess weaker advantages compared to both Group 1 and Group 2 traders. There is room to expand trade with the smallest RCEP member states, as well as to increase supplies of processed fishery products to higher-income economies (further discussed in Section 4.4).
- Smallest traders obtain the weakest advantages, while the fishery sector plays a crucial role in the economic development of and social stability in the poor rural and coastal communities. For these countries, the mismatches between high untapped trade potentials and disadvantages or weak competitive advantages are particularly common (further discussed in Section 4.5).

4.2. Major Traders: China, Japan, South Korea

In confirmation of the earlier addressed asymmetries in the intra-RCEP trade, we see that bigger higher-income traders such as China, Japan, and South Korea make the greatest contribution to the intra-regional fish trade. Compared to less developed and smaller economies, the ITP values in bigger traders demonstrate a higher degree of utilization of trade potential. Commonly, in [*i;j*] pairs with low trade potentials, a Group 1 country *i* experiences a disadvantage in trade with a country *j* or exhibits a weak advantage (China-Philippines, Japan-Thailand, Japan-New Zealand).

Group 1 countries have almost maximized trade values between themselves. In this situation, further liberalization of fish trade would not result in a significant transformation of either trade flows or competitive advantages of the three nations–a confrontation with earlier findings of negative effects of South Korea-China and South Korea-Japan free trade agreements made by Kim [116]. In all bilateral pairs within Group 1, trade potential is below average (even though China still enjoys a strong advantage in trade with Japan and South Korea). China's advantages are particularly prominent in trade in crustaceans, mollusks, and aquatic invertebrates (p_4). According to Einarsson and Óladóttir [35] and Luo et al. [72], this advantage can be attributed to China's aquaculture sector that is larger than Japan's and South Korea's aquaculture sectors combined.

From an optimization standpoint, a situation when actual trade is close to a potential value or even exceeds it could be addressed by diversification towards destinations where untapped gains are higher. Dunmore [112] admitted that such transformations could arise in an undistorted trade pattern based on differences in advantages between two countries. However, bilateral flows exist in the broader economic context, they are contributed by many factors aside from advantages or relative efficiencies. While free trade agreements in Asia have increased bilateral trade, they have also contributed to widening deficits in smaller countries' trade with higher-income Group 1 economies [117–119]. Governments all over the world have been widely applying conventional customs measures such as tariffs and non-tariff regulations to cope with deficits, optimize trade balance, and redirect trade flows [120–123]. Still, there is no economic reason why trade between any pair of countries should balance [124], as well as why the potential-actual trade gap should be reduced by any means for the sake of optimization. Previously in ASEAN and now in RCEP, tariffs are no longer dominant as they have been reduced to rather modest levels and are not widely divergent [125]. Therefore, for RCEP countries, the optimization of bilateral trade should focus on the improvement of efficiency gains rather than rerouting existing trade. These should include the most pressing issues that hinder the competitiveness of smaller traders in the intra-RCEP fisheries trade, such as diversification of the export-product mix, production and logistics costs, quality assurance and licensing, post-harvest losses, small-scale fisheries, and infrastructure.

According to our projections, South Korea can potentially increase trade in fresh fish (p_2) with Thailand, Philippines, Lao PDR, and Brunei Darussalam, in dried and salted fish (p_3) with Cambodia, Malaysia, and Myanmar, and in crustaceans and mollusks (p_4) with Australia and New Zealand. As against the insignificant potential of South Korea-Singapore trade earlier demonstrated by Choi and Choi [119], we see an advantage in trade in dried and salted fish (p_3) and prepared and preserved aquatic invertebrates (p_5) in this pair of countries. Japan has been gradually losing competitive advantages in trade with Group 1 countries since the 2000s. According to the FAO's projection [12], fish production in Japan will fall by 6.7% in 2030 compared to 2018. However, amid losing advantages in the global market, we see that Japan has the potential to improve its position in the intra-RCEP trade by increasing supplies to smaller and less developed economies of the region (Brunei Darussalam, Cambodia, and Lao PDR). Also, processed value-added prepared and preserved fishery products (p_5) from Japan possess a competitive advantage in Australia and New Zealand.

4.3. High Specialization in Fish and Seafood Trade: Myanmar, Thailand, Vietnam

In support of previous results of Hoang [70], Khai et al. [87], Teh and Pauly [29], and Kurien [126], we reveal that Group 2 countries have a huge potential to increase their contribution to the intra-RCEP trade. This can happen due to a favorable potential/advantage ratio in trade in fresh, chilled, and frozen fish (p_2) (major tuna processing and export facilities along with a long-distance tuna fleet in Thailand [12]) and crustaceans, mollusks, and aquatic invertebrates (p_4) (supplies of squid and cuttlefish by Vietnam [12]). Our findings of a high potential of Group 2 countries to increase their trade in various types of fish and seafood products agree with the FAO's projections [10] of the most substantial growth of the value of fish trade in Vietnam and Thailand by 2030 (by 39.8% and 20.6%, respectively). Group 2 countries can potentially supply fishery products to a variety of potential destinations within the RCEP. However, as Teh and Pauly [29] report an extremely high share of low productive small-scale fishers in total catch across the countries of Southeast Asia, a radical growth of fish output will be quite problematic. For example, Thailand has experienced a decline in the value of its fishery exports since 2012, mainly as a result of its eroded competitiveness in small-scale shrimp production [12]. Thailand and Vietnam are competitive in fish trade with many countries worldwide [87], but in the intra-RCEP trade, we record advantages in pairs where the indicative potential is below average, or vice versa, high values of indicative potential are associated with weak advantages or disadvantages. Such discrepancies were also revealed by Hoang [70], who studied correlations between trade and comparative advantages in agricultural trade of Thailand and Vietnam with ASEAN countries.

This reverse relationship between potentials and advantages can be explained by the fact that Group 2 countries have become increasingly dependent on the markets of Group 1 countries [12]. China and to a lesser extent Japan and South Korea absorb additional supply from Southeast Asian traders (even when competitive advantages of the latter are lower) and still have room to expand imports (high indicative trade potential). According to Kurien [126], countries of Southeast Asia have long been producing exports of higher-value fishery products (particularly, crustaceans and mollusks (p_4)) to more developed countries while at the same time importing lower-priced seafood products for domestic consumption. The FAO [12] forecasts a substantial increase in China's imports of shrimp from Vietnam attributable to a crackdown on illegal and unreported fishing, but we identified neither a distinct advantage nor a significant potential for Vietnam to expand exports of seafood, crustaceans, and mollusks (p_4) to China. Teh et al. [127,128] expect that the catches of demersal fisheries in Vietnam and Thailand must be increased by at least 20% to account for the unreported industrial catch, but a potential/advantage relationship in Vietnam-China and Thailand-China pairs must be checked further when previously unreported data on p_4 category becomes available in trade statistics.

4.4. Second-Tier Traders: Australia, Indonesia, Malaysia, New Zealand, Singapore

Similar to higher-income Group 1 countries, developed economies of Oceania (Australia and New Zealand) and Southeast Asia (Singapore) experience disadvantages in fish trade with Group 2 countries. Along with lower-income Indonesia and Malaysia, Australia and New Zealand are very much oriented on the markets of China, Japan, and South

Korea [129–131], where they utilize their advantages in p_2 category at the upper end of the market. Australia, New Zealand, Indonesia, and Malaysia have a reputation for supplying high-quality fish and seafood products to premium-class restaurants across Asia [130,132]. Their advantages in the intraregional fish trade are also driven by the proximity to Singapore and Brunei Darussalam (high potential for an increase in trade in all categories of fishery products) and Philippines (fresh, chilled, and frozen fish (p_2)). Free trade agreements between Australia and China and New Zealand and China have contributed much to an increase in fish and seafood exports. A rise in supplies of abalone, rock lobsters, and salmonids from Australia and New Zealand to China after the reduction of trade tariffs in 2017 and 2018 demonstrates the flexibility of trade exports to tariffs–a sign that the RCEP agreement could further improve Australia's and New Zealand's positions in the regional fish market.

Indonesia and Malaysia both have a promising prospect to gain from trade in high-priced fishery products with Group 1 countries. Khai et al. [87] revealed a disadvantage of Malaysia in shrimp trade but recorded some extent of competitiveness on non-frozen shrimp products. Alternatively, our study shows that Malaysia can improve its gains from the intra-RCEP trade by expanding exports of crustaceans and mollusks (p_4) to Group 1 and Group 3 countries. Indonesia's advantages (according to Jaya [133], they include marine, brackish water, and freshwater resources by aquaculture and capture fisheries) allow the country to emerge as a supplier of various kinds of fresh fish (p_2) (tilapia is most promising, according to the FAO estimates [12]), crustaceans, and mollusks (p_4) to all four groups of RCEP countries. However, special attention should be paid to quality control and safety of fishery products as the options to sharpen competitive advantage [134,135] (for instance, in light of earlier revealed cases of a high percentage of carcinogenic formaldehyde in salted fish [136] or evidence of COVID-19 transmission through cold supply chains [10,137,138]).

As regards Singapore, our calculations show untapped advantages in trade in aquaculture products with aquaculture-scarce Brunei Darussalam, Cambodia, and Lao PDR and disadvantages in trade with China, Japan, South Korea, Thailand, and Vietnam, where the aquaculture sector is more developed. The lack of space and stringent environmental regulations [139] challenge the potential of Singapore's aquaculture industry to emerge into a large supplier of fish and seafood products to the regional market. Due to such natural restrictions to large-scale fish production, Singapore primarily relies on an open international trade regime to ensure the food security of its population [140,141] and potentially gains much from joining the RCEP.

4.5. Small Traders: Brunei Darussalam, Cambodia, Lao PDR, Philippines

A consensus is yet to be reached about the gains and losses of small economies from the liberalization of fish trade [28,142,143]. While for a resource-deficit Singapore, opening up trade is the only option to sustain food supply and achieve food security, for such small fish traders as Group 4 countries, liberalization could mean potential losses to output and trade from more competitive neighboring economies [144]. Echoing earlier estimations of Hoang [70], Bene [28], Sneddon and Fox [145], and Chap et al. [146], we record the weakest advantages in the intra-RCEP fish trade across Group 4 countries. In most cases, high untapped potentials are negated by disadvantages or weak advantages across $p_{2–5}$ categories of fishery products.

Many scholars, including Srean et al. [147], Martin et al. [148], Hartje et al. [149], Joffre et al. [150], and Patricio et al. [151], directly link fisheries with sustained livelihoods, poverty reduction, and food security across the poor rural and coastal communities in Southeast Asia. According to the FAO [12], in Lao PDR and Philippines, people rely heavily on fish for food and protein, while in Cambodia, fish exceeds half of the animal protein intake. This emphasizes a disproportionally important role of fisheries for survival, nutrition, and food security in Group 4 countries. At the same time, as recognized by Bene [28], fishing-related communities in Asia are amongst the most vulnerable categories of the society due to weak institutional and human capacities to address current challenges to the fishery sector. Such external vulnerabilities as climate change [152], declining fish stocks [149], chronic overexploitation of marine resources by extensive fisheries [41,153], and the rise in illegal, unregulated and environmentally unsustainable fishing practices [154], aggravate poverty and food insecurity problems and threaten the entire sustainability of livelihoods. In this sense, further liberalization of fish trade could become an additional source of vulnerability and degradation of competitive advantages for the poor communities who are most dependent on capture fishery.

In the meantime, while losses are often felt immediately, gains from opening up trade for smaller countries could potentially become much larger and more widespread (although they are usually dispersed over time) [144]. Our calculations demonstrate that in some destinations and products, Group 4 countries could match untapped trade potentials with competitive advantages. This well agrees with Kim [155], who found that Brunei Darussalam, Lao PDR, and other small fish traders in Southeast Asia could improve their competitiveness due to export specialties. As Nielsen [16] suggests, the optimal policy in this situation is to remain open to free trade and simultaneously employ fisheries management practices to improve advantages where possible. In general, Group 4 countries can increase their gains from the intra-RCEP trade through increased catches in fishing areas where stocks of certain species are recovering (Cambodia and Philippines), the growth in catches in waters with underfished resources (Brunei Darussalam) and improved utilization of the harvest (Lao PDR) [12]. It can be assumed that an increase in output and exports can substantially enhance the incomes and wellbeing of poor fishers. However, comprehensive research is needed to understand how more intensive fish exports will affect food security in the poor fish-dependent communities. Bene [28] provides an example of Cambodia, one of Asia's top freshwater capture fisheries, where over one-third of rural communities suffer from chronic food shortages. This is just one of many evidences of a complex relationship between the current and potential balance of trade, actual and potential competitive advantages, and food security.

5. Conclusions

International trade in fish and seafood products will continue to grow with Asia increasingly gaining importance and becoming the world's largest supplier (about 73% of the additional exported volumes by 2030, according to the FAO projection [12]). Sustainability of growth in the fish trade, however, can be hampered by the three asymmetries that currently exist between Asian countries: higher dependence on intraregional trade of smaller countries compared to bigger traders, the dominance of higher-income countries in the regional fish market, and income inequality patterns in fish trade that directly affect standards of living, employment, and food security in poorer rural and coastal communities. Given these misbalances, a recent establishment of the RCEP free trade area could further widen the gap between already divergent members of the agreement, increase the outward orientation of fish supplies at the expense of the intraregional trade, degrade competitive advantages of smaller economies, and endanger overall economic and social development of fish-dependent communities.

In an attempt to find solutions to the optimization of the intra-RCEP trade in fish and seafood products, we revealed indicative untapped potentials in bilateral trade between individual RCEP members (210 pairs of countries) and then matched them with comparative, trade, and competitive advantages in the fishery sector (overall trade in fish plus trade in the four categories of fishery products). Having superimposed the advantages scale (strong, average, weak advantages, or a disadvantage) upon the potentials scale (high, above average, below average, or low potentials), we found that in many pairs of countries, the two parameters were mismatched. Specifically, in extreme points, high untapped values of bilateral trade coexisted with disadvantages in one of the countries, while strong advantages were observed in pairs where a potential to increase trade was low. The differentiation of potentials/advantages relationships across higher-income and less-developed RCEP countries allowed us to identify advantageous, disadvantageous, and neutral trading destinations and products for each of the fifteen economies. The revealed tendencies and policy implications can be summarized as follows:

- Group 1: major fish traders (China, Japan, and South Korea) have made good use of their potentials and advantages in trade with other countries of the region, as well as between themselves. Still, there are advantages in trade in high-priced fishery products with Group 3 countries (bivalves and fresh and frozen fish (p_2) from China and South Korea to Australia and Singapore and prepared and preserved fishery products (p_5) from Japan to Australia and New Zealand) and Group 4 economies (all four categories of fishery products to Brunei Darussalam, Cambodia, Lao PDR, and Philippines).
- Group 2: Myanmar, Thailand, and Vietnam have the RCEP's highest share of fishery products in trade turnover and enjoy the strongest advantages in trade with higher-income Group 1 countries. Group 2 countries can further gain from the intra-RCEP trade by increasing exports of fresh, chilled, and frozen fish (p_2) and crustaceans, mollusks, and aquatic invertebrates (p_4) all over the region. However, we underline a growing dependence of Group 2 countries on Chinese, Japanese, and Korean markets which could transform into a threat to food security for the former: by exporting higher-value fishery products to more developed economies, Group 2 countries import lower-priced seafood products of lower nutritional value and quality for domestic consumption.
- Group 3: Australia, Indonesia, Malaysia, New Zealand, and Singapore have a low contribution to the intra-RCEP trade in fish and possess weaker advantages in trade with both Group 1 and Group 2 countries. For them, the most promising trading destinations are smaller Group 4 economies, such as Brunei Darussalam, Cambodia, Lao PDR, and Philippines. Also, there is a potential to increase supplies of high-quality fishery products from Australia and New Zealand to Group 1 countries.
- Group 4: the RCEP's smallest traders (Brunei Darussalam, Cambodia, Lao PDR, and Philippines) are the least advantageous countries in the region in terms of fish trade. At the same time, the fishery sector plays a crucial role in supporting livelihood, providing employment, and ensuring food security in the poor rural and coastal communities. For Group 4 countries, we recorded the highest frequency of mismatches between high untapped trade potentials and disadvantages or weak competitive advantages. Still, our findings show an opportunity to increase exports of chilled and frozen fish (p_2) from Philippines and Cambodia to Australia, Singapore, and Thailand, crustaceans and mollusks (p_4) from Brunei Darussalam to Australia, Japan, and South Korea, and fresh fish (p_2) from Lao PDR to other Group 4 countries.

The five-stage approach applied in this paper allowed us to reveal comparative, trade, and competitive advantages in the intra-RCEP trade, match those advantages with existing untapped trade potentials, and identify advantageous and disadvantageous trading destinations and products for individual RCEP countries. The implications of these findings are two-fold, covering methodological and practical issues. The latter adds to the knowledge about fish trade in Asia by detailing the analysis of the country-to-country and the country-to-region trade flows and revealing how each RCEP member can better utilize an individual combination of competitive advantages in order to optimize its gains from the intraregional trade. The methodological implication for further research is that neither simple calculation of indicative trade flows, nor separate studies of any type of advantage, are sufficient to decide whether trade between countries i and j could be gainful for both sides. In bilateral trade, exports and imports flows could be affected by many non-trade contributing factors, including size and level of development of counterparts, distance between them, transportation costs and logistics, customs regulations, currency exchange rates, and a variety of economic, social, and political parameters. In our study, we focused on comparing current trade volumes with advantages, that is, how far a country-to-country trade deviates from a country-to-region trade and how this deviation corresponds with the three types of advantages. Matching between the RCA, the RTA, and the LI values, as well as between advantages and indicative trade potentials, might necessarily be undertaken to establish a reliable and realistic picture of potential gains or losses of a particular country in trade with its counterparts. However, the establishment of more comprehensive multi-factor models could be helpful for a deeper investigation of the potentials-advantages framework, where diverse effects on the intra-RCEP bilateral trade should be further tested in the extra-area format with the use of estimation models like the gravity equation [58] and consideration of trade costs [156], non-unitary elasticities [157], market volatilities and price expectations of fish traders and stakeholders [158,159], and sector-level variables (tariffs and non-tariff measures on fishery products, support of medium and small-scale fisheries, fleet renewal programs, food safety regulations, etc.) [160–164].

Author Contributions: V.E. and G.T. designed the research framework; V.E. conceptualized the materials and methods; A.I. performed the data collection; V.E., G.T. and A.I. analyzed the data; V.E. wrote the paper. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. Degrees of trade potential (R_{ij}) in trade in fish, crustaceans, and mollusks (p_1) within the RCEP, average in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS		0.011 *	0.009 *	0.614 **	0.348 *	0.805 **	0.002 *	0.109 *	1.736 ***	1.544 ***	0.031 *	0.069 *	0.014 *	0.512 *	5.054 ***	0.411 *
BRN	0.432 *		0.004 *	1.291 ***	0.325 *	0.212 *	0.001 *	15.987 ****	0.273 *	0.248 *	0.168 *	3.961 ***	0.074 *	1.063 **	0.640 **	1.541 ***
KHM	0.110 *	0.001 *		0.675 **	0.005 *	0.236 *	0.004 *	0.014 *	0.001 *	0.029 *	0.002 *	0.077 *	0.128 *	3.718 ***	1.711 ***	0.380 *
CHN	0.385 *	0.053 *	0.202 *		11.905 ****	1.202 ***	0.346 *	1.965 ***	5.878 ***	2.387 ***	2.263 ***	0.334 *	2.373 ***	1.066 **	1.899 ***	1.318 ***
IDN	0.046 *	0.010 *	0.001 *	0.249 *		1.213 ***	0.004 *	0.180 *	0.169 *	0.015 *	0.068 *	0.182 *	0.037 *	0.125 *	0.706 **	0.240 *
JPN	0.419 *	0.011 *	0.078 *	6.321 ***	6.364 ***		0.077 *	0.156 *	11.029 ****	1.363 ***	1.570 ***	0.078 *	1.542 ***	2.124 ***	8.214 ****	1.920 ***
LAO	0.157 *	0.001 *	0.415 *	15.418 ****	0.433 *	6.527 ***		0.037 *	0.001 *	1.350 ***	0.001 *	0.109 *	0.983 **	14.498 ****	13.462 ****	7.564 ***
MYS	0.168 *	0.220 *	0.005 *	0.634 **	1.293 ***	0.261 *	0.001 *		5.353 ***	0.081 *	0.039 *	0.380 *	0.087 *	0.395 *	0.663 **	0.363 *
MMR	0.028 *	0.003 *	0.001 *	0.412 *	0.011 *	0.228 *	0.001 *	0.108 *		0.001 *	0.001 *	0.107 *	0.012 *	0.397 *	0.022 *	0.127 *
NZL	0.460 *	0.011 *	0.008 *	0.638 **	0.015 *	0.276 *	0.005 *	0.018 *	0.016 *		0.024 *	0.036 *	0.088 *	0.107 *	0.083 *	0.175 *
PHL	0.015 *	0.005 *	0.001 *	0.458 *	0.070 *	1.830 ***	0.001 *	0.018 *	0.008 *	0.022 *		0.086 *	0.169 *	0.060 *	0.200 *	0.195 *
SGP	0.304 *	0.301 *	0.023 *	0.939 **	0.847 **	0.510 *	0.003 *	1.462 ***	5.020 ***	0.167 *	0.132 *		0.116 *	0.566 **	0.731 **	0.560 **
KOR	0.010 *	0.003 *	0.046 *	1.350 ***	0.393 *	2.038 ***	0.010 *	0.058 *	0.585 **	0.743 **	0.288 *	0.025 *		0.281 *	2.845 ***	0.629 **
THA	0.477 *	0.049 *	4.263 ***	0.331 *	1.393 ***	1.683 ***	12.342 ****	0.219 *	11.340 ****	0.605 **	0.256 *	0.144 *	0.133 *		1.426 ***	0.526 *
VNM	0.194 *	0.035 *	1.659 ***	0.549 **	0.285 *	0.804 **	0.201 *	0.115 *	0.572 **	0.128 *	0.459 *	0.154 *	0.306 *	0.174 *		0.375 *

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); $\overline{R_{ij}}$, = 1.088; * = high potential; ** = potential above average; *** = potential below average; **** = low potential. Source: Authors' development.

Table A2. Degrees of trade potential (R_{ij}) in trade in fresh, chilled, and frozen fish (p_2) within the RCEP in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS		0.005 *	0.013 *	0.202 *	0.227 *	4.123 ***	0.001 *	0.025 *	1.759 ***	3.707 ***	0.008 *	0.024 *	0.010 *	0.061 *	0.426 **	0.302 *
BRN	0.253 *		0.011 *	1.488 ***	0.544 **	0.283 *	0.001 *	26.079 ****	0.106 *	0.445 **	0.040 *	5.688 ***	0.019 *	0.465 **	1.488 ***	2.033 ***
KHM	0.017 *	0.002 *		0.199 *	0.005 *	0.178 *	0.024 *	0.022 *	0.001 *	0.001 *	0.001 *	0.157 *	0.015 *	2.422 ***	1.187 ***	0.221 *
CHN	0.179 *	0.039 *	0.148 *		26.435 ****	1.059 ***	0.004 *	0.489 **	3.359 ***	2.920 ***	3.265 ***	0.172 *	2.705 ***	0.357 **	1.285 ***	1.057 ***
IDN	0.079 *	0.013 *	0.003 *	0.321 *		0.498 **	0.012 *	0.234 *	0.111 *	0.031 *	0.069 *	0.435 **	0.054 *	0.175 *	0.430 **	0.234 *
JPN	0.862 ***	0.014 *	0.154 *	2.497 ***	2.655 ***		0.001 *	0.087 *	1.729 ***	6.033 ***	0.853 ***	0.126 *	1.616 ***	0.875 ***	1.773 ***	1.236 ***
LAO	0.001 *	0.001 *	0.839 ***	0.280 *	0.224 *	0.007 *		0.017 *	0.001 *	0.001 *	0.001 *	0.040 *	0.226 *	12.857 ***	6.706 ***	2.562 ***
MYS	0.051 *	0.131 *	0.018 *	0.802 ***	1.407 ***	0.311 *	0.001 *		5.070 ***	0.133 *	0.012 *	0.543 **	0.035 *	0.888 ***	0.504 **	0.467 **
MMR	0.030 *	0.004 *	0.001 *	0.477 **	0.003 *	0.027 *	0.001 *	0.127 *		0.001 *	0.001 *	0.137 *	0.013 *	0.618 **	0.003 *	0.121 *
NZL	1.099 ***	0.013 *	0.001 *	0.350 *	0.013 *	0.430 **	0.001 *	0.012 *	0.009 *		0.020 *	0.017 *	0.078 *	0.037 *	0.041 *	0.170 *
PHL	0.010 *	0.001 *	0.001 *	1.030 ***	0.128 *	2.460 ***	0.001 *	0.013 *	0.004 *	0.058 *		0.062 *	0.150 *	0.108 *	0.468 **	0.302 *
SGP	0.105 *	0.303 *	0.095 *	0.390 **	0.855 ***	0.689 **	0.002 *	0.772 ***	5.063 ***	0.112 *	0.057 *		0.133 *	0.335 *	0.647 **	0.425 **
KOR	0.017 *	0.001 *	0.014 *	1.849 ***	0.308 *	1.965 ***	0.011 *	0.014 *	0.452 **	7.597 ***	0.133 *	0.041 *		0.195 *	1.109 ***	0.690 **
THA	0.053 *	0.006 *	2.024 ***	0.415 **	1.680 ***	3.064 ***	8.999 ***	0.172 *	29.242 ****	0.362 **	0.240 *	0.102 *	0.325 *		0.710 **	0.562 **
VNM	0.311 *	0.073 *	6.005 ***	0.503 **	0.190 *	0.479 **	0.285 *	0.129 *	0.046 *	0.146 *	0.485 **	0.246 *	0.187 *	0.126 *		0.277 *

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); $\overline{R_{ij}}$, = 0.711; * = high potential; ** = potential above average; *** = potential below average; **** = low potential. Source: Authors' development.

Table A3. Degrees of trade potential (R_{ij}) in trade in dried, salted, and smoked fish (p_3) within the RCEP in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS		0.002 *	0.727 **	0.514 *	0.138 *	1.830 ***	0.001 *	0.298 *	0.076 *	1.696 ***	4.387 ***	0.432 *	0.309 *	0.324 *	0.394 *	0.502 *
BRN	0.826 **		0.001 *	1.657 ***	0.370 *	0.014 *	0.001 *	4.130 ***	0.001 *	0.333 *	0.296 *	12.457 ***	0.044 *	6.922 ***	1.072 ***	2.009 ***
KHM	0.124 *	0.001 *		0.008 *	0.006 *	0.002 *	0.001 *	0.001 *	0.001 *	0.001 *	0.001 *	0.042 *	0.009 *	5.865 ***	0.099 *	0.107 *
CHN	0.036 *	0.016 *	0.001 *		0.346 *	5.812 ***	0.001 *	0.056 *	2.074 ***	0.047 *	3.133 ***	0.221 *	2.036 ***	0.683 **	9.833 ***	1.735 ***
IDN	0.024 *	0.001 *	0.048 *	0.161 *		3.680 ***	0.001 *	0.164 *	1.299 ***	0.189 *	0.264 *	0.244 *	0.145 *	0.613 **	2.639 ***	0.600 **
JPN	0.361 *	0.001 *	0.001 *	15.052 ****	2.231 ***		0.001 *	0.011 *	1.990 ***	0.958 **	2.437 ***	0.417 *	1.255 ***	3.446 ***	1.083 ***	2.566 ***
LAO	0.001 *	0.001 *	0.001 *	10.305 ***	0.002 *	0.001 *		0.150 *	0.001 *	0.001 *	0.001 *	2.962 ***	4.005 ***	23.813 ****	27.800 ****	4.931 ***
MYS	0.099 *	0.063 *	0.001 *	0.100 *	0.893 **	0.039 *	0.001 *		12.883 ***	0.059 *	3.525 ***	0.551 *	0.012 *	3.094 ***	2.515 ***	0.645 **
MMR	0.018 *	0.001 *	0.001 *	0.828 **	0.050 *	0.028 *	0.001 *	0.349 *		0.002 *	0.004 *	0.045 *	0.035 *	0.813 **	0.162 *	0.185 *
NZL	0.754 **	0.005 *	0.001 *	0.063 *	0.034 *	0.490 *	0.001 *	0.027 *	0.009 *		1.652 ***	0.182 *	0.122 *	0.018 *	0.024 *	0.162 *
PHL	0.042 *	0.001 *	0.001 *	0.020 *	0.002 *	4.318 ***	0.001 *	0.003 *	0.001 *	0.379 *		0.028 *	0.080 *	0.018 *	0.008 *	0.145 *
SGP	0.094 *	0.238 *	0.205 *	0.743 **	1.078 ***	0.254 *	0.030 *	0.642 **	4.198 ***	0.595 **	2.025 ***		0.081 *	0.599 **	3.265 ***	0.581 **
KOR	0.106 *	0.001 *	0.050 *	2.442 ***	0.365 *	1.940 ***	0.024 *	0.006 *	0.024 *	0.443 *	7.719 ***	0.092 *		0.178 *	4.210 ***	0.737 **
THA	0.103 *	0.008 *	19.065 ****	0.677 **	0.523 *	0.351 *	3.584 ***	0.869 **	2.447 ***	0.044 *	0.850 **	0.064 *	0.047 *		2.696 ***	0.338 *
VNM	0.089 *	0.002 *	0.962 **	12.246 ***	0.224 *	0.321 *	0.146 *	0.180 *	1.959 ***	0.031 *	0.105 *	0.208 *	0.776 **	0.734 **		0.517 *

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); $\overline{R_{ij}}$, = 1.051; * = high potential; ** = potential above average; *** = potential below average; **** = low potential. Source: Authors' development.

Table A4. Degrees of trade potential (R_{ij}) in trade in crustaceans, mollusks, and aquatic invertebrates (p_4) within the RCEP in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS		0.035 *	0.008 *	0.602 **	1.015 ***	0.518 **	0.032 *	0.152 *	3.736 ***	0.795 ***	0.011 *	0.105 *	0.005 *	0.416 **	3.029 ***	0.453 **
BRN	0.581 **		0.001 *	0.833 ***	0.094 *	0.126 *	0.001 *	6.235 ***	0.393 **	0.053 *	0.002 *	1.768 ***	0.036 *	0.112 *	0.100 *	0.718 **
KHM	0.009 *	0.001 *		0.822 ***	0.003 *	0.088 *	0.001 *	0.002 *	0.001 *	0.009 *	0.003 *	0.024 *	0.302 *	1.326 ***	0.917 ***	0.234 *
CHN	0.527 **	0.088 *	0.318 *		4.117 ***	0.688 **	0.001 *	3.720 ***	9.745 ****	3.430 ***	1.569 ***	0.240 *	1.411 ***	2.892 ***	1.138 ***	1.178 ***
IDN	0.041 *	0.009 *	0.002 *	0.229 *		2.082 ***	0.035 *	0.110 *	0.373 **	0.012 *	0.048 *	0.113 *	0.025 *	0.074 *	1.958 ***	0.305 *
JPN	0.564 **	0.018 *	0.066 *	7.300 ***	9.266 ****		0.002 *	0.317 *	6.537 ***	0.540 **	2.935 ***	0.032 *	1.177 ***	2.580 ***	6.257 ***	2.339 ***
LAO	0.728 **	0.001 *	0.001 *	0.253 *	1.544 ***	0.027 *		0.129 *	0.001 *	6.468 ***	0.001 *	0.088 *	0.510 **	7.513 ***	2.398 ***	2.282 ***
MYS	0.126 *	0.155 *	0.002 *	0.662 **	2.120 ***	0.344 *	0.006 *		13.747 ****	0.082 *	0.060 *	0.322 *	0.141 *	0.182 *	1.564 ***	0.349 *
MMR	0.029 *	0.005 *	0.001 *	0.265 *	0.061 *	0.669 ***	0.001 *	0.073 *		0.002 *	0.001 *	0.090 *	0.008 *	0.216 *	0.060 *	0.142 *
NZL	0.223 *	0.008 *	0.005 *	1.490 ***	0.034 *	0.152 *	0.092 *	0.022 *	0.044 *		0.018 *	0.022 *	0.117 *	0.084 *	0.127 *	0.186 *
PHL	0.001 *	0.001 *	0.001 *	0.269 *	0.065 *	1.507 ***	0.001 *	0.010 *	0.019 *	0.010 *		0.071 *	0.252 *	0.013 *	0.142 *	0.169 *
SGP	0.580 **	0.267 *	0.019 *	1.320 ***	1.759 ***	0.485 **	0.003 *	3.809 ***	14.516 ****	0.137 *	0.308 *		0.120 *	0.600 **	1.189 ***	0.884 ***
KOR	0.006 *	0.005 *	0.209 *	2.259 ***	1.003 ***	1.937 ***	0.015 *	0.143 *	1.707 ***	0.594 **	0.590 **	0.018 *		0.546 **	4.448 ***	0.864 ***
THA	0.226 *	0.010 *	2.002 ***	0.252 *	0.914 ***	1.652 ***	9.901 ****	0.113 *	8.471 ****	0.225 *	0.064 *	0.126 *	0.125 *		4.758 ***	0.421 **
VNM	0.192 *	0.004 *	1.885 ***	0.768 ***	1.401 ***	0.937 ***	0.172 *	0.114 *	2.591 ***	0.188 *	0.464 **	0.171 *	0.477 **	0.378 **		0.559 **

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); $\overline{R_{ij}}$, = 0.739; * = high potential; ** = potential above average; *** = potential below average; **** = low potential. Source: Authors' development.

Table A5. Degrees of trade potential (R_{ij}) in trade in prepared and preserved fish and aquatic invertebrates (p_5) within the RCEP in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS		0.001 *	0.004 *	2.037 ***	0.477 *	0.129 *	0.001 *	0.401 *	0.881 **	0.689 *	0.452 *	0.170 *	0.039 *	2.128 ***	4.882 ***	0.804 **
BRN	0.370 *		0.001 *	6.316 ***	2.371 ***	1.035 **	0.001 *	11.624 ***	0.041 *	1.716 ***	5.052 ***	23.316 ****	1.494 ***	25.890 ****	1.135 **	5.718 ***
KHM	0.076 *	0.001 *		3.283 ***	0.013 *	1.381 **	0.001 *	0.058 *	0.001 *	0.272 *	0.004 *	0.124 *	0.157 *	21.141 ****	15.099 ****	2.131 ***
CHN	0.429 *	0.052 *	0.181 *		11.573 ***	2.178 ***	0.513 *	2.281 ***	2.039 ***	1.249 **	1.487 ***	0.709 *	4.746 ***	22.828 ****	1.921 ***	2.123 ***
IDN	0.095 *	0.006 *	0.001 *	0.144 *		1.790 ***	0.001 *	0.156 *	0.009 *	0.004 *	0.126 *	0.074 *	0.024 *	0.204 *	0.301 *	0.201 *
JPN	0.296 *	0.001 *	0.063 *	4.562 ***	6.713 ***		0.104 *	0.106 *	1.188 **	0.156 *	9.392 ***	0.266 *	2.128 ***	9.827 ***	6.499 ***	2.950 ***
LAO	0.016 *	0.001 *	0.009 *	8.437 ***	0.001 *	22.280 ****		0.001 *	0.001 *	0.001 *	0.001 *	0.165 *	6.692 ***	15.970 ****	5.681 ***	4.232 ***
MYS	0.529 *	0.664 *	0.003 *	0.441 *	0.483 *	0.060 *	0.001 *		0.752 **	0.046 *	0.468 *	0.549 *	0.032 *	0.395 *	1.033 **	0.297 *
MMR	0.019 *	0.001 *	0.001 *	1.381 **	0.003 *	0.037 *	0.001 *	0.022 *		0.002 *	0.004 *	0.027 *	0.015 *	0.654 *	0.013 *	0.106 *
NZL	0.527 *	0.012 *	0.011 *	0.854 **	0.009 *	0.065 *	0.001 *	0.033 *	0.011 *		0.048 *	0.155 *	0.072 *	0.393 *	0.352 *	0.237 *
PHL	0.060 *	0.021 *	0.001 *	0.117 *	0.019 *	1.397 **	0.001 *	0.054 *	0.008 *	0.005 *		0.198 *	0.045 *	0.110 *	0.058 *	0.131 *
SGP	0.598 *	0.354 *	0.006 *	1.768 ***	0.844 **	0.334 *	0.002 *	2.148 ***	0.311 *	0.360 *	1.131 **		0.091 *	1.049 **	4.157 ***	0.831 **
KOR	0.023 *	0.008 *	0.009 *	1.249 **	0.352 *	2.772 ***	0.009 *	0.046 *	0.224 *	0.198 *	2.088 ***	0.018 *		0.377 *	13.277 ***	0.584 *
THA	1.319 **	0.225 *	10.005 ***	0.602 *	0.856 **	1.379 **	14.550 ****	0.684 *	1.650 ***	1.642 ***	3.850 ***	0.216 *	0.156 *		7.778 ***	0.909 **
VNM	0.142 *	0.001 *	1.094 **	0.087 *	0.020 *	1.236 **	0.188 *	0.053 *	0.093 *	0.078 *	0.091 *	0.057 *	0.447 *	0.294 *		0.334 *

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); $\overline{R_{ij}}$, = 1.439; * = high potential; ** = potential above average; *** = potential below average; **** = low potential. Source: Authors' development.

Appendix B

Table A6. RCA, RTA, and LI values for total trade in fish, crustaceans, and mollusks (p_1) in RCEP countries, average in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS RCA		0.266	0.079	0.255	0.139	0.769	0.048	0.211	0.069	0.137	0.050	0.633	0.013	0.232	7.513 *	0.475
AUS RTA		0.222 **	−0.287	−0.300	−1.043	0.656 **	0.048 **	−0.719	−60.380	−3.317	−0.690	0.552 **	−0.088	−4.120	2.419 **	−0.642
AUS LI		−0.006	−0.008	1.734 ***	−1.793	19.942 ***	0.001 ***	−2.301	−0.565	−8.080	−0.142	2.369 ***	−0.187	−14.847	3.884 ***	−0.035
BRN RCA	0.045		0.001	0.180	0.005	0.004	0.001	0.184	0.001	0.001	0.013	0.037	0.002	0.022	0.034	0.022
BRN RTA	−0.611		−0.347	−0.107	−0.823	−0.121	0.001 **	−4.204	−75.809	−6.337	−3.721	−1.320	−0.086	−1.558	−13.116	−1.816
BRN LI	1.773 ***		−0.001	2.681 ***	0.011 ***	0.657 ***	0.001 ***	−3.680	−0.135	−0.109	−0.061	−1.244	0.132 ***	0.087 ***	−0.110	−0.954
KHM RCA	1.437 *	0.219		0.473	0.005	0.121	1.016 *	0.086	0.001	0.001	0.017	0.121	0.850	1.132 *	0.163	0.406
KHM RTA	1.355 **	0.219 **		0.339 **	−0.009	−0.436	1.016 **	0.061 **	−0.029	−7.637	−0.095	0.096 **	0.806 **	0.470 **	−0.766	−0.010
KNM LI	3.130 ***	0.022 ***		3.118 ***	−0.036	0.900 ***	0.101 ***	0.211 ***	0.001 ***	−0.250	−0.006	1.356 ***	3.019 ***	−0.818	−10.747	−0.131
CHN RCA	0.622	0.157	0.102		0.485	2.686 *	0.169	1.305 *	0.011	0.797	1.585 *	0.419	1.779 *	1.732 *	0.258	1.546 *
CHN RTA	0.406 **	−0.094	−0.486		−0.523	2.497 **	0.168 **	1.205 **	−1.409	−4.174	1.419 **	0.379 **	1.668 **	1.155 **	−0.426	1.259 **
CHN LI	−1.616	−0.010	−0.032		−3.275	9.018 ***	0.006 ***	0.816 ***	−0.743	−4.650	0.636	0.453 ***	2.862 ***	−1.439	−2.027	1.367 ***
IDN RCA	1.002 *	0.385	0.009	1.107 *		3.101 *	0.354	1.008 *	0.031	0.265	0.199	0.666	0.468	2.143 *	3.640 *	1.578 *
IDN RTA	0.873 **	0.380 **	0.004 **	0.688 **		2.986 **	0.354 **	0.695 **	−1.667	0.096 **	−0.221	0.604 **	0.417 **	2.028 **	3.308 **	1.381 **
IDN LI	−0.059	0.001 ***	0.001 ***	−7.391		8.093 ***	0.001 ***	−1.143	−0.111	−0.089	−0.166	−0.295	0.198 ***	0.510 ***	0.451 ***	0.589 ***
JPN RCA	0.081	0.106	0.539	0.222	0.089		0.461	0.090	0.014	0.730	0.128	0.121	0.300	0.463	0.938	0.255
JPN RTA	−0.858	0.098 **	0.396 **	−2.102	−3.909		0.461 **	−0.332	−13.809	−5.005	−2.247	−0.134	−2.715	−6.437	−8.200	−2.477
JPN LI	−0.423	0.003 ***	0.026 ***	−0.750	−1.694		0.008 ***	0.143 ***	−0.161	0.075 ***	−0.108	0.606 ***	1.950 ***	0.371 ***	−0.044	−1.004
LAO RCA	0.001	0.001	0.001	0.001	0.001	0.001		0.006	0.001	0.001	0.001	0.001	0.073	0.003	0.002	0.003
LAO RTA	−0.071	0.001 **	−1.409	−0.168	−0.658	−0.788		−0.017	0.001 **	−13.476	0.001 **	−0.018	0.018 **	−0.226	−0.351	−0.232
LAO LI	−0.001	0.004 ***	−0.005	−0.134	−0.005	−0.133		0.017 ***	0.004 ***	−0.024	0.004	0.002 ***	0.494 ***	−0.157	−0.067	−2.593
MYS RCA	0.772	1.017 *	0.023	0.217	0.350	0.359	0.016		0.033	0.276	0.084	0.371	0.413	0.282	1.204 *	0.376
MYS RTA	0.521 **	0.897 **	−0.075	−0.692	−1.836	0.229 **	0.001 **		−21.596	−1.088	−0.048	0.310 **	0.339 **	−1.337	−1.028	−0.350
MYS LI	5.573 ***	0.632 ***	0.001 ***	−9.846	−8.487	6.587 ***	0.001 ***		−2.672	−0.305	0.087	11.729 ***	2.988 ***	−6.825	0.537 ***	−0.082
MMR RCA	48.069 *	18.029 *	0.001	4.324 *	2.160 *	11.568 *	0.001	14.540 *		5.629 *	0.222	8.312 *	1.837 *	3.477 *	5.800 *	5.199 *
MMR RTA	48.027 **	18.029 **	0.001 **	4.256 **	2.102 **	11.542 **	0.001 **	14.524 **		5.070 **	0.220 **	8.294 **	1.833 **	3.054 **	5.763 **	5.104 **
MMR LI	0.088 ***	0.001 ***	0.001 ***	0.100 ***	−0.078	0.603 ***	0.001 ***	0.324 ***		−0.035	0.001 ***	0.189 ***	0.036 ***	−1.245	0.017 ***	3.037 ***
NZL RCA	2.704 *	4.757 *	5.828 *	4.092 *	0.137	4.232 *	2.864 *	1.107 *	0.273		0.557	2.955 *	1.981 *	3.429 *	1.464 *	3.069 *
NZL RTA	2.521 **	4.756 **	5.828 **	3.425 **	−0.170	3.763 **	2.864 **	0.799 **	−4.164		−0.454	2.904 **	−0.439	−1.063	−4.174	2.298 **
NZL LI	6.753 ***	0.019 ***	0.011 ***	4.937 ***	−0.261	3.675 ***	0.001 ***	−0.276	−0.012		−0.025	0.864 ***	−4.494	−8.634	−2.558	1.480 ***
PHL RCA	0.558	2.069 *	0.068	0.365	0.351	1.288 *	0.001	0.124	0.047	0.988		0.330	0.872	0.452	0.815	0.734
PHL RTA	0.521 **	2.061 **	0.051 **	−0.493	0.038 **	1.072 **	0.001 **	0.065 **	−0.187	0.350 **		0.256 **	0.639 **	0.375 **	−2.073	0.315 **
PHL LI	0.537 ***	0.035 ***	0.002 ***	−16.625	−2.160	24.538 ***	0.001 ***	0.073 ***	−0.012	−0.645		2.097 ***	1.631 ***	1.315 ***	−10.787	0.281 ***
SGP RCA	0.054	0.774	0.019	0.031	0.050	0.171	0.027	0.109	0.026	0.040	0.075		0.058	0.075	0.200	0.083

Table A6. *Cont.*

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
SGP RTA	−0.808	0.727 **	−0.103	−0.354	−0.738	−0.011	0.027 **	−0.299	−9.499	−3.654	−0.217		−0.010	−0.789	−3.429	−0.416
SGP LI	−0.371	1.526 ***	0.035 ***	−3.400	−1.842	3.584 ***	0.003 ***	2.747 ***	−1.315	−0.875	0.504		1.141 ***	−1.580	−0.157	−0.324
KOR RCA	0.081	0.055	0.043	0.198	0.054	2.406 *	0.042	0.069	0.017	4.006 *	0.172	0.059		1.641 *	0.217	0.552
KOR RTA	0.058 **	0.051 **	−0.992	−1.620	−0.521	2.029 **	−0.034	−0.332	−1.519	2.162 **	−0.787	−0.045		−2.122	−7.556	−0.698
KOR LI	0.179 ***	0.002 ***	−0.016	−17.179	−1.050	25.013 ***	0.001 ***	−0.517	−0.083	1.325 ***	−0.123	0.181 ***		0.891 ***	−8.624	−0.774
THA RCA	3.999 *	1.265 *	0.594	0.713	0.082	6.291 *	0.186	0.826	0.503	3.745 *	0.110	0.775	3.387 *		1.062 *	2.198 *
THA RTA	3.753 **	1.247 **	−0.871	−0.174	−4.023	5.701 **	0.183 **	0.438 **	−2.273	−0.797	−1.361	0.716 **	1.404 **		−4.814	1.101 **
THA LI	5.231 ***	0.024 ***	0.160 ***	−6.225	−8.260	18.165 ***	0.092 ***	0.066 ***	−2.531	−0.173	−1.234	1.303 ***	−2.518		−4.100	1.626 ***
VNM RCA	4.480 *	6.424 *	0.788	2.796 *	0.297	9.211 *	0.272	2.054 *	0.094	5.225 *	2.295 *	3.110 *	6.881 *	5.257 *		4.756 *
VNM RTA	4.129 **	6.402 **	0.639 **	2.621 **	−1.573	8.620 **	0.272 **	1.819 **	−4.412	3.787 **	1.460 **	2.969 **	6.688 **	4.899 **		4.442 **
VNM LI	0.5648 ***	0.005 ***	0.059 ***	−0.529	−2.473	2.797 ***	0.006 ***	−0.140	−0.241	−0.212	−0.084	0.022 ***	0.706 ***	−0.480		3.093 ***

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); * = revealed comparative advantage; ** = relative trade advantage; *** = competitive advantage. Source: Authors' development.

Table A7. RCA, RTA, and LI values for fresh, chilled, and frozen fish (p_2) in RCEP countries, average in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS RCA		0.565	0.001	0.102	0.298	1.288 *	0.001	0.075	0.137	0.092	0.102	0.140	0.027	0.272	0.528	0.428
AUS RTA		0.563 **	−0.264	−0.057	−0.885	1.262 **	0.001 **	−0.096	−71.917	−6.223	−0.139	0.068 **	0.007 **	−0.040	−4.230	−0.293
AUS LI		0.017 ***	−0.011	0.782 ***	−2.514	39.766 ***	0.001 ***	−0.610	−1.084	−25.558	0.021 ***	0.237 ***	0.254 ***	−0.819	−10.483	−0.488
BRN RCA	0.001		0.001	0.194	0.013	0.002	0.001	0.289	0.001	0.002	0.004	0.013	0.001	0.055	0.056	0.023
BRN RTA	−1.070		−0.946	−0.129	−1.258	−0.234	0.001 **	−5.506	−29.054	−11.115	−0.862	−2.010	−0.029	−0.355	−29.901	−2.396
BRN LI	−0.071		−0.002	2.239 ***	0.206 ***	0.229 ***	0.001 ***	−1.878	−0.029	−0.100	−0.007	−1.430	−0.003	1.003 ***	−0.160	−1.492
KHM RCA	0.242	0.614		0.293	0.015	0.202	2.830 *	0.212	0.001	0.001	0.047	0.294	0.103	1.554 *	0.020	0.404
KHM RTA	0.234 **	0.613 **		0.272 **	0.001 **	0.046 **	2.828 **	0.204 **	−0.078	0.001 **	0.009 **	0.275 **	0.096 **	1.397 **	−0.667	0.223 **
KNM LI	0.750 ***	0.085 ***		3.888 ***	−0.121	4.074 ***	0.401 ***	0.869 ***	−0.002	0.001 ***	0.019 ***	4.908 ***	0.465 ***	15.697 ***	−31.034	0.401 ***
CHN RCA	0.146	0.148	0.023		0.983	2.286 *	0.001	0.887	0.008	0.374	2.714 *	0.213	2.212 *	1.718 *	0.322	1.500 *
CHN RTA	0.028 **	−0.131	−0.261		0.051 **	2.004 **	−0.001	0.799 **	−0.991	−4.816	2.522 **	0.169 **	2.076 **	1.279 **	−0.855	1.183 **
CHN LI	−1.102	−0.011	−0.018		−2.335	6.065 ***	0.001 ***	0.551 ***	−0.526	−4.940	1.651 ***	0.168 ***	4.568 ***	−0.444	−3.631	1.231 ***
IDN RCA	0.987	0.637	0.010	1.285 *		1.879 *	0.478	1.909 *	0.064	0.247	0.472	1.305 *	0.685	4.344 *	4.672 *	1.635 *
IDN RTA	0.717 **	0.623 **	−0.005	0.430 **		1.619 **	0.475 **	1.499 **	−0.956	−0.129	−0.267	1.263 **	0.604 **	4.284 **	4.237 **	1.292 **
IDN LI	−0.291	0.001 ***	0.001 ***	−13.194		5.443 ***	0.001 ***	0.345 ***	−0.053	−0.179	−0.071	2.421 ***	0.725 ***	3.544 ***	1.308 ***	1.029 ***
JPN RCA	0.011	0.280	0.209	0.316	0.215		0.001	0.164	0.013	1.663 *	0.333	0.092	0.625	1.164 *	1.589 *	0.463
JPN RTA	−1.576	0.273 **	−0.041	−1.305	−2.510		0.001 **	−0.083	−2.555	−10.881	−2.141	−0.594	−4.553	−1.958	−0.773	−1.682
JPN LI	−2.710	0.008 ***	0.004 ***	−2.321	−2.421		0.001 ***	0.343 ***	−0.068	−0.692	−0.195	0.239 ***	0.706 ***	4.978 ***	2.130 ***	−0.927
LAO RCA	0.001	0.001	0.001	0.002	0.001	0.001		0.016	0.001	0.001	0.001	0.001	0.001	0.006	0.001	0.004
LAO RTA	−0.001	−0.001	−3.815	−0.001	−0.457	−0.001		0.015 *	−0.001	−0.005	−0.001	−0.009	−0.035	−0.115	−0.249	−0.101
LAO LI	0.023 ***	0.023 ***	−0.133	0.801 ***	−0.018	0.023 ***		0.097 ***	0.023 ***	0.024 ***	0.023 ***	0.016 ***	−0.018	0.094 ***	−0.978	−0.128
MYS RCA	0.129	0.871	0.009	0.169	0.512	0.178	0.001		0.046	0.100	0.088	0.322	0.041	0.367	0.760	0.258
MYS RTA	−0.032	0.716 **	−0.232	−0.600	−3.975	−0.098	−0.040		−24.123	−1.966	0.051 **	0.254 **	−0.066	−1.944	−3.055	−0.759

Table A7. *Cont.*

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
MYS LI	0.948 ***	0.617 ***	−0.005	−2.320	−8.340	2.696 ***	0.001 ***		−1.641	−0.387	0.327 ***	11.845 ***	0.063 ***	−3.072	−0.729	−0.610
MMR RCA	70.785 *	30.964 *	0.001	6.487 *	0.660	2.243 *	0.001	22.844 *		1.167 *	0.198	14.080 *	2.623 *	6.463 *	1.470 *	7.068 *
MMR RTA	70.740 **	30.957 **	−0.001	6.357 **	0.547 **	2.221 **	0.001 **	22.833 **		0.565 **	0.196 **	14.051 **	2.622 **	6.115 **	1.391 **	6.955 **
MMR LI	0.087 ***	0.001 ***	−0.001	−0.341	−0.137	0.038 ***	0.001 ***	0.354 ***		−0.030	0.001 ***	0.194 ***	0.039 ***	−0.166	−0.041	4.338 ***
NZL RCA	5.074 *	7.588 *	0.001	4.383 *	0.313	9.225 *	0.004	1.516 *	0.352		1.269 *	1.378 *	1.917 *	5.425 *	3.340 *	4.761 *
NZL RTA	4.919 **	7.585 **	0.001 **	4.101 **	−0.029	8.289 **	0.004 **	1.439 **	−0.751		0.938 **	1.302 **	−2.314	5.004 **	1.622 **	4.200 **
NZL LI	4.894 ***	0.010 ***	0.001 ***	2.405 ***	−0.237	1.120 ***	0.001 ***	0.065 ***	−0.002		0.078 ***	−0.004	−7.693	−0.162	−0.475	2.173 ***
PHL RCA	0.243	0.365	0.017	0.542	0.692	1.219 *	0.001	0.018	0.001	0.309		0.112	0.117	0.816	0.785	0.667
PHL RTA	0.176 **	0.350 **	−0.026	−1.157	−0.064	0.645 **	0.001 **	−0.070	−0.169	−1.136		−0.040	−0.455	0.763 **	−5.745	−0.237
PHL LI	0.211 ***	0.006 ***	0.001 ***	−11.312	−1.833	23.816 ***	0.001 ***	−0.238	−0.004	−0.747		0.156 ***	−3.004	3.909 ***	−10.959	−0.692
SGP RCA	0.045	1.060 *	0.016	0.047	0.035	0.431	0.010	0.093	0.038	0.063	0.111		0.121	0.147	0.258	0.117
SGP RTA	−0.321	1.041 **	−0.279	−0.138	−1.249	0.262 **	0.009 **	−0.248	−11.097	−1.596	0.029 **		0.045 **	−0.413	−4.210	−0.331
SGP LI	−0.007	1.862 ***	−0.018	−0.653	−9.225	9.764 ***	0.001 ***	−0.285	−2.199	−0.437	1.236 ***		2.237 ***	0.173 ***	−2.450	−0.497
KOR RCA	0.036	0.023	0.007	0.298	0.088	4.168 *	0.028	0.078	0.001	7.482 *	0.357	0.064		4.388 *	0.473	0.983
KOR RTA	−0.016	0.022 **	−0.126	−2.296	−0.688	3.406 **	0.026 **	−0.005	−1.463	5.660 **	−0.138	−0.148		3.308 **	−3.369	−0.469
KOR LI	−0.091	0.001 ***	−0.002	−25.921	−1.341	22.389 ***	0.001 ***	−0.004	−0.075	1.566 ***	0.315 ***	−0.079		5.751 ***	−2.509	−0.505
THA RCA	0.238	0.070	0.159	0.583	0.028	3.410 *	0.083	0.864	0.136	0.066	0.052	0.472	0.950		0.709	1.080 *
THA RTA	−0.130	0.022 **	−1.879	−0.600	−9.141	1.973 **	0.079 **	0.302 **	−5.069	−7.563	−3.418	0.331 **	−4.224		−7.631	−1.054
THA LI	0.410 ***	−0.001	0.054 ***	−1.682	−10.427	20.763 ***	0.091 ***	2.387 ***	−2.782	−0.790	−1.664	1.771 ***	−5.782		−2.347	−0.846
VNM RCA	4.313 *	17.490 *	0.580	2.847 *	0.392	4.454 *	0.165	3.525 *	0.097	1.644 *	5.407 *	4.310 *	3.413 *	7.437 *		3.594 *
VNM RTA	3.850 **	17.457 **	0.568 **	2.544 **	−1.768	3.090 **	0.164 **	3.428 **	−0.073	−1.944	4.009 **	4.150 **	2.938 **	7.049 **		3.050 **
VNM LI	1.739 ***	0.045 ***	0.183 ***	0.668 ***	−3.082	−1.445	0.009 ***	1.329 ***	−0.007	−0.724	0.940 ***	1.152 ***	−2.170	1.364 ***		2.974 ***

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); * = revealed comparative advantage; ** = relative trade advantage; *** = competitive advantage. Source: Authors' development.

Table A8. RCA, RTA, and LI values for dried, salted, and smoked fish (p_3) in RCEP countries, average in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS RCA		0.417	0.001	0.003	0.037	0.142	0.001	0.048	0.001	0.090	0.331	0.367	0.004	0.047	0.074	0.069
AUS RTA		0.415 **	−10.065	−0.239	−0.446	−0.162	0.001 **	−0.615	−7.777	−2.471	−7.678	0.142 **	−0.685	−0.589	−1.594	−0.533
AUS LI		0.059 ***	−0.370	−4.414	−0.656	16.458 ***	0.002 ***	−2.128	−0.098	−6.323	−1.127	6.704 ***	−2.917	−2.367	−2.824	−0.498
BRN RCA	0.001		0.001	0.112	0.001	0.001	0.001	0.070	0.001	0.001	0.415	0.135	0.001	0.030	0.095	0.016
BRN RTA	−4.264		0.001 **	−0.449	−1.213	−0.017	0.001 **	−18.800	0.001 **	−10.253	−3.979	−3.567	−0.084	−12.083	−23.473	−7.019
BRN LI	−0.032		0.013 ***	0.811 ***	−0.007	−0.001	0.013 ***	−1.904	0.013 ***	−0.005	0.319 ***	0.528 ***	0.011 ***	0.037 ***	0.204 ***	−5.291
KHM RCA	5.047 *	0.001		0.061	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.188	0.030	6.915 *	0.124	1.249 *
KHM RTA	4.989 **	0.001 **		0.060 **	−0.109	−0.037	0.001 **	0.001 **	0.001 **	−0.334	−0.093	0.104 **	−0.063	6.719 **	−0.127	1.131 **
KNM LI	3.141 ***	0.004 ***		0.224 ***	−0.863	−0.265	0.007 ***	−0.008	0.004 ***	−0.027	−0.032	−1.587	−1.022	10.835 ***	−10.411	1.038 ***
CHN RCA	0.025	0.091	0.001		0.015	2.899 *	0.001	0.198	0.001	0.021	0.237	0.234	3.514 *	0.324	0.084	1.598 *
CHN RTA	0.014 **	−0.315	0.001 **		−1.226	2.781 **	0.001 **	0.196 **	−1.636	−0.052	−0.396	−0.790	3.488 **	0.009 **	−4.377	1.235 **
CHN LI	−0.053	−0.012	0.001 ***		−2.941	9.786 ***	0.001 ***	0.176 ***	−0.544	−0.042	−1.098	−2.617	8.151 ***	−0.853	−9.954	1.284 ***
IDN RCA	0.162	0.068	0.068	0.773		9.172 *	0.002	0.825	0.008	1.955 *	0.053	1.230 *	1.631 *	0.599	1.795 *	3.228 *
IDN RTA	0.105 **	0.067 **	0.066 **	0.734 **		9.110 **	0.002 **	−2.448	−4.036	1.540 **	−0.128	0.783 **	1.272 **	−2.724	−4.529	2.376 **
IDN LI	−0.021	0.001 ***	0.002 ***	0.705 ***		16.567 ***	0.001 ***	−5.780	−0.816	−0.009	−0.016	−1.661	0.447 ***	−6.374	−3.043	2.501 ***
JPN RCA	0.008	0.001	0.001	0.036	0.015		0.001	0.009	0.001	0.007	0.008	0.194	0.090	0.047	0.060	0.055
JPN RTA	−0.291	0.001 **	0.001 **	−2.380	−2.860		0.001 **	0.007 **	−7.367	−3.797	−0.498	0.106 **	−0.537	−4.849	−1.218	−1.807
JPN LI	−0.112	0.001 ***	0.001 ***	−3.372	−1.075		0.001 ***	0.089 ***	−0.074	−0.166	−0.023	2.757 ***	2.688 ***	−0.812	0.100 ***	−0.506
LAO RCA	0.001	0.001	0.001	0.002	0.001	0.001		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
LAO RTA	−0.001	−0.001	−0.001	−0.041	−0.002	−0.001		−0.072	−0.001	−0.001	−0.001	−0.271	−0.258	−0.453	−0.457	−0.349
LAO LI	0.021 ***	0.021 ***	0.021 ***	0.687 ***	0.021 ***	0.021 ***		0.020 ***	0.021 ***	0.021 ***	0.021 ***	0.009 ***	0.005 ***	−0.799	−0.089	−0.227
MYS RCA	0.368	0.793	0.001	0.025	2.468 *	0.012	0.055		0.079	0.085	0.518	0.439	0.053	0.148	0.461	0.340
MYS RTA	0.315 **	0.790 **	0.001 **	−0.231	1.557 **	−0.122	0.054 **		−15.318	−0.659	0.298 **	0.337 **	0.034 **	−15.913	−8.028	−1.928
MYS LI	2.536 ***	0.436 ***	0.001 ***	−0.531	14.735 ***	−0.181	0.001 ***		−4.655	−0.002	1.540 ***	12.526 ***	0.352 ***	−23.972	−2.784	−1.493
MMR RCA	27.568 *	0.001	0.001	15.839 *	26.461 *	3.984 *	0.001	91.153 *		0.001	0.192	8.813 *	12.630 *	4.410 *	14.639 *	12.305 *
MMR RTA	27.502 **	0.001 **	0.001 **	15.198 **	26.455 **	3.983 **	0.001 **	91.056 **		−1.848	0.190 **	8.783 **	12.628 **	4.235 **	14.528 **	12.026 **
MMR LI	0.018 ***	0.001 ***	0.001 ***	−1.095	0.059 ***	0.073 ***	0.001 ***	0.654 ***		−0.031	0.001 ***	0.048 ***	0.093 ***	0.165 ***	0.014 ***	10.400 ***
NZL RCA	1.267 *	4.660 *	0.001	0.060	0.201	2.275 *	0.001	0.531	0.709		0.023	4.523 *	1.200 *	0.103	0.089	1.051 *
NZL RTA	1.110 **	4.658 **	0.001 **	−0.328	−1.890	2.013 **	0.001 **	0.201 **	0.693 **		−43.206	4.391 **	−0.074	−0.443	−1.158	0.491 **
NZL LI	11.179 ***	0.063 ***	0.001 ***	−5.018	−3.085	8.914 ***	0.001 ***	−0.502	0.019 ***		−11.234	4.602 ***	−2.249	−1.753	−0.936	0.306 ***
PHL RCA	2.275 *	0.001	0.001	0.087	0.100	3.063 *	0.001	0.031	0.001	26.555 *		0.155	1.119 *	0.197	0.024	1.333 *
PHL RTA	2.133 **	0.001 **	0.001 **	0.032 **	0.094 **	3.023 **	0.001 **	0.005 **	0.001 **	26.504 **		−0.006	1.105 **	0.169 **	−0.045	1.279 **
PHL LI	−0.214	0.001 ***	0.001 ***	−1.153	−0.036	3.591 ***	0.001 ***	−0.180	0.001 ***	0.223 ***		−1.979	0.213 ***	−0.215	−0.250	1.037 ***
SGP RCA	0.078	1.461 *	0.031	0.328	0.217	0.232	0.234	0.234	0.082	0.064	0.590		0.094	0.367	0.168	0.251
SGP RTA	−0.597	1.181 **	−0.217	−0.331	−3.550	−0.349	0.233 **	−0.606	−20.678	−9.317	−0.230		−0.203	−1.395	−14.608	−1.112
SGP LI	0.232 ***	1.285 ***	0.020 ***	6.633 ***	−5.718	0.372 ***	0.013 ***	2.313 ***	−1.392	−1.196	3.109 ***		0.186 ***	0.673 ***	−6.529	−0.855
KOR RCA	0.353	0.001	0.045	0.057	0.257	0.713	0.124	0.033	0.048	0.866	0.066	0.163		0.091	0.026	0.179
KOR RTA	0.344 **	0.001 **	0.028 **	−1.953	−1.783	0.349 **	0.122 **	0.031 **	0.046 **	−0.996	−2.727	−0.076		−1.774	−9.189	−1.244
KOR LI	2.516 ***	0.001 ***	0.018 ***	−12.806	−0.865	17.073 ***	0.010 ***	0.205 ***	0.024 ***	0.582 ***	−0.724	1.910 ***		−0.523	−7.419	−0.997
THA RCA	0.319	0.440	0.082	1.732 *	1.358 *	1.809 *	0.141	5.367 *	0.050	0.218	0.007	0.600	1.310 *		0.502	1.528 *
THA RTA	0.082 **	0.412 **	−13.901	1.553 **	−0.396	1.664 **	0.140 **	5.358 **	−1.636	0.114 **	−0.708	0.513 **	1.022 **		−6.549	1.021 **
THA LI	−0.111	0.002 ***	−2.631	3.471 ***	−3.000	3.973 ***	0.060 ***	8.537 ***	−2.162	0.009 ***	−0.831	0.684 ***	−0.113		−7.890	0.933 ***
VNM RCA	0.722	0.890	0.107	6.972 *	3.605 *	5.925 *	0.186	6.276 *	2.144 *	0.630	0.058	6.700 *	9.120 *	4.448 *		5.660 *
VNM RTA	0.596 **	0.888 **	0.105 **	6.940 **	3.447 **	5.296 **	0.184 **	6.217 **	−14.721	0.430 **	0.056 **	6.336 **	8.998 **	4.163 **		5.461 **
VNM LI	−0.030	0.001 ***	0.004 ***	1.602 ***	0.012 ***	−0.953	0.001 ***	0.259 ***	−0.503	−0.020	0.002 ***	−0.373	0.371 ***	−0.373		4.005 ***

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); * = revealed comparative advantage; ** = relative trade advantage; *** = competitive advantage. Source: Authors' development.

Table A9. RCA, RTA, and LI values for crustaceans, mollusks, and aquatic invertebrates (p_4) in RCEP countries, average in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS RCA		0.157	0.099	0.306	0.090	0.843	0.138	0.446	0.056	0.121	0.017	0.945	0.010	0.368	18.382 *	0.700
AUS RTA		0.024 **	−0.038	−0.703	−1.067	0.639 **	0.136 **	−0.660	−71.383	−1.518	−0.093	0.905 **	−0.043	−2.225	12.915 **	−0.356
AUS LI		−0.043	−0.002	−8.403	−2.209	14.479 ***	0.002 ***	−2.901	−0.738	−4.143	−0.019	2.655 ***	−0.114	−9.413	10.850 ***	−0.299
BRN RCA	0.136		0.001	0.322	0.001	0.009	0.001	0.196	0.001	0.001	0.001	0.082	0.007	0.001	0.035	0.040
BRN RTA	−0.383		0.001 **	0.084 **	−0.473	−0.010	0.001 **	−3.317	−20.362	−2.510	−0.099	−0.979	−0.013	−0.341	−3.410	−1.351
BRN LI	6.368 ***		0.001 ***	5.600 ***	−0.240	2.031 ***	0.001 ***	−10.442	−1.004	−0.131	−0.006	−2.478	0.547 ***	−0.260	0.015 ***	−0.956
KHM RCA	0.104	0.001		0.982	0.001	0.145	0.001	0.002	0.001	0.001	0.001	0.034	2.445 *	1.034 *	0.168	0.499
KHM RTA	−0.015	0.001 **		0.868 **	−0.011	0.072 **	0.001 **	−0.009	0.001 **	−2.960	−0.228	0.018 **	2.428 **	0.746 **	−0.450	0.268 **
KNM LI	0.177 ***	0.001 ***		8.219 ***	−0.074	2.631 ***	0.001 ***	−0.048	0.001 ***	−0.249	−0.079	0.163 ***	10.453 ***	−1.681	−19.511	0.195 ***
CHN RCA	0.760	0.147	0.004		0.102	1.377 *	0.001	1.458 *	0.004	0.824	1.321 *	0.295	1.751 *	2.056 *	0.185	1.129 *
CHN RTA	0.525 **	−0.289	−1.316		−1.660	1.141 **	0.001 **	1.295 **	−2.733	−6.057	1.183 **	0.268 **	1.595 **	1.150 **	−0.249	0.742 **
CHN LI	−0.922	−0.017	−0.101		−6.742	7.349 ***	0.001 ***	2.130 ***	−1.508	−6.698	1.409 ***	0.738 ***	6.627 ***	−1.205	−1.059	0.604 ***
IDN RCA	0.842	0.277	0.008	1.742 *		5.449 *	0.554	0.676	0.010	0.260	0.052	0.415	0.462	0.666	5.556 *	2.234 *
IDN RTA	0.758 **	0.275 **	0.007 **	1.621 **		5.416 **	0.552 **	0.586 **	−2.284	0.183 **	−0.246	0.393 **	0.427 **	0.641 **	5.339 **	2.167 **
IDN LI	−0.209	0.001 ***	0.001 ***	−1.558		2.893 ***	0.001 ***	−0.367	−0.123	−0.035	−0.144	−0.274	−0.106	−0.063	−0.016	1.882 ***
JPN RCA	0.156	0.009	0.080	0.272	0.020		0.002	0.026	0.025	0.286	0.006	0.074	0.174	0.086	0.941	0.199
JPN RTA	−0.795	−0.006	−0.077	−1.079	−6.419		0.002 **	−0.945	−37.887	−2.116	−2.678	0.071 **	−1.837	−6.582	−15.885	−2.495
JPN LI	−0.021	−0.001	0.003 ***	4.594 ***	−2.637		0.001 ***	−0.252	−0.379	0.052 ***	−0.403	0.426 ***	1.320 ***	−1.660	−1.043	−2.007
LAO RCA	0.001	0.001	0.001	0.001	0.001	0.001		0.001	0.001	0.001	0.001	0.001	0.029	0.003	0.001	0.002
LAO RTA	−0.212	−0.001	−0.001	−0.002	−1.515	−0.002		−0.069	−0.001	−41.659	−0.001	−0.009	0.010 **	−0.038	−0.039	−0.043
LAO LI	−0.165	0.001 ***	0.001 ***	−0.057	−0.351	−0.006		−0.017	0.001 ***	−1.470	0.001 ***	−0.019	0.985 ***	1.064 ***	0.034 ***	−0.087
MYS RCA	0.895	0.540	0.009	0.403	0.099	0.828	0.045		0.031	0.319	0.046	0.440	1.109 *	0.311	2.593 *	0.600
MYS RTA	0.430 **	0.382 **	0.007 **	−1.054	−1.237	0.763 **	0.040 **		−29.987	−0.906	−0.087	0.372 **	1.035 **	−0.301	0.998 **	−0.098
MYS LI	3.344 ***	0.201 ***	0.001 ***	−19.627	−6.727	11.289 ***	0.001 ***		−3.955	−0.355	−0.128	8.552 ***	5.401 ***	−1.690	3.694 ***	−0.105
MMR RCA	63.104 *	20.466 *	0.001	3.998 *	4.051 *	31.988 *	0.001	12.877 *		10.742 *	0.137	9.130 *	1.615 *	2.787 *	14.463 *	6.651 *
MMR RTA	63.052 **	20.403 **	0.001 **	3.970 **	4.049 **	31.971 **	0.001 **	12.861 **		9.780 **	0.135 **	9.125 **	1.611 **	2.524 **	14.462 **	6.598 **
MMR LI	0.032 ***	0.001 ***	0.001 ***	0.019 ***	0.008 ***	0.592 ***	0.001 ***	0.081 ***		−0.048	0.001 ***	0.093 ***	0.006 ***	−0.822	0.038 ***	5.883 ***
NZL RCA	1.266 *	2.472 *	1.831 *	5.453 *	0.061	2.186 *	8.633 *	1.063 *	0.394		0.275	1.589 *	2.521 *	3.262 *	0.744	2.602 *
NZL RTA	1.102 **	2.468 **	1.829 **	4.498 **	−0.240	1.956 **	8.629 **	0.677 **	−6.554		0.266 **	1.580 **	0.181 **	0.784 **	−9.697	1.859 **
NZL LI	2.992 ***	0.012 ***	0.004 ***	8.824 ***	−0.306	2.647 ***	0.006 ***	−0.451	−0.020		0.085 ***	0.655 ***	−4.141	−4.713	−5.595	1.436 ***
PHL RCA	0.050	0.087	0.111	0.427	0.239	1.719 *	0.001	0.125	0.004	0.003		0.441	2.244 *	0.154	1.389 *	1.011 *
PHL RTA	0.039 **	0.085 **	0.110 **	−0.194	0.176 **	1.709 **	0.001 **	0.108 **	−0.369	−0.331		0.424 **	2.178 **	0.134 **	−0.095	0.798 **
PHL LI	−0.014	0.001 ***	0.002 ***	−17.394	−0.524	18.725 ***	0.001 ***	0.085 ***	−0.028	−0.524		1.689 ***	4.902 ***	0.072 ***	−6.991	0.504 ***
SGP RCA	0.032	0.506	0.014	0.016	0.017	0.030	0.006	0.100	0.013	0.007	0.028		0.011	0.020	0.150	0.045
SGP RTA	−0.966	0.404 **	−0.018	−0.301	−0.576	−0.136	0.005 **	−0.368	−15.430	−2.030	−0.431		−0.054	−0.552	−3.098	−0.420
SGP LI	−0.488	1.280 ***	0.044 ***	−2.015	−1.486	−0.036	0.001 ***	5.072 ***	−1.686	−0.395	−0.213		0.048 ***	−1.092	0.967 ***	−0.328
KOR RCA	0.046	0.003	0.014	0.187	0.035	1.606 *	0.016	0.070	0.001	3.765 *	0.086	0.059		0.163	0.104	0.372
KOR RTA	0.035 **	−0.009	−3.028	−1.751	−0.451	1.380 **	0.015 **	−0.975	−2.572	3.214 **	−1.155	0.035 **		−6.714	−13.726	−1.183
KOR LI	0.149 ***	−0.002	−0.041	−7.959	−0.529	21.548 ***	0.001 ***	−0.959	−0.093	1.883 ***	−0.219	0.384 ***		−3.339	−10.821	−0.846
THA RCA	2.027 *	0.198	0.232	0.892	0.019	6.235 *	0.034	0.266	0.093	1.451 *	0.008	0.650	5.930 *		2.128 *	2.120 *
THA RTA	1.715 **	0.196 **	−1.133	0.130 **	−0.898	6.097 **	0.029 **	−0.147	−2.040	−0.916	−0.196	0.640 **	5.727 **		−2.709	1.565 **

Table A9. *Cont.*

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
THA LI	1.381 ***	0.003 ***	−0.174	−8.240	−2.585	16.011 ***	0.010 ***	−1.823	−2.944	−0.432	−0.252	0.855 ***	2.463 ***		−4.273	0.983 ***
VNM RCA	4.033 *	0.433	0.441	4.687 *	0.176	15.592 *	0.044	1.576 *	0.008	8.564 *	1.062 *	3.065 *	12.019 *	4.625 *		7.258 *
VNM RTA	3.492 **	0.401 **	0.248 **	4.538 **	−3.110	15.375 **	0.042 **	1.004 **	−12.277	8.206 **	0.221 **	2.900 **	11.977 **	4.112 **		6.959 **
VNM LI	−0.034	−0.001	−0.013	0.025 ***	−2.998	3.731 ***	0.001 ***	−0.709	−0.450	0.002 ***	−0.188	−0.172	1.763 ***	−0.957		4.296 ***

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); * = revealed comparative advantage; ** = relative trade advantage; *** = competitive advantage. Source: Authors' development.

Table A10. RCA, RTA, and LI values for prepared and preserved fish and aquatic invertebrates (p_5) in RCEP countries, average in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS RCA		0.011	0.148	0.404	0.007	0.091	0.007	0.120	0.006	0.214	0.003	0.903	0.001	0.043	4.245 *	0.305
AUS RTA		0.009 **	−0.163	−0.158	−1.232	−0.019	0.006 **	−1.568	−36.428	−1.717	−1.720	0.774 **	−0.229	−11.397	−1.014	−1.392
AUS LI		0.001 ***	0.001 ***	13.833 ***	−1.063	2.332 ***	0.001 ***	−2.071	−0.158	−0.927	−0.207	3.961 ***	−0.348	−18.825	3.473 ***	−0.994
BRN RCA	0.001		0.001	0.005	0.001	0.001	0.001	0.049	0.001	0.001	0.009	0.008	0.001	0.004	0.001	0.002
BRN RTA	−0.133		0.001 **	−0.277	−0.647	−0.108	0.001 **	−2.907	−1.154	−4.423	−11.214	−0.742	−0.237	−3.906	−2.465	−1.376
BRN LI	0.057 ***		0.001 ***	0.071 ***	−0.018	−0.010	0.001 ***	0.076 ***	0.001 ***	−0.016	−0.028	−0.017	−0.014	−0.090	−0.011	−1.053
KHM RCA	0.281	0.001		0.144	0.001	0.001	0.021	0.034	0.001	0.001	0.001	0.001	0.005	0.284	0.336	0.133
KHM RTA	0.146 **	0.001 **		−0.159	−0.014	−1.603	0.020 **	−0.031	0.001 **	−22.524	−0.076	−0.037	−0.111	−1.432	−1.261	−0.791
KNM LI	0.397 ***	0.001 ***		0.560 ***	−0.003	−0.347	0.001 ***	0.054 ***	0.001 ***	−0.071	−0.001	−0.021	−0.027	−1.384	0.842 ***	−0.504
CHN RCA	1.095 *	0.183	0.318		0.345	4.661 *	0.583	1.728 *	0.023	1.346 *	0.600	0.827	1.145 *	1.487 *	0.275	2.076 *
CHN RTA	0.771 **	0.177 **	0.128 **		0.076 **	4.635 **	0.579 **	1.678 **	−0.471	−1.487	0.454 **	0.822 **	1.113 **	1.083 **	0.098 **	1.938 **
CHN LI	−2.918	0.001 ***	−0.001		−0.830	7.610 ***	0.007 ***	0.341 ***	−0.243	−2.495	−0.275	0.398 ***	0.456 ***	−1.605	−0.447	1.553 ***
IDN RCA	1.267 *	0.218	0.006	0.185		1.458 *	0.001	0.294	0.016	0.165	0.041	0.123	0.118	1.241 *	0.317	0.631
IDN RTA	1.261 **	0.216 **	0.005 **	−0.037		1.431 **	0.001 **	−0.012	0.015 **	0.163 **	−0.127	0.010 **	0.100 **	1.102 **	0.251 **	0.501 **
IDN LI	2.213 ***	0.008 ***	0.001 ***	−10.143		15.923 ***	0.001 ***	−3.642	0.003 ***	0.029 ***	−0.162	−5.152	0.237 ***	0.620 ***	0.065 ***	0.472 ***
JPN RCA	0.089	0.010	1.510 *	0.062	0.020		1.589 *	0.078	0.005	0.143	0.023	0.205	0.058	0.060	0.199	0.078
JPN RTA	−0.065	0.009 **	1.509 **	−4.190	−2.941		1.586 **	0.019 **	−1.756	−0.884	−1.976	0.201 **	−1.479	−11.857	−9.289	−3.461
JPN LI	0.252 ***	0.001 ***	0.067 ***	−1.072	−0.248		0.025 ***	0.240 ***	−0.004	0.055 ***	−0.023	0.961 ***	0.449 ***	−0.636	−0.066	−2.495
LAO RCA	0.001	0.001	0.001	0.001	0.001	0.001		0.001	0.001	0.001	0.001	0.001	0.218	0.001	0.004	0.003
LAO RTA	−0.007	−0.001	−0.031	−0.562	−0.001	−2.655		−0.001	−0.001	−0.001	−0.001	−0.026	0.107 **	−0.557	−0.812	−0.596
LAO LI	−0.001	−0.001	−0.001	−0.137	−0.001	−0.070		−0.001	−0.001	−0.001	−0.001	−0.001	0.582 ***	−0.442	0.067 ***	−0.604
MYS RCA	1.453 *	1.762 *	0.057	0.077	0.278	0.071	0.001		0.017	0.460	0.091	0.349	0.100	0.155	0.217	0.270
MYS RTA	1.318 **	1.720 **	0.027 **	−0.435	−0.043	0.050 **	0.001 **		−3.577	−0.215	−0.154	0.305 **	0.066 **	−1.064	−0.470	−0.060
MYS LI	15.993 ***	1.590 ***	0.018 ***	−16.830	−0.725	1.745 ***	0.001 ***		−0.997	0.040 ***	−0.444	15.568 ***	0.763 ***	−14.773	−1.948	−0.106
MMR RCA	4.423 *	0.001	0.001	1.158 *	0.001	0.258	0.001	0.394		5.702 *	0.352	0.231	0.302	0.515	0.547	0.695
MMR RTA	4.397 **	0.001 **	0.001 **	1.149 **	−0.053	0.217 **	0.001 **	0.375 **		5.692 **	0.345 **	0.214 **	0.295 **	−0.186	0.526 **	0.583 **
MMR LI	0.423 ***	0.001 ***	0.001 ***	13.706 ***	−0.501	0.068 ***	0.001 ***	0.262 ***		0.042 ***	0.039 ***	−0.408	0.292 ***	−14.048	0.126 ***	0.735 ***
NZL RCA	1.537 *	3.892 *	18.029 *	2.482 *	0.002	0.572	0.001	0.696	0.004		0.043	6.343 *	1.501 *	1.413 *	0.081	1.673 *
NZL RTA	1.298 **	3.881 **	17.884 **	1.639 **	−0.189	0.410 **	0.001 **	0.188 **	−6.019		−1.022	6.283 **	1.184 **	−10.492	−5.367	0.601 **

Table A10. *Cont.*

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
NZL LI	11.266 ***	0.044 ***	0.099 ***	10.380 ***	−0.210	1.407 ***	0.001 ***	−0.525	−0.021		−0.163	5.970 ***	1.849 ***	−27.116	−2.981	0.583 ***
PHL RCA	1.398 *	6.646 *	0.064	0.096	0.078	0.745	0.001	0.258	0.156	1.013 *		0.483	0.214	0.366	0.253	0.452
PHL RTA	1.374 **	6.637 **	0.061 **	−0.016	0.026 **	0.740 **	0.001 **	0.190 **	−0.016	1.012 **		0.450 **	0.209 **	0.194 **	0.221 **	0.395 **
PHL LI	1.018 ***	0.088 ***	0.002 ***	−8.970	−1.481	13.159 ***	0.001 ***	−1.058	−0.030	0.103 ***		1.960 ***	0.711 ***	−5.302	−0.199	0.499 ***
SGP RCA	0.087	0.677	0.028	0.006	0.095	0.007	0.055	0.128	0.022	0.049	0.047		0.032	0.026	0.189	0.070
SGP RTA	−1.248	0.668 **	0.026 **	−0.690	−0.162	−0.190	0.053 **	−0.278	−0.551	−7.720	−0.302		−0.018	−1.492	−2.323	−0.490
SGP LI	0.226 ***	1.294 ***	0.072 ***	−7.230	4.343 ***	−1.242	0.007 ***	5.537 ***	0.033 ***	−1.395	0.138 ***		0.613 ***	−3.839	1.443 ***	−0.394
KOR RCA	0.156	0.158	0.120	0.097	0.017	1.280 *	0.085	0.060	0.056	0.238	0.050	0.044		0.065	0.045	0.254
KOR RTA	0.155 **	0.152 **	0.112 **	−0.621	−0.340	1.215 **	−0.174	−0.050	−0.511	−3.045	−1.092	−0.005		−3.706	−5.920	−0.403
KOR LI	1.019 ***	0.016 ***	0.043 ***	−9.718	−1.273	31.011 ***	0.004 ***	−0.006	−0.033	−1.196	−1.032	0.395 ***		−5.598	−13.632	−0.357
THA RCA	11.172 *	4.023 *	1.582 *	0.590	0.125	10.248 *	0.491	1.075 *	1.460 *	11.174 *	0.306	1.304 *	3.639 *		0.318	3.717 *
THA RTA	11.149 **	4.001 **	1.278 **	−0.097	−1.296	10.192 **	0.488 **	0.913 **	0.942 **	7.881 **	−0.104	1.294 **	3.587 **		−3.587	3.287 **
THA LI	3.694 ***	0.021 ***	0.192 ***	−6.599	−2.923	9.090 ***	0.058 ***	−0.155	−0.358	−0.152	−0.315	0.552 ***	0.500 ***		−3.603	2.840 ***
VNM RCA	5.483 *	0.090	1.493 *	0.250	0.066	8.018 *	0.671	0.468	0.034	6.165 *	0.042	1.410 *	5.101 *	3.357 *		3.254 *
VNM RTA	5.469 **	0.084 **	1.217 **	0.201 **	0.028 **	7.979 **	0.665 **	0.420 **	−0.802	6.057 **	−0.127	1.329 **	5.090 **	3.200 **		3.203 **
VNM LI	0.439 ***	0.001 ***	−0.053	−1.392	−0.083	1.875 ***	0.006 ***	−0.139	−0.076	0.031 ***	−0.118	−0.375	0.638 ***	−0.752		2.981 ***

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); * = revealed comparative advantage; ** = relative trade advantage; *** = competitive advantage. Source: Authors' development.

Appendix C

Table A11. Degrees of trade potentials and advantages of RCEP countries in trade in fresh, chilled, and frozen fish (p_2) in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS		A	D	W	D	S	A	D	D	D	W	A	A	D	D	D
BRN	D		D	W	W	W	A	D	D	D	D	D	D	W	D	D
KHM	A	A		A	W	A	S	A	D	A	A	A	A	S	D	A
CHN	W	D	D		W	S	W	A	D	D	S	A	S	A	D	S
IDN	W	A	W	A		S	A	S	D	D	D	S	A	S	S	S
JPN	D	A	W	D	D		A	W	D	W	D	W	W	W	W	D
LAO	W	W	D	W	D	W		A	W	W	W	W	D	W	D	D
MYS	W	A	D	D	D	W	W		D	D	A	A	W	D	D	D
MMR	S	S	D	W	W	S	A	S		W	A	S	S	W	W	S
NZL	S	S	A	S	D	S	S	S	D		S	W	W	W	W	S
PHL	A	S	W	D	D	S	A	D	D	D		W	D	A	D	D
SGP	D	S	D	D	D	A	A	D	D	D	A		A	W	W	W
KOR	D	A	D	D	D	S	A	D	D	S	W	D		S	D	D
THA	W	W	W	D	D	S	A	A	D	D	D	A	D		D	W
VNM	S	S	A	S	D	W	A	S	D	W	S	S	W	S		S

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); green cells = high trade potential; blue cells = trade potential above average; yellow cells = trade potential below average; red cells = low trade potential; S = strong advantage; A = average advantage; W = weak advantage; D = disadvantage. Source: Authors' development.

Table A12. Degrees of trade potentials and advantages of RCEP countries in trade in dried, salted, and smoked fish (p_3) in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS		A	D	D	D	W	A	D	D	D	D	A	D	D	D	D
BRN	D		A	W	D	D	A	D	A	D	W	W	W	W	W	D
KHM	S	A		A	D	D	A	W	A	D	D	W	D	S	D	S
CHN	W	D	A		D	S	A	A	D	D	D	D	S	W	D	S
IDN	W	A	A	A		S	A	D	D	W	D	W	S	D	W	S
JPN	D	A	A	D	D		A	A	D	D	D	A	W	D	W	D
LAO	W	W	W	W	W	W		W	W	W	W	W	W	D	D	D
MYS	A	A	A	D	S	D	A		D	D	A	A	A	D	D	D
MMR	S	A	A	W	S	S	A	S		D	A	S	S	S	S	S
NZL	S	S	A	D	D	S	A	W	A		D	S	W	D	D	S
PHL	W	A	A	W	W	S	A	W	A	S		D	S	W	D	S
SGP	W	S	W	W	D	W	A	W	D	D	W		W	W	D	D
KOR	A	A	A	D	D	A	A	A	A	W	D	W		D	D	D
THA	W	A	D	S	W	S	A	S	D	A	D	A	W		D	S
VNM	W	A	A	S	S	W	A	S	W	W	A	W	S	W		S

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); green cells = high trade potential; blue cells = trade potential above average; yellow cells = trade potential below average; red cells = low trade potential; S = strong advantage; A = average advantage; W = weak advantage; D = disadvantage. Source: Authors' development.

Table A13. Degrees of trade potentials and advantages of RCEP countries in trade in crustaceans, mollusks, and aquatic invertebrates (p_4) in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS		W	D	D	D	A	A	D	D	D	D	A	D	D	S	D
BRN	W		A	A	D	W	A	D	D	D	D	D	W	D	W	D
KHM	W	A		A	D	A	A	D	A	D	D	A	S	W	D	A
CHN	W	D	D		D	S	A	S	D	D	S	A	S	W	D	S
IDN	W	A	A	W		S	A	W	D	W	D	W	W	W	W	S
JPN	D	D	W	W	D		A	D	D	W	D	A	W	D	D	D
LAO	D	W	W	D	D	D		D	W	D	W	D	A	W	W	D
MYS	A	A	A	D	D	A	A		D	D	D	A	S	D	S	D
MMR	S	S	A	S	S	S	A	S		W	A	S	S	W	S	S
NZL	S	S	S	S	D	S	S	W	D		A	S	W	W	D	S
PHL	W	A	A	D	W	S	A	A	D	D		A	S	A	W	S
SGP	D	A	W	D	D	D	A	W	D	D	D		W	D	W	D
KOR	A	D	D	D	D	S	A	D	D	S	D	A		D	D	D
THA	S	A	D	W	D	S	A	D	D	W	D	A	S		W	S
VNM	W	W	W	S	D	S	A	W	D	S	W	W	S	W		S

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); green cells = high trade potential; blue cells = trade potential above average; yellow cells = trade potential below average; red cells = low trade potential; S = strong advantage; A = average advantage; W = weak advantage; D = disadvantage. Source: Authors' development.

Table A14. Degrees of trade potentials and advantages of RCEP countries in trade in prepared and preserved fish and aquatic invertebrates (p_5) in 2000–2019.

Countries	AUS	BRN	KHM	CHN	IDN	JPN	LAO	MYS	MMR	NZL	PHL	SGP	KOR	THA	VNM	RCEP
AUS		A	W	W	D	W	A	D	D	D	D	A	D	D	W	D
BRN	W		A	W	D	D	A	W	W	D	D	D	D	D	D	D
KHM	A	A		W	D	D	A	W	A	D	D	D	D	D	W	D
CHN	W	A	W		W	S	A	S	D	W	W	A	S	W	W	S
IDN	S	A	A	D		S	A	D	A	A	D	W	A	S	A	A
JPN	W	A	S	D	D		S	A	D	W	D	A	W	D	D	D
LAO	D	D	D	D	D	D		D	D	D	D	D	A	D	W	D
MYS	S	S	A	D	D	A	A		D	W	D	A	A	D	D	D
MMR	S	A	A	S	D	A	A	A		S	A	W	A	D	A	A
NZL	S	S	S	S	D	A	A	W	D		D	S	S	W	D	S
PHL	S	S	A	D	W	A	A	W	D	S		A	A	W	W	A
SGP	W	A	A	D	W	D	A	W	W	D	W		W	D	W	D
KOR	A	A	A	D	D	S	W	D	D	D	D	W		D	D	D
THA	S	S	S	D	D	S	A	W	W	W	D	S	S		D	S
VNM	S	A	W	W	W	S	A	W	D	S	D	W	S	W		S

Note: Country abbreviations (AUS = Australia; BRN = Brunei Darussalam; KHM = Cambodia; CHN = China; IDN = Indonesia; JPN = Japan; LAO = Lao PDR; MYS = Malaysia; MMR = Myanmar; NZL = New Zealand; PHL = Philippines; SGP = Singapore; KOR = South Korea; THA = Thailand; VNM = Vietnam); green cells = high trade potential; blue cells = trade potential above average; yellow cells = trade potential below average; red cells = low trade potential; S = strong advantage; A = average advantage; W = weak advantage; D = disadvantage.
Source: Authors' development.

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Economic Spillover Effects of Industrial Structure Upgrading in China's Coastal Economic Rims

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Abstract: As a vital element affecting economic efficiency, the impact of marine industrial structure upgrading on marine economy has become a hot topic, and China is not an exception. This paper analyzed the dynamic relationship of marine industrial structure upgrading and marine economy efficiency to verity the "structural bonus" and "cost disease" effects. The results confirmed the existence of cost disease in China's marine economy, although occasionally it illustrated structural bonus effects with the improvement of the regional marine economy efficiency. The spatial Durbin model (SDM) was introduced to study the spillover effect of local marine industrial structure upgrading (MISU) on the adjacent regions' marine economy efficiency, and this spillover effect was verified to have agglomerate characteristics in China's coastal areas. Then several countermeasures were proposed to realize marine ecological civilization and promote regional cooperation in the development of China's marine economy.

Keywords: marine economic efficiency; marine industrial structure upgrading; spillover effect; spatial Durbin model

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1. Introduction

China's marine economy had experienced significant development over the past 20 years. Its gross ocean product (GOP) increased at an average annual rate of 6.7% in the last five years, accounting for nearly 10% of the GDP in 2019 [1]. However, the rapid industrial expansion has brought in resources misallocation and marine pollution. The Ocean Development Report of China (2014) showed the growth rate of China's marine economy had entered a transition from rapid to moderate, as it encountered unwieldy industry structures and low transformation rates in innovation and technological achievement [2]. "Blue Growth Agenda" highlights the need to "harness the untapped potential of Europe's oceans, seas and coasts for jobs and growth." [3]. Realizing the need to create not just a prosperously but more importantly sustainable marine economy, the Chinese government had taken many steps to promote the transformation of its marine industry. Efforts had been made to assist the transfer of marine industries through a series of favorable policies in terms of talents, funds, finance, taxes, and services as well as encourage marine companies to develop environmental-friendly facilities [4]. In 2011, the 12th Five-Year (2011–2015) Plan was announced and specified "marine industry structure optimization" and "strengthening comprehensive marine management" as key points. Furthermore, in 2012, the 18th National Congress of the Communist Party of China set forth a nationally strategic aimed of building an ocean power through putting emphasis on developing marine economy and reinforced the concept of "ecological civilization". (The "ecological civilization" concept first appeared in 2007, in a report to the 17th National

People's Congress. At the Third Plenary Session of the 18th Central Committee in 2014, Xi stressed that China would implement "ecological civilization" reforms that are made to reconcile contradictions between economic development and the environment.)

With these important development strategies, China's marine economy was gradually shifting towards improvement in quality and efficiency. The restructuring process in marine industry is evident with the primary industry dropping from 50.43% to 4.6% and in the meantime the share of the secondary and tertiary industries rising from 16.78% to 38.8% and 32.79% to 56.6%, respectively from 2000 to 2017 (See Figure 1). The added value of marine tertiary industry in China had surpassed that of secondary industry and showed the highest contribution to marine economy [5]. It is well known that the industrial structure upgrading is crucial to economic efficiency with two contrary effects, "structural bonus hypothesis" and "cost disease hypothesis". Does the above statistics illustrate the positive interaction between China's marine industrial structure and the marine economic efficiency? Recently, the "Development Plan for the Blue Economic Rim" (this is the first national development strategy approved in the first year of the 12th Five-Year Plan, and the first regional development strategy with marine economy as the theme in China [6]) of the Bohai Economic Rim, the "822" Action Plan (the "822" Action Plan for Zhejiang Marine Economic Development refers to supporting the development of eight modern marine industries, cultivating, and constructing marine industrial bases, and implementing major marine economic construction projects [7]) for marine economic development in Zhejiang province and the development plan for Marine Science and Technology Talents in Jiangsu province were put forward successively. (The development plan for Marine Science and Technology innovation during the 13th Five-Year Plan period has clarified the development ideas, development objectives, key technological development directions, key tasks and safeguard measures for Marine Science and Technology innovation [8].) Have these regional coordinated development policies brought positive demonstration effect to the surrounding areas? This paper seeks empirical evidences to provide an answer to the above questions by looking into China's marine industry. To depict the dynamic relationship between marine industrial structure upgrading and marine economy efficiency, this paper calculated marine economic efficiency with undesired output and introduced the Spatial Durbin Model (SDM) to illustrate the spatial spillover effect. Finally, several policy implications were detected.

The remainder of the paper is organized as follows: Section 2 reviews the related literature. Section 3 introduces the measurement of MISU (marine industrial structure upgrading) where marine economy sustainable development is calculated. The empirical results are given and discussed in Sections 4 and 5. The final section concludes the paper with policy implications.

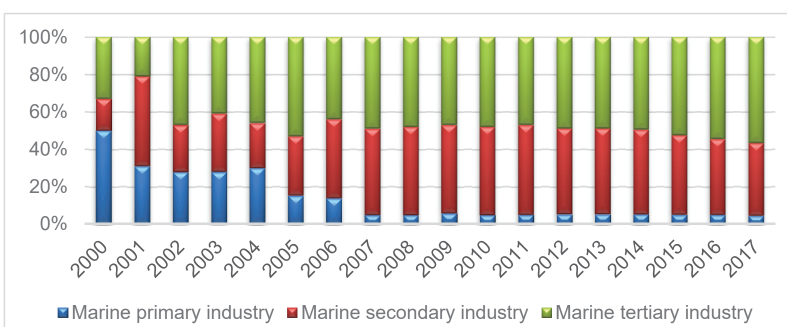

Figure 1. The ongoing restructuring process of China's marine industry from 2000 to 2017. Source: researcher, derived from SOA (2018).

2. Literature Review

The industrial structure upgrading refers to the process of production factors such as capital, labor, land, and technology flow from the production sectors or links of industrial chains with low value-added, poor efficiency, and high consumption, such as industries of overcapacity and high pollution, to those with high value-added, high efficiency, and low consumption, such as advanced manufacturing industry and high-end producer services [9]. The industrial structure upgrading was proven to be the main force to drive less developed economies to developed economies [10,11]. Baumol (1967) and Hartwig (2016) pointed the industrial structure adjustment might brought out "cost disease". Namely, when the industrial structure was adjusted, the rendered resources flowed to the tertiary industry sector, without considering its relatively backward efficiency, and brought in the decline of economic efficiency, known as "cost disease hypothesis" [12,13]. However, Peneder (2003) and Jin (2012) challenged this viewpoint by structural bonus hypothesis. They commented that the input factors flowing from low efficiency sectors or low efficiency growth rate sectors to high efficiency sectors or high efficiency growth rate sectors can promote the whole efficiency of the society [14,15].

Over the past 40 years, a substantial body of literature has been seeking the justification of these two hypotheses in various countries and industries; however, no definite conclusion has been drawn. Zhao (2018) examined the sources of economic growth and the nature of industrial structure change in China over the past decade, with a comparison to those in Russia. The results showed that structural change had not been conducive to economic efficiency [16]. Aldrighi (2013) used the shift share method to study the relationship between Brazilian economic growth and structural adjustment. They found that the "structural bonus" was obvious in economic growth [17], although many scholars argued this shift was not universal [13]. Other studies have reported that economy efficiency was either unaffected or enhanced by industrial structure upgrading [18]. De Vries et al. (2012) analyzed the impact of industrial restructuring on economy efficiency in Brazil since 1980 and found there was no structural bonus [19]. Havlik (2015) took European countries as example and found the effect of industrial structure upgrading on economic growth was ambiguous as the industrial sectors was different [20]. Padilla (2017) used data from Mexico over the past 30 years to study the relationship between structural changes and efficiency growth and found that industrial structure adjustment would restrain the economy efficiency improvement [18].

This controversial issue about industrial structure upgrading and economy efficiency has also obtained great academic interests in China facing the dilemma between "steady growth" and "structural adjustment". Empirical researches on it have flourished in recent years aiming to offer policy support in its new normal economic development. Research samples are usually collected from manufacturing industry [21,22], service industry [23], and so on. Similar with the previous studies, no consensus has been reached. Several researches tried to identify the explicit links for the two opinions. For them, the rationalization of industry structure and the elevation of industry structure are typical index variables representing industry structure upgrading. (The rationalization of industry structure refers to the effective allocation of resources among industries, and the elevation of industry structure refers to the service orientation of economy structure [24].) The former one was proved to have a significant "U-shaped" relationship with economy efficiency, meanwhile the latter one had an inverted U-shaped relationship [25,26]. The structure bonus was closely bound up with economy efficiency, capital, income gap, etc. [27,28].

A handful of studies attempting to identify the spillover effect of industry structure on economy efficiency from the macro point of view [29]. Most of the research confirmed industry structure upgrading and agglomeration were vital elements to the spillover effect of regional economy but failed to reveal the formation mechanism [30–32]. In the empirical analysis, spatial lag model (SLM), spatial error model (SEM) and spatial Durbin model (SDM) gradually took place of ordinary least square model to analyze the spillover effect, as they could effectively solve the spatial distance bias by maximum likelihood estimate [33,34].

The above plenty empirical literature mainly focuses on the land regional economy, but fewer evidence has been presented in the context of marine economy efficiency. The limited research had been formed on the "structural bonus hypothesis", using data from coastal areas, such as Liaoning, Hebei, etc. [35,36]. Very few articles mentioned the possible spatial differences of marine economy efficiency. Yan et al. (2015) found the regions with strong competitiveness in marine industry structure did little to promote marine economic development for neighboring regions [37]. However, Ma and Zhang (2017) argued the rationalization of industry structure could wider the gaps of China's regional marine economic performance [38].

The review of literature has identified a clear gap in the existing research, i.e., the validity of structural bonus hypothesis and cost disease hypothesis in China's marine sustainable economy, and the details of it. In order to describe the dynamic relationship between marine industrial structure upgrading and marine economy efficiency, this paper uses DEA method with undesired output to value the marine economy efficiency and introduces the spatial Durbin model (SDM) to illustrate the spatial spillover effect. Finally, several policy implications are detected.

3. Data and Methodology

3.1. Data

The marine industry structure refers to the internal components and proportional relationship among various marine industries. The MISU aims to rationally allocate production factors in the development of marine industry, and to achieve a dynamic transformation of the high-knowledge, high-tech, and high-value-added of the marine industry structure [39]. According to Clark's law, this paper introduced the inter-industry ratio coefficient to measure marine industry structure, and the formulas are set as follows:

$$\mathrm{TL} = \frac{\mathrm{Y}_2 + \mathrm{Y}_3}{\mathrm{Y}}, \mathrm{TS} = \frac{\mathrm{Y}_3}{\mathrm{Y}_2}$$

where Y_2 represents the output value of the marine secondary industry; Y_3 represents the output value of the marine tertiary industry; Y represents the gross ocean product. Figure 2 illustrates the elevation and rationalization of the marine industry have been growing for the last decade. (All the data are obtained from the China Marine Statistical Yearbook and the State Oceanic Administration for the 11 coastal provinces and cities in China from 2005 to 2015.)

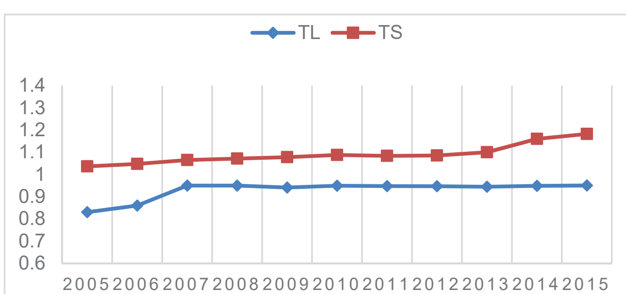

Figure 2. The changing process of China's marine industry structure. Source: researcher, derived from SOA (2005–2015).

To select the spatial measurement model, we set the weight of neighboring provinces (or municipalities) as zero, and the weight of nonadjacent provinces (or municipalities) as one. The following control variables are also included:

Economic foundation: we use Ln (GDP) and Ln^2 (GDP) to illustrate the economic growth, which determines the efficiency improvement [40].

Urbanization: Urbanization is helpful for narrowing the income gap and releasing the spatial spillover effect of economic development [41,42]. This paper set the ratio of urban population and total population to measure the urbanization rate.

Institutions: Institutions is a deep-seated factor affecting the ecological environment, which is vital to marine sustainable economy [43,44]. This paper uses the regional sewage charges (REG) and the per capita educational time (PET) to reflect environmental regulation and environmental awareness, respectively.

Foreign capital: Foreign capital (FDI) is treated as an important constituent of economic efficiency increasing [45,46].

Marine economic efficiency refers to an economic state where marine resources are optimally allocated to serve each individual or entity in the best way while minimizing waste and inefficiency [47,48]. Its traditional input–output index usually contains labor, land, capital, and gross value of industrial output. Recently, the introduction of undesired outputs has been widely proved to be more scientific and feasible in measuring sustainable growth of marine economy [49]. The input–output index used to calculate marine economic efficiency is set in Table 1. (According to the GDP conversion index announced by the National Bureau of Statistics of China (2018), the fixed investment amount is based on 2005 as the base period for constant price processing to eliminate price factors.

Table 1. The variables of the input–output indicators.

Input-Output Index	Indicators	Variables
input index	labor input	sea-related employment
	capital input	fixed assets investment
	ecological input	industrial wastewater treatment capacity
		nature reserve area
output index	desired output	the total value of marine production
	undesired output	marine pollution emission index

Notes: researcher, all the data derived from the China Ocean Statistical Yearbook (2005–2015), the China Statistical Yearbook (2005–2016); sea-related employment: Due to different statistical conditions around 2005, the 'number of the employment in the main marine industry at the end of the year' was used to replace 'employment in the sea' in 2005; the total value of marine production marine pollution emission index: Following Ren et al. (2018) and Wang et al. (2018), the improved entropy method is adopted to integrate the marine waste water, marine waste gas and marine solid waste ('three wastes') as the index of environmental pollution [50,51].

3.2. Methodology

In order to solve the data limitations in traditional DEA model, the super-efficiency slacks-based measure model (the super-efficiency SBM model) was newly proposed to avoid the deviation brought by the difference in dimension and the choice of angles. The new model can solve such a problem as ordering and differentiation among decision making units (DMUs) [52,53]. Several studies had verified the advantages of this model in analyzing marine economic efficiency [54–56]. This paper adopts a super-efficiency SBM model to measure the marine economic efficiency denoted by ρ. The specific model is set as follows:

$$\rho* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{X_{i0}}}{1 + \frac{1}{S_1 + S_2}\left(\sum_{r=1}^{s_1}\frac{S_r^g}{y_{r0}^g} + \sum_{r=1}^{s_2}\frac{S_r^b}{Y_{r0}^b}\right)}$$

$$S.T\begin{cases} x_0 = X\lambda + s^- \\ y_0^g = Y^g\lambda - s^g \\ y_0^b = Y^b\lambda - s^b \\ \lambda \geq 0, s^- \geq 0, s^g \geq 0, s^b \geq 0 \end{cases}$$

There are m decision making units (DMUs), each of which consists of m input (x_0), S_1 desired output (y_0^g) and S_2 undesired output (y_0^b). The relaxation moduli of them are expressed by s^-, s^g, s^b. λ is a constant vector, and X is the weight vector. The objective function ρ is strictly decreasing, given $0 < \rho \leq 1$. DMU is valid when and only when $\rho = 1$ ($s^- = 0$, $s^g = 0$, $s^b = 0$), and it will be invalid when $0 \leq \rho \leq 1$ (at least one of s^-, s^g, s^b does not equal 0).

The basic models of spatial lag model (SLM), spatial error model (SEM) and spatial Durbin model (SDM) are as follows:

$$Y = \rho WY + X\beta + \epsilon$$

$$Y = X\beta + \epsilon\epsilon = \lambda W\epsilon + \mu$$

$$Y = \rho WY + X\beta + \theta WX + \alpha l_n + \varepsilon$$

where Y is the dependent variable, representing marine economic efficiency; X is an exogenous variable matrix of n*k; W is a spatial weight matrix of n*n; ρ and λ are special auto-regression coefficient and special auto-correlation coefficient, representing the influence direction and degree of the observations of the adjacent area to the local observation, respectively.

Changes of independent variables not only affect the dependent variables in one region, but also affect the independent variables in other regions. This total effect is subdivided into direct and indirect effects. The direct effects represent the average impact of the dependent variable on one region, and the indirect effects represent the average impact of the dependent variable on other regions. The specific calculation method is as follows:

$$Y = \sum_{r=1}^{k} S_r(W)x_r + V(W)l_n\alpha + V(W)\varepsilon$$

for which $S_r(W) = V(W)(l_n\beta + W\theta_r)$, $V(W) = (I_n - \rho W)^{-1}$, I_n is an n-order identity matrix. The converting matrix form is

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \sum_{r=1}^{k} \begin{bmatrix} S_r(W)_{11} & S_r(W)_{12} & \cdots & S_r(W)_{1n} \\ S_r(W)_{21} & S_r(W)_{22} & \cdots & S_r(W)_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ S_r(W)_{n1} & S_r(W)_{n2} & \cdots & S_r(W)_{nn} \end{bmatrix} \begin{bmatrix} x_{1r} \\ x_{2r} \\ \vdots \\ x_{nr} \end{bmatrix} + V(W)_\varepsilon$$

The partial derivative $S_r(W)_{ii}$ measures the average effect of the change of x on the observations of y in one region. The direct effect is calculated by the average value of the diagonal elements in the numerical matrix $S_r(W)$. The partial derivative $S_r(W)_{ji}$ measures the average effect of the change of x on the observations of y in other regions. The indirect effect is measured by the average value of the diagonal elements in the non-numerical matrix $S_r(W)$.

4. Results

The results in Table 2 show that the Moran's I index—which is usually used to test whether economic variables have spatial interaction effects, and can effectively reduce analysis errors [57,58]—is significant at the confidence level of 10% and indicates that there exists spatial autocorrelation between marine industrial structure upgrading and marine economic efficiency.

Table 2. The Moran's I index of marine industrial structure upgrading (MISU) and marine economic efficiency.

	Moran's I Index		
Year	**Variables**		
	Y	**TL**	**TS**
2005	0.1182 ***	0.1723 *	01644 **
2006	0.1424 ***	0.1885 **	0.2312 **
2007	0.1355 **	0.1587 **	0.2103 **
2008	0.1766 **	0.1249 *	0.1623 **
2009	0.1484 **	0.1227 ***	0.1346 ***
2010	0.2793 ***	0.169 **	0.2093 **
2011	0.1452 *	0.1796 **	0.1964 ***
2012	0.1557 **	0.1477 ***	0.2152 **
2013	0.1934 ***	0.1253 **	0.2374 **
2014	0.1843 *	0.1792 ***	0.1689 **
2015	0.1828 **	0.2048 **	0.1733 ***

Note: ***, **, * indicate the level of significance 1%, 5%, and 10%.

Table 3 shows the spatial Durbin model has the best fitting effect. Based on the Wald test and the LR test, if both null hypotheses ($H_0 : \theta = 0$ and $H_0 : \theta + \rho\beta = 0$) are rejected, the spatial Durbin model is selected, otherwise should be the spatial lag and spatial error model. In addition, the spatial Durbin model with double fixed effects was selected as the final model according to the results of Wald test, LR test, and Hausmann test. China's marine industry structure upgrading affects marine economic efficiency negatively, where the elevation of marine industry structure plays a major role. The significant test further indicates local marine industrial structure upgrading has negative spillover effect on marine economic efficiency for adjacent areas. In particular, economic foundation, environmental awareness and urbanization respectively illustrated positive influence and negative influence on marine economic efficiency both for local areas and neighboring areas. This is in consistent with the research on landing territory [59]. In addition, foreign direct investment (FDI) and environmental regulation intensity (REG) both failed to pass the significant test.

Table 3. Estimation results of the spatial measurement model.

Variables	**SDM**		
	Time Fixation Effect	**Spatial Fixation Effect**	**Double Fixation Effect**
TS	−0.2340 **	−0.3941 *	−0.2034 **
TL	−0.3029 **	−0.1220 **	−0.4921 ***
CRI	−0.5329 ***	−0.3921 ***	−0.6711 **
Ln (GDP)	0.2562 **	0.3913 **	0.8329 ***
Ln^2GDP	−0.3019 ***	−0.1291 **	−0.5592 *
REG	−0.7180 *	−0.9302 *	−0.7821
PET	0.3001 **	0.3911 *	0.1822 **
FDI	−0.0481 *	−0.0302 ***	−0.0283
W*Y	−0.2829 ***	−0.1031 ***	−0.1564 **
W*CRI	−0.3918 *	−0.1901	−0.9212 **
W*Ln (GDP)	0.8391 ***	0.3812 ***	0.3456 *
W*Ln^2 (GDP)	−0.2123 *	−0.3829 *	−0.8312 **
W*REG	−0.7663 *	−0.9112 ***	−0.6212 ***
W*PET	0.2910 ***	0.3918 **	0.1839 ***
W*FDI	−0.5819 *	−0.9281 ***	0.6461 ***
R-squared	0.8039	0.8829	0.9201
Log-likelihood	82.9302	87.2039	193.2910

Note: ***, **, * indicate the level of significance 1%, 5% and 10%.

As China is in the period of deep adjustment and transformation for the marine industry structure upgrading over 2005–2015, a large amount of resources is invested in tertiary industry. Due to the immature internal structure system and operational processes, this adjustment brings in a negative impact on the efficiency of the marine economy, and the cost disease hypothesis is verified.

With continuous adjustment and optimization of the marine industry structure, emerging industries will gradually replace traditional resource-dependent industries. We introduce the spillover effect to identify where the cost burden brought about by the upgrading of industrial structure can be transformed into a cost dividend. Considering the regional characteristics of marine industry policy and the similarity of social and economic status in neighboring regions, the spillover effect was tested by China's coastal economic Rims [60]. Figure A1 (See Appendix A) shows the location of the five coastal economic Rims.

5. Discussion

Table 4 shows the decomposition results of the spatial spillover effect. The spillover effects of the MISU and marine economic efficiency have agglomeration effect in China's coastal areas. For the Bohai Economic Rim and the Yangtze River Delta Economic Rim, the positive direct and indirect effects contributed to positive total impact, and the elevation of marine industrial structures had more powerful influences. For the Straits West Coast Economic Rim and the Beibu Gulf Economic Rim, the total impact of marine industrial structure upgrading on marine economic efficiency was negative, with rather subtle appearance of the direct and indirect effects.

Table 4. Estimation results of spillover effects.

Variables		Direct Effect	Indirect Effect	Total Effect
		Coef.	Coef.	Coef.
Bohai Economic Rim	TS	0.2033 **	0.1762 *	0.3795 ***
	TL	0.3421 ***	0.2931 **	0.63552 **
	CRI	−0.2034 ***	−0.1331 **	−0.3365 ***
	Ln (GDP)	0.1932 **	0.1102 **	0.3034 **
	Ln^2 (GDP)	−0.1301 **	−0.0845 **	−0.2146 **
	PET	0.0102 *	0.0023 ***	0.0125 **
The Yangtze River Delta Economic Rim	TS	0.2103 *	0.1192 **	0.3295 ***
	TL	0.3223 ***	0.2312 *	0.5535 **
	CRI	−0.1938 **	−0.1190 **	−3128 **
	Ln (GDP)	0.0341 ***	0.0143 ***	0.0484 ***
	Ln^2 (GDP)	−0.0945 ***	−0.0701 **	−0.1646 **
	PET	0.0923 ***	0.0391 ***	0.1314 ***
The Straits West Coast Economic Rim	TS	−0.3224 ***	−0.2102 **	−0.5326 ***
	TL	−0.4323 *	−0.2934 ***	−0.7257 ***
	CRI	−0.4912 ***	−0.2982 ***	−0.7894 **
	Ln (GDP)	0.4029 ***	0.2201 **	0.6230 **
	Ln^2 (GDP)	−0.0722 **	−0.0132 **	−0.0854 **
	PET	0.0720 ***	0.0341 **	0.1061 ***
The Beibu Gulf Economic Rim	TS	−0.3321 **	−0.1334 **	−0.4655 ***
	TL	−0.4432 *	−0.3821 ***	−0.8253 ***
	CRI	−0.3302 ***	−0.2910 **	−0.6212 **
	Ln (GDP)	0.5044 **	0.3981 ***	0.9025 *
	Ln^2 (GDP)	−0.2002 *	−0.1732 **	−0.3734 **
	PET	0.0501 **	0.0291 ****	0.0792 ***

Note: ***, **, * indicate the level of significance 1%, 5% and 10%.

These findings backed up the feasibility and effectiveness of the cooperation mechanisms in the Bohai Economic Rim and the Yangtze River Delta Economic Rim. Benefited from the strategic full-scale development principles, these coastal areas learned from each other and made full use of the optimization and upgrading of the marine industry structure to realize jointly development. These policies also expanded the scale of the marine service industry and speeded up the formation of pillar industries such as marine fisheries, marine transportation, marine oil and gas, coastal tourism, marine shipbuilding, and marine biomedicine, then promoted the shifting of marine economy development pattern from resource-dependent to technology-driven. In reality, the Yangtze River Delta Economic Rim has superior marine resource endowments, abundant marine science and technology resources, and a complete marine industry chain. Supported by national development strategies and policies, marine industrial transformation is at the forefront of the country. It has changed from relying solely on resource-consuming industries to high-tech industries and marine service industries, while traditional marine industries with high resource consumption and high pollution levels have gradually shifted from extensive development to intensive benefits. In the Bohai Economic Rim, with the support of superior location conditions and government policies, coastal tourism, marine transportation, and other industries have been developed rapidly. The marine engineering construction industry, electric seawater industry and other marine emerging industries have maintained strong growth momentum, and the marine industry sector has become more diversified. For these regions, structural bonus hypothesis had already replaced cost disease hypothesis.

However, it has been verified that most of the main marine industries for the Straits West Coast Economic Rim and the Beibu Gulf Economic Rim are high resource-dependent, such as marine transportation, coastal tourism, and marine fishery. The un-rational layout of industry structure exacerbates the deterioration of the ecological environment and does little to promote the sustainable development of marine economy. So cost disease hypothesis still exists in these regions.

The brief discussion here shows it is vital to realize the coordinated development between the marine industrial structure upgrading and the marine economic efficiency. It is advised China's coastal areas to focus on developing competitive marine industries and give priority to emerging marine ecological industries to rectify the development mode characterized by high material consumption, high emission, and low output. For provinces (or municipalities) that have negative spillover effects, breaking through the dilemma between the marine industrial structure upgrading and the deterioration of marine economic efficiency, establishing a long-term mechanism for inter-regional development of marine sustainable economy and improvements of ecological environment should be the key point of policy design. Although the Straits West Coast Economic Rim and the Beibu Gulf Economic Rim are rich in marine resources, their development and utilization efficiency are still weak. These regions should focus on enhancing the coordination capabilities and correlation of factor endowments and industrial structures, such as deeply exploiting "strait economy", "gulf economy", and "island economy"—these refer to the type of regional economy based on island resources, surrounding marine resources and their geographical location.

It is suggested that for provinces (or municipalities) with positive spillover effects, the regional synergy strategy of the marine industry development policy is scientific and effective, which can become a powerful guarantee for the construction of marine ecological civilization. Based on the current coordinated state of MISU and marine economic efficiency, they are recommended to increase investment on perfecting the eco-environmental protection mechanism. For instance, some typical environment friendly marine industries, such as marine biological industries, marine new energy industries, deserve more policy support as multi-faceted funding and favorable taxation.

6. Conclusions

China's marine economic efficiency is generally inhibited by the continuous evolution of the marine industry structure. This conclusion strongly supports the cost disease hypothesis. The upgrading of the marine industry structure has a benign spillover effect on regional marine economic efficiency in the Bohai Economic Rim and the Yangtze River

Delta Economic Rim but shows negative spillover relationships in the Straits West Coast Economic Rim and the Beibu Gulf Economic Rim. Therefore, the findings also verify the feasibility and effectiveness of the regional cooperation policies in the Bohai Economic Rim and the Yangtze River Delta Economic Rim.

Furthermore, this cost disease hypothesis is ubiquitous. With the development of the regional marine economy, the cost disease hypothesis may shift to structural bonus hypothesis.

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Appendix A

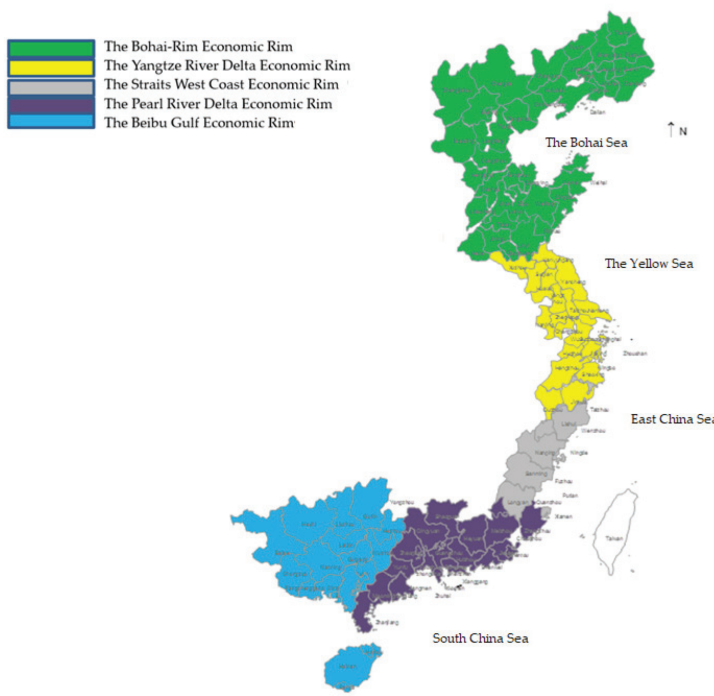

Figure A1. Five Economic Circles.

Figure A2. The Bohai-Rim Economic Rim.

Figure A3. The Yangtze River Delta Economic Rim.

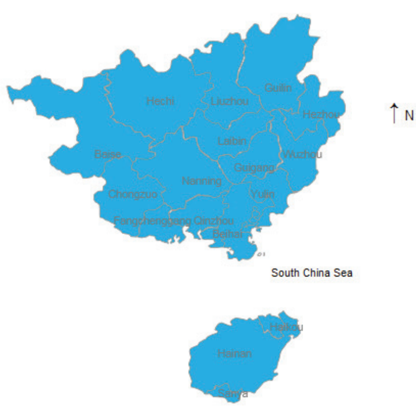

Figure A4. The Beibu Gulf Economic Rim.

Figure A5. The Pearl River Delta Economic Rim.

Figure A6. The Straits West Coast Economic Rim.

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sustainability

Article

Online Education in the Russian Arctic: Employers' Confidence and Educational Institutions' Readiness

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Abstract: The rapid spread of online learning demonstrates that it is becoming one of the trends in the development of vocational education in the modern world. Along with the obvious advantages of online learning such as cost reduction, cross-border opportunities for receiving it, and adaptability for students, educational institutions encounter specific difficulties: a lack of optimal teaching methods, inflexibility of the institutional environment to the use of new teaching technologies, the transformation of communication between teachers and students, and technological unpreparedness for the development of online learning. At the same time, the need to solve the problem of accessibility of education and fill the shortage of labor resources in Russia, in particular its Arctic zone (AZRF), will contribute to the spread of online learning practices. To consider developing online education, this article, on the one hand, presents the results of a study of the regional employers' confidence in education in a non-traditional format and, on the other hand, shows the readiness of vocational educational institutions to implement training programs in a distance format. The main research method was a questionnaire survey, in which 2240 organizations and 344 professional educational institutions located in the Russian Arctic took part. The survey results indicate that more than half of employers (58%) declared the applicability of online learning in the Russian Arctic, but about 40.6% of companies do not consider applicants with a diploma from online education. At the same time, employers' confidence in distance learning in higher education is lower than in vocational secondary education. Additionally, the majority of institutions of higher education (62.5%) believe in the possibility of using distance education in the Russian Arctic, while organizations of vocational secondary education (64.98%) have the opposite opinion. Based on the results of the study, recommendations for federal and regional authorities were prepared.

Keywords: online education; distance learning; the Arctic region; educational institutions; employers

1. Introduction

Discussions about online learning in education have been active for several decades. The development of technology platforms is increasingly driving the explosive growth of online learning [1], while the popularity of distance learning as a distinct lifestyle is becoming more evident [2].

During the COVID-19 pandemic, many companies and educational institutions switched over to remote learning, becoming participants in a large-scale "experiment" to introduce online education. Minimizing social interaction was considered as a factor in reducing the spread of infections [3]. In March 2020, 1.2 billion students in 186 countries found themselves outside of their educational institutions, and the volume of the online education market in 2020 exceeded USD 250 billion. Additionally, the predicted value of its growth will be about 21% in the period until 2027 [4].

The explosive growth in the volume of online learning has provoked controversy around issues related to ensuring the quality of teaching, the development of new teaching methods, the nature of communication between students and teachers, and institutional barriers concerning changes in the timing of the educational process and obtaining qualifications. At the same time, in practice, teachers and students face a large number of technical, social, and financial problems [5,6].

Feedback from students, the development of differentiated teaching and grading practices, the recording of online lectures, and the academic support of students are considered as the key factors for quality online education and increasing student satisfaction with learning [7].

Data from surveys of online students indicate the convenience of mastering the educational program at their own pace but, at the same time, this format of education is inferior to classroom teaching [8]. In addition, students note that online learning has a negative impact on health and social interaction [9].

In general, the online learning format in scientific research is considered as an alternative to classroom learning without compromising its quality [10]. According to the rector of the Higher School of Economics, Yaroslav Kuzminov, the introduction of online courses can replace low-quality distance education courses at the university, and the money can be redirected to the creation of scientific laboratories [11].

In other cases, the epithet "diploma factory" has been applied to educational institutions that have institutional barriers to creating conditions for high-quality learning of an educational program in a distance format [12]. At the same time, the inferiority of communication in the process of distance learning between teachers and students is emphasized [13].

The rector of the European University at St. Petersburg, Vadim Volkov, notes that online education can act as an addition, but not a replacement for traditional education. Complete remote learning, in many cases, cannot replace practice-oriented training, ensure socialization and education of students, form networks of friendly contacts for the future, or create a holistic lifestyle that changes a person. In his opinion, the leading universities are unlikely to decide to "trade" full-fledged diplomas for distance learning, but the sale of individual courses, additional programs, and various certificates will increase [14].

Discussions about the quality of education [15] may have an impact on the credibility of different educational formats among students, clients of educational services, and employers. When looking for candidates for vacancies, employers determine the criteria for selection, recruitment, and hiring techniques [16].

When recruiting, employers pay more attention to the qualifications, experience and skills of a specialist [17], interpersonal skills, and reputation of the university, sometimes demonstrating negative bias towards new universities [18]. At the same time, the level of education is one of the conditions for employment and the basis for career trajectories [19]. The very format of obtaining an education can have an impact on employment opportunities. Employer surveys show that hiring decision makers rate traditional education more positively than online education [20]. A negative attitude towards it associates it with a lower level of education quality, fragmentation of the courses studied, insufficient opportunity to develop competencies for a career, as well as a high risk of the spread of academic dishonesty among students [21].

With the existing effect of distrust in online education, employers impose such requirements on employee training as reducing the cost of implementing educational programs, ensuring transparency of training content, and increasing confidence in learning outcomes, as well as the release of demanded human resources for corporate activities and replenishing missing resources [22].

Thus, the advantages and disadvantages of distance learning for consumers, developers, suppliers, and organizers of the educational process and other stakeholders are due to various factors that are combined into the following groups: economic (lower cost of training, but costs for hardware and software are required); social (the possibility of obtaining a prestigious certificate or diploma without leaving home, but this is impossible without a high degree of self-organization of the student); organizational (the process of monitoring training is simplified); and meaningful (there is a possibility of multiple repetition of the material) [23].

Russian legislation provides for the possibility of online education. Based on Chapter 2 of Art. 16.1 of the Federal Law of 29 December 2012 No. 273-FZ "On Education in the Russian Federation", e-learning means the organization of educational activities using the information contained in databases for educational programs and information technologies, technical means, providing its processing, as well as information and telecommunication networks that ensure the transmission of this information over communication lines, and the interaction of students and teachers [24].

Organizations can implement educational programs or their parts exclusively using e-learning, distance learning technologies, organizing training sessions in the form of online courses that provide students, regardless of their location and organization in which they master the educational program, the achievement and assessment of results of training by organizing educational activities in an electronic information and educational environment to which open access is provided via the Internet.

The applicability of online education in the Arctic zone of the Russian Federation (AZRF) is significantly influenced by its specificity of settlement and socio-economic development. On the one hand, low population density and the presence of remote settlements with a low level of development in educational and social infrastructure [25] are prerequisites for the development of distance learning, which can itself contribute to responding to these challenges. At the same time, the problem of the topic is reinforced by the growing imbalance between the demand and supply of labor resources in the Russian Arctic [26] and the widespread manifestation of emigration sentiments of students at universities in the Arctic region [27].

At the same time, an objective obstacle to the development of e-learning is the limited share of households with broadband Internet access (81.3% in 2019) [25]; most of them live in large cities and metropolitan areas with a developed education system. An additional limitation to the development of online education may be the low level of employers' confidence in graduates with distance education certification.

To study the possibility of developing online education for training specialists for the needs of the economy and social sphere of the Russian Arctic, it is necessary to study, on the one hand, regional employers' confidence in education in a non-traditional format and, on the other hand, the readiness of the network of vocational educational institutions to implement training programs in a distance format.

2. Materials and Methods

Sociological data on the development of online education and the opinions of employers were obtained within the framework of applied research work on the topic: "Compliance of the existing network of educational institutions of vocational secondary and higher professional education with the staffing needs of employers operating in the Arctic zone of the Russian Federation, and prospects development of personnel policy in the Arctic zone of the Russian Federation". This project was implemented by the Petrozavodsk State University (Russia, Republic of Karelia) together with the Northern (Arctic) Federal University named after M.V. Lomonosov (Russia, Arkhangelsk) under the guidance of Professor V.A. Gurtov.

The questionnaire toolkit was developed by specialists of Petrozavodsk State University (V.A. Gurtov, I.S. Stepus, A.V. Simakova), and the survey was carried out jointly by the project team.

Section 5, "Online education for the Arctic zone of Russia", of the questionnaire for employers was aimed at determining the applicability of the practice of obtaining professional education online for the conditions of the Arctic zone, the degree of acceptability of the existing online education system, and the willingness to hire a specialist with a diploma from a professional online education. These variables of the questionnaire were tested in previously conducted sociological studies among organizations [17].

Section 4, "Online education", of the questionnaire for vocational education organizations contained variables aimed at determining the acceptability of online learning practice, its compliance with the requirements for the Arctic regions, the possibility of distance learning in a number of specialties, and an opinion on the willingness of employers to hire graduates of distance educational programs to vacancies.

The questionnaires used closed-ended questions for further quantitative analysis of data and generalization of information [20].

The sample includes a total of 2240 organizations from all entities that form part of the Russian Arctic. Data on the number of interviewed employers in each region are presented in Figure 1.

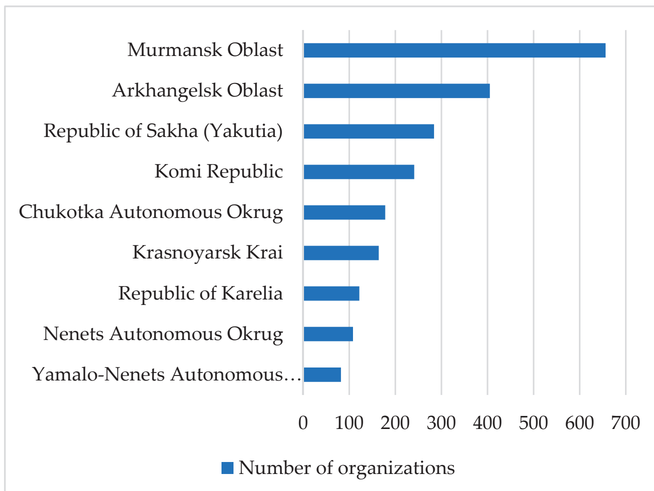

Figure 1. The number of employing organizations that took part in the survey, by subjects of the Russian Arctic, n = 2240.

Figure 2 presents data on the number of organizations by type of economic activity.

The sample of vocational educational institutions is represented by 344 institutions, including 277 organizations of secondary vocational education and 67 of higher education. Figure 3 shows the distribution of institutions by the subjects of the Russian Arctic.

The survey of employers of the Russian Arctic was carried out from June to September 2020, and organizations of secondary and higher professional education were sampled from August to October 2020 by sending them invitations to participate in the study, including instructions and links to the information system for filling out the questionnaire forms.

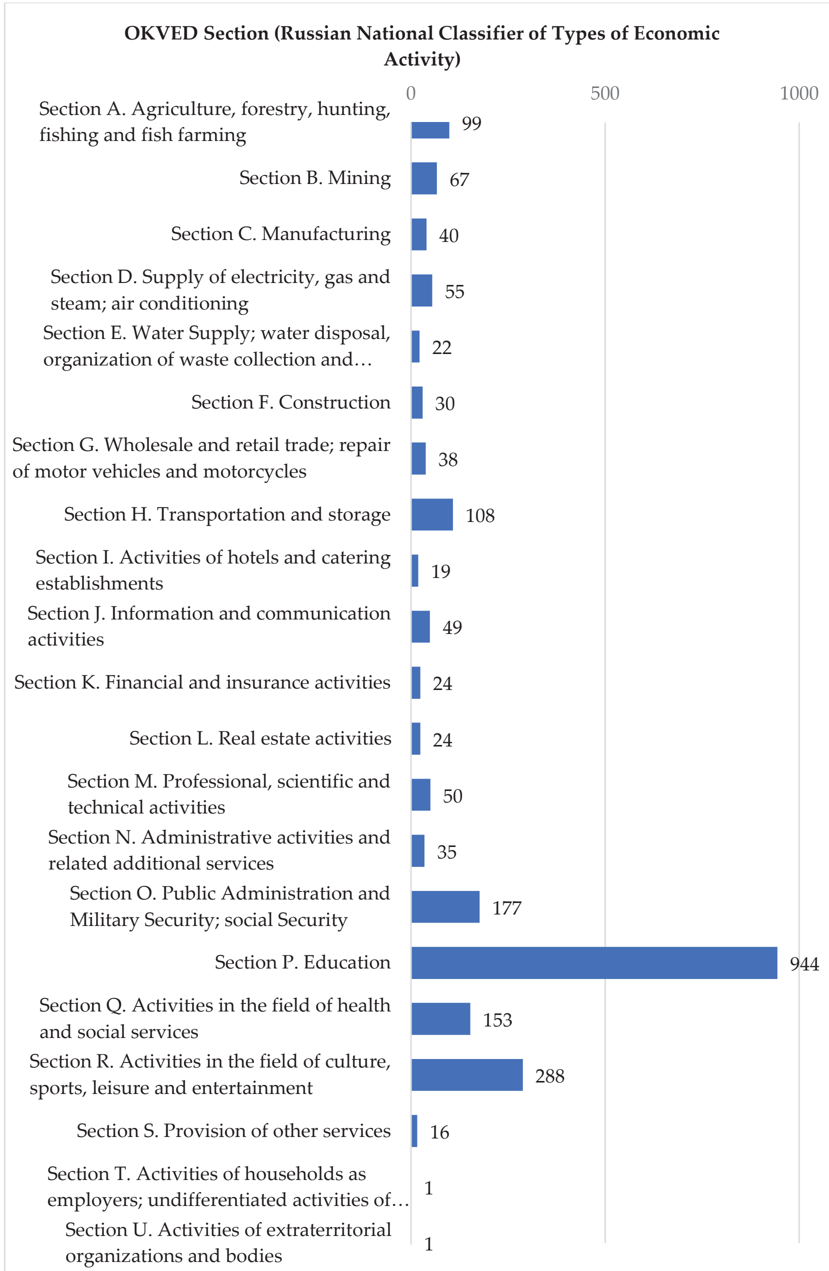

Figure 2. The number of employing organizations that took part in the survey by OKVED, in units, n = 2240.

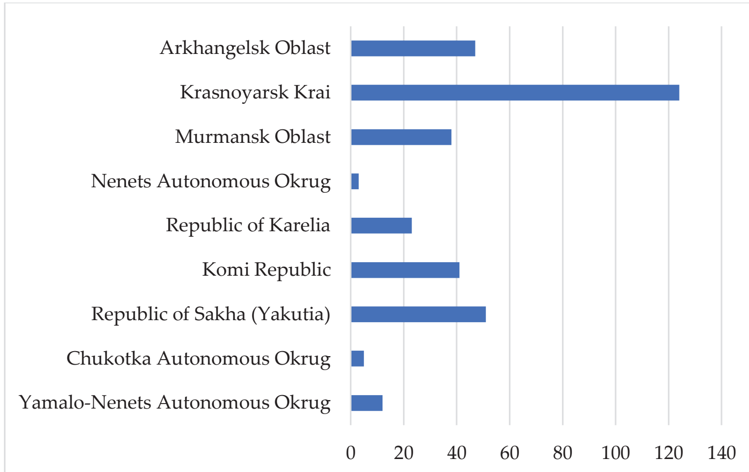

Figure 3. The number of vocational educational institutions that took part in the survey, by subjects of the Russian Arctic, n = 344.

3. Results

More than half of employers (58%) declared the applicability of online education in the Russian Arctic. This share in the context of regions as a whole does not change, with the exception of the Chukotka Autonomous Okrug, where two thirds (66%) of the respondents stated the possible advantages of distance education (Figure 4).

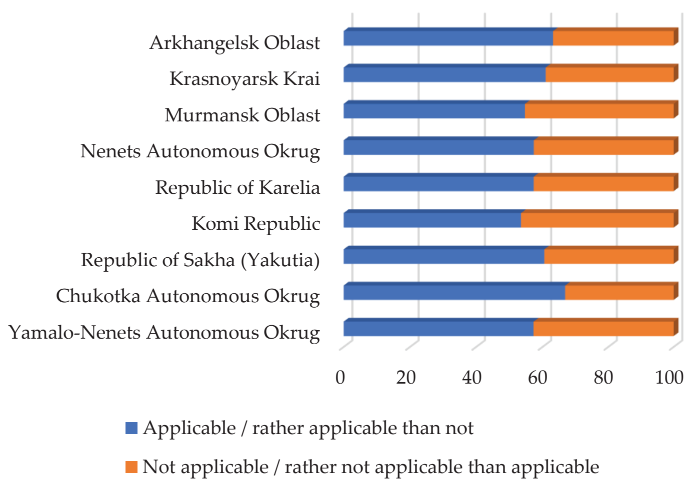

Figure 4. Attitude of employers to the applicability of online education in the context of the subjects of the Russian Arctic, in %.

By type of economic activity, the largest share of employers who positively consider the applicability of online education relates to information and communication activities (69%), water supply, wastewater disposal, waste collection and disposal, pollution elimination activities (68%), processing industries (65%), as well as to professional, scientific, and technical activities (about 68%). The most pessimistic on this issue are the enterprises from the areas of "administrative activities and related additional services" (48.57%) and "financial and insurance activities" (45.83%), despite the fact that there is a high level of digitalization in finance and insurance.

When asked about the correspondence of the online education system to the one that would be successful and applicable for their organization, employers answered identically. About 58.7% of employers noted that the existing online education system is consistent with the ideas of success and acceptability for their organizations. The ratio of the shares practically did not change either in the context of the constituent entities of the Russian Federation or in the context of the types of economic activity (the deviation was in the range of 0.01–2.91%).

When asked about the readiness to hire a specialist who has a diploma from an online form of professional education, the opinions of employers were divided. About 16.3% of organizations already have such specialists on their staff, and 43.1% of employers are considering such an opportunity, provided that the applicant successfully passes entrance examinations (interviews) and a probationary period. At the same time, 40.6% of companies do not consider applicants with a diploma from an online education platform. This generalization of unequal attitude toward online and traditional diplomas correlates with similar surveys [20].

Small differences in educational levels were revealed: employers are less willing to hire candidates with "online diplomas" for positions requiring higher education, and welcome such applicants for positions requiring vocational secondary education in programs for training mid-level specialists. This circumstance may be associated with a large shortage of blue collar workers.

In the context of the regions, companies from the Republic of Karelia and the Republic of Sakha (Yakutia) are the most positive in terms of the recruitment of a specialist with a professional diploma from an online platform. The least optimistic are the organizations of the Arkhangelsk Oblast and the Yamalo-Nenets Autonomous Okrug (Figure 5).

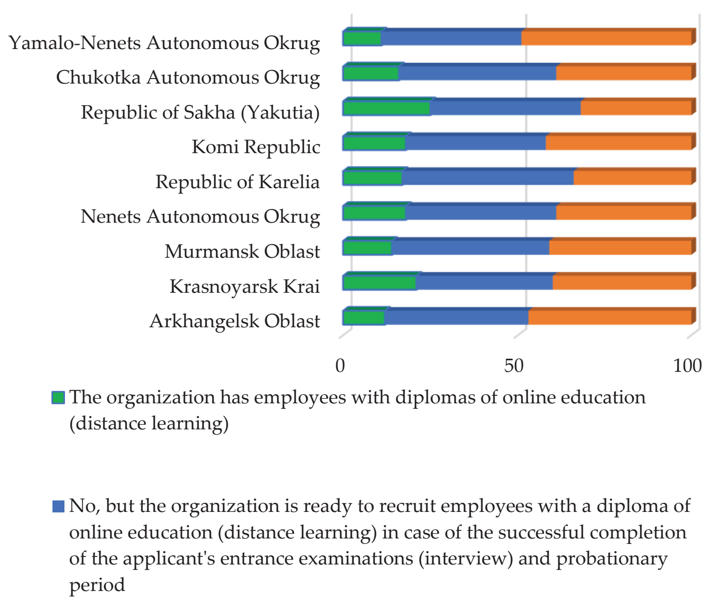

Figure 5. Willingness of employers of the Russian Arctic to hire a specialist with a professional diploma granted by an online platform, by regions, in %.

The answers of employers to the same question are multivariate, depending on the type of their economic activity. The impossibility of considering applicants with an online education diploma was mainly stated by organizations working in the fields of mining (53%), manufacturing (51%), water supply (52%), construction (51%), transportation and storage (55%), and real estate (58%). Employers in the following types of economic activities declared their readiness to hire such candidates: the activities of hotels and catering establishments (63%), activities in the field of information and communications (63%), and financial and insurance activities (75%). A noteworthy fact was that there was a certain discrepancy in the answers to previous questions from employers in the water supply sector (68% stated the applicability of online education) and finance (only 46% supported the idea of the applicability of distance learning). Perhaps this is due to the lack of a clear understanding of the various forms of distance education.

A survey of educational institutions of higher and vocational secondary education operating in the Russian Arctic revealed the following results of work. Unlike employers, organizations of secondary vocational education (64.98%) believe that the practice of obtaining an online education is not applicable to the conditions of the Arctic region. At the same time, a significant difference was recorded in the answers of organizations of higher education. On the contrary, most of them (62.5%) believe in the possibility of using distance education in the Russian Arctic. In the context of the regions, only in the Yamalo-Nenets Autonomous Okrug (54.55%) and the Republic of Karelia (60.87%) did the majority of educational organizations recognize the applicability of this form of education (Figures 6 and 7).

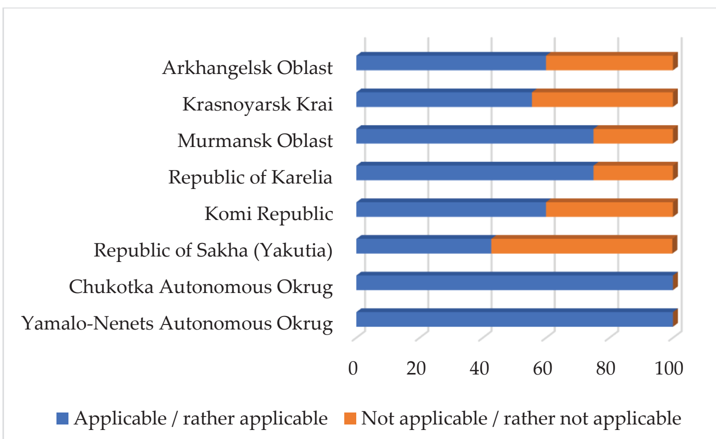

Figure 6. The attitude of higher education institutions towards online professional education for the Russian Arctic conditions, in %.

It is important to note that the question did not indicate whether it was about transferring the entire educational process to a distance format or only a part of it. It was possible that the surveyed organizations answered only the question regarding the complete transition to online learning.

According to educational organizations, the practice of distance learning is most applicable for the following enlarged groups of specialties: economics and management (the specialties of this group were named 73 times), computer science and computing (28 times), service and tourism (19 times), jurisprudence (18 times), education and pedagogical sciences (17 times), and applied geology, mining, oil and gas business and geodesy (15 times). Moreover, educational organizations did not indicate specific forms of online learning when answering this question. Thus, there is no information on whether educational organizations consider all forms of e-learning acceptable, according to the specified enlarged groups of specialties, such as full-fledged diplomas of online learning, blended learning, and open online courses.

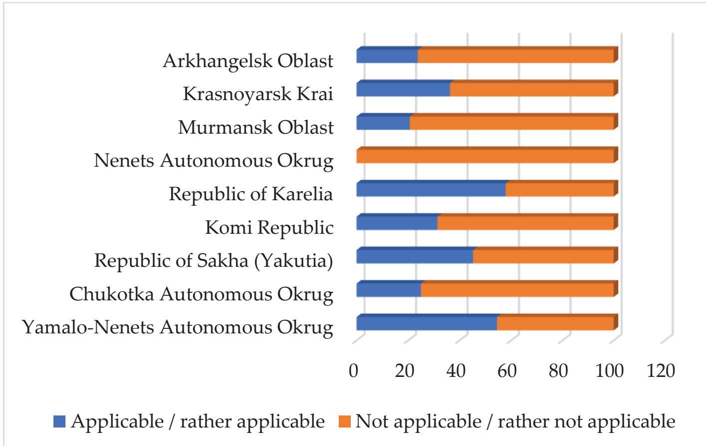

Figure 7. The attitude of organizations of vocational secondary education towards online professional learning for the Russian Arctic conditions, in %.

When asked about the possibility of switching to distance learning in a number of specialties, a majority of institutions of higher education indicated this as a possibility (60%). Institutions of vocational secondary education, on the contrary, demonstrated pessimism on this issue, pointing out the impossibility or rather the impossibility of switching to distance learning in a number of specialties (64.19%).

Similarly, specialties for which educational organizations considered such an opportunity were distributed: economics and management (specialties of this group were named 51 times), informatics and computing (20 times), service and tourism (18 times), jurisprudence (14 times), education and pedagogical sciences (21 times), and applied geology, mining, oil and gas business and geodesy (13 times).

In general, respondents from educational organizations assess the compliance of the online education system of their organizations rather highly in relation to the requirements for this system in the Arctic regions (Figure 8).

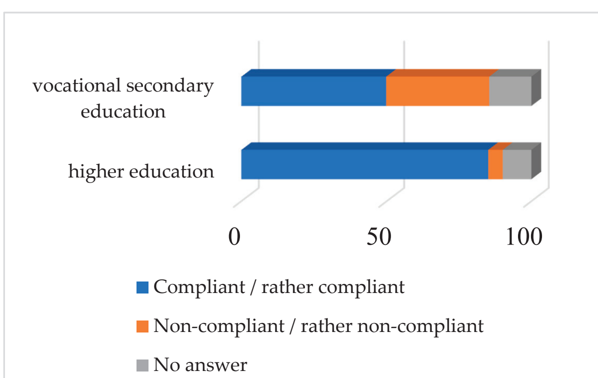

Figure 8. The opinion of educational organizations on the compliance of the online education system with the Arctic regions requirements, by education level, in %.

Yamalo-Nenets Autonomous Okrug (100%), the Republic of Sakha (Yakutia) (73.40%), and the Republic of Karelia (60.80%) rate their online education systems as very high. This indicator is at a rather low level in the Nenets Autonomous Okrug (33.3%) and Chukotka Autonomous Okrug (40%).

4. Discussion

The skepticism of educational organizations regarding the applicability of online education for the Arctic territories is partially confirmed by their low level of readiness to hire a specialist with an online education diploma; only 27.68% of organizations are ready to do this. At the same time, the share of university representatives who are positively disposed on this issue is slightly higher (35%) than the share of colleges and technical schools (26.69%). Among the subjects, the Yamalo-Nenets Autonomous Okrug (only 18.18% are ready to apply this practice) and the Chukotka Autonomous Okrug (20%) stand out on this issue. The highest indicator of readiness for adoption is shown by the Komi Republic educational organizations—37.5%.

Learning with the use of distance technologies today is becoming an integral part of the educational process, including higher and vocational secondary education.

The key advantages of e-learning, especially significant for the Russian Arctic, are the lower cost of training, the possibility of receiving quality education remotely, and unlimited access.

According to the survey findings of educational organizations, the use of online learning is most applicable in the fields of economics and management, computer science, service and tourism, law, education and pedagogical sciences, and applied geology, mining, oil and gas business and geodesy.

According to the study, most AZRF employers already have an employee with an online education diploma on their staff or are ready to accept such a job seeker. However, the share of pessimistic employers is quite high, which requires a change in attitude towards online education and a decision on the question of how qualifications are awarded by educational institutions [2].

At the same time, online learning has a number of significant limitations. First, distance education, in many cases, cannot replace practice-oriented training [28] and ensure the socialization of students. Secondly, distance education requires a corresponding development of the information and communication infrastructure: the availability of high-speed Internet access and access to teaching aids (personal computers, platforms, and resources for online learning). This problem is especially relevant for organizations of vocational secondary education. Thirdly, since online learning requires the appropriate skills of students and a high level of their self-organization, it is necessary to provide high-quality methodological support for this process [29].

Thus, it is possible to form the following recommendations for federal and regional authorities:

- To provide access to high-speed Internet for residents of the regions of the Russian Arctic;
- Modernize the digital environment of educational organizations of the Russian Arctic and provide access to modern platforms of distance education;
- To study the possibility of creating distance learning resource centers on the basis of regional universities of the Russian Arctic for training pedagogical personnel in the region;
- To stimulate and support the implementation of educational programs in a network form, including distance formats, in educational institutions of higher and vocational secondary education located in the territory of the Russian Arctic and leading Russian educational institutions.

5. Conclusions and Future Research

The results of the study indicate the widespread use of distance learning technologies in vocational education. However, the further development of online education in the Russian Artic will be associated with contradictions between the reduction in economic costs of training and the risk of a decrease in the quality of education; with the possibility of remote education and the lack of practice-oriented training of specialists; with the adaptability of online education and the lack of resources for high-quality methodological support of the educational process; and finally, with the rapid training of specialists in professions with shortages and the inadequacy of their competencies for work in the Arctic.

Further research prospects are associated with identifying mechanisms and technologies for optimizing the implementation of online vocational education to meet the trust and interests of employers and students, as well as to overcome the imbalance in training personnel for the needs of the economy and social sphere of the Russian Arctic.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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A Forecasting and Prediction Methodology for Improving the Blue Economy Resilience to Climate Change in the Romanian Lower Danube Euroregion

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Abstract: European Union (EU) policy encourages the development of a blue economy (BE) by unlocking the full economic potential of oceans, seas, lakes, rivers and other water resources, especially in member countries in which it represents a low contribution to the national economy (under 1%). However, climate change represents a main barrier to fully realizing a BE. Enabling conditions that will support the sustainable development of a BE and increase its climate resiliency must be promoted. Romania has high potential to contribute to the development of the EU BE due to its geographic characteristics, namely the presence of the Danube Delta-Black Sea macrosystem, which is part of the Romanian Lower Danube Euroregion (RLDE). Aquatic living resources represent a sector which can significantly contribute to the growth of the BE in the RLDE, a situation which imposes restrictions for both halting biodiversity loss and maintaining the proper conditions to maximize the benefits of the existing macrosystem. It is known that climate change causes water quality problems, accentuates water level fluctuations and loss of biodiversity and induces the destruction of habitats, which eventually leads to fish stock depletion. This paper aims to develop an analytical framework based on multiple linear predictive and forecast models that offers cost-efficient tools for the monitoring and control of water quality, fish stock dynamics and biodiversity in order to strengthen the resilience and adaptive capacity of the BE of the RLDE in the context of climate change. The following water-dependent variables were considered: total nitrogen (TN); total phosphorus (TP); dissolved oxygen (DO); pH; water temperature (wt); and water level, all of which were measured based on a series of 26 physicochemical indicators associated with 4 sampling areas within the RLDE (Brăila, Galați, Tulcea and Sulina counties). Predictive models based on fish species catches associated with the Galati County Danube River Basin segment and the "Danube Delta" Biosphere Reserve Administration territory were included in the analytical framework to establish an efficient tool for monitoring fish stock dynamics and structures as well as identify methods of controlling fish biodiversity in the RLDE to enhance the sustainable development and resilience of the already-existing BE and its expansion (blue growth) in the context of aquatic environment climate variation. The study area reflects the integrated approach of the emerging BE, focused on the ocean, seas, lakes and rivers according to the United Nations Agenda. The results emphasized the vulnerability of the RLDE to climate change, a situation revealed by the water level, air temperature and water quality parameter trend lines and forecast models. Considering the sampling design applied within the RLDE, it can be stated that the Tulcea county Danube sector was less affected by climate change compared with the Galați county sector as confirmed by water TN and TP forecast analysis, which revealed higher increasing trends in Galați compared with Tulcea. The fish stock biodiversity was proven to be affected by global warming within the RLDE, since peaceful species had a higher upward trend compared with predatory species. Water level and air temperature forecasting analysis proved to be an important tool for climate change monitoring in the study area. The resulting analytical framework confirmed that time series methods could be used together with machine learning prediction methods to highlight their synergetic abilities for monitoring and predicting the impact of climate change on the marine living resources of the BE sector within the RLDE. The forecasting models developed in the present study were meant to be used as methods of revealing future information, making it possible for decision makers to adopt proper management solutions to prevent or limit the negative impacts of climate change on the BE. Through the identified independent variables, prediction models offer a solution for managing the dependent variables and the possibility of performing less cost-demanding aquatic environment monitoring activities.

Keywords: blue economy; fish stocks; water quality; machine learning; forecast models

1. Introduction

1.1. EU Blue Economy and Blue Growth

In the scientific literature, a blue economy (BE) is most widely associated with actions related to the governance and management of seas and oceans [1,2]. There is no widely accepted definition of the term BE [2]. Therefore, according to some authors [3], the definition of a BE includes aquatic and marine spaces (e.g., seas, coasts, lakes, wetlands, floodplains, rivers and underground water resources) while also covering a variety of production sectors including fishing, aquaculture, tourism, shipbuilding, underwater mining, transport, bioprospecting and other related activities. Other research papers [4] pointed out that a BE encompasses all economic activities related to the oceans, seas and coasts, covering a wide range of interlinked established and emerging sectors. The BE is considered a consequence of the growing worldwide interest in the growth of water-based activities [5] seeking to curb biodiversity loss while stimulating economic development [6]. The EU concept of a BE includes all economic activities related to the oceans, seas and coasts, which includes a wide range of interlinked sectors [7] compared with the World Bank BE concept, which is strictly based on the sustainable use of ocean resources [8]. According to the European Commission Report on BEs elaborated in 2021 [9], the EU BE includes a series of established sectors such as marine living resources, marine extraction of non-living resources, maritime transport, port activities, shipbuilding and repair as well as coastal tourism, all of which are considered highly important for the development of the EU economy in addition to emerging sectors such as marine renewable energy, BE biotechnology, desalination, marine minerals, marine defense, security and surveillance. The importance of the EU BE is revealed by the fact that it directly employs over 4 million people (1.8% of the overall EU economy), with over EUR 600 billion in turnover and almost EUR 200 billion in gross value added (1.3% of the overall EU economy) [7]. Marine living resources represent the second most important sector for the EU BE which, according to Eurostat, employs on average 573,000 persons per year (more than 15% of the total EU BE employment) and yields an annual average gross value added (GVA) of over EUR 18 billion, which has been expanding since 2013. This sector is mostly composed of fisheries and aquaculture, as well as aquatic animal processing and distribution activities. Since both processing and distribution activities dependent on the fish supply and marine living resources represent a key sector of the EU BE, the fisheries and aquaculture subsectors can be ranked as the most important for ensuring blue growth (BG). Recent research [10] has characterized BG as an emerging concept which aims to achieve economic growth based on the exploitation of marine resources while avoiding their degradation, excessive use and pollution. The presence of BG is characterized by the key aspects demanded by a BE to overcome economic, social and environmental challenges [11]. Martínez-Vázquez et al. (2021) revealed that the relationship between a BE and a circular economy (CE) is mediated by BG and emphasizes the link between fisheries as a BE component and water as a CE component [11]. This is valid since fisheries depend on water, as their life cycle depends on this natural environment and both its conditions (e.g., quality, temperature and salinity) [12] and its proper management influences the sustainability and conservation of marine species [8]. Fisheries and water are important components linked by EU BG, a situation also confirmed by the EU Common Fisheries Policy (CFP), which promotes fish consumption and trade, underlining the value of fish to society from both the social and ecological perspectives [13]. Thus, it is important to maintain the aquatic systems in good health by constant monitoring and control of the water quality, water level and fish stock status to improve BE resilience to emerging challenges.

1.2. Impact of Climate Change on Aquatic Ecosystems

Climate change can be considered one of the main challenges which a BE has to deal with, since it affects both fisheries and aquaculture and, therefore, the marine living resources subsector. Climate variation influences water quality, food security and the socio-economies of different regions [14]. It also has a significant effect on stock abundance dynamics [15] and generally on biological assets [16]. Thus, fish stock assessment highly depends on the ability to predict the impacts of climate change on the dynamics of aquatic ecosystems [15,17]. Climate change impacts aquatic ecosystems by altering biodiversity patterns [18,19], the abundance and distribution of species (15), biological interactions, phenology and organism physiology [20,21]. Several research studies [22,23] revealed that the impacts of climate change upon aquatic biodiversity are expected to intensify soon. Changes in distributions and the community structures of fish species may influence fishing activities and have socioeconomic impacts on vulnerable coastal communities [24,25]. An increase in water temperature and water level are both primary indicators of climate change [26–28]. According to several studies [29–31], water level fluctuations could have a major impact on communities of fish species within rivers and, therefore, on commercial fish stocks, in addition to a considerable influence upon the topography of the basin in time and space [32]. Under climate change, the supply of water resources is unlikely to remain constant, and regional water availability is no longer assured [33].

Therefore, water level variations directly influence the abundance of periphyton, aquatic macrophytes and benthos and can indirectly affect phytoplankton and zooplankton [34], which are important nutritional sources for fish stocks. Moreover, according to previous studies [35], fish stocks can be affected if the water level changes rapidly during the reproduction period, a situation that applies particularly to substrate spawning fish species. Additionally, the nitrogen and phosphorus concentrations in water will increase due to global warming [36,37]. Therefore, a rise in temperature increases the concentration of soluble phosphate in the water [36] and salter nitrogen cycling processes affecting terrestrial and aquatic ecosystems, as well as human health [37].

According to several studies [38,39], climate change may alter the discharge regime of rivers and, therefore, their magnitude, duration, frequency, rate and timing of discharge events. Dysfunctionalities related to water level dynamics can reduce estuary flushing rates if river flow decreases, while if the flow rate increases, the N and P upward loading of aquatic ecosystems will appear by transferring these nutrients from agriculture fields, as confirmed by other studies. Nutrients, especially phosphorus and nitrogen from various sources, and increasing temperatures constitute the major causes of degradation of the aquatic ecosystems, namely in the form of eutrophication [40]. Climate change will significantly alter nitrogen cycling processes, with a negative impact on aquatic ecosystems as well as human health [37]. Furthermore, according to recent studies [41–43], the oxygen content of aquatic environments has declined substantially in the past few decades as a direct consequence of global warming. Therefore, surface water oxygen solubility decreases with increasing temperatures [41]. The water pH is also affected by global warming and, more specifically, by the increase of atmospheric CO_2. This increases ocean acidification [44]. Water is considered a scarce resource in the modern era (given the rapid growth of populations and enormous water-intensive industries); thus, competition for water rights among sectors usually results in conflicts of interest [45]. This can generate serious shortages within a BE [46] and give rise to already-existing climate change pressure. Thus, according to the authors of [47], water use equilibrium is dependent on climate-induced impact.

1.3. Romania BE in Relation to Climate Change

Although the EU targets the development of a BE, there are still member countries that register low contributions of BEs to their national economies (under 1%), such as Romania, Slovenia and Belgium. Despite these results, Romania has significant potential for sustaining the European Union BG strategy, especially due to its geographical characteristics [48]. This potential is based on the presence of the Danube River (1075 km out of a total of 2857 km are in Romanian territory) connected to the Black Sea and its marginal ecosystems, with the vast surface of the Danube Delta (3446 km^2 of a total of 4152 km^2 is in Romania territory) and many natural lakes, canals and ponds present within the Romanian Lower Danube Euroregion (Brăila, Galați and Tulcea county). According to Eurostat data, the Romanian marine living resources sector implies that there is an average of 7000 employed persons and an annual GVA of approximately EUR 64 million. The Romanian Lower Danube Euroregion (RLDE) represents the most significant contribution to the marine living resources sector. This is due to both high fishery and aquaculture activities. The country's national BE is mostly based on the Danube–Danube Delta–Black Sea macrosystem. This presupposes strict aquatic environment monitoring and control activity, which are essential for the proper functionality of a BE. This activity can be performed by using prediction and forecasting methodologies facilitating the control and identifying in advance the effects of possible threats, such as climate change, on the water's physicochemical parameters and the fish stocks status. According to different scenarios, the projected extinction rates of aquatic biodiversity are higher compared with those of terrestrial biodiversity [49] due to climate change, which is increasingly threatening fish, resulting in an uncertain future for both wild fish diversity and global fisheries [50,51]. What is more, climate warming-induced environmental changes can negatively affect several migratory fish species which are characterized by a high degree of synchronization between their reproductive cycles and seasonal river flow dynamics [24]. Most fish species respond to climate change through biological adaptation [52], aquatic area shifting [53] and even extinction [54]. Fish growth alteration is considered a main direct and common consequence of climate change [55] and can have long-term influences on stock dynamics and characteristics [56]. Predicting the impacts of climate change on aquatic ecosystems based on fish stocks response can represent a monitoring solution for improving the resilience management plan, a fact confirmed by other studies [57,58]. However, climate change affects aquatic environments from different climate zones in various manners [59], and its effect is specifically attributed to each fish species. Therefore, the impact prediction models must be unique for each aquatic ecosystem. Studies [60,61] which analyzed the climate change effect on the Danube–Danube Delta–Black Sea macrosystem reported an upward trend for eutrophication within the Danube River Basin, with urban settlement and agriculture contributing majorly to amplifying the nitrogen and phosphorus emissions, respectively [61]. The monitoring of aquatic macrosystem water quality is essential for developing a BE and indicates trends over time, which offers the possibility of identifying the sustainability of a BE and selecting the most appropriate direct remedial actions. Additionally, an evaluation of water quality parameters is necessary to plan and develop better water resource management [62,63].

Several papers approached the subject of water quality in the Danube River. For instance, Mănoiu and Crăciun (2021) realized a thorough review of the water quality trends in the Danube River [64], focusing on Serbia, Romania, Slovakia, Hungary, Germany and

Austria. They observed reductions in the nutrient loads in the water of the Danube River; however, the river is still at risk of degradation due to organic pollution. Other studies calculated the Water Quality Index (WQI), which integrates different physicochemical parameters into the formula and synthetizes the data into a single number to highlight the ecological status of the water body in Chiciu, Romania [65] near Galați, Romania [66], between the sector of Brăila and Tulcea within Romania [67]. All authors highlighted in their studies a general good water quality status in the Danube River. Frîncu (2021) developed a complex methodology for assessing the water quality of the Lower Danube [68] using the WQI and Principal Component Analysis (PCA) between the years 1996 of 2017. In their study, Krtolica et al. (2021) predicted the Danube water quality by using macrophyte binary data through neural network modeling [69]. However, none of the mentioned studies approached the interlinked impact involving the water quality and fish stocks status within the Danube-Danube Delta-Black Sea macrosystem.

1.4. Deep Learning Approach in Aquatic Ecosystems

Traditional methods for synthetically evaluating the water quality of aquatic ecosystems have been replaced by new modeling approaches, multivariate statistical techniques, artificial neural networks, artificial intelligence, ARIMA, SARIMA or ETS models. For example, artificial neural network models were used to predict the dissolved oxygen and biochemical oxygen demand by other nutrients or basic physicochemical parameters such as explanatory variables [70,71], while others aimed to explore the relationship between nutrients and biological quality elements [72].

The water quality variables are changing continuously through time. This dynamic process containing random error components with stochastic variations in space and time is difficult to model or explain with normal analytical procedures. Still, the analysis of time series datasets containing water quality parameters using ARIMA-type models provided relevant results [73]. Long-term trends in water quality can reveal information about chemical, biological and physical changes and variations due to manmade and seasonal interventions. For example, in [74], the authors developed an ARIMA model to forecast several water quality variables like the pH, color (TCU), turbidity (ppm), Al^{3+} (ppm), Fe^{2+} (ppm), NH^{4+} (ppm) and Mn^{2+} (ppm) through the respective hydrological variables, namely rainfall and river discharge, for the Johor River in Malaysia. In [75], it is also emphasized that weather parameters such as humidity, wind speed, rainfall or air temperature are non-linear and complex phenomena involving mathematical simulation and proper modeling for correct forecasting. Aside from ARIMA, the authors also used Exponential Smoothing (ETS) models to forecast the exemplified parameters. The seasonal variation (seasonal autoregressive integrated moving average (SARIMA)) model was also used in different water-related studies. For example, in [76], the authors used a SARIMA model to forecast the water level of the Sungai Bedup River in Malaysia. Aside from water quality forecasting, the analysis of the relationship between some physicochemical parameters is also of great interest, as it could help to determine the concentrations of certain water parameters with the use of minimal equipment. This is important because developing countries lack the standard water analysis equipment—specifically, the adequately trained personnel—and many researchers are discouraged from executing water quality research [77]. A study of the specific scientific literature revealed a series of empirical research which had been performed to investigate the relationship between economic growth and environment quality [78,79]. Thus, in [77], by using multiple linear regression, the authors identified the mathematical relationship among several physicochemical parameters (e.g., turbidity, electrical conductivity (EC), pH, alkalinity, chloride ion (Cl^-), dissolved oxygen (DO) and total hardness) that could help to perform future determinations with the use of minimal equipment. Therefore, prediction models such as MLR can represent a suitable cost-effective method which can partially substitute the standard, routine laboratory analysis, offering accessible monitoring of aquatic environments. Another example can be found in [80], where monthly water quality datasets from 10 stations on the Tigris River within

Baghdad for the year 2016 were studied. The Water Quality Index (WQI) and a Water Quality Model (WQM) were calculated by using 11 important parameters (Al^{3+}, F^{1-}, $NO_2{}^{1-}$, $NO_3{}^{1-}$, NH_3, temperature, total alkalinity, turbidity, total hardness, Ca^{2+}, Cl^{1-}, Mg^{2+}, pH, electrical conductivity, $SO_4{}^{2-}$, TDS, Fe^{2+}, SiO_2, $PO_4{}^{3-}$, DO, BOD5, COD and Na^{1+}) and multiple linear regression analysis.

In [81], the authors elaborated on the widely applicable water economics models which incorporate economic and environmental components, identifying the response of the agricultural production sector to climate change as part of the BE. Other studies [82] developed water models widely applicable in the BE by considering all major water use sectors.

1.5. Aim and Uniqueness of This Study

The current study aims to use the autoregressive integrated moving average (ARIMA), seasonal autoregressive integrated moving average (SARIMA), error, trend and seasonality (ETS) and multiple linear regression (MLR) models to develop an analytical framework which aims to strengthen the resilience and adaptive capacity of a BE within the context of climate change in the Romanian Lower Danube Euroregion (RLDE). If the ARIMA, SARIMA and ETS methods are used for time series forecasting, the multiple linear regression technique should be the preferred choice if the relation between the predictors and the dependent variable displays a linear pattern. Therefore, this study led to the development of several predictive forecasting models that are suitably used for determining the following water-dependent variables: total nitrogen (TN), total phosphorus (TN), dissolved oxygen (DO), pH, water temperature (wt) and water level, based on a series of 26 indicators (independent variables). Additionally, the research targets to elaborate several fish species structure predictive models that can be used to assure a better aquatic environment resilience framework related to climate variation, guaranteeing BG within the RLDE.

The study's uniqueness is underlined first; no other similar research was conducted within the RLDE. Additionally, we offer a holistic approach to the Danube–Danube Delta–Black Sea macrosystem, since we consider the water quality parameters, water level variation and fish species interactions. The targeted framework of this research is meant to be used for monitoring the water quality, water level and fish stock status but also for identifying methods of controlling the ecological balance of fish species. The specificity of the research area was considered while designing the experimental data collection, revealing an original approach in the aquatic macrosystem-developed methodology for monitoring, evaluation and control.

2. Materials and Methods

2.1. Study Area

The present paper studies water level, water quality and fish catch data from the RLDE. The Brăila, Galați, Tulcea and Sulina hydrometric stations (Figure 1) were considered for characterizing the RLDE in terms of water level, water temperature and air temperature, since these are considered key monitoring points due to high anthropogenic pressure from heavy industry, agriculture, aquaculture and navigation activities. Additionally, the highest air temperatures in Romania are attributed to this region, with a record of an absolute maximum air temperature of 44.5 °C recorded in Brăila county. The desertification process within this region is the most intense [83] in Romania and could lead to unfavorable conditions for assuring BG.

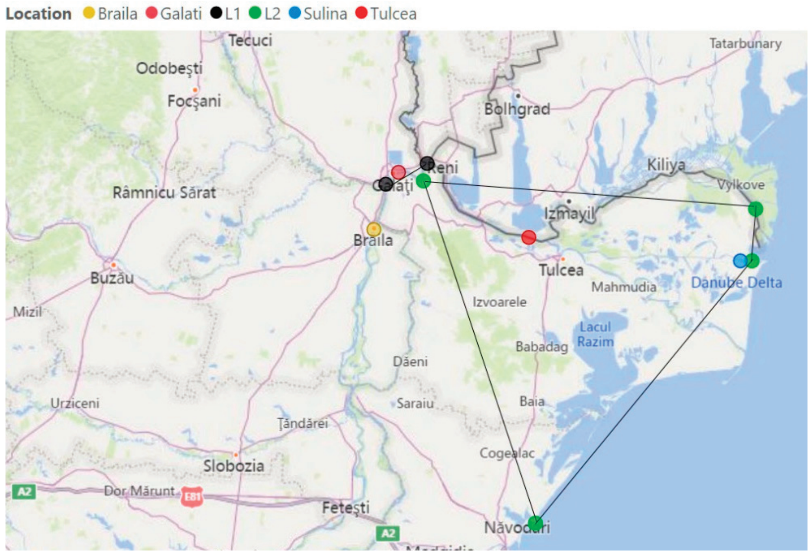


Figure 1. The RLDE sampling areas from which data were collected for developing the present study's analytical framework.

The Danube water quality data was collected from the Galați and Tulcea sampling points, since Galați and Tulcea have the most intense naval industry and port activity, therefore being exposed to water pollution.

Data relating to fish catches were recorded from the Galati county Danube River Basin segment (L1) and from the "Danube Delta" Biosphere Reserve Administration territory (L2) (Figure 1). The data on fish catches are monitored within these two sectors because of administrative division of the RLDE territory.

2.2. Dataset Description

The present research is based on a dataset which is divided in two groups, specifically 26 physicochemical parameters (Table 1) and 27 fish catch parameters (Table 2). The first group (Table 1) consisted of 7668 samples, of which 2340 belonged to Tulcea county, 2448 belonged to Galați county and 1440 belonged to both Brăila and Sulina. Data surrounding the Danube River water level, water temperature and air temperature parameters, presented in Table 1, were collected daily between 2017 and 2020. Furthermore, the rest of the data related to Danube water quality (presented in Table 1) was collected monthly from Galați county between 2017 and 2020 and once every 2 months from Tulcea county between 2015 and 2020. The dataset's standard method of determination is presented for each of the first group's parameters in Table 1.

The second group (Table 2) consisted of 340 samples, of which 90 were for L1 and 250 were for L2. All reported catches associated with the main RLDE fish species were considered.

Table 1. Dataset of physicochemical parameters.

Parameter	Measurement Unit	Standard Method of Determination	Sampling Area
Water level (wt)	(cm)	SOP 2043	Brăila, Galați, Tulcea, Sulina
Water temperature (wt)	(°C)	Sensor's methods	Galați, Tulcea
Air temperature (aw)	(°C)	Sensor's method	Galați, Tulcea
Total suspended solids (TSS)	(mg/L)	SE EN 875:2005	Galați, Tulcea
Turbidity (tb)	(NTU)	SR EN ISO 7027:2001	Galați
Dissolved oxygen (DO)	(mg/L)	SR EN ISO 5814:2013	Galați, Tulcea
Dissolved oxygen saturation (DO sat.)	(%)	-	Galați, Tulcea
Biochemical oxygen demand (BOD5)	(mg/L)	SR EN 1899:2:2002	Galați, Tulcea
Chemical oxygen demand (COD)	(mg/L)	SR EN 1484:2001	Galați
Total organic carbon (TOC)	(mg/L)	SR EN 1484:2001	Galați
Electrical conductivity (EC)	(µS/cm)	SE EN 27888:1997	Galați, Tulcea
Fixed solids (FS)	(mg/L)	STAS 9187:1984	Galați, Tulcea
Calcium (Ca)	(mg/L)	SE ISO 6058:2008	Galați, Tulcea
Magnesium (Mg)	(mg/L)	SE ISO 6059:2008	Galați, Tulcea
Total hardness (TH)	(°G)	SR ISO 6059:2008	Galați
Chloride (Cl)	(mg/L)	SE ISO 9297:2001	Galați, Tulcea
Sulfate (SO_4)	(mg/L)	EPA 9038:1986	Galați, Tulcea
pH	(upH)	SR ISO 10523:2012	Galați, Tulcea
Alkalinity (Alk)	(mmol/L)	SR ISO 9963-1/A99:2002	Galați, Tulcea
Bicarbonates (Bi)	(mg/L)	SR ISO 9963-1/A99:2002	Galați, Tulcea
Ammonium-nitrogen ($N\text{-}NH_4$)	(mg/L)	SR ISO 7150-1:2001	Galați, Tulcea
Nitrite-nitrogen ($N\text{-}NO_2$)	(mg/L)	SR ISO 26777/C91:2006	Galați, Tulcea
Nitrate-nitrogen ($N\text{-}NO_3$)	(mg/L)	SR ISO 7890-3:2000	Galați, Tulcea
Total nitrogen (TN)	(mg/L)	SR EN 12260:2004	Galați, Tulcea
Orthophosphate as phosphorus ($P\text{-}PO_4$)	(mg/L)	SR EN ISO6878:2005	Galați, Tulcea
Total phosphorus (TP)	(mg/L)	SR EN ISO 6878:2005	Galați, Tulcea

Table 2. Dataset of fish catches.

Fish Species	Abbreviation	Study Area
Abramis brama danubii (freshwater bream)	Fbr	L1, L2
Alburnus alburnus (common bleak)	Cbl	L1
Alosa caspia (Caspian shad)	Csh	L2
Alosa immaculata (Pontic shad)	Psh	L1, L2
Aspius aspius (asp)	Asp	L1, L2
Barbus barbus (common barbel)	Cbb	L1, L2
Blicca bjoerkna (white bream)	Wbr	L1, L2
Carassius gibelio (Prusian carp)	Pcp	L1, L2
Other cyprinids	Ocp	L1, L2
Cyprinus carpio carpio (common carp)	Ccp	L1, L2

Table 2. *Cont.*

Fish Species	Abbreviation	Study Area
Esox lucius (pike)	Pk	L1, L2
Liza aurata (golden grey mullet)	Ggm	L2
Mullus barbatus ponticus (red mullet)	Rmt	L2
Neogobius kessleri (bighead goby)	Bgb	L2
Pelecus cultratus (sabre carp)	Scp	L2
Perca fluviatilis fluviatilis (perch)	Prc	L2
Psetta maxima maeotica (turbot)	Tbt	L2
Raja clavata (thornback ray)	Tr	L2
Rutilus rutilus carpathorosicus (roach)	Rch	L1, L2
Sander lucioperca (pikeperch)	PkPrc	L1, L2
Scardinius erytrophthalmus (common rudd)	Crd	L1, L2
Silurus glanis(catfish)	Ctf	L1, L2
Sprattus sprattus (European sprat)	Esp	L2
Tinca tinca (tench)	Tnch	L2
Trachurus ponticus (horse mackerel)	Hmk	L2
Vimba vimba carinata (vimba)	Vmb	L1, L2

2.3. The Analytical Framework Forecasting and Prediction Methodology

2.3.1. Multiple Linear Regression (MLR) Method

The linear approach used in this research was performed by identifying and testing multiple linear regression models (Equation (1)) by using the stepwise selection methods (with the inclusion criteria set at $p < 0.05$) for choosing the most relevant predictors:

$$Y = \alpha_1 \times X_1 + \alpha_2 \times X_2 + \ldots + \alpha_p \times X_p + \beta + e \quad (1)$$

where X_1, $X_2 \ldots X_p$ are the predictor variables; β is the intercept; α_1, $\alpha_2 \ldots \alpha_p$ are the independent variable coefficients describing the contribution of each predictor in determining the dependent variable; e is the residual term indicating the difference between the actual and the fitted response value; and Y is the dependent variable.

The overfitting situation was avoided by using dimensionality reduction and cross-validation. When the number of features was high, choosing the optimal features could improve the model reliability; therefore, all MLR models considered the stepwise regression method to reduce the model complexity, leading to an easier interpretation. For the validation of the MLR models, we used the adjusted R-sq statistical indicator that penalized the model when there were many parameters that were not contributing to explaining the variance of the dependent variable.

The multiple linear regressions presented in the current research also took into consideration the Variance Inflation Factor (VIF), which measured the effect of multicollinearity among the predictors. The VIF measures how much the variance of an estimated regression coefficient increases if the predictors are correlated. The reference VIF value was 10, but the developed models presented VIF values far less than 10.

The multiple linear models were validated using previously unseen data, comparing the real values with the predicted ones. The overall dataset was split in two: a training dataset and a test dataset. The training dataset contained 80% of the data, while the remaining 20% of the data contained previously unseen samples.

2.3.2. Time Series Analysis

For validating the future trends of the interest parameters, the current research implemented three types of time series analysis: (1) error, trend and seasonality (ETS) exponential smoothing, (2) ARIMA and (3) SARIMA.

The exponential smoothing method, described in [84] and [85], represents a successful forecasting method based on weighted averages of past observations, with the weights being exponentially reduced as the observations get older (Equation (2)):

$$\hat{y}_{T+h|T} = y_T \ , \ h = 1, 2, \ldots, n \tag{2}$$

According to this method, the most recent observation is the important one. Thus, all future forecasts should be equal to an average of the observed data (Equation (3)):

$$\hat{y}_{T+h|T} = \frac{1}{T}\sum_{t=1}^{T} y_t \qquad h = 1, 2 \ldots, n \tag{3}$$

This time series model can be transformed by considering larger weights for more recent observations, with the forecasts being calculated by using weighted averages and the weights decreasing exponentially as the observations come from further in the past (Equation (4)):

$$\hat{y}_{T+h|T} = \alpha y_T + \alpha(1-\alpha)y_{T-1} + \alpha(1-\alpha^2)y_{T-2} + \ldots \tag{4}$$

where $0 \leq \alpha \leq 1$ is the smoothing parameter. As an example, the forecast for time T + 1 represents a weighted average of the observations in the series *y1* ... *yT*, with the parameter α controlling the rate at which the weights decrease.

The Holt [86] exponential time series model allows the forecasting of data presenting a trend by using both a forecast equation and smoothing equations (Equations (5)–(7)):

$$\textit{Forecast equation}: \ \hat{y}_{t+h|t} = l_t + hb_t \tag{5}$$

$$\textit{Trend equation}: \ b_t = \beta^*(l_t - l_{t-1}) + (1-\beta^*)b_{t-1} \tag{6}$$

$$\textit{evel equation}: \ l_t = \alpha y_t + (1-\alpha)(l_{t-1} + b_{t-1}) \tag{7}$$

where ℓt is the estimate of the level of the series at time t, bt is the estimate of the trend (slope) of the series at time t, α is the smoothing parameter for the level, $0 \leq \alpha \leq 1$, β^* is the smoothing parameter for the trend, and $0 \leq \beta^* \leq 1$.

The ARIMA forecasting model is constructed as follows, with y denoting the *dth* difference of Y (Equations (8)–(11)):

$$d = 0 \ \rightarrow \ y_t = Y_t \tag{8}$$

$$d = 1 \ \rightarrow \ y_t = Y_t - Y_{t-1} \tag{9}$$

$$d = 2 \ \rightarrow \ y_t = (Y_t - Y_{t-1}) - (Y_{t-1} - Y_{t-2}) \tag{10}$$

$$d = 2 \ \rightarrow \ y_t = (Y_t - Y_{t-1}) - (Y_{t-1} - Y_{t-2}) \tag{11}$$

The moving average parameters (θs) were considered with a negative sign in the equation, according to the convention introduced by Box and Jenkins. To determine the optimal values for the p, d and q hyperparameters, the order of differencing (d value, the minimum differencing required to get a near-stationary series) was determined by using the autocorrelation function (ACF). For testing the stationarity of the time series, the augmented Dickey–Fuller test was used. For determining the p value (if the model needed any AR terms), the partial autocorrelation (PACF) plot was used. Lastly, the q value—the order of the MA term—was also determined by using an ACF plot, in which the number of lags above the significance line determined the q value. An extension of the ARIMA model that was used in the current research is SARIMA, a model that is used when there is the phenomenon of seasonality at the level of the variable for which the forecast is desired. The acronym SARIMA comes from Seasonal Autoregressive Integrated Moving Average and is a method of predicting univariate time series that contain trends and seasonality. The seasonal part of the model refers to terms that are very similar to the non-seasonal components of the model but involve changes in the seasonal period. SARIMA models consist of two parts: a trend component containing three elements (autoregressive trend, trend integration and moving order trend) and a seasonal component containing four elements (autoregressive seasonality, seasonal difference order, moving average order of seasonality and the number of steps of a single seasonal period). A seasonal ARIMA model uses differentiation at a lag equal to the number of periods to eliminate seasonal effects, just as gap differentiation eliminates the trend and that of forecast delays introduces a moving term [87]. Thus, a seasonal ARIMA model will be written in the following form (Equation (12)):

$$SARIMA(p, d, q)(P, D, Q)_m \tag{12}$$

where p represents the autoregressive order of the trend, d represents the integration order at which the trend was stationary, q is the moving average order of the trend, P is the autoregressive order of seasonality, D is the order of integrating seasonality, Q is the order of the moving average of the seasonality, and m is the number of periods in which the seasonality is observed.

For example, an ARIMA model (1,1,1) (1,1,1) $_m$ can be written as follows (Equation (13)):

$$(1 - \phi_1 B)(1 - \Phi_1 B^m)(1 - B)(1 - B^m)y_t = (1 + \theta_1 B)(1 + \Theta_1 B^m)\varepsilon_t \tag{13}$$

3. Results and Discussion

3.1. Water Level Forecast Analysis

The water level is an important indicator of the impact of climate change on water ecosystems. According to other studies [88], an average increase in temperature by 0.74 °C has been recorded in the previous 100 years. The fluctuation of sea water temperature may affect water quality parameters and therefore the biodiversity of aquatic ecosystems. Water level fluctuations affect not only the marine living resources sector but also other sectors of a BE, such as maritime transport, port activities and coastal tourism. Therefore, an analytical framework based on water level time series analysis proves to be useful to improving BG's resilience to climate change. The RLDE peculiarity is represented by the presence of the Danube River–Danube Delta–Black Sea macrosystem. Thus, data from four sampling points, placed in different sectors of this macrosystem, were collected, as presented in Figure 1. The analysis of forecast models requires the time series to be stationary. Therefore, the augmented Dickey–Fuller (ADF) test was applied. To achieve this, two scenarios will be formulated: the first scenario considers the series as stationary, and the second scenario considers the series as non-stationary. The results of the ADF test indicate the following values: −2.859 for Brăila, −3.622 for Galați, −3.14 for Tulcea and −3.630 for Sulina. All values were under the ADF critical value (−2.863), and therefore, all four data series were stationary. For the time series afferent to the Brăila, Galați and Tulcea sampling points, a second-order autoregressive type model (AR 2) was considered, since the correlograms emphasized that at time t = 2, the partial autocorrelation coefficient (PAC) manifested a sudden decrease. The statistical analysis of the proposed autoregressive models revealed that homoscedasticity was not fulfilled in any of the models, a fact which concludes that the errors did not have a constant dispersion. If this situation was ignored, the estimators of the model parameters would not be efficient and would not have a maximum likelihood. To eliminate this phenomenon, the models were transformed into Autoregressive Conditional Heteroscedasticity (ARCH) models that aimed to include the repetitive manifestations of the occurrence of forecast errors in several time sequences. Therefore, at the Brăila sampling point, the following forecast model for the Danube River water level was elaborated (Equation (14)). The model emphasized that if the water level increased by 1 m the day before, the current level was bound to increase by 1.857 m. Moreover, if it is 2 days before the water level increases by 1 m, then the current level will decrease by 0.861 m. All estimator parameters are significant, and the model is plausible (R-squared coefficient of determination is 99.90%) and can be used in the forecast:

$$waterlevel_t = 0.716 + 1.857 \times waterlevel_{t-1} - 0.861 \times waterlevel_{t-2} \quad (14)$$

The forecast model elaborated based on the water level dataset for the Danube River sampling point in Galați (Equation (15)) revealed that if the water level increased 1 m the day before, the current level would increase by 1.820 m. Additionally, if the water level increased by 1 m 2 days before, then the current level would decrease by 0.823 m. All estimator parameters were significant, and the model was plausible (R-squared coefficient of determination was 99.90%) and could be used in the forecast. Both models (Equations (14) and (15)) were similar, which could be explained by the low geographical distance between the sampling points of both Brăila and Galați:

$$waterlevel_t = 0.769 + 1.820 \times waterlevel_{t-1} - 0.823 \times waterlevel_{t-2} \quad (15)$$

The forecast model for the water level of the Danube River at the Tulcea sampling point (Equation (16)) revealed that water level depended on the moments of both one and two antecedent days such that a 1-m increase in the water level the day before would generate a present-day level increase of 1.735 m. At the same time, if the water level increased by 1 m 2 days before, then the current level would decrease by 0.738 m. All estimator parameters were significant, and the model is plausible and can be used in the forecast:

$$waterlevel_t = 0.384 + 1.735 \times waterlevel_{t-1} - 0.738 \times waterlevel_{t-2} \quad (16)$$

To generate the Danube River water level forecast model for the Sulina sampling point, the data series must be stabilized, since it has an oscillating evolution. Therefore, the data series was placed into a logarithm previously. The model also started with a third-order autoregressive model. Considering that the errors were heteroscedastic, the model was transformed into an ARCH type. The Sulina forecast model (Equation (17)) revealed that the current water level of the Danube River depended on moments 1 day, 2 days and 3 days prior such that if a 1-m increase was registered the day before, the current level would decrease by 0.100 m. At the same time, if the water level would increase by 1 m 2 days before, then the current level would decrease by 0.188 m. An increase by 1 m 3 days before would lead to a decrease by 0.116 m for the current level. All estimator parameters were significant, although the model was not plausible:

$$dlwaterlevel_t = -0.100 \times dlwaterlevel_{t-1} - 0.188 \times dlwaterlevel_{t-2} - 0.116 \times dlwaterlevel_{t-3} \quad (17)$$

All four time series models (Equations (14)–(17)) can be used to forecast the water level of the Danube River in Brăila, Galați, Tulcea and Sulina. This can be useful in elaborating RLDE BG management plans, thereby targeting the optimization of all BE activities and assuring a positive synergy between all blue sectors.

3.2. Physicochemical Parameter Trend Lines

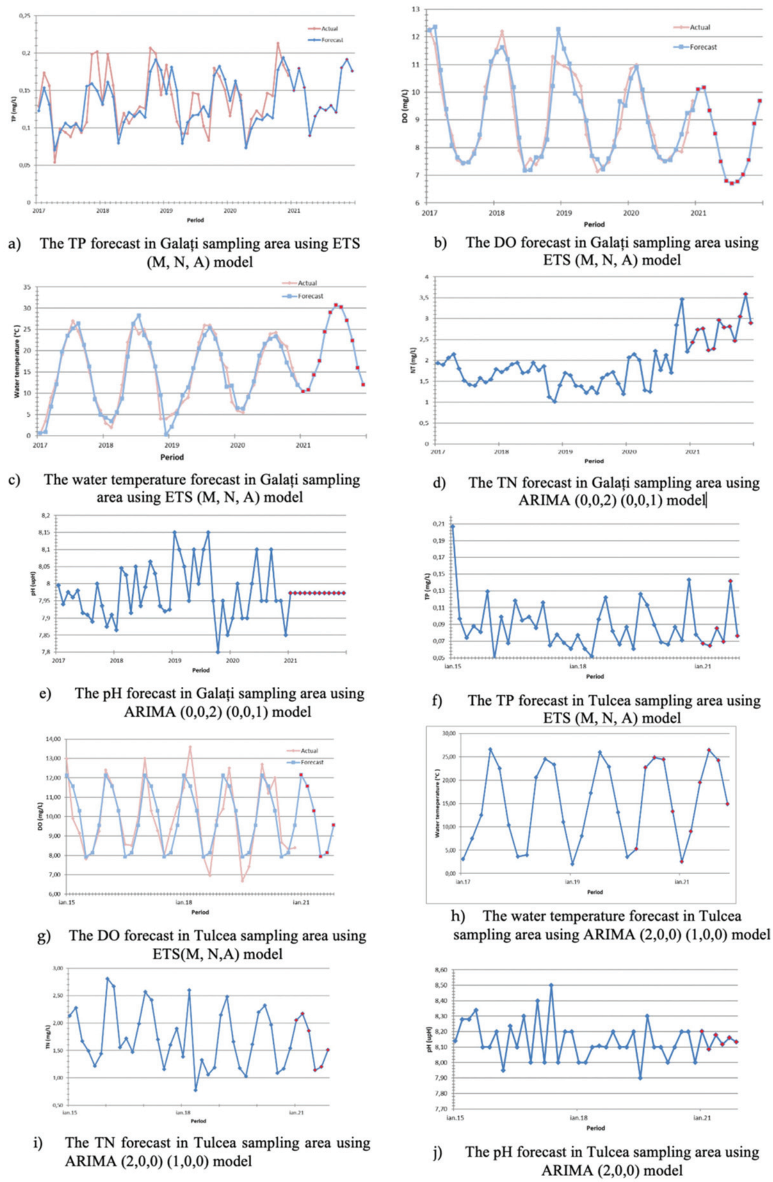
The physicochemical parameters were monitored monthly during a 4-year period in Galați county and once every 2 months during a 6-year period at the Tulcea county sampling point, as presented in Figure 1. The registered results were analyzed to determine the trend lines and used to establish multi-linear regression (MLR) models and forecast analysis. Therefore, in the case of the Galați county sampling point, the recorded data for the air temperature was divided into two groups: maximum air temperature and minimum air temperature. The trend lines of both groups revealed a clear upward dynamic (Figures A1 and A2) from 2017 until 2020. Thus, the data revealed that the maximum air temperature increased by 7.06% during the hot season and by 23.28% during the cold season within the analyzed period. Additionally, the minimum air temperature recorded a higher increase, being 8.11% during the hot season and 109.5% during the cold season. The upward trend line in the air temperature caused the increase in the water temperature, something also revealed in the Danube River Galați sampling point (Figure A3). Thus, in the hot season, the water temperature registered a 0.79% increase, while in the cold season, a 30.95% increase was recorded during the analyzed period. Additionally, the water DO and DO saturation presented a decreasing trend line (Figures A4 and A5), a situation which was correlated with the upward trend lines associated with the air and water temperatures (Figures A1–A3). Other authors revealed that an increase in the surface temperature leads to an outgassing of oxygen from the ocean and a reduction in the surface water oxygen concentration [89]. The pH trend line (Figure A6) registered a decreasing trend line of 0.27% during the analyzed period, thus confirming the findings reported by other authors [90] related to an inverse pH response to temperature variations. The pH dynamics were sustained by both the water alkalinity and bicarbonate concentration trend lines, which revealed a decreasing trend (Figures A7 and A8). The nitrite-nitrogen, ammonium-nitrogen and total nitrogen registered an upward trend (Figures A10–A12), while nitrate registered a decrease (Figure A9). However, there are studies which predicted an increase in the nitrate concertation as well as an increase in the rate of mineralization linked to the increase in temperature [91]. This scenario was confirmed by the significant upward trend lines registered for TP, Mg and Ca (Figures A13–A15). However, the turbidity and TSS (Figures A16 and A17) trend lines revealed a decreasing tendency, while the TOC trend line presented a small increase (Figure A18). In addition, the BOD5 and fixed solids trend lines indicated a relatively stable dynamic for these parameters (Figures A19 and A20). This may have been due to the high water flow of Danube River and, therefore, its capacity to transport solids and organic matter, revealing the river's auto-epuration capacity. At the Tulcea county sampling point, the trend lines for both the maximum and minimum air temperature revealed a clear upward dynamic (Figures A21 and A22) from 2017 to 2020. Thus, the data revealed that the maximum air temperature increased by 9.27% during the hot season and by 19.07% during the cold season in the analyzed period. Additionally, the minimum air temperature recorded a higher increase, being 7.45% during the hot season and 44.65% during the cold season. Therefore, the Galati sampling point was exposed to a more aggressive climate change impact when considering the air temperature trend lines (Figures A1, A2, A21 and A22). In addition, the water temperature revealed an upward trend line (Figure A23) with a 30.11% increase during the cold season, while the DO presented a decreasing trend line (Figure A24). The pH trend line (Figure A25) revealed a decreasing trend line, being 1.30% during the analyzed period. This can be due to sediments and therefore organic matter deposits, which accumulate more in Tulcea compared with the Galați sampling area due to the geographic position of this sampling point (i.e., closer to Danube Delta). Both the water alkalinity and bicarbonate concentration trend lines revealed a decreasing trend (Figures A26 and A27) of 12.29% and 12.33%, respectively, during the analyzed period.

The total water nitrogen and nitrate-nitrogen at the Tulcea sampling point revealed a decreasing trend line, whereas the nitrite-nitrogen recorded a relatively constant trend (Figures A28, A29 and A31), and the ammonium-nitrogen (Figure A30) registered the only upward trend among the nitrogen compounds analyzed in present study. This could indicate a relatively better ecological status in the Tulcea sampling area, mostly due to lower climate change impact revealed by the air temperature trend line compared with the Galați sampling point. This can be confirmed by the decreasing trend lines registered for TP and Ca (Figures A32 and A34) and the small increasing trend of Mg compared with the Galați sampling station. The TSS and BOD5 revealed upward trend lines (Figures A35 and A36), the evolution of which supports the scenarios of a superior solids accumulation rate in Tulcea compared with the Galați sampling point.

3.3. Physicochemical Parameter Forecast Analysis

To perform the forecast analysis for both the Galați and Tulcea sampling points, five physicochemical parameters were analyzed: the TN, TP, water temperature, pH and dissolved oxygen concentration. The parameters were considered as the most suggestive to characterize the analyzed area status in relation to climate change, a fact confirmed by their trend line evolutions (Figures A3, A4, A12, A13, A24, A25, A31 and A32). Therefore, the TP forecast in the Galați sampling area was performed by applying the ETS (M, N, A) model (Figure 2a), which was selected by considering the Akaike coefficient. EST Smoothing is a multiplicative error model without trends and with additive seasonality. The model keeps its oscillating trend for the forecasted period, obtaining values close to those that were used in determining the model (Figure 2a). The forecasted average concentration of the TP in water for the year 2021 was 2.41% higher compared with the 2020 average and 6.47% higher than the 2017–2020 period's average. For the DO forecast, an ETS (M, N, M) multiplicative errors model (Figure 2b) was selected without trends and with multiplicative seasonality. The model (Figure 2b) revealed that the dynamics of DO would register the same oscillation for the forecasted period, but with a slightly significant decrease compared with the current values for July and August. The forecasted average concentration of the DO in water for 2021 was 6.56% lower compared with the 2020 average and 9.78 % lower than the 2017–2020 period's average. For the water temperature forecast, an ETS (A, N, A) additive model without trends and with additive seasonality was applied (Figure 2c). The time series maintained its oscillating trend during the year due to the seasons that demanded seasonality on the series. For the summer months, higher forecasted values were obtained compared with the actual values (Figure 2c), emphasizing the future global warming effect on the water DO at the Galați sampling point. The forecasted average value of the water temperature for 2021 was 28.71% higher compared with the year 2020 average and 37.92% higher than the 2017–2020 period's average. The TN and pH forecast analysis were performed by using a Seasonal Autoregressive Integrated Moving Average (SARIMA) model (Figure 2d,e), since the seasonality characteristic of the forecasted variable existed. SARIMA is considered a method of predicting univariate time series that contain trends and seasonality. The forecasted average value of pH in the water for 2021 was 0.12% higher compared with the average pertaining to the year 2020 and 0.007% lower than the 2017–2020 time period's average. Additionally, the forecasted average concentration of the TN in the water for the year 2021 was 30.72% higher compared with the 2020 average and 57.99% higher than the 2017–2020 time period's average. The TP forecast in the Tulcea sampling area was performed by applying the ARIMA seasonal model (1,0,1) (0,0,1) (Figure 2f). This model considers the first gap as well as the first delay of the trend side. The estimated series continued its oscillating evolution, having actual values like the previous ones. The forecasted average concentration of the TP in the water for 2021 was 0.09% higher compared with the 2020 average and 0.03% higher than the 2017–2020 time period's average.

For the DO forecast, an ETS (M, N, A) multiplicative error model (Figure 2f) without trends and with additive seasonality was selected. Noticeably (Figure 2g), the predicted values had the same tendency as those used for training. The series would keep its oscillating trend for the next period. The average concentration of the DO in the water forecasted for 2021 was 2.70% lower than that for the 2020 average and 0.01% lower than the 2017–2020 time period's average. For the water temperature forecast (Figure 2h), an ARIMA (2,0,0) (1,0,0) seasonal model was applied. The forecasted average value of the water temperature for the year 2021 was 2.62% higher compared with the 2020 average and 9.39% higher than the 2017–2020 time period's average. The TN forecast analysis was performed by using an ARIMA seasonal model (2,0,0) (1,0,0) (Figure 2i) which was autoregressive for both the trend and the season. The estimated data revealed that the variable would keep its oscillations given by the seasons. Furthermore, the forecasted average concentration of the TN in the water for 2021 was 3.44% lower compared with the 2020 average and 4.68% lower than the 2017–2020 time period's average. The pH forecast analysis was performed by using a second-order autoregressive model; thus, the current value of the water pH depended on two previous moments (lags). From the analysis of the forecasted data (Figure 2j), very small oscillations could be observed for the next period. The forecasted average value of the pH in the water for 2021 was 0.57% higher compared with the 2020 average and 0.04% higher than the 2017–2020 time period's average.



a) The TP forecast in Galați sampling area using ETS (M, N, A) model

b) The DO forecast in Galați sampling area using ETS (M, N, A) model

c) The water temperature forecast in Galați sampling area using ETS (M, N, A) model

d) The TN forecast in Galați sampling area using ARIMA (0,0,2) (0,0,1) model

e) The pH forecast in Galați sampling area using ARIMA (0,0,2) (0,0,1) model

f) The TP forecast in Tulcea sampling area using ETS (M, N, A) model

g) The DO forecast in Tulcea sampling area using ETS(M, N,A) model

h) The water temperature forecast in Tulcea sampling area using ARIMA (2,0,0) (1,0,0) model

i) The TN forecast in Tulcea sampling area using ARIMA (2,0,0) (1,0,0) model

j) The pH forecast in Tulcea sampling area using ARIMA (2,0,0) model

Figure 2. The physicochemical parameter forecast analysis of both the Galați and Tulcea sampling points.

3.4. Physicochemical Parameter Multiple Linear Regression (MLR) Models

Ten MLR models were identified after processing the physicochemical parameter dataset. Therefore, for each of the sampling areas (Tulcea and Galați), five MLR models for determining the $P\text{-}PO_4$, $N\text{-}NO_3$, $N\text{-}NO_2$, $N\text{-}NH_4$ and SO_4 dependent variables were elaborated (Table 3). All variables used within the models had p-values < 0.05.

Table 3. Physicochemical parameters of the Multiple Linear Regression (MLR) models recorded for the Galați and Tulcea study sectors.

Sampling Point	MLR Prediction Model	Model No.
Galati	$P\text{-}PO_4 = -2.918 - 0.276\ SO_4 + 1.162$ Bicarbonates $+ 0.457\ N\text{-}NO_3 + 0.8701$ TP $+ 0.095$ water level	M1
	$N\text{-}NO_3 = -3.818 + 0.514$ EC $+ 1.051$ Mg $+ 0.401\ SO_4 - 0.166\ N\text{-}NO_2 + 1.047$ NT	M2
	$N\text{-}NO_2 = -5.285 - 0.378$ DO $+ 1.618$ Mg $+ 0.497\ SO_4 - 0.775\ N\text{-}NO_3 + 1.277$ NT $+ 0.313$ water level	M3
	$N\text{-}NH_4 = -6.077 + 0.557$ TSS $+ 0.667$ Mg $+ 0.772$ Chloride $+ 1.004$ Bicarbonates	M4
	$SO_4 = 3.523 + 0.701$ COD $- 0.987$ Ca $- 0.614$ Mg $+ 0.588\ N\text{-}NO_3 - 0.386$ NT	M5
Tulcea	$P\text{-}PO_4 = 3.010 + 3.344$ DO $- 0.671$ BOD5 $+ 0.275\ N\text{-}NH_4 + 0.605\ N\text{-}NO_2 - 0.776\ N\text{-}NO_3 + 0.472$ TP $-$ 0.402 TSS $- 0.426$ FS $+ 0.819$ Mg $- 1.975$ TH $- 1.254$ Cl $- 0.860\ SO_4$	M6
	$N\text{-}NO_3 = -0.178 + 0.940$ TN	M7
	$N\text{-}NO_2 = 1.340 - 6.920$ pH $+ 0.992$ EC $- 2.787$ DO $- 0.240$ COD $+ 0.5887$ BOD5 $- 0.237\ N\text{-}NH_4 + 0.650$ $N\text{-}NO_3 + 0.227\ P\text{-}PO_4 + 0.2435$ TSS $+ 0.3081$ FS $- 0.694$ Mg $+ 1.391$ TH $+ 0.648$ Chloride $+ 0.669\ SO_4$	M8
	$N\text{-}NH_4 = 2.080 - 17.370$ pH $+ 4.430$ EC $- 7.310$ DO $- 0.780$ COD $+ 1.492$ BOD5 $- 1.785\ N\text{-}NO_2 + 1.520$ $N\text{-}NO_3 + 0.541\ P\text{-}PO_4 + 0.548$ TSS $+ 0.906$ FS $- 1.658$ Mg $+ 3.168$ TH $+ 1.608\ SO_4$	M9
	$SO_4 = -1.430 + 4.690$ pH $+ 2.667$ DO $- 0.511$ BOD5 $+ 0.213\ N\text{-}NH_4 + 0.643\ N\text{-}NO_2 - 0.644$ N-NO3 $-$ $0.318\ P\text{-}PO_4 - 0.275$ TSS $- 0.324$ FS $+ 0.723$ Mg $- 1.389$ TH $- 0.891$ Cl	M10

The first MLR model (M1) (Table 3) determined the concentration of $P\text{-}PO_4$ in the Danube River's water at the Galați sampling area based on the bicarbonates, water level, TP, SO_4 and $N\text{-}NO_3$ recorded values. The model explained 81.40% of the variance of $P\text{-}PO_4$ in the water. Additionally, the value of the predicted R-sq was close to the R-sq value, indicating good model performance. Additionally, the S-value was low, indicating that the model achieved the best degree of precision. The coded coefficients permitted us to identify the variable with the largest impact on the model response. Thus, for M1, the bicarbonate value had the strongest influence on the resulting concentration of $P\text{-}PO_4$ in the water, followed by TP and $N\text{-}NO_3$. The second MLR model (M2) determined the concentration of $N\text{-}NO_3$ in the Danube River's water at the Galați sampling area based on the EC, Mg, SO_4, $N\text{-}NO_2$ and NT recorded values (Table 3). The model explained 85.79% of the variance of N-NO3 in the water. The model had good performance, and the S-value was low, indicating the best performance and degree of precision. Therefore, for M2, the values of Mg and NT had the strongest influence on the resulting concentration of $N\text{-}NO_3$ in the water, followed by EC and SO_4. The third model (M3) determined the concentration of $N\text{-}NO_2$ in the Danube River's water at the Galați sampling area based on the DO, Mg, SO_4, NT, water level and $N\text{-}NO_3$ concentrations (Table 3). The model explained 73.25% of the variance of $N\text{-}NO_2$ in the water. The model indicated good performance (the predicted R-sq value was close to R-sq), a situation also revealed by the low S-value, which indicated a high degree of precision. By analyzing the coded coefficients of the third model, it can be stated that the values of Mg, NT and $N\text{-}NO_3$ had the strongest influence on the resulting concentration of $N\text{-}NO_2$ in the Danube River's water at the Galați sampling area. The fourth model (M4) determined the concentration of $N\text{-}NH_4$ within the Danube River's water at the Galați sampling area based on the TSS, Mg, chloride and bicarbonate concentrations (Table 3). The model explained 69.52% of the variance of $N\text{-}NH_4$ in the water. The low S-value indicated a high degree of precision. By analyzing the coded coefficients of M4, it can be stated that the values of the bicarbonate and chloride concentrations had the most significant impact over the dependent variable. The fifth model (M5) determined the concentration of SO_4 in the Danube River's water at the Galați sampling area based on the concentrations of Ca, COD, Mg, N-NO_3 and NT (Table 3). The model explained 71.55% of the variance of SO_4 in the water. The model indicated good performance (the predicted R-sq value was close to R-sq), and the situation also revealed through a relatively low S-value that it had good precision. By analyzing the coded coefficients of the fifth model, it can be stated that Ca had the most significant impact over the dependent variable, followed by COD, Mg and N-NO_3. The sixth model (M6) determined the concentration of P-PO_4 within the Danube River's water at the Tulcea sampling area based on the DO, BOD5, N-NH_4, N-NO_2, N-NO_3, TP, TSS, FS, Mg, TH, chloride and SO_4 concentrations (Table 3). The model explained 61.80% of the variance of P-PO_4 in the water. The model indicated good performance (the predicted R-sq value was close to R-sq), and the situation also revealed through a low S-value that it had a high degree of precision. By analyzing the coded coefficients of the sixth model, it can be stated that the DO, TH, chloride, SO_4 and N-NO_3 had the most significant impact on the dependent variable. The seventh MLR model (M7) determined the concentration of N-NO_3 within the Danube River's water at the Tulcea sampling area based on the TN concentration (Table 3). The model explained 71.52% of the variance of N-NO_3 in the water. The model indicated very good performance (the predicted R-sq value was close to R-sq), and the situation also revealed through a low S-value that it had a considerably high degree of precision. The values of the coded coefficients presented for the seventh model indicated a significant impact from the TN variation over the dependent variable. The eighth MLR model (M8) determined the concentration of N-NO_2 within the Danube River's water at the Tulcea sampling area based on the pH, EC, DO, COD, BOD5, N-NH_4, N-NO_3, P-PO_4, TSS, FS, Mg, TH, chloride and SO_4 concentrations (Table 3). The model explained 81.83% of the variance of N-NO_2 in the water. When considering the predicted R-sq value, the R-sq and the S-value, it can be stated that M8 had a high degree of precision. The coded coefficients revealed that the pH, DO and TH had the most significant impact on the dependent variable.

The ninth model (M9) determined the concentration of N-NH_4 in the Danube River's water at the Tulcea sampling area based on the pH, EC, DO, COD, BOD5, N-NO_2, N-NO_3, P-PO_4, TSS, FS, Mg, TH and SO_4 concentrations (Table 3). The model explained 75.12% of the variance of N-NH_4 in the water. Additionally, the value of the predicted R-sq was close to the R-sq value, indicating good model performance. However, the S-value was high, indicating that the model did not achieve the best degree of precision. The coded coefficients permitted us to identify the variable with the largest impact on the model's response. By analyzing the coded coefficients of the ninth model, it can be stated that the values of the pH, DO, EC, TH, N-NO_3, N-NO_2, Mg and SO_4 concentrations had the most significant impact over the dependent variable. The last MLR model (M10) determined the concentration of SO_4 in the Danube River's water at the Tulcea sampling area based on the pH, DO, BOD5, N-NH_4, N-NO_2, N-NO_3, N-NH_4, TSS, FS, Mg, TH and chloride concentrations. The model explained 75.36% of the variance of SO_4 in the water. The model indicated good performance (the predicted R-sq value was close to the R-sq value), a situation also revealed by the low S-value that indicated a high degree of precision. By analyzing the coded coefficients of M10 (Table 3), it can be stated that the values of the pH, DO, TH and chloride concentrations had the strongest influence on the resulting concentration of SO_4 in the Danube River's water at the Tulcea sampling area.

Positive correlation (Pearson and Spearman coefficients) was highlighted in the study of Kovač et al. (2016) in an aquifer from Zagreb between the nitrate concentrations and the levels of DO due to the high nitrate mobility in aerobic conditions [92]. Furthermore, water EC values are associated with high nitrate concentrations due to low precipitation [93]. Other authors [94] conducted a study where they performed linear regression analysis between the EC values and nitrate concentrations in soil samples from Tsukuba, Japan, and they highlighted the positive correlation between the two variables.

It is well known that under the conditions of low DO values, the maximum conversion of ammonia to nitrite is achieved [95,96].

The positive correlation between ammonium and suspended solids has been previously elucidated in the estuary waters of the Gulf of Mexico [97].

The presence of PO_4 in water systems indirectly influences the concentration of DO by stimulating the rapid development of microalgae (through algal blooms) which consume the DO [98].

According to other authors [99], increased DO levels in water inhibit NO_2^- oxidation rates. Additionally, it has been pointed out that species of nitrite are stable at a pH of 7 and 10.6 (NO_2^-), while unstable species (HNO_2) are formed at lower pH values (2.5) [100]. Furthermore, pH is one of the key factors for controlling the NH_4^+ content in surface waters, and low pH values can increase the ammonium content [101].

3.5. Multiple Linear Regression (MLR) Models Based on the Fish Catch Dataset for the L1 and L2 Study Area

To develop an efficient toll for BE resilience, based on the evaluation of fish stocks from the L1 and L2 study regions, presented in Figure 1, MLR predicting methods were used based on the existing fish catch dataset. Therefore, 23 models were elaborated, with 13 of them having applicability in the L1 while the other 10 in were in the L2 study region (Table 4).

Table 4. Multiple Linear Regression (MLR) models based on the fish catch dataset for the L1 and L2 study areas.

Study Area	MLR Prediction Model	Model No.
L1	Ccp = −0.413 + 0.350 Pcp + 0.2316 Wbr + 0.607 Ctf	L1M1
	Pcp = −0.182 + 1.0377 Fbr	L1M2
	Fbr = 0.289 + 0.6836 Pcp + 0.2827 PkPrc	L1M3
	Vmb = 0.256 + 0.780 Psh	L1M4
	Cbb = 0.688 + 0.783 PkPrc	L1M5
	Rch = −0.198 + 0.4816 Pcp + 0.452 Wbr	L1M6
	Wbr = 0.202 + 0.375 Vmb + 0.926 Rch − 0.447 Asp	L1M7
	Asp = −0.010 + 0.9502 PkPrc	L1M8
	Ctf = 0.385 + 0.6213 Ccp + 0.748 PkPrc − 0.3336 Pk − 0.2185 Psh	L1M9
	PhPrc = −0.003 + 0.370 Asp + 0.475 Ctf + 0.2058 Pk	L1M10
	Pk = 1.007 + 0.754 Rch + 1.037 PkPrc − 1.159 Ocp	L1M11
	Ocp = 0.346 + 0.335 Rch + 0.365 Ctf − 0.3086 Pk + 0.449 Psh	L1M12
	Psh= 0.243 + 0.3145 Vmb + 0.7288 Ocp	L1M13
L2	Fbr = −3745 − 1.258 Pk + 1.906 Rch + 2.188 PkPrc	L2M1
	Pcp = 10049 + 7.092 Rch − 1.970 PkPrc	L2M2
	Ocp = −2419 + 0.1091 Fbr + 0.700 Ccp	L2M3
	Ccp = 231 + 0.364 Ocp + 0.798 Ctf − 0.1683 PkPrc	L2M4
	Pk = −2032 − 0.1722 Fbr + 0.0290 Pcp + 0.725 Rch + 1.503 Tnch	L2M5
	Rch = 1391 + 0.1286 Fbr + 0.0752 Pcp + 0.2934 Pk	L2M6
	Ctf = 3003 + 0.6943 Ccp + 0.2869 Pk − 1.215 Tnch	L2M7
	Tnch = 2746 + 0.0794 Ocp + 0.1264 Pk − 0.1522 Ctf	L2M8
	Prc = 1259 + 0.1830 Rch	L2M9
	PkPrc = −643 + 0.2382 Fbr	L2M10

Thus, the first model (L1M1) helped to predict common carp fish stocks based on Prussian carp, catfish and white bream stocks. The model explained 94.94% of the variance of the common carp stocks within the L1 study area. The model indicated good performance (the predicted R-sq value was close to the R-sq value) and revealed that the catfish and Prussian carp statuses had the strongest influence on the common carp stocks in the L1 study area (Table 4). The second model (L1M2) predicted Prussian carp stocks based on the freshwater bream stocks within the L1 study area. The model explained 95.51% of the variance of Prussian carp stocks in L1. The model indicated good performance (the predicted R-sq value (94.82%) was close to the R-sq value) and revealed that the situation of Prussian carp stocks was strongly influenced by the freshwater bream in L2 (Table 4). The third model (L1M3) confirmed the interspecies fish relationship presented in previous models and predicted the freshwater bream stocks in L1 based on Prussian carp and pikeperch stocks. The model explained 97.37% of the variance of freshwater bream stocks in L1. The model indicated good performance (the predicted R-sq value (96.61%) was close to the R-sq value) and confirmed the strong relation between the freshwater bream stocks and Prussian carp as the main independent variable of L1M3 (Table 4). The fourth model (L1M4) predicted the vimba stocks based on the Pontic shad stocks in L1. The model explained 58.81% of the variance of vimba stocks in L1. Additionally, the value of the predicted R-sq was further from the R-sq value, and the S-value was high, indicating that the model did not achieve the best degree of prediction and precision. However, the coded coefficient revealed the significant contribution of the Pontic shad independent variable in the prediction of the vimba dependent variable (Table 4). The fifth model (L1M5) predicted the common barbel stocks based on the pikeperch in L1. The model explained 42.56% of the variance of common barbel stocks in L1. Additionally, the value of the predicted R-sq was close to the R-sq value, and the S-value was relatively low, a situation that indicated that L1M5 did achieve an acceptable degree of prediction and precision. The coded coefficient analysis revealed the significant contribution of the pikeperch independent variable in the prediction of the common barbel dependent variable (Table 4). The sixth model (L1M6) predicted the roach stocks in L1 based on the Prussian carp and white bream stocks. The model explained 86.13% of the variance of roach stocks in L1. The model indicated good performance (the predicted R-sq value (79.81%) was close to the R-sq value) and revealed that the situation of the roach stocks was strongly influenced by both the Prussian carp and white bream stocks in an almost equal manner (Table 4). The seventh model (L1M7) predicted the white bream stocks in L1 based on the vimba, roach and asp stocks. The model explained 79.99% of the variance of white bream in L1. The model indicated good performance (the predicted R-sq value (69.28%) was relatively close to the R-sq value) and revealed that the status of the white bream stocks was mostly influenced by the roach stock followed by the asp stock, as revealed by the coded coefficient analysis (Table 4). The eighth model (L1M8) predicted the asp stocks in L1 based on the pikeperch stocks. The model explained 88.99% of the variance of asp stocks in L1. Additionally, the value of the predicted R-sq (86.90%) was close to the R-sq value, indicating that M18 did achieve a good degree of prediction and precision. The coded coefficient analysis revealed the significant contribution of the pikeperch independent variable in the prediction of the asp dependent variable (Table 4). The ninth model (L1M9) predicted the catfish stocks in L1 based on the common carp, pikeperch, pike and Pontic shad stocks. The model explained 97.15% of the variance of catfish stocks in L1. The model indicated good performance (the predicted R-sq value (92.50%) was close to the R-sq value), and the coded coefficient analysis revealed the significant contribution of the common carp and pikeperch independent variables in the prediction of the catfish dependent variable (Table 4). The tenth model (L1M10) predicted the pikeperch stocks in L1 based on the asp, catfish and pike stocks. The model explained 95.05% of the variance of pikeperch stocks in L1. However, the model indicated relatively good performance (the predicted R-sq value (88.29%) was close to the R-sq value), and the coded coefficient analysis revealed that catfish and asp contributed the most to the pikeperch prediction model (Table 4). The eleventh model (L1M11) predicted the pike stocks in L1 based on the roach and pike stocks and other cyprinid species, which were recorded as a different category in the reported catches. The model explained 78.24% of the variance of pike stocks in L1. Additionally, the value of the predicted R-sq was close to the R-sq value, and the S-value was relatively low, a situation indicating that L1M11 did achieve an acceptable degree of prediction and precision. The coded coefficient analysis revealed the significant contribution of pikeperch and the other cyprinid category in the prediction of the pike dependent variable (Table 4). The category of other cyprinids was composed of all cyprinid species recorded as catches, except for the cyprinid species considered a separate group in the present analytical framework. Therefore, the twelfth model (L1M12) predicted the other cyprinid stocks in L1 based on the roach, catfish, pike and Pontic shad stocks. The model explained 92.74% of the variance of the other cyprinids group in L1. Additionally, the value of the predicted R-sq was close to the R-sq value, and the S-value was relatively low, a situation indicating that L1M12 did achieve an acceptable degree of prediction and precision. The coded coefficient analysis revealed an almost equal contribution by the roach, catfish, pike and Pontic shad stocks in the prediction of the other cyprinids dependent variable. The last MLR model (L1M13) for fish stock prediction in L1 targeted the prediction of the Pontic shad stocks based on vimba and also other members of the cyprinids group. The model explained 90.00% of the variance of the Pontic shad stocks in L1. The model indicated good performance (the predicted R-sq value (88.25%) was close to the R-sq value), and the coded coefficient analysis revealed the significant contribution of the other cyprinids group in the prediction of the Pontic shad dependent variable (Table 4).

The analysis of the fish stock dataset from the L2 sampling area revealed 10 MLR prediction models (Table 4). Therefore, the first model (L2M1) generated predictions for the freshwater bream stocks within the L2 study area based on the pike, roach and pikeperch stocks. The model explained 88.88% of the variance of freshwater bream stocks in L2. Additionally, the predicted R-sq value was relatively far from the R-sq value, and the S-value was high. This indicates that L2M1 did not achieve the best degree of prediction and precision. However, the coded coefficient analysis revealed the significant contribution of all other pikeperch, roach and pike to the prediction of the freshwater bream dependent variable (Table 4). The second MLR model (L2M2) predicted the Prussian carp stocks within the L2 study area based on the roach and pikeperch stocks. The model explained 84.83% of the variance of the Prussian carp stocks in L2 and indicated good performance (the predicted R-sq value (81.66%) was close to the R-sq value). The coded coefficient analysis revealed that the roach stocks contributed significantly as an independent variable to the prediction of the Prussian carp dependent variable (Table 4). The third MLR model (L2M3) predicted the other cyprinids group. The L2 study area of the other cyprinids group consisted (as also described also for L1) of all cyprinid species recorded as catches, except for the cyprinid species considered a separate group in the present analytical framework. The model explained 77.29% of the variance for the stocks of the other cyprinids group and indicated an acceptable degree of prediction and precision, considering the high S-value. The coded coefficient analysis indicated that common carp was the main independent variable for the dependent variable of the L2M3 model (Table 4). The fourth MLR model (L2M4) targeted the prediction of common carp stocks in the L2 study area based on the other cyprinids group, catfish and pikeperch stocks. The model explained 88.82% of the variance for common carp stocks and indicated relatively good performance (the predicted R-sq value (72.78%) was close to the R-sq value). However, the S-value was high, indicating that the model did not achieve the best degree of precision. The coded coefficient analysis indicated that the stocks of the catfish and other cyprinids group were the main independent variables in predicting the common carp stocks (Table 4). The fifth MLR model (L2M5) generated, based on the L2 study area's fish stock database, predictions for the pike stocks based on the freshwater bream, Prussian carp, roach and tench stocks. The model explained 75.03% of the variance for the pike stocks within the L2 area and indicated relatively good performance. The coded coefficient analysis indicated that the stocks of roach and Prussian carp were the main independent variables in predicting the pike stocks (Table 4). The sixth MLR model (L2M6) targeted the prediction of the roach stocks within the L2 area based on the freshwater bream, Prussian carp and pike stocks. The model explained 92.99% of the variance for the roach stocks in the L2 area and indicated good performance (the predicted R-sq value (88.27%) was close to the R-sq value), and the coded coefficient analysis revealed that the pike stocks had the most significant contribution in predicting the roach stock dependent variable (Table 4). The seventh MLR model (L2M7) predicted the catfish stocks within the L2 area based on the tench, common carp and pike stocks. The model explained 91.17% of the variance for the catfish stocks in the L2 area and indicated relatively acceptable performance (the predicted R-sq value (83.00%) was relatively close to the R-sq value), and the coded coefficient analysis revealed that the tench and common carp stocks had the most significant contribution in predicting the catfish stocks dependent variable in L2 study area (Table 4). The eighth MLR model (L2M8) predicted the tench stocks in the L2 area based on the catfish, pike and other cyprinids group stocks. The model explained only 55.77% of the variance for the tench stocks within the L2 area. Additionally, the predicted R-sq value was not as close to the R-sq value, and the S-value was high, a situation which indicates that the model did not achieve the best degree of prediction and precision. However, the coded coefficient revealed a relatively significant contribution from the catfish and pike stock independent variables in the prediction of the tench dependent variable (Table 4). The ninth MRL model (L2M9) predicted the perch stocks within the L2 area based on the roach stocks. The model explained only 66.43% of the variance for the perch stocks within the L2 area and indicated acceptable performance (the predicted R-sq value (61.02%) was close to the R-sq value), although the S-values were high. The coded coefficient analysis revealed that the roach stocks contributed to the prediction of the perch stocks dependent variable (Table 4). The last MLR model (L2M10) for fish stock prediction in L2 aimed to predict the pikeperch stocks based on the freshwater bream stocks. The model explained 82.42% of the variance of the pikeperch stocks within L2. However, the predicted R-sq value was further away from the R-sq value, and the S-value was high, indicating that the model did not achieve the best degree of prediction and precision. The coded coefficient analysis revealed a relatively significant contribution from the freshwater bream stocks to the prediction of the pikeperch stocks as a dependent variable (Table 4).

Fish stock forecasting models contribute to a better quantification of the climate change impact on fish biodiversity, improving the precision of the proposed analytical framework by offering the possibility of correlating the fish stock dynamics and diversity with the water's physicochemical parameters. Additionally, by dividing the fish species database into two major groups according to their feeding behavior (predatory and peaceful species), it was observed that peaceful species had a higher upward trend in contrast with the predatory species (Figure 3) in both of the studied areas (L1 and L2).

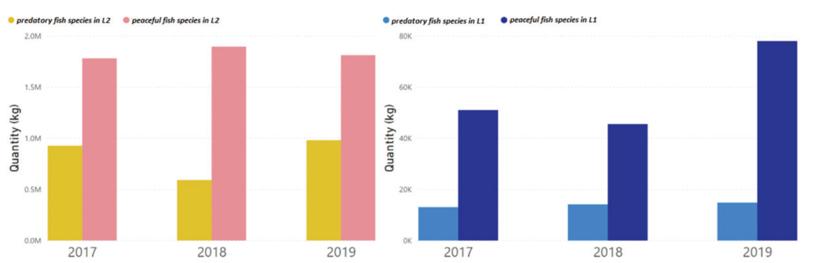


Figure 3. The evolution of peaceful and predatory species for both L1 and L2 during the 2017–2019 time period.

These findings were confirmed by other authors, who emphasized that a high water temperature is associated with low fish diversity, and fish species from the ichthyophagous group suffered a decline in biodiversity [102].

Due to morphological differences in the feeding habits of different fish species, the interaction between them is established as predator and prey species, a fact that can negatively influence the density of prey populations [103].

The feeding diet of the common carp, Prussian carp and white bream is planktivorous, being based on phytoplankton and zooplankton [104,105]. Thus, it is expected that either all the species thrive when food resources are abundant, or they compete with one another if the resources are scarce. The catfish is known as an opportunistic feeder and its diet is predominantly based on animals living in the benthic area, such as crustaceans (in lentic ecosystems) and fish (in lotic ecosystems) [106]. In rivers, catfish prefer to prey on migratory fish species such as *Alosa* sp., potentially leading to a decline in the *Alosa* sp. stocks [103,106]. Another important characteristic in the feeding process of the catfish is the specimen size. It has been observed that individuals with a biomass below 5 kg prey on roach and perch, while bigger individuals prey on sander, bream and common carp [107]. In the case of the feeding habits of the pike, it prefers cyprinids such as rudd and roach and *Percidae* sp. such as the European perch [108,109].

4. Conclusions

Here, we confirm the vulnerability of the Romanian Lower Danube Euroregion (RLDE) to climate change based on the trend lines of the most suggestive water physicochemical parameter dataset recorded in the last 4 years. Thus, the water temperature, ammonium, nitrite and TOC revealed an upward dynamic, while the pH and DO were associated with a decreasing trend. These are signs of the impact of climate change. However, there are sectors among the RLDE, such as the Galați study area, which can be considered more vulnerable to the evergrowing impact of climate change. This was revealed by the present analytical framework's TN and TP forecast analysis, which indicated a more accentuated increasing trend compared with the studied Tulcea sector. The fish catch structure within the RLDE was proven to be affected by global warming, since the stocks of ichthyophagous fish species were less predominant compared with the stocks of peaceful fish species. Furthermore, this phenomenon was more obvious within the Galati County Danube River Basin than in the "Danube Delta" Biosphere Reserve Administration territory, confirming the more vulnerable character of the Galati study area compared with that of the Tulcea area.

The water level and air temperature forecasting analysis proved to be an important tool for climate change monitoring and can efficiently assist in the real-time management decisions related to water distributions among BE sectors, preventing possible conflicts which can induce shortages within the BG process.

The forecast and prediction methodology we presented here confirms that time series methods can be used together with machine learning prediction methods to highlight their synergetic abilities to monitor and predict the impact of climate change on the marine living resources BE sector within the RLDE.

The developed forecasting models are meant to be used as methods for elucidating future information, rendering the decision makers capable of adopting proper management solutions to prevent or limit the negative impacts of climate change on a BE. Through the identified independent variables, fish stock prediction models offer a solution for managing the dependent variables, which is mostly possible through restocking programs or by fishing policy adaptation. Moreover, water quality prediction models can be characterized as suitable solutions for less cost-demanding aquatic environment monitoring activities.

Forecasting methods like ETS, ARIMA, SARIMA were considered the most efficient for predicting water's physicochemical parameters, while multiple linear regression has been proven to offer consistent results both for water's quality parameters and for fish stock biodiversity monitoring purposes.

The volume of the available data was enough to develop both the forecasting and prediction procedures, with sufficient data for the training and testing phases. However, like other studies which apply forecasting and prediction methodologies, this can be subject to limitations. Indeed, most algorithms will positively benefit from a larger dataset when extra data are available. Therefore, the analytical framework applicability is mostly limited to the RLDE. However, not all the dataset parameters were collected from the entire RLDE surface. Therefore, more geographically widespread studies within the RLDE are to be performed to improve the performance of the established analytical framework.

Future studies should be performed to develop the analytical framework elaborated within the research at hand by integrating other important parameters into the dataset (such as the water's heavy metal concentration and atmospheric parameters such as carbon dioxide and other greenhouse gases, in addition to heavy industry and agriculture sustainability indicators) to assure more accurate monitoring and control of the climate change impact on a BE from the RLDE. Moreover, future studies should aim to include data related to invasive and declining species into both the forecast analysis and the prediction models in order to identify possible impacts in terms of biodiversity loss and establish methods for managing the biodiversity.

Author Contributions: Conceptualization, writing, validation, formal analysis and visualizations, S.M.P.; formal analysis, software programming, methodology and visualization, C.Z.; writing and data curation, I.A.S. and A.M.; methodology, resource identification and writing, F.M.N.; methodology, materials and literature review, A.T.R.; conceptualization and resource identification, D.N.; conceptualization and data curation, F.M.B.; conceptualization, writing, validation, formal analysis and visualization, D.S.C. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

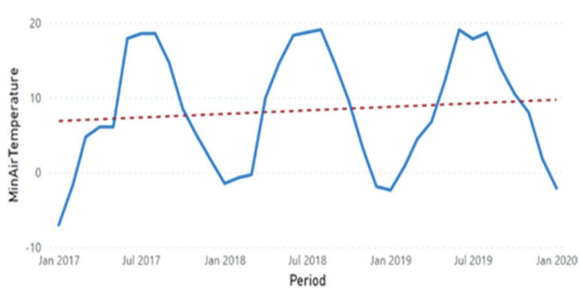

Figure A1. Minimum air temperature trend line at the Galați sampling point.

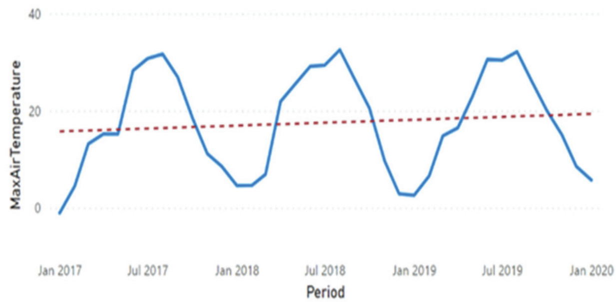

Figure A2. Maximum air temperature trend line at the Galați sampling point.

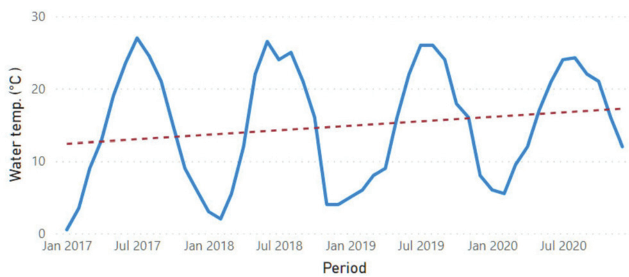

Figure A3. Water temperature trend line in the Danube River at the Galați sampling point.

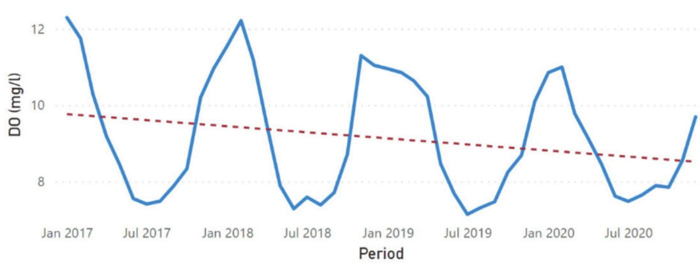

Figure A4. The DO trend line in the Danube River at the Galați sampling point.

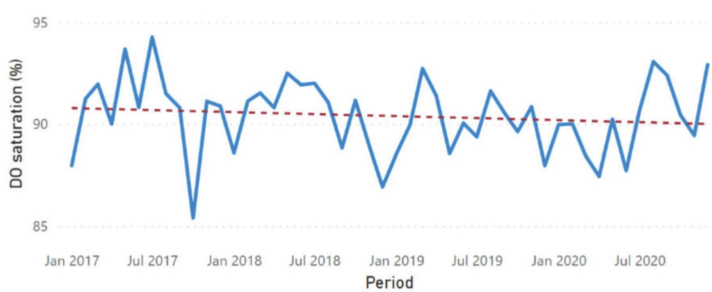

Figure A5. The DO saturation trend line in the Danube River at Galați.

Figure A6. The water pH trend line in the Danube River at Galați.

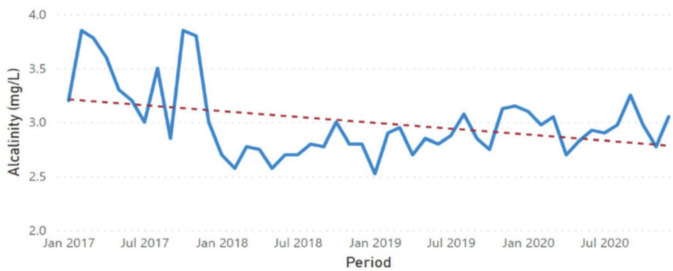

Figure A7. The water alkalinity trend line in the Danube River at Galați.

Figure A8. The water bicarbonates trend line in the Danube River at Galați.

Figure A9. The water nitrate-nitrogen trend line in the Danube River at Galați.

Figure A10. The water nitrite-nitrogen trend line in the Danube River at Galați.

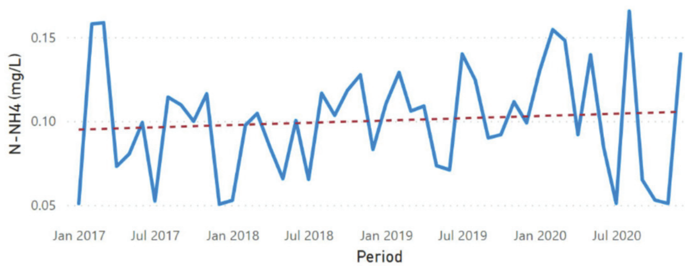

Figure A11. The water ammonium-nitrogen trend line in the Danube River at Galați.

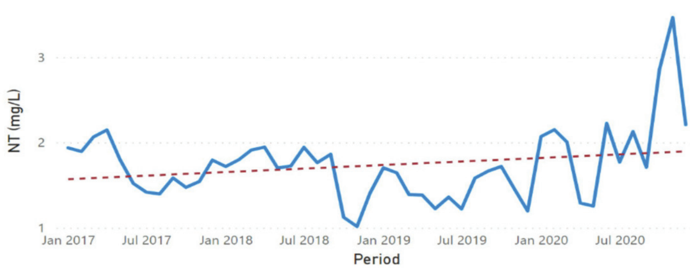

Figure A12. The water total nitrogen trend line in the Danube River at Galați.

Figure A13. The water total phosphorus trend line in the Danube River at Galați.

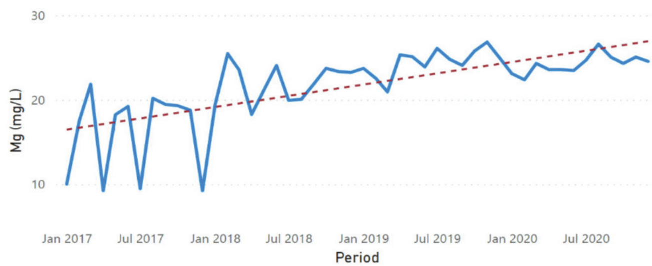

Figure A14. The water magnesium trend line in the Danube River at Galați.

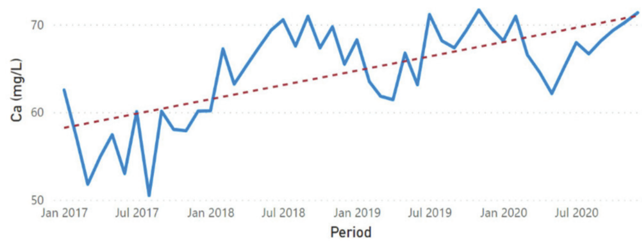

Figure A15. The water calcium trend line in the Danube River at Galați.

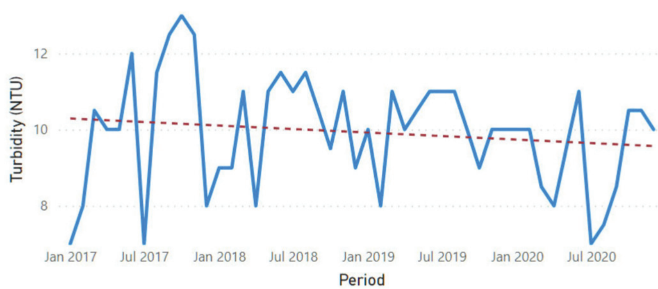

Figure A16. The water turbidity trend line in the Danube River at Galați.

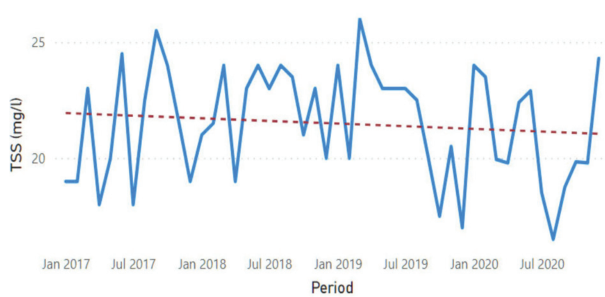

Figure A17. The water TSS trend line in the Danube River at Galați.

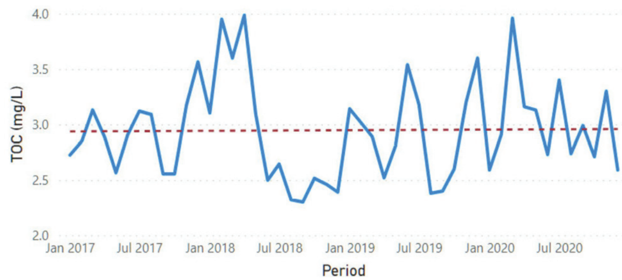

Figure A18. The water TOC trend line in the Danube River at Galați.

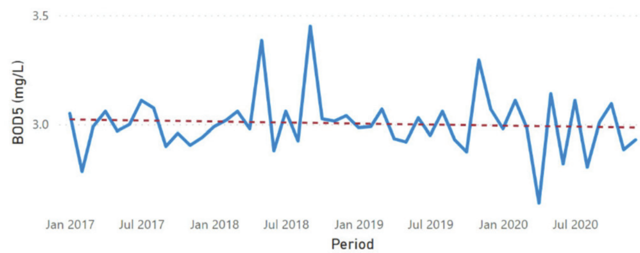

Figure A19. The water BOD5 trend line in the Danube River at Galați.

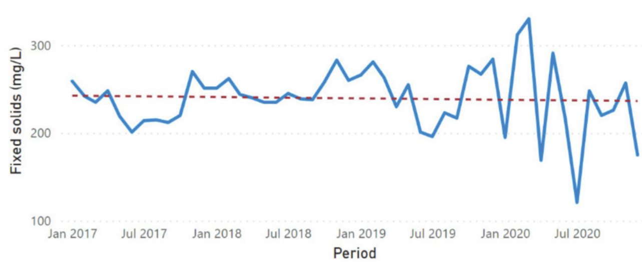

Figure A20. The water fixed solids trend line in the Danube River at Galați.

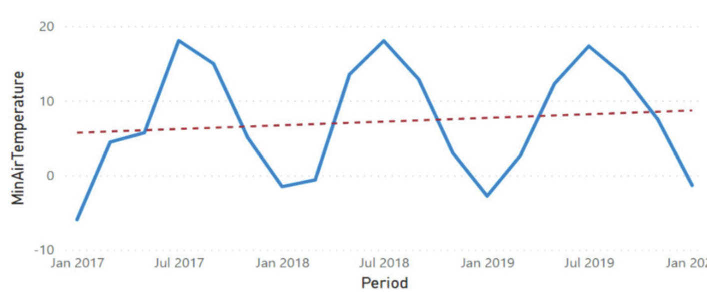

Figure A21. Minimum air temperature trend line in the Tulcea sampling point.

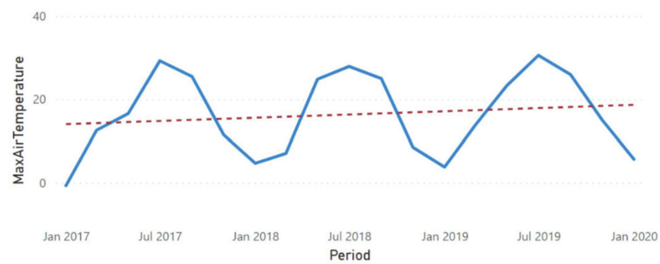

Figure A22. Maximum air temperature trend line in the Tulcea sampling point.

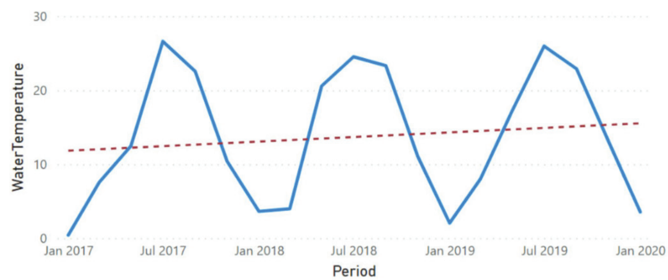

Figure A23. Maximum water temperature trend line in the Tulcea sampling point.

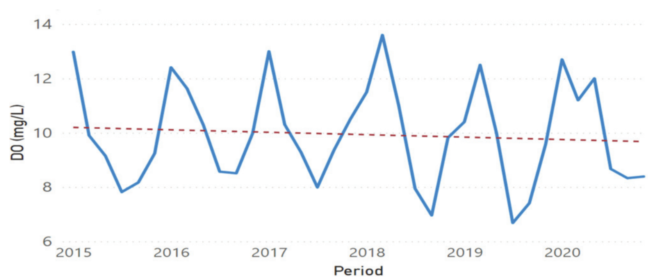

Figure A24. Maximum water DO trend line in the Tulcea sampling point.

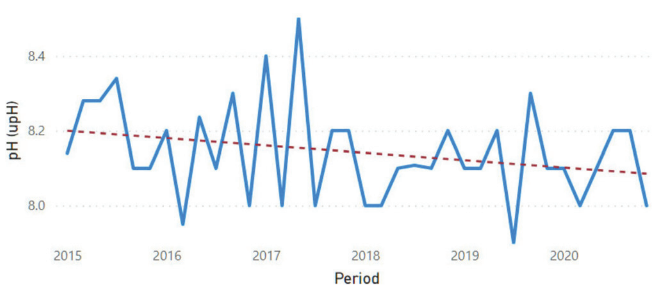

Figure A25. The water pH trend line in the Tulcea sampling point.

Figure A26. The water alkalinity trend line in the Tulcea sampling point.

Figure A27. The water bicarbonate trend line in the Tulcea sampling point.

Figure A28. The water nitrate-nitrogen trend line in the Tulcea sampling point.

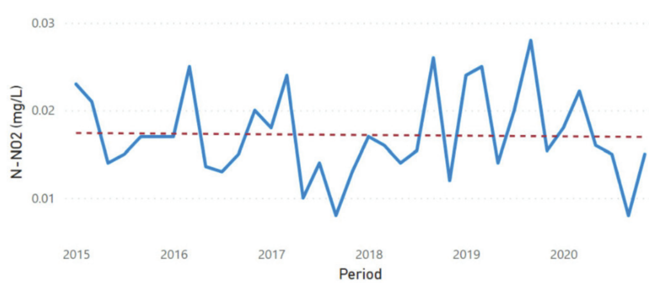

Figure A29. The water nitrite nitrogen trend line in the Tulcea sampling point.

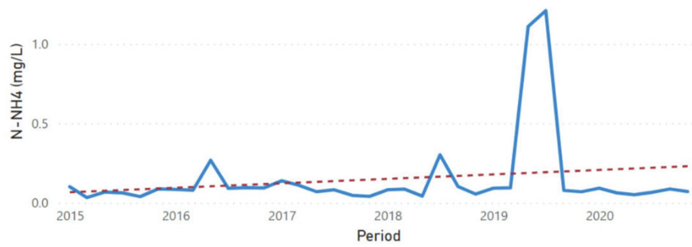

Figure A30. The water ammonium-nitrogen trend line in the Tulcea sampling point.

Figure A31. The water total nitrogen trend line in the Tulcea sampling point.

Figure A32. The water total phosphorus trend line in the Tulcea sampling point.

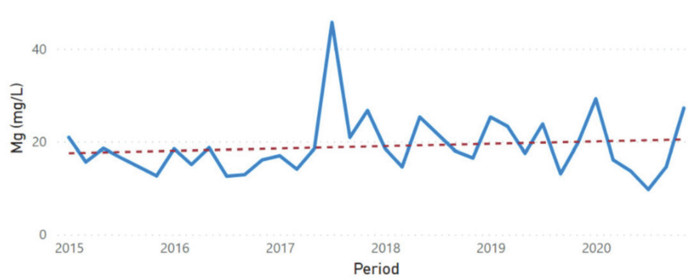

Figure A33. The water magnesium trend line in the Tulcea sampling point.

Figure A34. The water calcium trend line in the Tulcea sampling point.

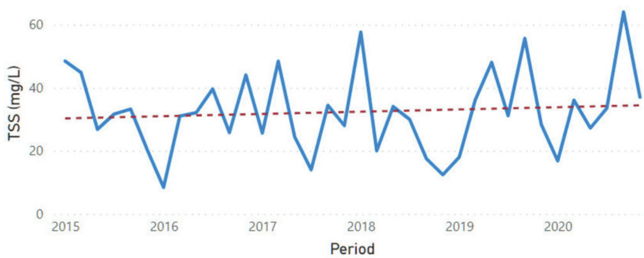

Figure A35. The water TSS trend line in the Tulcea sampling point.

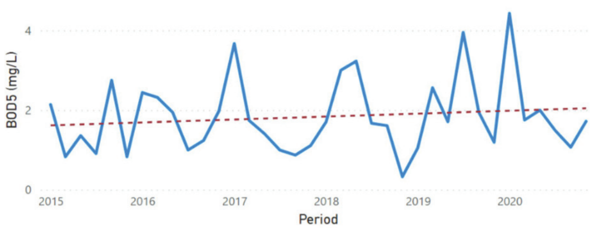

Figure A36. The water BOD5 trend line in the Tulcea sampling point.

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Predictive Innovative Methods for Aquatic Heavy Metals Pollution Based on Bioindicators in Support of Blue Economy in the Danube River Basin

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Abstract: Heavy metal pollution is still present in the Danube River basin, due to intensive naval and agricultural activities conducted in the area. Therefore, continuous monitoring of this pivotal aquatic macro-system is necessary, through the development and optimization of monitoring methodologies. The main objective of the present study was to develop a prediction model for heavy metals accumulation in biological tissues, based on field gathered data which uses bioindicators (fish) and oxidative stress (OS) biomarkers. Samples of water and fish were collected from the lower sector of Danube River (DR), Danube Delta (DD) and Black Sea (BS). The following indicators were analyzed in samples: cadmium (Cd), lead (Pb), iron (Fe), zinc (Zn), copper (Cu) (in water and fish tissues), respectively, catalase (CAT), superoxide dismutase (SOD), glutathione peroxidase (GPx), malondialdehyde (MDA) (in fish tissues). The pollution index (PI) was calculated to identify the most polluted studied ecosystem, which revealed that Danube River is seriously affected by the presence of Fe (IP = 4887) and strongly affected by the presence of Zn (IP = 4.49). The concentration of Cd in fish muscle tissue was above the maximum permitted level (0.05 μg/g) by the EU regulation. From all analyzed OS biomarkers, MDA registered the highest median values in fish muscle (145.7 nmol/mg protein in DR, 201.03 nmol/mg protein in DD, 148.58 nmol/mg protein in BS) and fish liver (200.28 nmol/mg protein in DR, 163.67 nmol/mg protein, 158.51 nmol/mg protein), compared to CAT, SOD and GPx. The prediction of Cd, Pb, Zn, Fe and Cu in fish hepatic and muscle tissue was determined based on CAT, SOD, GPx and MDA, by using non-linear tree-based RF prediction models. The analysis emphasizes that MDA in hepatic tissue is the most important independent variable for predicting heavy metals in fish muscle and tissues at BS coast, followed by GPx in both hepatic and muscle tissues. The RF analytical framework revealed that CAT in muscle tissue, respectively, MDA and GPx in hepatic tissues are most common predictors for determining the heavy metals concentration in both muscle and hepatic tissues in DD area. For DR, the MDA in muscle, followed by MDA in hepatic tissue are the main predictors in RF analysis.

Keywords: oxidative stress; heavy metals; Danube River; Black Sea; machine learning

1. Introduction

The Romanian Danube River basin, especially the lower sector, represents the basis for developing the country's blue growth potential, to align to the European Union average performance registered by the blue economy sector. Therefore, the living resources subsector must be developed, while assuring both the safety and security of aquatic food products. However, this objective can pose a real challenge to achieve since in the lower sector of the Romanian Danube River (LRDR) basin several important economic/anthropogenic activities related to shipyard industry (in the area of Brăila, Galați and Tulcea city), steel industry (Galați county), alumina industry (Tulcea county) and intensive agricultural activity (especially in Brăila and Tulcea county) are present. Thus, all the activities generate significant concentrations of heavy metals released in the nearby environment, creating a risk of heavy metal accumulation in the aquatic ecosystem, situation which requires periodic pollution monitoring activities. Additionally, the LRDR connects to the Black Sea through the Danube Delta and if pollution occurs upstream of the river, the negative effects of this phenomenon can extend on the Romanian Black Sea and Danube Delta coastal areas as well.

According to [1], the coastal area accumulates large quantities of metals from agricultural and industrial activities. Fish are often used as bioindicators for water pollution caused by heavy metals [2–4], through fish liver analysis. Furthermore, the Regional Organization for the Protection of the Marine Environment recommends the use of fish as environmental monitoring tools [5]. According to [3], machine learning based models for the detection of heavy metals in aquatic environments are increasing the economic efficiency of monitoring campaigns conducted to identify the ecological status of surface waters and, additionally, the health risk that is associated with the ingestion of heavy metals after fish consumption.

Fish stocks are key components in the development of a blue economy based on marine living resources. Thus, fish meat analysis must be performed to verify food safety in terms of heavy metal concentration. However, heavy metal analysis involves a high financial cost, complex logistics and the development of complex working protocols [3]. In addition, since heavy metals are not equally distributed in the aquatic environment and the identifications of hot spots imply the collection of many samples for analysis, the monitoring campaigns are cost-demanding. Therefore, even though ecotoxicological mathematical models were performed to predict internal concentrations of organic chemicals in fish [6], more recent studies recommend the continual development and upgrade of these models [7].

The oxidative stress (OS) biomarkers analysis is less expensive and offers information related to fish welfare status.

Manifestation of the OS within an organism occurs due to the disparity between the production of reactive oxygen species (ROS) and the organism's capacity to convert ROS into less harmful oxygen species or to repair the oxidative damage [8]. Enzyme activity is a well-known inhibition mechanism for oxidative cytotoxicity and antioxidant enzymes can catalyze the reaction of free radicals' reduction [9,10]. Antioxidant enzymes such as superoxide dismutase (SOD), glutathione peroxidase (GPx) and catalase (CAT) are the main components of the first line antioxidant defense mechanism and can prevent ROS production [10,11].

The main free radicals which can cause the oxidation of cellular components such as lipids, proteins and DNA, and which eventually lead to mutagenesis or cell death, are the superoxide radical (O_2^-), the hydroxyl radical (OH) and hydrogen peroxide (H_2O_2) [12,13]. The defense mechanism of SOD acts by inhibiting the activity of superoxide anion, through the transformation of O_2^- in H_2O_2 [13]. Furthermore, the CAT and GPx antioxidant enzymes act as catalyzers for the decomposition of H_2O_2 to H_2O and O_2, and, therefore, provide a detox mechanism in living cells [9,14]. In addition, ROS cytotoxic effects includes the peroxidation of membrane lipids (oxidation of polyunsaturated fatty acids) which causes high levels of malondialdehyde (MDA) [15].

The exposure of biota to heavy metals is known to induce OS [16–19]. OS biomarkers are sensitive to environmental contaminants and respond fast in their presence, including heavy metals [20,21]. OS biomarkers have been previously used to highlight the effects induced by heavy metal pollution in the aquatic environments, by using different model organisms such as crabs [22], mussels [15,23], frogs [24], jellyfish [25] and fish [14,26,27]. Fish are the vertebrates which manifest the fastest biological response to aquatic environmental pollution [9,28]. Metals with redox potential (Cu, Fe, Ni) are involved in the Fenton reaction as ROS catalyzers, while metals with no redox potential (Cd, Pb, Zn) compromise the antioxidant defense system by depletion of antioxidants [12,14,16]. Fish species inhabiting metal contaminated aquatic environments manifest high level of antioxidant enzymes such as SOD, GR, GST, GPx, CAT and free antioxidants such as GSH [16].

Several studies have conducted research linking the oxidative stress in fish liver and intestine [10,12,14,21,26,29–36], in fish blood plasma [20,37,38], in fish muscle [21,32], in fish gill, kidney and brain [29–31,39] to heavy metals presence in the aquatic environment, proving that fish OS biomarkers can be used to determine heavy metal pollution since the trace element contamination directly affects fish welfare status.

However, mathematical modelling of oxidative stress induced by heavy metals is a new concept and few research have been undertaken regarding this subject. For instance, Ning with co-authors [40] applied the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), using the software Matlab, to analyze the degree of toxicity to the earthworms after various stress concentrations. Gao et al. [41] fitted a toxicodynamic (TD) and toxicokinetic (TK) model for oxidative stress depended on the presence of heavy metals in zebrafish gills. However, the authors concluded that the TD model needs to be improved. Sahlo et al. [42] trained a neural network using sine-cosine algorithm to predict CAT, SOD and GPx in fish exposed to selenium nanoparticles.

The main goal of the European Common Fisheries Policy is to ensure that fishing and aquaculture activities provide a source of healthy food for EU citizens.

The precocious identification of heavy metal hot spot occurrence can be vital to assuring a sustainable blue economy in LRDR since this phenomenon may not only affect wild fish stocks, but also aquaculture facilities supplied with water from the Danube River. Therefore, heavy metal pollution can affect the sustainability of a blue economy both through the impact on wild fish stocks and on the aquaculture productions, situation which could create pressure on fish stocks from other fishing areas, which are not affected by pollution. Recent papers [43] highlighted that strategic and tactical decision-making within the blue economy concept can be achieved through the exploitation of aquatic numerical modelling and observations, which can represent common monitoring practices among coastal areas [44].

The present paper develops an innovative analytical framework which can be used to monitor the heavy metal pollution status in LRDR, based on fish OS biomarkers and the use of random decision forests (RF) algorithms. The analytical framework targets the identification of proper, high precision mathematical models and methodology, which can predict heavy metal concentrations in the tissues of different economically valuable fish species from the Danube River—Black Sea Basin, based on the enzymatic and non-enzymatic activity in muscle and liver tissues. The results of the present research can provide a cost-effective tool, which can support the Danube River Basin Management Plan (DRBMP), which is the most important task in the implementation of the Water Framework Directive (WFD). As well, the proposed tool can support the blue economy through the development of standardized, machine-learning based, monitoring methods of heavy metal pollution in the macro-system Danube River-Danube Delta-Black Sea, by using OS biomarkers as predictors.

In order to determine a reliable predictive model framework for identifying the heavy metals concentration in fish muscle and liver tissue, a non-linear methodology based on random forest algorithms was used. Random forest algorithms were successfully used in different contexts requiring heavy metals concentration prediction. For example, in [45], the authors are proposing a random forest approach for a rapid evaluation of heavy metals concentration (Cd, Cu, Pb, Zn) in *Tegillarca granosa* (a species of clam known as the blood clam because of the red hemoglobin liquid inside the soft tissues), to assess the magnitude of contamination. In [46], various machine learning algorithms were used for differentiating between organic and non-organic cattle production based on the analysis of the concentration of 14 mineral elements (As, Cd, Co, Cr, Cu, Fe, Hg, I, Mn, Mo, Ni, Pb, Se and Zn) in 522 serum samples from cows (341 from organic farms and 181 from non-organic farms), the best results being obtained with the decision tree C5.0, Random Forest and AdaBoost neural networks. Random forests were also used for determining heavy metals soil pollution. In their study, Zhang et al. [47], determined the concentrations of As, Cr, Cu, Ni, Pb, Zn, Cd, Hg, organic carbon, nitrogen, phosphorus, pH, Cl, clay, silt, sand, CaO, Fe_2O_3, Al_2O_3 and SiO_2 in samples of soil and sediment collected in the region of Eastern China and the potential sources/concentration of heavy metals were identified using random forest (RF) and positive matrix factorization (PMF) models. Similarly, [48] emphasizes on the fact that heavy metals lead to food contamination endangering the human health. The objective of their study was to estimate the concentrations of heavy metals, such as zinc, chromium, arsenic by using random forest (RF) algorithm on collected data from the study area of Xuzhou, China. The obtained results were conclusive with an R-Sq around 0.9 for all their models and also very low RMSEs. Random forest methodology was also used in establish heavy metals impact on human health. For example, in [49], the authors show that lead, mercury and cadmium have a significant impact on hypercholesterolemia (HC). They used various machine learning models (k-nearest neighbors, decision trees, random forests and support vector) with data collected from 10,089 participants to predict the prevalence of HC associated with exposure to lead, mercury and cadmium. In addition to predicting heavy metals concentrations in organic tissues or soil sediments, random forests were also used, as a prevention method, to assess the water heavy metal pollution. Thus, [50] shows how it is possible, based on a random forest approach, to predict the pollution level in Marilao-Meycauayan-Obando River System, located in the province of Bulacan, Philippines, where the inhabitants are continuously exposed to pollution coming from informal industries such as used lead-acid battery or open dumpsites metal refining.

2. Materials and Methods

2.1. Study Area

The study area is represented by the macro-system Danube River (DR)—Danube Delta (DD)—Black Sea (BS), on the LRDR territory. It is well documented that the LRDR tends to concentrate the highest levels of different heavy metals accumulated from the Upper and Middle sectors [4]. Furthermore, according to the last DRBMP, Romania discharges the highest rates of Pb (7477 kg/year) and Cd (1605 kg/year) compared to other riparian countries. The LRDR could be considered the basis for improving Romanian blue growth in the context of European Union intention for developing a more sustainable blue economy, due to large diversity of fish stocks and aquaculture fish farm facilities connected to the Danube River for assuring their inlet water. Thus, this region must be subject to a strict operational management which should prevent possible pollution situations. Since heavy metals are pollutants difficult to be controlled or removed and they tend to accumulate in various trophic levels within an ecosystem, a rigorous monitoring management must be implemented especially in areas which are considered hot spots due to their specific heavy industrial activity. Therefore, the present study considers the Danube section between the city of Galati (45°25′50″ N 28°3′33″ E) and the city of Tulcea (45°10′51″ N 28°47′43″ E) (Figure 1, orange spots), as monitoring heavy metal pollution in this area is imperative due to the anthropogenic pressure exercised on Danube River water column through the naval (the largest naval shipyard on the Danube is in Galați city and shipyard industry is presented also in the city of Tulcea) and metallurgical (the largest steel mill in Romania is located in the city of Galați and the largest alumina refinery from Romania is located in the city of Tulcea) activities conducted in this region. In the Danube Delta, sampling was performed in 3 representative lakes located on the Saint George branch (45°3′9″ N 29°7′40″ E, 44°58′38″ N 29°12′46″ E, 44°59′4″ N 29°10′29″ E) (Figure 1, purple spots) since in these lakes significant fishing activities are reported and their geographical position, surrounded by intensive agriculture fields, is representative of most of the lakes presented in this study region. The practice of intensive agriculture near lakes, rivers and ponds is a common practice within Danube Delta and can be a threat to the sustainability of marine living resources blue economy subsector. In the Black Sea area, sampling was undertaken between the flowing mouth of the Danube River in the Black Sea, in the Saint George locality (44°52′14.8″ N 29°37′15.4″ E), and the Perisor Beach (44°47′43″ N 29°16′8″ E), since this is considered an important fishing area and is situated immediately after Danube Delta buffer zone (Figure 1, blue spots).

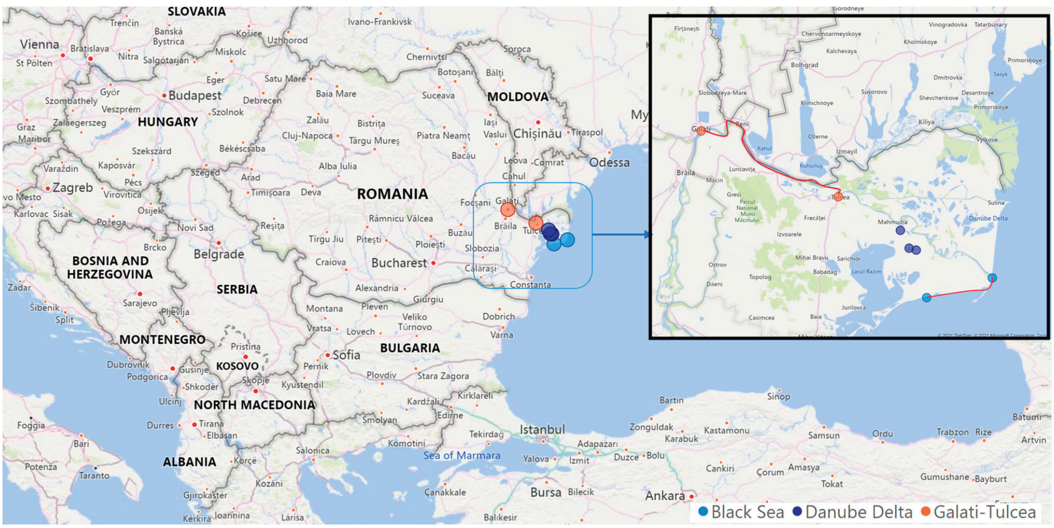

Figure 1. Map of the study area (orange spots—Danube River sector, purple spots—Danube Delta area, blue spots—Black Sea costal area).

2.2. Pollution Index

There are several water quality indices that can describe the ecological status of a water body. For instance, water quality index (WQI), Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) and heavy metal pollution index (HPI) use in their specific equations more than 1 variable. In addition to Fe, Zn and Cr, WQI takes into consideration other water quality parameters such as phosphorous, nitrates, chlorides, alkalinity, total dissolved solids, total hardness, pH, electrical conductivity, dissolved oxygen, turbidity, biological oxygen demand, chemical oxygen demand [51,52]. In addition, HPI takes into consideration the concentrations of chromium, cobalt, nickel, copper, zinc, cadmium, mercury, arsenic, manganese and iron [52]. The pollution index (PI) is calculated based on the concentration of the individual metal; thus, each metal has its specific *PI* value [53]. The *PI* was chosen in this present study because it was targeted to highlight the impact of each studied metal on the investigated areas and to identify possible ecological risks generated by a specific contaminant, and not by the mixture of analyzed metals. To better characterize the study area in terms ecological status, the pollution index was calculated. According to [54], this index facilitates the identification of the impact of different heavy metals presence in a certain area, to identify the pollution degree and possible hotspot. Therefore, the following Formula (1) was applied:

$$PI = \frac{\sqrt{\left(\frac{C_i}{S_i}\right)^2_{max} + \left(\frac{C_i}{S_i}\right)^2_{min}}}{2} \quad (1)$$

where:

C_i = Metal Measured Value

S_i = Metal Standard Value

For this study, the metal standard value in surface waters was taking into consideration according to the Romanian Regulation Order no. 161/2006.

The results of PI can be evaluated as it follows: $PI < 1$ = no effect, $PI < 2$ = slightly affected, $PI < 3$ = moderately affected, $PI < 5$ = strongly affected, $PI > 5$ = seriously affected.

2.3. Sample Collection and Preparation

Samples of water (n = 50) were collected from the Danube River, Danube Delta and Black Sea in 50 mL polyethylene (PE) Falcon tubes, previously washed with ultrapure water. Each sample was mineralized with 65% Suprapure HNO_3 to ensure metals dissolution and kept in the freezer until analysis.

A total number of 158 fish specimens were caught by commercial fishermen using specialized fishing nets (approved by the National Authority for Fishing and Aquaculture) and taxonomically identified as it follows: in the Danube River, *Abramis brama* (Linnaeus, 1758) (n = 9), *Alosa immaculata* (Bennett, 1835) (n = 10), *Leuciscus aspius* (Linnaeus, 1758) (n = 5), *Silurus glanis* (Linnaeus, 1758) (n = 8), *Cyprinus carpio* (Linnaeus, 1758) (n = 6); in the Danube Delta, *Silurus glanis* (Linnaeus, 1758) (n = 20), *Cyprinus carpio* (Linnaeus, 1758) (n = 19), *Carassius gibelio* (Bloch, 1752) (n = 37); in the Black Sea: *Trachurus mediterraneus ponticus* (Steindachner, 1868) (n = 12), *Platichthys flesus* (Linnaeus, 1758) (n = 7), *Mugil cephalus* (Linnaeus, 1758) (n = 10), *Alosa immaculata* (Bennett, 1835) (n = 15).

The biological material was placed in PE bags, stored in the icebox and transported to the laboratory, where it was kept in the freezer until analysis. Samples of muscle and hepatic tissue were collected from each fish and each sample was submitted to the digestion procedure, using certified Merck reagents (65% Suprapure HNO_3 and 30% H_2O_2) and the microwave digestion system Berghof Speedwave MWS-2. The muscle tissue was chosen for sampling because all fish species analyzed in the present study are economically important and are consumed by the local population. Thus, a possible fish contamination with heavy metals would pose health risks to the human population. In addition, the liver is an active detoxification mechanism of different pollutants and heavy metals are known to degrade the lipid mechanism [34]. Therefore, liver tissue from each fish was sampled.

The protocol for sample preparation was conducted according to [2,55]. A total number of 316 samples were analyzed.

2.4. Heavy Metals Analysis

For metal quantification in samples the high-resolution continuum source atomic absorption spectrometry (HR-CS-AAS) technique was used. Cd, Pb, Cu, Fe and Zn were determined due to their high toxicity potential to exposed biota. All samples were analyzed using the ContrAA® 700 equipment, produced by Analytik Jena, Germany. The graphite furnace method was applied for Cd, Pb and Cu analysis; and for Fe and Zn, the flame method was applied, following the optimization program previously described by [55,56].

To verify the accuracy of the results registered in case of the samples laboratory analysis, a certified reference material (CRM) for fish muscle was used (for heavy metal analysis), according to [2].

2.5. Enzymatic and Non-Enzymatic Biomarkers Determination

The CAT, SOD, GPx and MDA were analyzed from fish muscle and hepatic tissues. Each sample was homogenized in 10 volumes of ice-cold saline solution (0.90% NaCl) and centrifuged at 5500 rpm, at 4 °C. The resulting supernatant was discharged in clean tubes and divided in aliquots for biomarker analysis. Merck certified assay kits were used to determine CAT (CAT100-1KT), SOD (19190-1KT-F), GPx (CGP1-1KT) and MDA (MAK085-1KT). The working protocol was previously described by [57]. All samples were measured using Specord 210 Plus, AnalytikJena equipment. For OS biomarkers, the enzyme activities were determined as outlined in the detailed protocol provided by Merck for each assay kit.

2.6. Model Development

In order to identify a predictive modelling framework for determining heavy metals concentration in fish hepatic and muscle tissues from LRDR, based on OS biomarkers, a series of procedures were performed, starting from the raw data and ending to final prediction models (Figure 2).

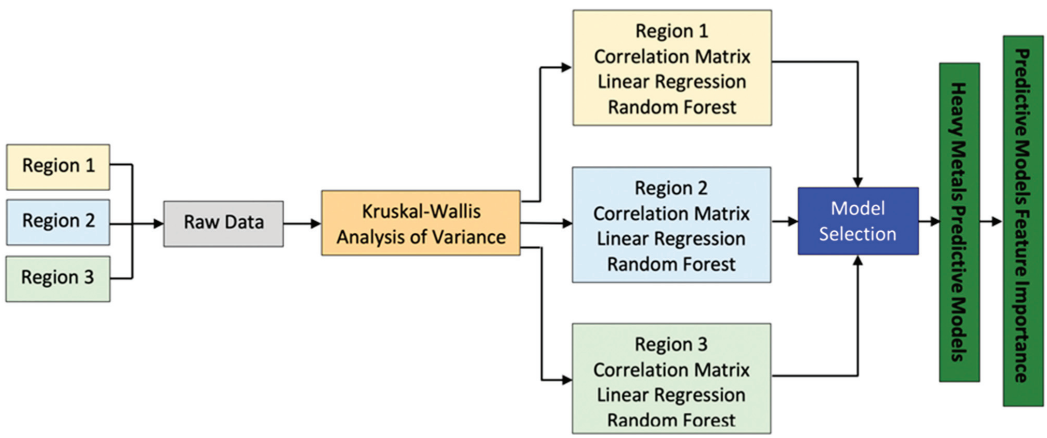

Figure 2. Predictive models procedure for determining heavy metals concentration in fish liver and muscle tissues.

According to Figure 2, after collecting the raw data parameters from the three regions presented above, in order to understand if there are significant data differences between the regions, due to the non-normal distribution of the data, a Kruskal-Wallis analysis of variance was performed. The results indicated significant differences in regions data distribution, therefore each region was independently analyzed. A region analysis involved three main steps: (a) calculate the correlation matrix for acquiring the perspective over the existing linear relations in the dataset—with possible impact over the predictive techniques such as linear regression, retaining only the relevant values, respectively, above 0.6 and below −0.6; (b) develop linear regression models on normalized datasets (scaled regressors), using stepwise backward and forward selection for obtaining the most relevant predictors [58] and comparable coefficients that would help to distinguish between predictors relevancy; (c) develop predictive random forest models for the targeted features.

For choosing the final predictive models, the model selection procedure took into consideration two main metrics, respectively, R-Sq and Root Mean Square Error (RMSE). The R-sq has an intuitive scale as it ranges from zero to one, where zero indicates no improvement over the mean model, and one indicating perfect prediction having the entire dependent variable variance described by the predictors. The RMSE, the square root of the variance of the residuals, indicates the absolute fit of the model to the data. If R-sq is a relative measure of fit, RMSE is an absolute measure. RMSE is interpreted as the standard deviation of the unexplained variance, being in the same units as the response variable.

RMSE is a good measure for describing how accurately a model predicts the response, being one of the most important fit criteria for predictive models based on OLS (ordinary least square) estimations [59].

Last step of the research procedure was to identify for each reliable predictive model the order of the most relevant predictors, being able this way to assess strong prediction influences of the various dependent variables. Regarding the predictive modelling procedure to determine the heavy metals concentration in fish liver and muscle tissues, the current research started with the multiple linear regressions, a technique that uses a number of explanatory variables to predict the outcome of the dependent variable, with the goal of modelling the linear relationship between the independent variables and the response variable. The following assumptions were tested: there is a linear relationship between the dependent variables and the independent variables, the predictors are not highly correlated with each other; yi observations are selected independently and randomly from the population; residuals should be normally distributed.

Due to the fact that for the existing context, all linear models poorly described the relations between predictors and dependent variables (low Adj-Rsq values), the current research needed to use a non-linear approach for obtaining reliable predictive models. Even if the MLR models explained a low to medium percentage of the dependent variable variance, the current research presents in Table A1 the MLR models for heavy metals prediction in both muscle and hepatic tissues as a reference for the subsequently RF models. There are many ways to handle non-linearity problems by using the current machine learning methodologies (e.g., polynomial regressions, artificial neural networks, tree-based regressors, ensemble learning, etc.).

When choosing one of these approaches, several factors should be considered: (a) volume of available data, (b) avoiding overfitting, (c) feature importance determination, (d) prediction accuracy, (e) data distribution

Measuring heavy metals concentration in muscle or liver tissue of the aquatic organic organisms is an expensive task in terms of time and financial resources. Thus, the volume of data cannot be expected to be large, therefore, any chosen prediction algorithm, should consider this aspect.

Random Forests (RF), the methodology used for the current research, handles well low volumes of data, performing optimal when a larger number of features are available.

RF represents an ensemble learning method [60]. That involves generating many classifiers/regressors, subsequently aggregating their results by using a boosting [61] or a bagging approach [62]. Boosting involves giving extra weight to points that were incorrectly predicted by earlier predictors, while for bagging, successive trees do not depend on earlier trees, being completely independent. The random forest approach offers an estimator that fits a number of decision trees on different subsamples of the dataset and uses averaging to control overfitting and to improve the predictive accuracy.

During the past six years, the random forest usage has steadily increased. By using Google Trends service, it was possible to collect historic data that was used to visualize the search interest for five prediction related terms: (a) linear regression—one of the most used prediction algorithms, (b) random forest, (c) XGBoost—a regularizing gradient boosting algorithm enforced by a strong community of data scientists [63], (d) CatBoost—one of the newest gradient boosting prediction algorithms [64], (e) prediction model—a generic term used to describe any of the previous mentioned algorithms (Figure 3).

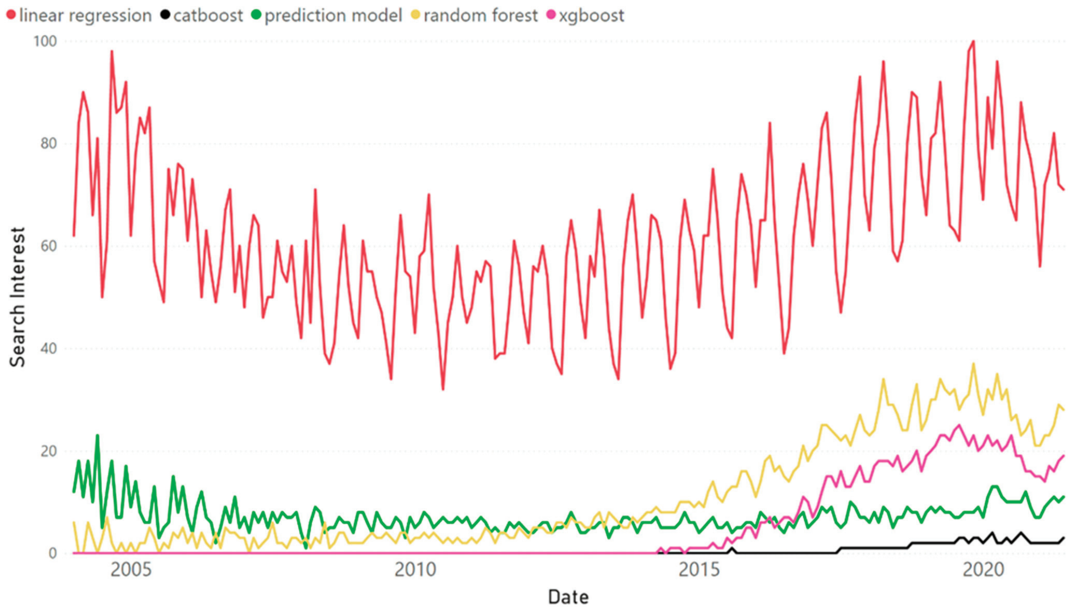

Figure 3. Search interest of various regressions related terms (Source: Google Trends).

As it can be observed in Figure 3, the search interest value for the 'linear regression' term is the highest (which is to be expected due to its age and worldwide popularity). However, both 'random forest' and 'xgboost' terms presents a consistent ascending trend in search popularity. On the other hand, from all the above algorithms, CatBoost is the newest one (released in 2017), hence it is not yet as popular as its counterparts.

In terms of comparison, it was possible, by using the collected data through the Google Trends service, to highlight country level differences for the above search terms. Thus, considering for each country all the above terms, their sum of search percentage value would be 100. For a visualization purpose, the search percentage value of each term for every country allowed several classes definition as follows: (a) six classes for linear regression term—class A with search percentages below 40%, class B with values between 40% and 50%, class C between 50–60%, class D between 60% and 70%, class E between 70% and 80%, class F above 80%, (b) four classes for random forest term—class A with search percentages below 10%, class B with values between 10% and 20%, class C between 20–30%, class D above 40%, (c) four classes for XGBoost term—class A with search percentages below 5%, class B with values between 5% and 10%, class C between 10–15%, class D above 15%, (d) four classes for CatBoost term—class A with search percentages below 2%, class B with values between 2% and 3%, class C between 3–4%, class D above 4%. For the linear regression term, the number of classes needed to be higher because the percentage values (of each country) were spread out on a larger interval.

Thus, clear differences related to the search interest in the above-mentioned search terms can be observed from the Figures A1–A4 between countries. If referring to linear regression term it can be noticed that the highest search interest percentage can be found in the USA, Canada, Australia, Norway or Finland and the lowest values in countries such as Russia, China, France or Spain. Switching to the remaining terms involving non-linear and more recent methodologies, it can be noticed that Europe and Russia display higher search interest percentage values.

Several papers [65–68] described the advantages of using random forest: (a) data normalization is not required, (b) reduced overfitting results, (c) works well with both continuous and categorical variables, (d) works well with a reduced number of samples; (e) data distribution is not relevant.

The RF predictions could be improved (if required) by adjusting several hyperparameters: the maximum depth of the trees), the number of trees in the forest of the model, the minimum number of samples required to be at a leaf node or the minimum number of samples required to split an internal leaf node.

In term of model validation, the prediction methodology used both the root mean square error (RMSE) and the R-square metrics for assessing model's performance. All RF models were fitted using 80% of the data as training dataset. Thus, 20% of the data remained unseen to the models and could be used further on in the testing phase.

In addition to determining all reliable prediction models, another important aspect of the current research was to estimate the independent variables' importance when predicting the dependent one. For linear regression model, it is quite easy to assess the predictors feature importance. For example, after performing feature scaling that would bring all values into the range (0,1), parameter coefficients could be compared to see which one has a higher impact for the overall prediction. Furthermore, for a linear model, the p-value metric could be used to determine the predictors' importance in describing dependent parameter variance, being able to choose this way which one remains in the model. The random forest methodology offers also the possibility of assessing the importance of each predictor in predicting the dependent variable. For this, the 'eli5' Python library was used.

This library computes the parameter feature importance by measuring how the overall score decreases when a feature is not available. Thus, it is possible to rank the predictor variables in terms of relative significance, by calculating the decrease in node impurity weighted by the probability of reaching that node, probability that is calculated by the number of samples that reach the node, divided by the total number of samples [67,69–71]. When the value is high, the feature is more important.

$$n_{ij} = w_j C_j - w_{left(k)} C_{left(j)} - w_{right(j)} C_{right(j)} \tag{2}$$

where: n_{ij} represents the importance of node j; C_j = the impurity value of node j; left($_j$) = child node from left split on node j; right($_j$) = child node from right split on node j; w_j = weighted number of samples reaching node j.

The importance for each feature on a decision tree is calculated according to the following formula:

$$fi_i = \frac{\sum_{j:node\ j\ splits\ on\ feature\ i} ni_j}{\sum_{k \in all\ nodes} ni_k} \tag{3}$$

where: ni_j = the importance of node j; fi_i is the importance of feature i.

The values obtained from the above equation should be normalized ($normfi_j$) to values between 0 and 1 by dividing by the sum of all feature importance values:

$$normfi_i = \frac{\sum_{j \in all\ trees} normfi_{ij}}{T} \tag{4}$$

The feature importance is the average over all the trees. The sum of the feature's importance value on each tree is calculated and divided by the total number of trees:

$$RFfi_i = \frac{\sum_{j \in all\ trees} normfi_{ij}}{T} \tag{5}$$

where: T = total number of trees; $normfi_{ij}$ = normalized feature importance for i in tree j; $RFfi_i$ = the feature i importance, calculated from all the trees in the RF model.

3. Results and Discussion

3.1. Heavy Metals Data Analysis

Heavy metal concentration in the water samples collected from the Danube Delta and the Black Sea registered the following descendent trend: Fe > Cu > Zn > Pb > Cd, whereas in the Danube River the trend was Fe > Zn > Cu > Pb > Cd (Table 1). The highest values were recorded in the analyzed Danube River sector, followed by Black Sea Coast and Danube Delta (Table 1).

Table 1. Heavy metals concentration in the water matrix (μg/L).

Metal	Danube River (DR)			Danube Delta Area (DD)			Black Sea Coast (BS)		
	Min	Max	Median	Min	Max	Median	Min	Max	Median
Cd	0.03	0.10	0.06	0.00	0.02	0.01	0.02	0.08	0.04
Pb	1.27	3.58	2.12	0.50	0.88	0.67	0.50	3.11	1.97
Fe	841.80	1690.00	1330.00	42.70	686.00	428.97	111.70	1960.00	1131.30
Zn	2.30	81.90	20.55	1.90	2.70	2.11	1.00	5.60	2.37
Cu	3.31	7.80	5.10	0.39	2.59	2.27	0.62	6.89	3.68

Several papers [24,72] emphasize the high exposure of the Danube River to pollution since it passes through many industrial zones and receives urban and industrial wastes, as well as agriculture leachate. Therefore, this can explain the high concentrations of heavy metals recorded in the Danube River sampling sector. In addition, the findings emphasize the capacity of Danube Delta to act as a buffer zone for pollutants transported by the Danube.

According to other studies [4,73], the Danube Delta is the largest wetland of the complex system pertaining to the Danube River and forms a complex network of river channels, bays, lakes, sandy banks and numerous marshes that contribute to improving the quality of the Black Sea water, acting as a buffer zone for pollutants in the Danube. Therefore, the analysis of heavy metals in samples collected from the studied aquatic macro-system confirms the existing connections between its components. Fe registers the highest concentration among all analyzed metals, situation which correlates with both technological processes applied in the Galați steel factory and Tulcea alumina refinery (Table 1). In addition, Zn records considerable high concentrations in all the sampling area, which can be due to shipyard activity, namely galvanization processes. The natural presence of metals in the lower sector of Danube River, generated by the bedrock erosion should be taken into consideration also. Depth erosion and vertical erosion is manifested especially in the upper sector of the river due to the presence of stones and gravel. In the middle sector, the riverbed is represented by grit and gravel and horizontal erosion is manifested. The lower sector of the river is characterized by sand and very fine gravel and horizontal erosion occurs also. In this sector, the river substrate is sand, frequently interspersed with mud, organic sludge, silt, loam and clay. In small percentages gravel is present in fine to medium size.

According to [74] the erosion in this area is moderate. The grain size along the Sf. Gheorghe branch has been previously characterized as fine to median sands and silts [75]. The authors concluded in their study that the highest levels of heavy metals in the Danube River sediments, between Bazias and flowing mouth in the Black Sea, are associated in the areas where mining activities are conducted (km 1049–km 995). As well, cluster and PCA analysis highlighted the fact that the concentrations of Cd, Cu, Pb and Zn in the branches of Danube River (Chilia, Sulina and Sf. Gheorghe) are influenced by anthropogenic activities, whereas Cr and Ni concentrations are influenced mainly by the presence of rocks naturally rich in these metals in the Romanian sector of Danube River [76].

The median iron concentration in rivers has been reported to be 700 μg/L [77]. However, the concentrations reported within the present study are significantly much higher.

Hence, it can be stated that the bedrock of Danube River in the lower sector generates moderate concentrations of heavy metals and that abnormal high values are related to human activities. Similar results regarding Fe concentration in Danube River related to anthropogenic activities was previously reported in [54].

The data related to heavy metal concentration in water matrix are not considered proper to be included in the analytical framework prediction models since they could be highly variable among the Danube River basin during a short period of time, depending on a series of environmental factors such as water flow, water temperature, water level, occasional waste discharges.

Therefore, the data presented in Table 1 has the purpose of characterizing the environmental background of the analytical framework.

However, use of fish as bioindicators elaborating an analytical framework based on prediction models is more reliable since fish accumulate the metal concentrations during a longer time-period and due to their mobility, they can characterize a larger surface area.

The accumulation trend of heavy metals in the muscle tissue registered the following descending order: Fe > Zn > Cu > Cd > Pb in fish from Danube River, Danube Delta, respectively, and Fe > Zn > Cu > Pb > Cd in fish from the Black Sea (Table 2). In the case of the hepatic tissue, the accumulation tendency of heavy metals caught in the Danube River registered the same trend as for the muscle tissue (Table 2). Regarding the fish caught from the Danube Delta and the Black Sea, the accumulation trend of metals in the hepatic tissue was Fe > Zn > Cu > Pb > Cd, Fe > Zn > Cu > Cd > Pb (Table 2). Fe was the most abundant metal in both muscle and hepatic tissue. Nevertheless, the values registered for this element in the liver were at least 10 times higher compared to the values registered in the muscle. This fact is expected due to the liver's implication in the synthesis of red blood cells [41]. The least abundant metals detected in the muscle and hepatic tissues were Cd and Pb. However, these elements can induce toxic effects on fish even in trace amounts. To avoid human intoxication with heavy metals due to fish consumption, the European legislation [78] sets a maximum permitted level of Cd (0.05 μg/g) and Pb (0.3 μg/g) concentration in fish muscle. In the entire studied macro-system, 25 of the total analyzed fish specimens registered values of Cd concentration in the muscle tissue above the maximum permitted level. In natural aquatic ecosystems, metals are not equally distributed, instead they accumulate in certain "hot spots", influenced by hydraulics and water physico-chemical parameters. Thus, continuous monitoring of the water quality is needed to identify possible polluted sites.

By analyzing the differences between fish muscle tissue and fish hepatic tissue (Table 3), it can be observed that significant differences ($p < 0.05$) are recorded between DR and DD for heavy metal concentrations considered within this study. In addition, by comparing DR versus BS, it can be observed that Cd is the only metal which registered a statistically significant difference ($p < 0.05$). Furthermore, by comparing BS and DD, it was observed that Pb, Fe, Zn and Cu concentrations registered statistically significant differences ($p < 0.05$) (Table 3). In terms of heavy metals from the hepatic matrix, statistically significant differences ($p < 0.05$) were recorded for Pb, Cu and Fe between all the analyzed areas and, for Cd between DR and BS, respectively, DD and Zn between DD and DR, respectively, BS (Table 3).

3.2. Enzymatic and Non-Enzymatic Biomarkers Determination

All OS biomarkers register higher values in fish hepatic tissue matrix, compared to muscle tissue, except MDA in DD sampling area (Table 4). However, CAT, SOD and GPx registered the highest values in fish muscle tissues at DR, followed by DD and BS coast, while MDA records maximum values at DD, followed by BS coast and DR (Table 4). According to other studies [79] it can be stated that increased MDA levels are correlated to decreased SOD activity, under the context of heavy metals exposure. The SOD and MDA are the most sensitive OS biomarkers to metal exposure, followed by CAT and GPx. The hepatic matrix is first affected by pollution; thus, it can be used as a main indicator of environmental pollution occurrence. The highest values of SOD and GPx in hepatic matrix are recorded at DR, followed by DD and BS, while CAT registers the highest values in DR, followed by BS and DD (Table 4). This can be due to the fact that in the DR water, the highest values in case of the studied metals were registered, compared to DD and BS. The MDA hepatic values were in accordance with Cd values (Table 2) and revealed the highest concentrations in DD and DR (Table 4).

Table 2. Descriptive statistics for heavy metal concentration in both fish muscle tissues matrix and fish hepatic tissue matrix (μg/g fresh weight).

Sampling Matrix	Variable	Mean	SE Mean	StDev	Coef. Var.	Min.	Q1	Median	Q3	Max.	Range
BS Coast											
Fish muscle tissues matrix	Cd	0.03	0.00	0.01	47.65	0.02	0.02	0.02	0.03	0.06	0.04
	Pb	0.02	0.00	0.01	53.75	0.01	0.01	0.02	0.03	0.07	0.06
	Fe	13.14	0.86	5.68	43.20	5.06	6.88	12.82	17.65	22.89	17.83
	Zn	6.21	0.33	2.20	35.46	3.11	4.43	5.84	7.80	11.88	8.77
	Cu	1.04	0.19	1.29	124.82	0.05	0.25	0.51	0.68	4.55	4.50
Fish hepatic tissue matrix	Cd	0.26	0.04	0.26	102.34	0.05	0.11	0.13	0.20	0.91	0.86
	Pb	0.04	0.00	0.02	40.96	0.02	0.03	0.03	0.04	0.08	0.06
	Fe	656.50	54.41	360.91	54.97	91.82	167.13	737.19	915.52	1195.70	1103.88
	Zn	29.18	1.17	7.79	26.70	15.62	22.73	26.74	36.28	44.83	29.21
	Cu	9.68	2.35	15.58	160.85	1.16	1.70	1.89	2.35	51.36	50.20
DD											
Fish muscle tissues matrix	Cd	0.03	0.01	0.05	186.03	0.00	0.00	0.01	0.02	0.22	0.22
	Pb	0.02	0.00	0.03	156.72	0.00	0.01	0.01	0.02	0.23	0.23
	Fe	20.67	1.54	13.44	65.06	7.10	11.15	15.95	21.94	53.09	45.99
	Zn	18.41	1.37	11.91	64.71	4.09	7.36	14.19	29.25	45.77	41.68
	Cu	2.05	0.19	1.68	81.59	0.31	1.10	1.43	2.98	5.85	5.54
Fish hepatic tissue matrix	Cd	0.13	0.04	0.32	235.88	0.00	0.00	0.03	0.07	1.47	1.47
	Pb	0.07	0.01	0.08	104.04	0.01	0.01	0.03	0.14	0.36	0.35
	Fe	367.96	16.97	146.95	39.94	146.90	245.63	318.27	526.10	584.62	437.73
	Zn	58.05	5.25	45.77	78.86	11.71	24.95	37.99	73.52	199.34	187.63
	Cu	4.29	0.29	2.49	58.10	1.09	2.06	3.66	6.16	10.05	8.96
DR											
Fish muscle tissues matrix	Cd	0.04	0.01	0.05	111.07	0.02	0.02	0.02	0.03	0.19	0.18
	Pb	0.01	0.00	0.01	54.87	0.00	0.01	0.01	0.02	0.03	0.03
	Fe	12.11	1.46	9.02	74.44	3.10	4.56	7.15	22.68	31.33	28.23
	Zn	7.53	0.98	6.01	79.86	3.23	3.90	5.03	7.95	22.59	19.36
	Cu	0.55	0.08	0.48	87.51	0.12	0.23	0.38	0.63	1.76	1.64
Fish hepatic tissue matrix	Cd	0.28	0.04	0.24	85.33	0.08	0.11	0.21	0.34	1.04	0.96
	Pb	0.06	0.01	0.08	134.52	0.00	0.02	0.03	0.05	0.30	0.30
	Fe	98.17	7.72	47.60	48.48	42.00	54.37	85.17	144.31	182.56	140.55
	Zn	30.62	3.28	20.21	66.00	11.92	19.94	23.72	30.37	83.88	71.96
	Cu	4.40	0.67	4.15	94.48	0.90	1.04	2.59	6.70	15.24	14.34

Table 3. The *p*-value of Kruskal-Wallis Test for all analyzed metals elements in both sample matrix.

Kruskal-Wallis Test	Sampling Area	Fish Muscle Tissues Matrix					Fish Hepatic Tissue Matrix				
		Cd	Pb	Fe	Zn	Cu	Cd	Pb	Fe	Zn	Cu
Independent-Samples KW Test (*p*-value)		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.960	<0.001	<0.001	0.122
Pairwise Comparisons (*p*-value)	DR-BS	<0.001	0.457	0.199	0.827	0.219	<0.001	-	<0.001	0.209	-
	DR-DD	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	-
	BS-DD	0.183	0.008	0.011	<0.001	<0.001	0.315	-	0.004	0.003	-

Table 4. Descriptive statistics for OS biomarkers (CAT (U/mg protein), SOD (U/mg protein), GPx (U/mg protein) and MDA (nmol/mg protein) in both fish muscle tissues matrix and fish hepatic tissues matrix.

Sampling Matrix	Variable	Mean	SE Mean	StDev	Coef. Var.	Min.	Q1	Median	Q3	Max.	Range
BS Coast											
Fish muscle tissues matrix	CAT	71.42	3.66	24.27	33.99	30.98	50.20	81.11	88.78	107.71	76.73
	SOD	14.60	0.82	5.42	37.09	7.08	9.68	13.46	19.53	24.56	17.48
	GPx	1.36	0.07	0.46	34.12	0.67	0.96	1.25	1.92	2.08	1.40
	MDA	147.82	2.31	15.34	10.38	110.68	135.59	148.55	160.66	180.00	69.32
Fish hepatic tissue matrix	CAT	108.03	4.61	30.61	28.34	62.22	85.91	101.62	142.72	157.48	95.26
	SOD	20.50	0.93	6.14	29.97	11.18	15.08	19.84	27.54	29.38	18.19
	GPx	1.88	0.11	0.72	38.18	0.94	1.32	1.63	2.77	2.95	2.01
	MDA	154.82	1.38	9.13	5.90	140.07	147.07	154.69	162.38	169.46	29.39
DD											
Fish muscle tissues matrix	CAT	74.74	3.93	34.25	45.83	33.20	44.79	73.39	107.09	144.39	111.19
	SOD	16.03	0.89	7.74	48.31	6.01	8.27	17.89	22.81	29.52	23.51
	GPx	1.58	0.09	0.79	50.09	0.60	0.86	1.61	2.29	3.08	2.48
	MDA	195.70	4.19	36.51	18.66	132.08	166.50	201.03	221.55	286.35	154.27
Fish hepatic tissue matrix	CAT	95.48	4.12	35.91	37.61	45.06	61.61	94.16	131.34	160.86	115.79
	SOD	21.58	0.87	7.55	34.99	12.03	14.39	23.24	28.48	33.74	21.71
	GPx	1.91	0.10	0.84	43.84	0.92	1.10	2.02	2.93	3.13	2.21
	MDA	176.03	3.22	28.09	15.96	140.36	149.93	166.15	207.20	224.60	84.24
DR											
Fish muscle tissues matrix	CAT	97.64	6.18	38.08	39.00	35.47	58.17	109.63	120.49	164.06	128.59
	SOD	21.33	1.51	9.31	43.67	7.72	12.86	22.91	29.02	36.70	28.98
	GPx	2.15	0.14	0.84	39.29	0.81	1.43	2.42	2.83	3.31	2.50
	MDA	166.85	8.13	50.11	30.03	110.35	128.26	140.20	201.56	278.13	167.78
Fish hepatic tissue matrix	CAT	135.22	8.18	50.40	37.28	58.10	92.50	150.88	181.52	191.61	133.51
	SOD	29.17	1.76	10.82	37.10	12.66	19.09	30.12	38.58	44.00	31.34
	GPx	2.90	0.17	1.04	35.85	1.30	1.95	3.35	3.81	4.17	2.87
	MDA	169.42	6.83	42.07	24.83	120.99	127.68	168.01	207.99	230.81	109.82

Significant differences ($p < 0.05$) are recorded between DD and DR, respectively, BS, when analyzing both fish muscle and fish hepatic tissue matrix in terms of all OS biomarkers considered in the present study (Table 5). However, not significant differences were recorded between DR and BS ($p > 0.05$) in terms of CAT, SOD, GPx and MDA, in both analyzed sample matrix (Table 5).

Table 5. The *p*-value of Kruskal-Wallis Test for all analyzed OS biomarkers in both sample matrix.

Kruskal-Wallis Test	Sampling Area	Fish Muscle Tissues Matrix				Fish Hepatic Tissue Matrix			
		CAT	SOD	GPx	MDA	CAT	SOD	GPx	MDA
Independent-Samples KW Test (*p*-value)		<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	0.004
Pairwise Comparisons (*p*-value)	DR-BS	0.384	0.629	0.423	0.238	0.064	0.717	0.717	0.456
	DR-DD	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
	BS-DD	0.002	0.002	<0.001	<0.001	0.023	<0.001	<0.001	0.033

3.3. Pollution Index in the Analysed Area

The pollution index was calculated in order to better establish the experimental backgrounds for each study area. However, in order to calculate the pollution index, based on Romanian Regulation Order no. 161/2006 (Table 6), the study area was associated to a certain water quality class. According to the Romanian Regulation Order no. 161/2006, the quality class I is the best ranking, while quality class V is the worse. Thus, in terms of Cd concentration in water, both BS and DD are associated to I quality class, while DR is within the second class. Considering Pb, Zn and Cu, it can be stated that all analyzed area are associated to first water quality class. However, the Fe concentration places all analyzed areas in the fifth water quality class.

Table 6. The quality of surface waters, according to Romanian Regulation Order no. 161/2006.

Quality Class	Cd $\mu g\ L^{-1}$	Pb $\mu g\ L^{-1}$	Fe $\mu g\ L^{-1}$	Cu $\mu g\ L^{-1}$	Zn $\mu g\ L^{-1}$
I	0.5	5.0	0.3	29.0	100.0
II	1.0	10.0	0.5	30.0	200.0
III	2.0	25.0	1.0	50.0	500.0
IV	5.0	50.0	2.0	100.0	1000.0
V	higher values than class IV				

The pollution index points out a seriously affected aquatic environment by the presence of Fe in the entire macro-system Danube River-Danube Delta-Black Sea (Table 7). As well, Fe concentration in the water column is highly above the concentration specific to the quality class V for surface waters, mentioned in the Order 161/2006 by the Romanian Government (Table 6). In case of Zn accumulation in the water, a strongly affected aquatic environment was identified in the Danube River (Table 7). The presence of Fe and Zn in high concentrations is due to the intense naval activities conducted in the Lower sector of the river.

Table 7. Pollution index in the study area.

Studied Ecosystem	Pollution Index				
	Cd	Pb	Fe	Zn	Cu
Danube River	0.10	0.32	4887.00	4.49	0.13
Danube Delta	0.02	0.09	1529.00	0.10	0.04
Black Sea Coast	0.06	0.27	2618.00	0.02	0.09

The values for the pollution index registered for the rest of the analyzed metals manifest no effect on the entire studied macro-system.

3.4. The Correlation Matrix

According to previous studies [3], the correlation matrix can be used as a tool to summarize the linear relationships existent in a dataset, as well as for identifying strong and relevant relationships that could be further modelled. In present study, all data related to heavy metals and OS biomarkers in both muscle tissue and hepatic tissue matrix were processed using Python NumPy library. According to other studies [80], weak positive and negative correlations would be considered in the range of $0.1 \div 0.3/-0.1 \div -0.3$, moderate positive and negative correlation would range within $0.3 \div 0.5/0.3 \div 0.5$, and strong positive and negative correlation between $0.5 \div 1.0/0.5 \div 1.0$. However other studies which performed matrix correlation for heavy metals in different fish tissues considered as strong positive/negative all linear correlation with coefficient values over $+0.7/-0.7$. In addition, the correlation matrix is useful in analytical framework elaboration since in order to generate the prediction models, independent variables are supposed to be independent. According to similar studies [3], if the degree of correlation between variables is high enough, problems can arise when fitting the model and interpreting the results.

Positive significant correlations at BS are recorded within all OS biomarkers from both hepatic and muscle tissues (between 0.8–1). In addition, related heavy metals, Fe in muscle tissues is positively correlated with Cu (0.6) and Cd (0.6) in muscle, Fe (0.6), Cu (0.6) and Cd (0.7) in hepatic tissues. The Zn in muscle is positively correlated with Cd in both muscle and hepatic tissues (0.6) and negatively correlated with SOD (−0.6) in muscle and both CAT (−0.7) and GPx (−0.6) in hepatic tissue. In addition, Cd in muscle was found to be positively correlated with Cu (0.9) and Cd (0.9) in hepatic tissues, while Cu in muscle is strongly correlated with Cu (0.9) and Pb (0.7) in hepatic tissues.

In case of DD, positive significant correlations are recorded within all OS biomarkers from both hepatic and muscle tissues (between 0.7–0.9). In addition, related heavy metals concentration, the only strong positive correlation is observed between Zn in muscle and hepatic tissues (0.8). However, Pb in hepatic tissues is strongly correlated with CAT (0.7), SOD (0.8), GPx (0.7) and MDA (0.7) in hepatic tissues.

The correlation matrix revealed positive correlations between Cu in muscle and Cu (0.9), Pb (0.7) and Cd (0.9) in hepatic tissues, as well as Cd in muscle tissues (0.9). Some studies have emphasized that Cu enters the fish body mainly via food [81,82]. At the level of the intestine epithelium, Cu is transferred in the blood stream and then transported to the liver, due to its implication in organism detoxification. The presence of Cu in the liver is also related to the natural protein binding such as metallothioneins [83]. Even more, besides its storage purpose, the liver acts as a redistributor of metals to other organs, such as the muscle [83]. This phenomenon could stand as a possible explanation for the positive correlation registered between the Cu concentration in fish liver and fish muscle. This fact was confirmed in [84], where the authors highlighted a positive correlation in the concentration of Pb between the liver and muscle tissues. As well, the positive correlation between Cu and Cd in fish tissue (gonads) was previously observed in [85] in *Alosa braschinkowi*. Nevertheless, the correlation between metals in the fish body is highly dependent on the physiological processes within the organism, the presence of other metals and interactions between them [3].

In addition, Cd in muscle tissues is positively correlated with Cu (0.9), Pb (0.6) and Cd (0.9) in hepatic tissues, while Cd in hepatic tissue correlates positively with Cu (0.9) and Pb (0.6) determined from the same hepatic tissues. However, the Fe in hepatic tissue is the only elements which strongly correlate, positively, with OS biomarkers, more precisely, with MDA from hepatic tissues (0.8).

3.5. The Multi Linear Regression (MLR) Models

In order to generate predictive models between heavy metals and OS biomarkers from both hepatic and muscle tissues matrix, MLR was used. Therefore, the resulted equations are presented in Table A1. However, from a total of 29 MLR models, only 2 models record good performance. Both models help predicting the Fe in hepatic tissues, at BS and DR area, and explain 88.00%, respectively, 88.80% of the variance of this parameter. Therefore, the most important independent variable for the prediction of Fe concentration in hepatic fish tissues at both BS and DR are MDA, followed by CAT and SOD from hepatic tissue (Table A1).

It can be observed that MLR methods do not offer a substantial feed-back in order to elaborate an analytical framework aimed to predict the heavy metals concentration in fish tissues, based on OS biomarkers. In the literature, MLR were found useful for predicting micro-elements, based on macro-elements in fish tissues [3]. In addition, other authors manage to apply MLR for predicting elements in soil and crops [86], different water bodies [87] or different aquatic animals as mollusks [88].

Therefore, since MLR did not perform as expected, in order to accomplish the aim of this present study, RF based models were applied.

3.6. Non-Linear Models, Based on Random Forest (RF) Algorithm

According to other studies [3], non-linear models are tested for determining possible models among the parameters that did not register linear correlation between each other. Therefore, in the present study, after applying the RF technique on all the dataset, a number of 30 RF models were identified (Table 8), 10 models for each of the studied region (BS coast, DD and DR), all with high prediction accuracy (Figures A5–A34). The weight of all independent variables was identified after running the feature importance algorithm in order to determine the importance of a specific OS biomarker parameter in determining the heavy metal dependent variable value (Table 8).

The RF models for BS coast revealed that the prediction of Cd concentration in hepatic tissues is mostly based on MDA and CAT in hepatic tissues, while Cd in muscle tissues is influenced by GPX in both muscle and hepatic tissues and MDA in hepatic tissues. The prediction of Pb in hepatic tissues is significantly depended by MDA and GPx from hepatic tissues and SOD from muscle tissues, respectively, while Pb prediction in muscle tissues is mostly dependent by GPX in both hepatic and muscle tissues. The prediction of Fe in hepatic tissues depends on MDA and GPx from hepatic tissue, while Fe in muscle tissue is mostly dependent on GPx in hepatic tissues and CAT in muscle tissues. For Zn prediction in hepatic tissue, SOD hepatic and MDA muscle and hepatic are most significant independent parameters that must be considered, while for Zn prediction in muscle tissues, CAT hepatic and both GPX, hepatic and muscle, must be considered as most important. The Cu prediction in both muscle and hepatic tissues emphasizes MDA hepatic and SOD muscle, respectively, CAT muscle as most important parameters.

The analysis of RF models registered based on DD database revealed that Cd concentration in hepatic tissues is mostly based on CAT and SOD in muscle tissues, while Cd in muscle tissues is influenced by CAT and GPX in muscle, respectively, MDA in hepatic tissues. The prediction of Pb in hepatic tissues is significantly depended by MDA and CAT from hepatic tissues, while Pb prediction in muscle tissues is mostly dependent by GPX and MDA in muscle tissues. The prediction of Fe in hepatic tissues depends on CAT and GPx from muscle tissue, while Fe in muscle tissue is mostly dependent on SOD and GPx in hepatic tissues. For Zn prediction in hepatic tissue, CAT and SOD in muscle are most significant independent parameters that must be considered, while for Zn prediction in muscle tissues, both GPX and CAT in hepatic tissues must be considered as most important. The Cu prediction in both muscle and hepatic tissues emphasizes MDA and CAT in hepatic tissues, respectively, CAT in muscle and GPX in hepatic tissues as most important parameters.

Table 8. Random forest models for predicting heavy metals in both muscle and hepatic tissues.

Dependent Variable	Predictors and Weights	RMSE	R-sq.
	BS Coast		
Zn muscle	MDA hepatic (0.08); MDA muscle (0.05); CAT hepatic (0.31); CAT muscle (0.06); SOD hepatic (0.10); SOD muscle (0.10); GPx hepatic (0.12); GPx muscle (0.13).	0.14	84.00%
Zn hepatic	MDA hepatic (0.19); MDA muscle (0.22); CAT hepatic (0.10); CAT muscle (0.11); SOD hepatic (0.23); SOD muscle (0.02); GPx hepatic (0.13); GPx muscle (0.17).	0.21	75.00%
Fe muscle	MDA hepatic (0.13); MDA muscle (0.09); CAT hepatic (0.02); CAT muscle (0.19); SOD hepatic (0.11); SOD muscle (0.01); GPx hepatic (0.64); GPx muscle (0.02).	0.23	83.00%
Fe hepatic	MDA hepatic (0.75); MDA muscle (<0.01); CAT hepatic (0.03); CAT muscle (0.01); SOD hepatic (0.04); SOD muscle (0.01); GPx hepatic (0.12); GPx muscle (0.01).	0.75	98.00%
Cd muscle	MDA hepatic (0.15); MDA muscle (0.02); CAT hepatic (0.03); CAT muscle (0.07); SOD hepatic (0.08); SOD muscle (0.05); GPx hepatic (0.27); GPx muscle (0.17).	0.08	93.00%
Cd hepatic	MDA hepatic (0.43); MDA muscle (0.01); CAT hepatic (0.11); CAT muscle (0.08); SOD hepatic (0.07); SOD muscle (0.08); GPx hepatic (0.05); GPx muscle (0.06).	0.07	96.00%
Pb muscle	MDA hepatic (0.09); MDA muscle (0.01); CAT hepatic (0.10); CAT muscle (0.02); SOD hepatic (0.03); SOD muscle (0.02); GPx hepatic (0.33); GPx muscle (0.29).	0.11	82.00%
Pb hepatic	MDA hepatic (1.15); MDA muscle (0.03); CAT hepatic (0.03); CAT muscle (0.01); SOD hepatic (0.14); SOD muscle (0.16); GPx hepatic (0.16); GPx muscle (0.03).	0.27	68.00%
Cu muscle	MDA hepatic (0.24); MDA muscle (<0.01); CAT hepatic (0.08); CAT muscle (0.11); SOD hepatic (0.07); SOD muscle (0.08); GPx hepatic (0.04); GPx muscle (0.04).	0.11	96.00%
Cu hepatic	MDA hepatic (0.61); MDA muscle (0.01); CAT hepatic (0.08); CAT muscle (0.08); SOD hepatic (0.04); SOD muscle (0.11); GPx hepatic (0.08); GPx muscle (0.06).	0.07	95.00%
	DD		
Zn muscle	MDA hepatic (0.09); MDA muscle (0.08); CAT hepatic (0.40); CAT muscle (0.05); SOD hepatic (0.08); SOD muscle (0.05); GPx hepatic (0.47); GPx muscle (0.02).	0.18	82.00%
Zn hepatic	MDA hepatic (0.04); MDA muscle (0.02); CAT hepatic (0.06); CAT muscle (0.48); SOD hepatic (0.09); SOD muscle (0.34); GPx hepatic (0.10); GPx muscle (0.04).	0.13	86.00%
Fe muscle	MDA hepatic (0.12); MDA muscle (0.17); CAT hepatic (0.07); CAT muscle (0.09); SOD hepatic (0.22); SOD muscle (0.15); GPx hepatic (0.20); GPx muscle (0.12).	0.17	80.00%
Fe hepatic	MDA hepatic (0.04); MDA muscle (0.01); CAT hepatic (0.12); CAT muscle (0.25); SOD hepatic (0.02); SOD muscle (0.09); GPx hepatic (0.11); GPx muscle (0.24).	0.20	87.00%
Cd muscle	MDA hepatic (0.19); MDA muscle (0.05); CAT hepatic (0.04); CAT muscle (0.37); SOD hepatic (0.04); SOD muscle (0.01); GPx hepatic (0.13); GPx muscle (0.17).	0.24	66.00%
Cd hepatic	MDA hepatic (0.02); MDA muscle (0.12) CAT hepatic (0.04); CAT muscle (0.51); SOD hepatic (0.11); SOD muscle (0.44); GPx hepatic (0.03); GPx muscle (0.09).	0.18	73.00%
Pb muscle	MDA hepatic (0.09) MDA muscle (0.35) CAT hepatic (0.02); CAT muscle (0.09); SOD hepatic (0.03); SOD muscle (0.06); GPx hepatic (0.03); GPx muscle (0.53).	0.07	86.00%
Pb hepatic	MDA hepatic (0.67); MDA muscle (0.01) CAT hepatic (0.12); CAT muscle (0.02); SOD hepatic (0.09); SOD muscle (0.03); GPx hepatic (0.06); GPx muscle (0.03).	0.13	76.00%
Cu muscle	MDA hepatic (0.32); MDA muscle (0.09); CAT hepatic (0.17); CAT muscle (0.11); SOD hepatic (0.08); SOD muscle (0.08); GPx hepatic (0.14); GPx muscle (0.12).	0.24	71.00%
Cu hepatic	MDA hepatic (0.09); MDA muscle (0.12); CAT hepatic (0.14); CAT muscle (0.30); SOD hepatic (0.10); SOD muscle (0.11); GPx hepatic (0.16); GPx muscle (0.08).	0.23	69.00%
	DR		
Zn muscle	MDA hepatic (0.20); MDA muscle (0.92); CAT hepatic (<0.01); CAT muscle (<0.01); SOD hepatic (0.01); SOD muscle (0.01); GPx hepatic (<0.01); GPx muscle (<0.01).	0.05	97.00%
Zn hepatic	MDA hepatic (0.21); MDA muscle (0.86); CAT hepatic (<0.01); CAT muscle (0.01); SOD hepatic (0.01); SOD muscle (0.01); GPx hepatic (<0.01); GPx muscle (0.01).	0.10	95.00%

Table 8. Cont.

Dependent Variable	Predictors and Weights	RMSE	R-sq.
Fe muscle	MDA hepatic (0.08); MDA muscle (0.04); CAT hepatic (0.16); CAT muscle (0.01); SOD hepatic (0.02); SOD muscle (0.10); GPx hepatic (0.01); GPx muscle (0.01).	0.12	93.00%
Fe hepatic	MDA hepatic (0.99); MDA muscle (0.10) CAT hepatic (<0.01); CAT muscle (0.01); SOD hepatic (0.08); SOD muscle (<0.01); GPx hepatic (0.01); GPx muscle (<0.01).	0.10	96.00%
Cd muscle	MDA hepatic (0.06); MDA muscle (1.32); CAT hepatic (<0.01); CAT muscle (<0.01); SOD hepatic (0.01); SOD muscle (<0.01); GPx hepatic (0.01); GPx muscle (<0.01).	0.10	94.00%
Cd hepatic	MDA hepatic (0.04); MDA muscle (1.03); CAT hepatic (0.02); CAT muscle (0.02); SOD hepatic (0.05); SOD muscle (0.02); GPx hepatic (0.06); GPx muscle (0.01).	0.09	90.00%
Pb muscle	MDA hepatic (0.02); MDA muscle (0.03); CAT hepatic (0.15); CAT muscle (0.04); SOD hepatic (0.09); SOD muscle (0.06); GPx hepatic (0.09); GPx muscle (0.20).	0.16	88.00%
Pb hepatic	MDA hepatic (0.04); MDA muscle (0.17); CAT hepatic (0.10); CAT muscle (0.01); SOD hepatic (0.03); SOD muscle (0.06); GPx hepatic (0.08); GPx muscle (0.11).	0.02	98.00%
Cu muscle	MDA hepatic (0.08); MDA muscle (1.16); CAT hepatic (0.01); CAT muscle (0.01); SOD hepatic (0.01); SOD muscle (0.01); GPx hepatic (0.02); GPx muscle (0.01).	0.15	92.00%
Cu hepatic	MDA hepatic (0.21); MDA muscle (0.01); CAT hepatic (0.08); CAT muscle (0.06); SOD hepatic (0.09); SOD muscle (0.04); GPx hepatic (0.07); GPx muscle (0.05).	0.24	81.00%

The analyzed database from DR region reveals that Cd concentration in hepatic tissues is mostly based on MDA in muscle tissues, followed by GPx and SOD in hepatic tissues, while Cd in muscle tissues is influenced by MDA in both analyzed tissues. The prediction of Pb in hepatic tissues is significantly depended by MDA and GPx from muscle tissues, while Pb prediction in muscle tissues is mostly dependent by GPX in muscle tissues and CAT in hepatic tissues. The prediction of Fe in hepatic tissues depends on MDA from both analyzed tissues, while Fe in muscle tissue is mostly dependent MDA and CAT in hepatic tissues. For both Zn predictions in hepatic and muscle tissues, the MDA in both in muscle and hepatic tissues are most significant independent parameters that must be considered. The Cu prediction in hepatic tissues emphasizes MDA, followed by SOD, CAT and GPx in hepatic tissues as most important parameters, while Cu in muscle can be mostly predicted by considering MDA in both analyzed tissues.

Random forest represents a good alternative to linear regression when the observed phenomenon is not linear. It produces reliable results, works well on both small and large datasets and it also creates estimates in case of missing data. Still, one of the major challenges comes from the fact that, at times, random forests are not able to extrapolate well over previously unseen data. The value in the leaves is calculated as an average of n observations. This approach improves the algorithm's accuracy, reduce the over-fitting, but it can lead to the extrapolation issue, where the predicted values (for previously unseen data) will not be outside the training set values for the target variable. This issue can be minimized by increasing the number of samples in the training dataset, allowing the algorithm to train on a wider data interval. For the current research context, as the number of samples in the dataset is not high, the extrapolation problem could lower the accuracy of the RF models. However, by adding new data to the dataset, after performing new analysis, would mitigate this issue. The Danube River Basin Management Plan (DRBMP) targets the monitoring of the following metals: silver, bismuth, arsenic, cadmium, cobalt, chromium, copper, manganese, nickel, lead, rubidium, antimony, selenium, tin, thallium, uranium, vanadium, tungsten and zinc. The present study can support DRBMP through the effective prediction of metals in the muscle tissue, based on the prediction metrics performance. Therefore, 3 categories of heavy metals can be identified as it follows: 1st category (R-sq between 70.00–80.00%) includes only Cu, 2nd category (R-sq between 80.00–90.00%) includes Zn and Pb, 3rd category (R-sq between 90.00–100.00%) includes Cd and Zn. Therefore, in order to quantify the importance of OS biomarkers for predicting the heavy metals concentration in both fish muscle and hepatic tissues, weight level of each predictor was evaluated and presented in Table 9.

Table 9. Feature importance of elements in all Random Forest (RF) models from current study.

Predictor	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight 6	Weight 7	Weight 8
				BS Coast				
CAT muscle	0	2	2	0	1	2	2	1
CAT hepatic	1	1	1	3	0	0	3	0
MDA muscle	0	1	0	0	1	1	0	7
MDA hepatic	5	0	3	1	0	1	0	0
SOD muscle	0	1	2	2	0	2	1	2
SOD hepatic	1	0	1	3	4	0	1	0
GPx muscle	0	3	0	1	2	3	1	0
GPx hepatic	3	2	1	0	2	1	1	0
				DD				
CAT muscle	5	0	0	1	1	1	2	0
CAT hepatic	0	3	1	0	1	2	0	3
MDA muscle	0	1	2	1	2	1	0	3
MDA hepatic	2	1	2	0	0	2	2	1
SOD muscle	0	2	0	0	4	0	1	2
SOD hepatic	1	0	1	4	0	2	3	0
GPx muscle	1	1	1	1	2	2	0	2
GPx hepatic	1	2	2	3		00	2	0
				DR				
CAT muscle	0	0	0	1	4	1	2	2
CAT hepatic	0	2	2	0	1	2	2	1
MDA muscle	6	1	0	1	0	0	1	1
MDA hepatic	3	4	0	1	0	1	0	1
SOD muscle	0	0	1	3	4	1	1	0
SOD hepatic	0	1	5	1	1	0	1	1
GPx muscle	1	1	0	0	0	3	3	2
GPx hepatic	0	1	2	3	1	1	0	2

The analysis revealed in Table 9 emphasizes that MDA in hepatic tissue is the most important independent variable for predicting heavy metals in fish muscle and tissues at BS coast, followed by GPx in both hepatic and muscle tissues. The RF analytical framework revealed that CAT in muscle tissue, respectively, MDA and GPx in hepatic tissues are most common predictors for determining the heavy metals concentration in both muscle and hepatic tissues, in DD area (Table 9). For DR, MDA in muscle, followed by MDA in hepatic tissue are the main predictors in RF analysis (Table 9).

The presence of environmental pollutants can generate increased OS in fish and the main enzymes that mitigate the negative effects of this process are SOD, CAT and GPx. The SOD triggers ROS destruction by catalyzing the dismutation of O_2^- into H_2O_2, which CAT and GPx further reduces into H_2O and O_2 [21]. The GPx is the most important peroxidase and holds the essential role for erythrocyte protection against H_2O_2. The antioxidant defense system can be more intense in the liver, due to the occurrence of several oxidative reactions and ROS generation in this organ. Ratn et al. [89] revealed in their study a positive correlation between SOD and CAT activity in the liver of *Channa punctatus* and Zn bioaccumulation in the same organ. According to the pollution index calculated in this study, the concentration of Zn strongly affects the aquatic ecosystems of Danube River and, thus, induced OS to the resident biota. Table 10 presents centralized data related to OS biomarkers in different fish species and heavy metals in water/liver samples, according to different studies. Mohanty with co-authors [21] reported in their study a more intense activity of SOD and CAT in the muscle, specifically hepatic (SOD between 2–3 U/mg protein, respectively, 12 U/mg protein; CAT between 100–150 nkat mg protein, respectively, between 10,000–15,000 nkat/mg protein) tissues of *Notopterus notopterus* specimen collected from a polluted site of the Mahanadi river, in India, compared to a specimen collected from a non-polluted site. This phenomenon is also confirmed in the present study through higher enzymatic activity in the tissues of fish collected from Danube River, which is a seriously affected aquatic environment, according to the pollution index.

Table 10. OS biomarkers in different fish species and heavy metals in water/liver samples, according to different authors.

			OS Biomarkers in Liver Samples				Metals in Water * and Liver ** Samples				
Reference	Fish Species	Sampling Location	CAT	SOD	GPx	MDA	Cd	Pb	Fe	Zn	Cu
[35]	*Cyprinus carpio*	Henan, China	30 U/mg protein	100 U/mg protein	-	22 nmol/mg protein	0.5 mg/L *	-	-	-	-
[34]	*Hypostomus affinis*	Doce River, Brazil	1.4–1.7 nmol/min mL	3–7 U/mL	-	-	-	22.2 ± 23.7 µg/L *	455.6 ± 167 µg/L *	-	-
[90]	*Channa punctatus*	Kasimpur canal, India	17.7 ± 0.6 U/mg protein	9.4 ± 0.6 U/mg protein	-	19 ± 0.7 nmol/mg protein			1195 ± 14 µg/g **	148 ± 21.4 µg/g **	24.9 ± 1.5 µg/g **
[29]	*Leuciscus cephalus*	Tur River, Romania	8.6 U/mg protein	61.6 U/mg protein	-	3.3 U/mg protein	0.1 ± 0.0 µg/L *	2 ± 0 µg/L *	78 ± 1 µg/L *	117 ± 2 µg/L *	2 ± 0 µg/L *
[31]	*Acanthopagrus latus*	Kuwait Bay	57 µmol/min mg/protein	-	21 nmol/min/ mg/protein	16 pmol/min mg/protein	-	-	-	180.6 ± 16 µg/g **	112.8 ± 7.5 µg/g **

* Metals in Water; ** Liver Samples.

In addition, [35] pointed out in their study that the exposure of the common carp to Cd significantly increased the levels of MDA in the liver tissue (Table 10). Hajirezaee et al. [38] registered increased MDA level in the plasma collected from *Mugil cephalus* individuals exposed to Pb compared to the ones in the control group. This is similar to our results, since the sampled tissues from fish collected from Danube Delta registered the highest MDA levels and Cd concentration in the muscle of these fish was above the maximum permitted level by the EU regulation. The MDA represents the end-product of lipid peroxidation degradation and high levels indicate oxidative cell damage after toxicant exposure. In the study by [33], *Cyprinus carpio* individuals were exposed, for one week, to a mixture of metal pollutants (Cu: 4.8 µg/L; Cd: 2.9 µg/L and Zn: 206.8 µg/L). The authors registered no sign of OS in the liver and the gill tissues during that period. However, the decreased enzymatic activity of CAT and GPx under long-term metal exposure can lead to the manifestation of OS in the fish organism. It is difficult to define a narrow range for OS biomarkers in fish from the natural environment, because the concentrations of heavy metals are dynamic and the organism adapts its metabolism accordingly, by either increasing or decreasing the involved enzymes and antioxidants.

It is well known that aquatic organisms can be used as sentinels for an assessment of environmental contamination assessment by toxic chemicals, especially through the importance of ROS in physiological processes and toxicity mechanisms [79]. It is well known that heavy metals will accumulate in the fish liver tissue, compared to the muscle, due to the liver involvement in organism detoxification [4]. Increased metal levels in the liver generate a decreased SOD activity and increased lipid peroxidation [72]. Fish inhabiting water environments rich in Cd show increased generation of ROS, because Cd competes with essential metals for protein-binding sites, and thus, triggers the release of Fe^{2+} and Cu^{2+} ions [91]. In addition, in their study, [92] highlighted that oxidative stress caused by cadmium lead to cell death in trout hepatocytes. One mechanism of cellular injury in animals and indicator of oxidative stress in cells is lipid peroxidation [79]. An indicator of lipid peroxidation is malondialdehyde (MDA) and increased levels of MDA are associated to a variety of chronic diseases in vertebrates [79]. In their study, [79] highlighted a positive correlation (R^2 f = 0.966 and 0.987) between Cd and Pb concentrations in fish plasma and muscle, and the MDA levels in the same matrix. In addition, the author noted that increased MDA levels are correlated to decreased SOD activity, within the context of heavy metal exposure. [93] registered in their study elevated MDA levels in the liver of catfish exposed to Zn, Cu, Pb, Cd and As, which is attributed to the livers affinity to accumulate the aforementioned metals. Thus, metals are catalyzers in ROS formation. Further, high levels of SOD in the liver are a response to oxidative stress caused by the presence of heavy metals, which generated the production of superoxide anions which activated SOD to convert the superoxide radical to H_2O_2 [93]. In case of CAT, a decreased activity compared to the rest of the antioxidant enzymes is expected due to inhibition by the wave of superoxide radicals [94–96]. The decreased CAT activity may be due to the flux of superoxide radicals, which have been shown to inhibit CAT activity [93]. Li with co-authors [97] demonstrated in their study that lipid peroxidation is enhanced in animals exposed to Cd compared to animals exposed to Zn.

Similar to most of the studies, the design of the current study is subject to limitations. Therefore, the analytical framework from present study was entirely based on fish muscle and hepatic tissues heavy metals and OS biomarkers. However, in future studies, water quality parameters data are recommended to be integrated in order to create a more precise and complex analytical framework, since it is well known that water hardness, alkalinity and pH influence the uptake process of potentially toxic metals by fish [55] and metals as Cd and Pb are bioavailable for fish to absorb if the aforementioned factors are low. Data from a wider study area should be collected, for several scenarios, in order for testing different approaches requiring larger data volumes such as neural network/deep learning or support vector regression. Furthermore, the ensemble modelling techniques function similar to a black box, meaning it can provide excellent predictive models, but difficult to interpret in terms of existing relation among predictors or between predictors and the dependent variable. Thus, more interpretable models could be used, such as for example the General Additive Models (GAM) which are generalized linear models, having the response variable depending on various smooth functions applied to predictors [98].

4. Conclusions

The present study points out the pollution of DR with Fe and Zn, due to intensive naval activities conducted in the lower sector of the river. In DD, Cd is present in the fish muscles in concentrations above the maximum level permitted by the EU regulations, due to the intensive agricultural activities conducted in the area.

The resident fish from DR manifest OS, through the highest activity of biomarkers CAT, SOD and GPx in muscle and liver tissues, compared to fish from DD and BS. The fish from DD, registered the highest values for MDA level, compared to the rest of the studied aquatic ecosystems.

The use of machine learning, through random forest algorithms, for the prediction of Cd, Pb, Zn, Fe, Cu in fish muscle and liver has proven to be an effective, fast and cost-effective tool for monitoring pollution in DR, DD and BS.

This study revealed, for each analyzed region, the most important parameters used for the heavy metals' prediction. Thus, for the Black Sea coast, the MDA in hepatic tissue was identified as the most important independent variable for predicting heavy metals in fish muscle and tissues, followed by GPx in both hepatic and muscle tissues. For the Danube Delta, the random forest models revealed that CAT in muscle tissue, respectively, MDA and GPx in hepatic tissues were the most important predictors and for the remaining Danube regions, the MDA in muscle, followed by the MDA in hepatic tissue were the main predictors for the RF analysis.

Using the biomarker MDA from fish tissue to predict heavy metal concentrations in fish muscle can replace time-consuming and expensive field and laboratory analysis. In addition, it can help detect areas susceptible to pollution and it can identify contaminated fish with heavy metals in the Danube River Basin.

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Institutional Review Board Statement: This article does not contain any studies with human participants or laboratory animals performed by any of the authors. The fish were legally purchased.

Informed Consent Statement: Not applicable.

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Appendix A. Worldwide Distribution of the Keyword Search Percentage

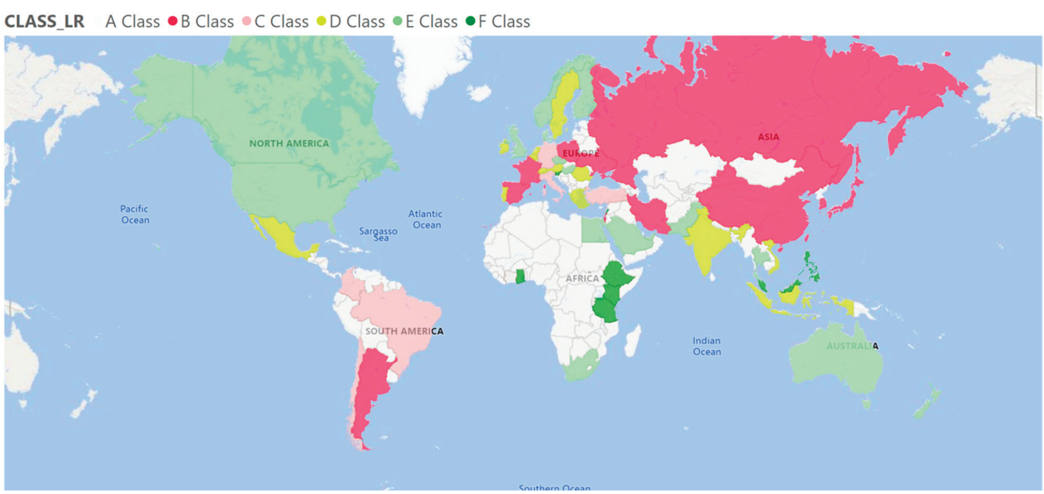

Figure A1. Worldwide term search distribution for 'linear regression' (data source: Google Trends Analytics).

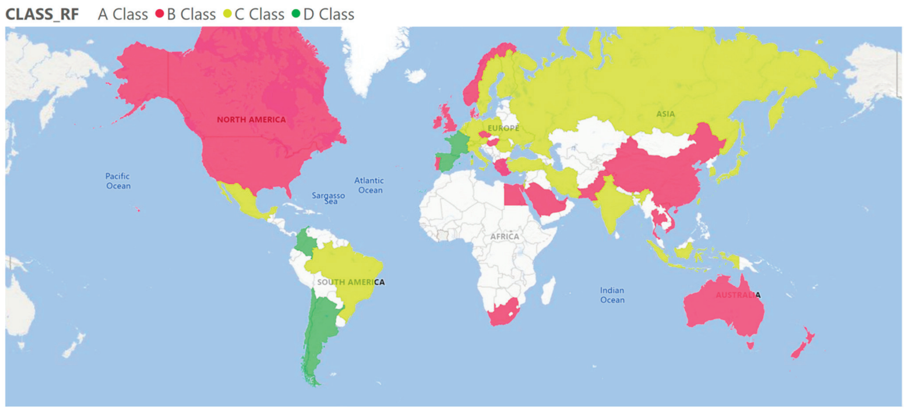

Figure A2. Worldwide term search distribution for 'random forest' (data source: Google Trends Analytics).

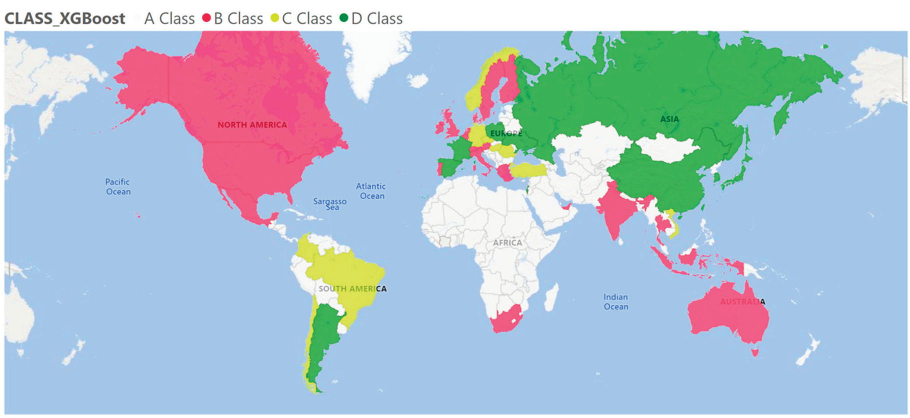

Figure A3. Worldwide term search distribution for 'linear regression' (data source: Google Trends Analytics).

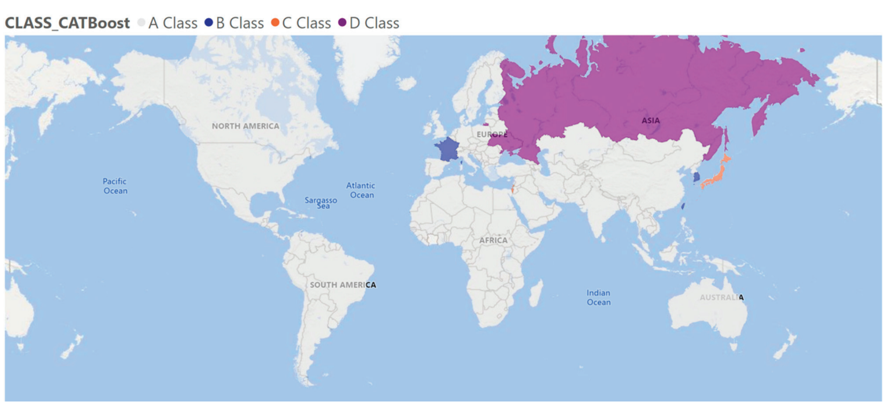

Figure A4. Worldwide term search distribution for 'linear regression' (data source: Google Trends Analytics).

Appendix B. The MLR Models for Heavy Metals Prediction

Table A1. The MLR models for heavy metals prediction in both muscle and hepatic tissues.

Dependent Variable	Predictors	MLR Equation	R-sq.
		BS Coast	
Zn muscle	GPx muscle, CAT hepatic	Zn muscle = 0.590 + 0.423 GPx muscle − 0.924 CAT hepatic	48.00%
Zn hepatic	CAT muscle, MDA muscle, CAT hepatic, SOD hepatic	Zn hepatic = 0.507 + 0.401 CAT muscle − 0.379 MDA muscle − 1.092 CAT hepatic + 0.926 SOD hepatic	37.49%
Fe muscle	GPx muscle, CAT hepatic, SOD hepatic	Fe muscle = 0.375 − 0.919 GPx muscle − 1.097 CAT hepatic + 2.067 SOD hepatic	43.00%
Fe hepatic	CAT muscle, SOD muscle, CAT hepatic, SOD hepatic, MDA hepatic	Fe hepatic = 0.043 + 0.397 CAT muscle − 0.705 SOD muscle − 0.939 CAT hepatic + 0.929 SOD hepatic + 1.072 MDA hepatic	88.00%
Cd muscle	CAT muscle, CAT hepatic, SOD hepatic, GPx hepatic	Cd muscle = 0.007 + 0.945 CAT muscle − 1.058 CAT hepatic + 1.321 SOD hepatic − 0.985 GPx hepatic	46.24%
Cd hepatic	CAT muscle, CAT hepatic, SOD hepatic, GPx hepatic	Cd hepatic = 0.085 + 0.843 CAT muscle − 1.019 CAT hepatic + 1.419 SOD hepatic − 1.127 GPx hepatic	48.15%
Pb muscle	CAT muscle, MDA hepatic	Pb muscle = 0.045 + 0.186 CAT muscle + 0.209 MDA hepatic	29.19%
Pb hepatic	CAT muscle, CAT hepatic, SOD hepatic, GPx hepatic	Pb hepatic = 0.243 + 0.631 CAT muscle − 0.776 CAT hepatic + 1.190 SOD hepatic − 1.006 GPx hepatic	41.68%
Cu muscle	CAT muscle, CAT hepatic, SOD hepatic, GPx hepatic	Cu muscle = −0.001 + 0.871 CAT muscle − 0.701 CAT hepatic + 1.413 SOD hepatic − 1.335 GPx hepatic	59.13%
Cu hepatic	CAT muscle, CAT hepatic, SOD hepstic,	Cu hepatic = 0.002 + 0.913 CAT muscle − 1.055 CAT hepatic + 1.531 SOD hepatic − 1.257 GPX hepatic	54.94%
		DD	
Zn muscle	CAT muscle, SOD muscle, GPx muscle, GPx hepatic	Zn muscle = 0.393 + 0.532 CAT muscle + 0.536 SOD muscle − 0.405 GPx muscle − 0.708 GPx hepatic	44.84%
Zn hepatic	CAT muscle, SOD muscle, GPx muscle, CAT hepatic	Zn hepatic = 0.224 + 0.471 CAT muscle + 0.497 SOD muscle − 0.422 GPx muscle − 0.457 CAT hepatic	46.72%
Fe muscle	SOD hepatic	Fe muscle = 0.168 + 0.288 SOD hepatic	11.71%
Fe hepatic	SOD muscle, GPx muscle, MDA hepatic	Fe hepatic = 0.743 − 0.759 SOD muscle − 0.554 GPx muscle + 0.691 MDA hepatic	52.41%
Cd muscle	CAT muscle, SOD muscle, MDA hepatic	Cd muscle = −0.039 + 0.554 CAT muscle − 0.446 SOD muscle + 0.340 MDA hepatic	37.32%
Cd hepatic	CAT muscle, MDA hepatic	Cd hepatic = 0.007 + 0.449 CAT muscle − 0.199 MDA hepatic	23.62%
Pb muscle	-	-	-
Pb hepatic	SOD muscle, SOD hepatic	Pb hepatic = 0.393 − 0.170 SOD muscle − 0.327 SOD hepatic	59.87%
Cu muscle	SOD hepatic	Cu muscle = 0.172 + 0.324 SOD hepatic	13.87%
Cu hepatic	SOD muscle, MDA hepatic	Cu hepatic − 0.424 + 0.571 SOD muscle − 0.732 MDA hepatic	31.24%
		DR	
Zn muscle	CAT in hepatic tissue and GPx in muscle tissue	Zn muscle = 0.589 − 0.924 CAT hepatic + 0.423 GPx muscle	48.00%
Zn hepatic	CAT hepatic, SOD hepatic, CAT muscle, MDA muscle	Zn hepatic = 0.507 − 1.092 CAT hepatic − 0.926 SOD hepatioc + 0.401 CAT muscle − 0.379 MDA muscle	37.49%

Table A1. *Cont.*

Dependent Variable	Predictors	MLR Equation	R-sq.
Fe muscle	CAT hepatic, SOD hepatic, GPx muscle	Fe muscle = 0.375 − 1.097 CAT hepatic + 2.067 SOD hepatic − 0.919 GPx muscle	43.00%
Fe hepatic	CAT hepatic, SOD hepatic, MDA hepatic, CAT muscle, SOD muscle	Fe hepatic = 0.024 − 0.717 CAT hepatic + 0.937 SOD hepatic + 1.221 MDA hepatic + 0.433 CAT muscle − 0.688 SOD muscle	88.80%
Cd muscle	CAT hepatic, SOD hepatic, GPx hepatic, CAT muscle	Cd muscle = 0.007 − 1.058 CAT hepatic + 1.321 SOD hepatic − 0.985 GPx hepatic + 0.945 CAT muscle	46.24%
Cd hepatic	CAT hepatic, SOD hepatic, GPx hepatic, CAT muscle	Cd hepatic = 0.085 − 1.019 CAT hepatic + 1.419 SOD hepatic − 1.127 GPx hepatic + 0.843 CAT muscle	48.15%
Pb muscle	MDA hepatic, CAT muscle	Pb muscle = 0.045 + 0.209 MDA hepatic + 0.186 CAT muscle	25.74%
Pb hepatic	CAT hepatic, SOD hepatic, GPx hepatic, CAT muscle	Pb hepatic = 0.243 − 0.776 CAT hepatic + 1.190 SOD hepatic +GPx hepatic + 0.631 CAT muscle	41.68%
Cu muscle	CAT hepatic, SOD hepatic, GPx hepatic, CAT muscle	Cu muscle = −0.001 − 0.701 CAT hepatic + 1.413 SOD hepatic − 1.335 GPx hepatic + 0.871 CAT muscle	59.13%
Cu hepatic	CAT hepatic, SOD hepatic, GPx hepatic, CAT muscle	Cu hepatic = 0.002 − 1.055 CAT hepatic + 1.531 SPD hepatic − 1.257 GPx hepatic + 0.913 CAT muscle	54.94%

Appendix C. Random Forest—Actual Values vs. Predicted Values for the Test Dataset

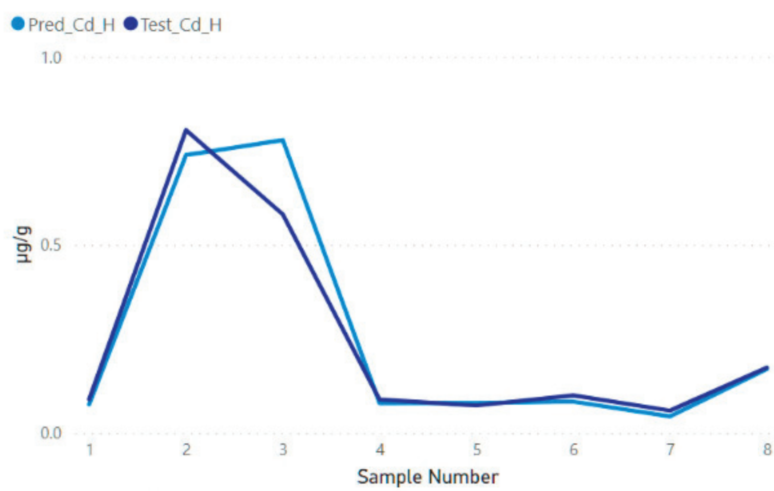

Figure A5. Prediction of Cd concentration for fish hepatic tissues—actual values vs. predicted value, at BS coast.

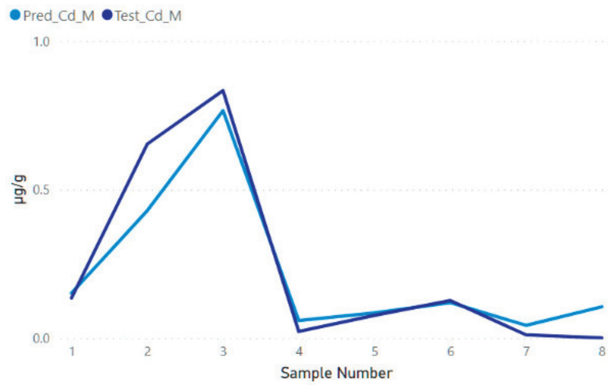

Figure A6. Prediction of Cd concentration for fish muscle tissues—actual values vs. predicted value, at BS coast.

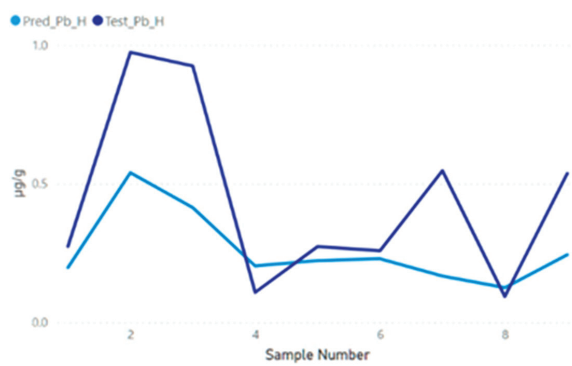

Figure A7. Prediction of Pb concentration for fish hepatic tissues—actual values vs. predicted value, at BS coast.

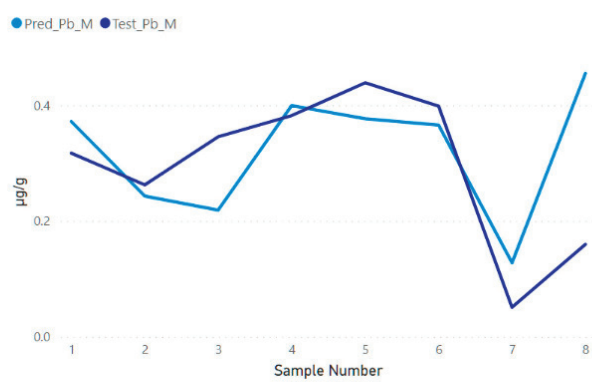

Figure A8. Prediction of Pb concentration for fish muscle tissues—actual values vs. predicted value, at BS coast.

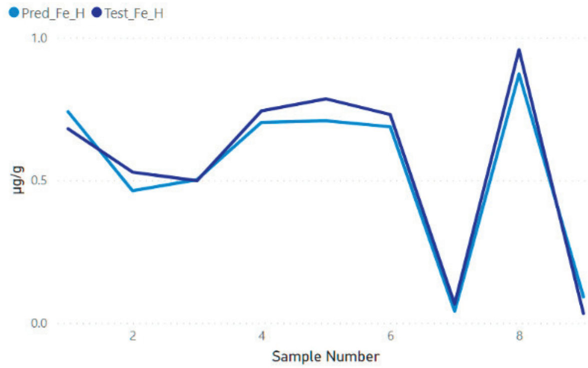

Figure A9. Prediction of Fe concentration for fish hepatic tissues—actual values vs. predicted value, at BS coast.

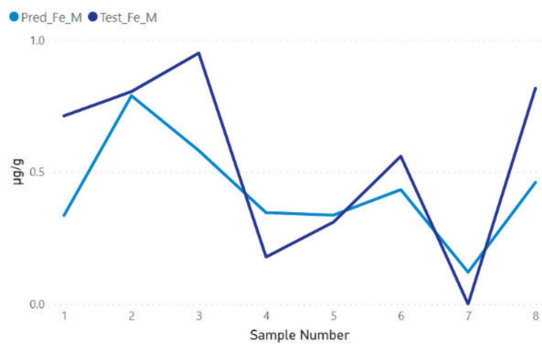

Figure A10. Prediction of Fe concentration for fish muscle tissues—actual values vs. predicted value, at BS coast.

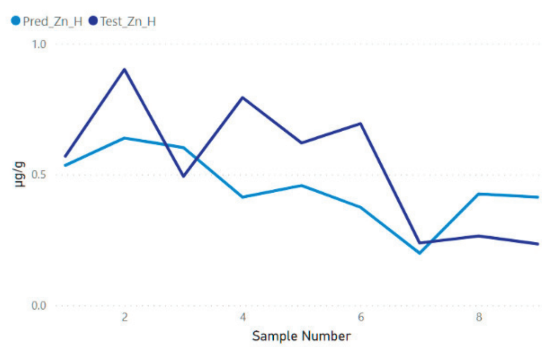

Figure A11. Prediction of Zn concentration for fish hepatic tissues—actual values vs. predicted value, at BS coast.

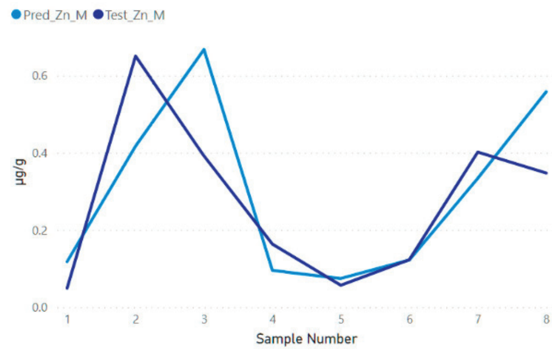

Figure A12. Prediction of Zn concentration for fish muscle tissues—actual values vs. predicted value, at BS coast.

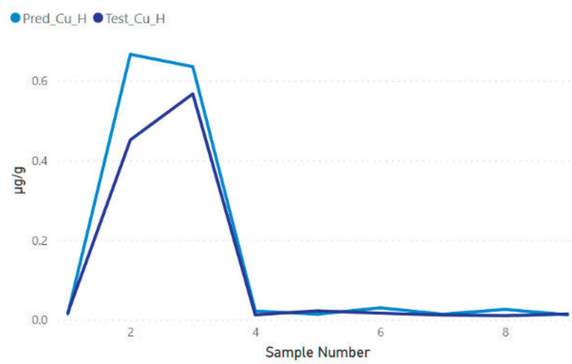

Figure A13. Prediction of Cu concentration for fish hepatic tissues—actual values vs. predicted value, at BS coast.

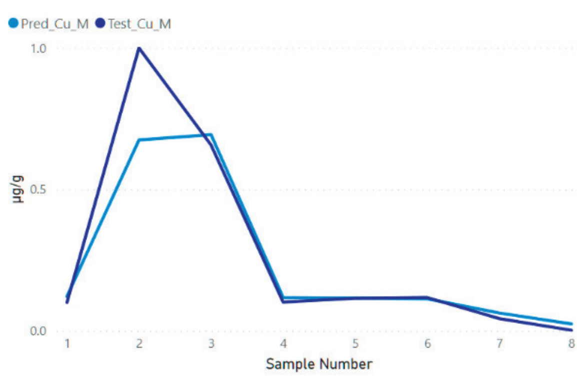

Figure A14. Prediction of Cu concentration for fish muscle tissues—actual values vs. predicted value, at BS coast.

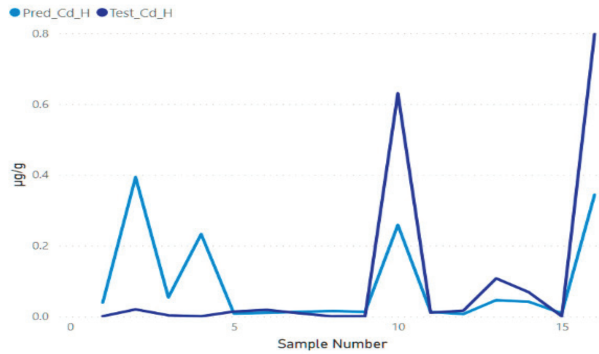

Figure A15. Prediction of Cd concentration for fish hepatic tissues—actual values vs. predicted value, at DD.

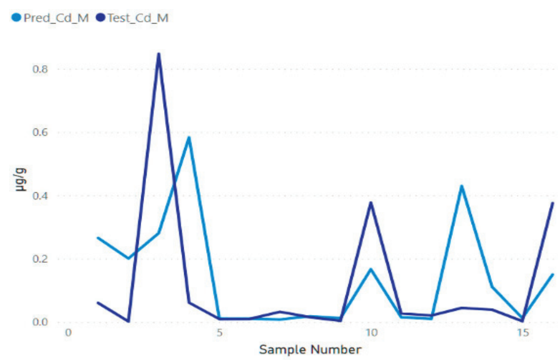

Figure A16. Prediction of Cd concentration for fish muscle tissues—actual values vs. predicted value, at DD.

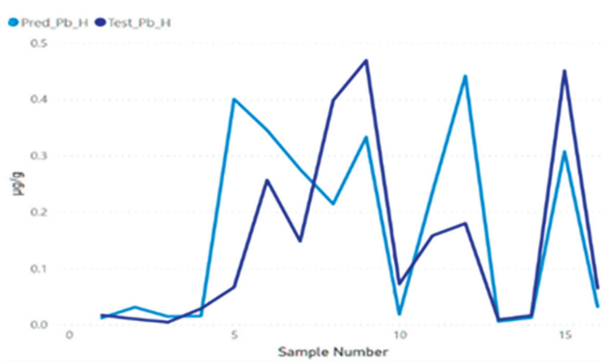

Figure A17. Prediction of Pb concentration for fish hepatic tissues—actual values vs. predicted value, at DD.

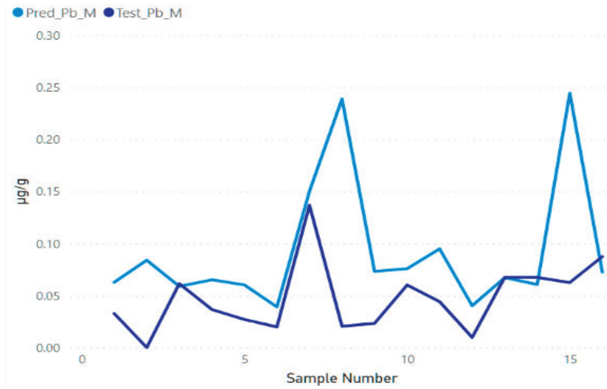

Figure A18. Prediction of Pb concentration for fish muscle tissues—actual values vs. predicted value, at DD.

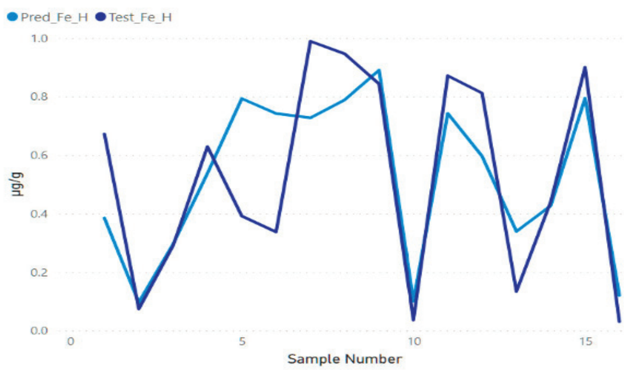

Figure A19. Prediction of Fe concentration for fish hepatic tissues—actual values vs. predicted value, at DD.

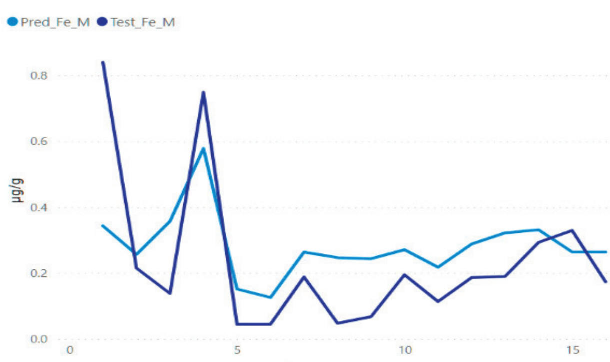

Figure A20. Prediction of Fe concentration for fish muscle tissues—actual values vs. predicted value, at DD.

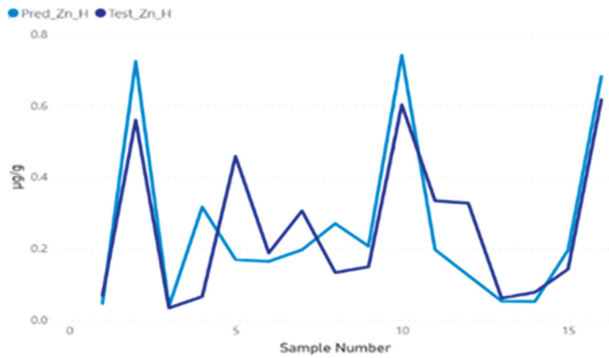

Figure A21. Prediction of Zn concentration for fish hepatic tissues—actual values vs. predicted value, at DD.

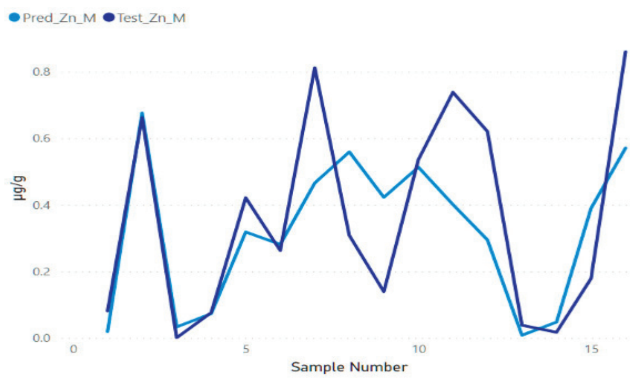

Figure A22. Prediction of Zn concentration for fish muscle tissues—actual values vs. predicted value, at DD.

Figure A23. Prediction of Cu concentration for fish hepatic tissues—actual values vs. predicted value, at DD.

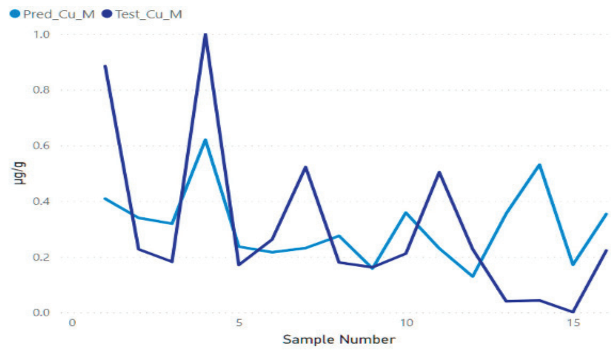

Figure A24. Prediction of Cu concentration for fish muscle tissues—actual values vs. predicted value, at DD.

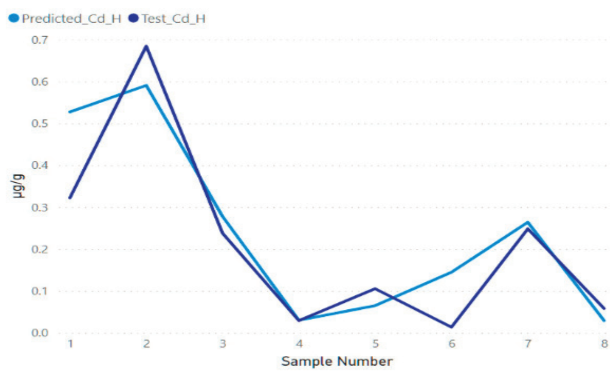

Figure A25. Prediction of Cd concentration for fish hepatic tissues—actual values vs. predicted value, at DR.

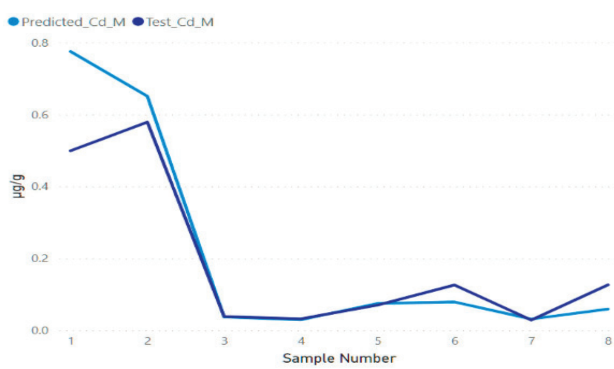

Figure A26. Prediction of Cd concentration for fish muscle tissues—actual values vs. predicted value, at DR.

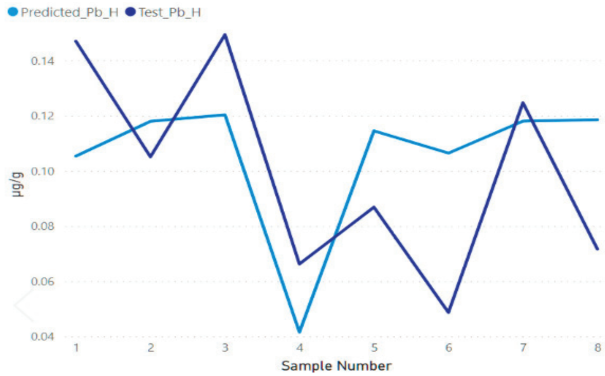

Figure A27. Prediction of Pb concentration for fish hepatic tissues—actual values vs. predicted value, at DR.

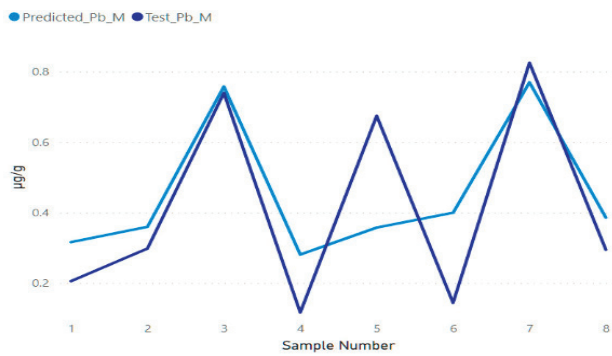

Figure A28. Prediction of Pb concentration for fish muscle tissues—actual values vs. predicted value, at DR.

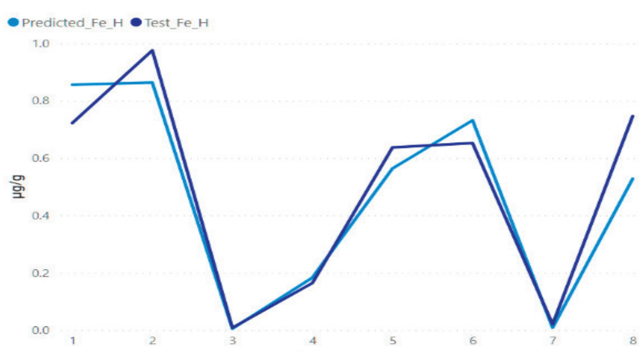

Figure A29. Prediction of Fe concentration for fish hepatic tissues—actual values vs. predicted value, at DR.

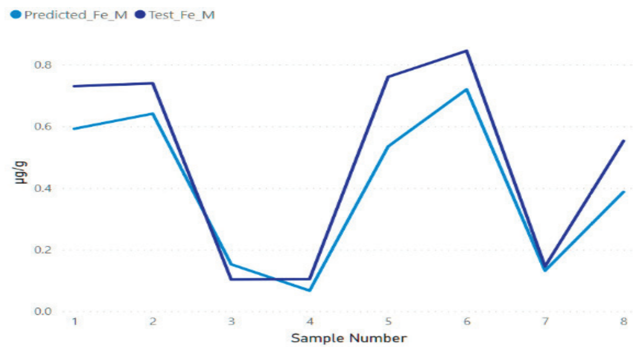

Figure A30. Prediction of Fe concentration for fish muscle tissues—actual values vs. predicted value, at DR.

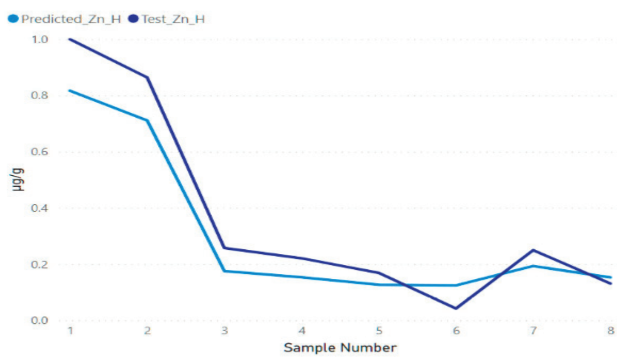

Figure A31. Prediction of Zn concentration for fish hepatic tissues—actual values vs. predicted value, at DR.

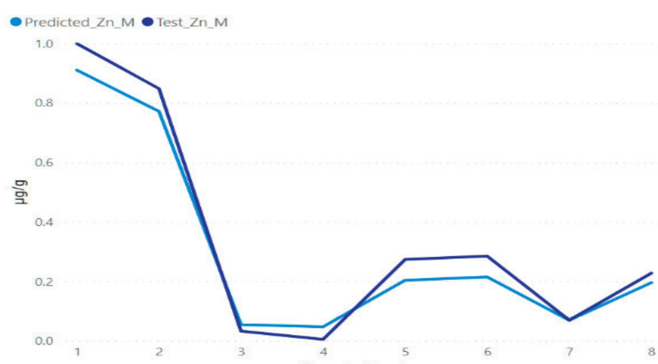

Figure A32. Prediction of Zn concentration for fish muscle tissues—actual values vs. predicted value, at DR.

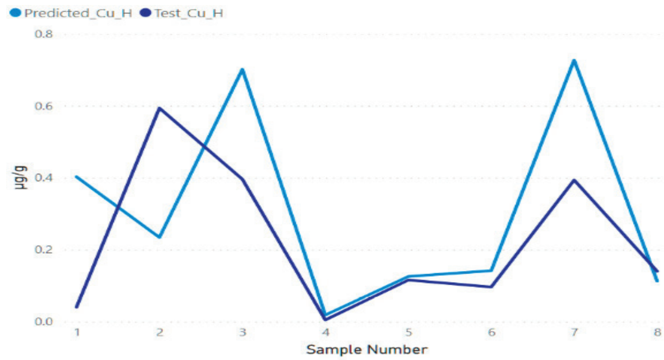

Figure A33. Prediction of Cu concentration for fish hepatic tissues—actual values vs. predicted value, at DR.

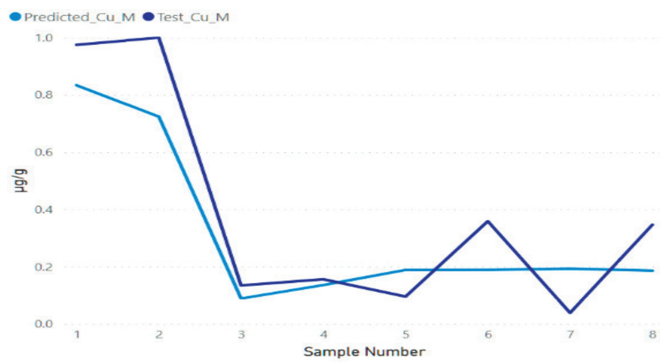

Figure A34. Prediction of Cu concentration for fish muscle tissues—actual values vs. predicted value, at DR.

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Article

A Contribution to the Sustainable Development of Maritime Transport in the Context of Blue Economy: The Case of Montenegro

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Abstract: Maritime transport and sustainable development require a recognizable global approach. The state, as the dominant structure in the world, enables the realization of sustainable maritime transport aims through its instruments. Therefore, it is very significant to consider the national maritime policies because the effective implementation of the global policy is impossible without considering the adequate mechanisms at the state level. The adopted Montenegrin strategic documents impact the institutional framework set-up of the Blue Economy (BE) sectors and potentials for ecologically sustainable maritime transport. Although there are no practical directions for the sustainable use of sea resources, Montenegro is affirmatively oriented to the BE concept. Knowing that Montenegro is in the process of the pre-accessing EU phase, it is of importance to be on the right road to creating a national maritime transport policy including environmental practices, to become part of the strategic implementation of the BE. The paper provides recommendations that can serve for the successful follow-up of the BE activities in Montenegro and the wider area.

Keywords: sustainability; Blue Economy (BE) sectors; maritime transport; legislative framework

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1. Introduction

It is almost needless to discuss the importance of ocean spaces. For a long time, it was seen that the sea represented an inexhaustible natural resource that we aimed to use indefinitely. On the contrary, due to natural events and human actions, the sea is a resource exposed to numerous dangers of its sustainability. Therefore, the Blue Economy (BE) concept appeared as a "pillar of protection" of the unsustainable use of sea resources.

The relatively new term BE has been used in various world studies as a comprehensive set of economic activities concerning the sea and promoting the context of sustainable development of the country or region. The main aim of the BE is to provide economic prosperity using sea resources whose realization only makes sense if marine resources are used sustainably. Sustainable use of marine resources is a complex phenomenon that requires an interdisciplinary approach. It means considering and establishing the optimal relationship between environmental, economic, and sociological factors of marine resources. In order to overcome the gap between economic prosperity and the need for the sustainability of marine resources, the ecological dimension is significant because it emphasizes the establishment of efficient sea resources management that includes a number of activities; in the first place, preventing marine pollution, protecting the marine and coastal ecosystems, stimulating regulated fishing, conserving coastal and marine areas, employing the new marine technologies, and acknowledging scientific background [1].

Besides that, the BE also includes the activities on the innovation principles in the development and application of new information technologies, digitalization of the logistics chains, alternative energy sources, new port infrastructure, and the orientation to transport intermodality, etc [2].

In recent literature, there have been different approaches in identifying the concept and problems found within BE as well as the solutions to overcome them. Further, there is a mismatch between the theory and practice in providing sustainable BE, representing one of the problems that urge for the proactive, systematic, and bold policies and actions needed to provide an environmentally sustainable and socially equitable BE [3]. From the cost-effectiveness point of view, it was elaborated the importance of understanding the economic benefit of the ocean-based economy and creation of national measurable data for following the employment, wages, establishments, and output [4,5]. In addition, it was pointed out the importance of the economic, societal, and environmental performances of maritime transport through the legislative framework review to provide a broader European initiative for the BE implementation [6]. On the other hand, one of the main issues in the global understanding of the BE term is the distinction in four prominent discourses of human-ocean relations [7]. Similarly, the problematic existence of different understandings of what the BE represents within the Caribbean Community led to compromise on the agreed policy and strategy that would effectively coordinate and operationalize BE development [8]. The researchers indicated the presence of ambiguities related to BE and offered solutions for its overcoming.

Although figuring out the related problems and the complexity of BE, many coastal countries and small-island developing states (SIDS) also see promise in ocean-based growth. Montenegro, located in southeast Europe, also recognizes the perspective in ocean resources, but it encounters doubts in the formulation and popularization of official policy and practice, oriented towards sustainable Blue Growth. Having it in mind, this paper tries to respond to some mentioned issues without experiencing the economic contribution of the BE sectors in the national economy. Therefore, there are two main objectives of the paper: first, to contribute to the strategic steps for engaging the concept of BE to the relevant government bodies that adopted the corresponding documentation and recommendations of ecologically sustainable marine transport development policy and integrated coastal area management; and second, to indicate to the governing bodies the importance of the practical dimension of BE implementation, especially maritime transport as one of the BE sectors and its ecological aspect, in the sense of key performance monitoring and smooth development.

This paper is structured as follows. The related literature on the BE concept is given in Section 2. The methodology of the research work is shown in Section 3. The empirical analysis of Montenegrin strategic documents and existing maritime administration for the BE activities are reported in Section 4. Section 5 elaborates the status and trends (supported by numerical data) of the BE sectors in Montenegro. Section 6 provides the scientific provisions for ecologically sustainable maritime transport activities including a statistical overview of achieved throughput in Montenegrin ports, and a legislative framework systemized through the two levels (global/regional, and national ones). The final discussion and recommendations are specified in the concluding remarks.

2. Literature Review

The term BE was first popularized in scholarly literature through Pauli [9] as the title of a book he authored which discussed moving society from scarcity to abundance by pioneering advances which replicate the waste-free efficiency of ecosystems [8]. Kildow and McIlgorm [4] used the term ocean economy to point out the studies that measured the economic benefit of the oceans and coasts by explaining that the highest losses in marine transport and coastal tourism are related to fuel costs and climate change, respectively. Also, in Colgan [5] the methodology for estimation of the ocean and coastal economic activities in the case of the Great Lakes in the US was investigated. The author used data series and identified the areas and actions for further development. The potential for the maritime transport sector of the BE is presented in Niavis et al. [6]. The authors gave, inter alia, the legislative framework through the analysis of maritime transport related to the Adriatic-Ionian region.

The implications of the BE are described in a study by Henderson [10]. The essential point is the sustainable development of coastal areas through the marine cultural heritage and benefits that act as a result of the implementation of the BE principles. A new study addressing various economic activities of oceans and seas with the background of the EU policy framework, initiatives, and actions related to the BE is explained in Scholaert et al. [11]. Chen et al. [12] examined the best practices of BE in coastal communities in China, Samoa, and Vietnam and the relationship between poverty and the environment. It is concluded that in obtaining the productivity of these communities, a more proactive approach should be dedicated to natural resource management. Lee et al. [13] examined the challenges and opportunities in the BE that are in line with the United Nations' Sustainable Development Goals (SDG). They noticed the gap between key stakeholders and their roles in the BE, and through the analysis of the literature review during the 21-year observed period, concluded that key stakeholders need to be concentrated more on the prosperous range for the ocean biosphere. Silver et al. [7] investigated the level of the BE employment concept in global environmental governance while prioritizing ocean problems, solutions, and participants. They pointed out the option of unreliable discourse existence between different actors within the maritime economy. Andriamahefazafy et al. [14] identified the contradiction within the current fisheries' policies, as one of the main sectors of the BE, in the islands of Madagascar, Mauritius, and Seychelles, emphasizing the practical ecological preservation that should be taken into account while providing the positive socio-ecological trends and implicit growth.

Reading the article by Bennett et al. [3] in the form of a comment provided in the Nature Sustainability Journal, on the global rush to develop the BE concept, it is concluded that the synergy between the social equity and environmental sustainability of the BE is urgently needed. Moreover, the article contains a proactive approach to implement systematic policies and bold actions based on interdisciplinary ocean science and inclusive governance processes. On the other hand, Christodoulou and Woxenius [15] explained the role of short sea shipping (SSS) in the frame of sustainable maritime transport. Referring to Europe, challenging areas for contribution to the scientific investigations are related to the Mediterranean, North Sea, and Baltic Sea and their modes of sustainable maritime transportation. The emphasis of the study is to provide more empirical analysis in the sense of improving sustainable maritime transport of SSS. Tirumala and Tiwari [16] assessed the current world initiatives and projects for the BE development elaborating features of the financing instruments for relevant stakeholders in the area. For example, in the case of the European Union, the most convenient strategy is the Blue Growth from 2012 and the report on the "Blue Growth Strategy Toward More Sustainable Growth and Jobs in the Blue Economy" prepared by the EU in 2017 [17]. Referring to the coastal and marine tourism sector, the incomes are identified from cruises, hotels, and resorts. In the case of ports and the shipping sector, the benefits are the results of the sale of products or services.

Through a literature review in this domain, some investigations deal with the BE in the context of sustainable development of specified regions. The World Bank and United Nations Department of Economic and Social Affairs in the report from 2017 [18] defined a sustainable BE as the activity that provides social and economic benefits of marine resources and marine ecosystems. Moreover, numerous international regulations require the shipping industry to invest significantly in environmental technologies, covering issues such as emissions, waste, and ballast water treatment. The International Maritime Organization (IMO) as a key organization for the BE sector outlines the safe, secure, efficient, and reliable maritime transport of goods within world trade satisfying the requirements for environment protection [19]. The statistics show that this sector of the BE comprises both operations at sea and ports counting around 25% of all international trade [1].

Toward the annual report on the EU BE, six established sectors comprise the sustainable development of oceans, seas, and coastal resources: extraction of marine living resources, offshore oil and natural gas, ports, warehousing and construction of water projects, shipbuilding and repair, maritime transport, and coastal tourism. Maritime transport includes sea and coastal passenger water transport, sea and coastal freight water transport, inland passenger water transport, inland freight water transport, and renting and leasing of water transport equipment. Sea and coastal passenger water transport include both passenger ferry services and cruise passengers [20]. Also, coastal tourism alongside the accommodation segment covers the transport sub-sector that comprises sea and coastal passenger water transport. Quantitative results from the study reported by EUNETMAR [21] indicate that the first and second most promising activities in the Adriatic and Ionian Seas are maritime transport and coastal tourism.

Similar analysis about the status of the BE sectors in the Mediterranean including marine natural ecosystems and maritime resources is related to coastal tourism, fisheries and aquaculture, maritime transport and port activities, shipbuilding and recycling, energy (offshore), bioprospecting, and deep-sea mining [1]. According to the BLUEMED [2] report delivered in 2018, the Mediterranean Sea represents a very dynamic crossroad with approximately 20% of the total world's maritime transport.

A special overview on the Adriatic-Ionian region is covered by the EU Strategy for the Adriatic-Ionian Region (EUSAIR) where the European Commission specified the opportunities in the development of the maritime economy [17]. Referring to the updates in the number of the participating countries, this consortia includes four EU Member States (Croatia, Greece, Italy, and Slovenia) and five non-EU countries (Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, and Serbia) [22]. Each state belongs to the appropriate pillar such as Blue Growth, Connecting the Region, Environmental Quality, and Sustainable Tourism.

This paper addresses two segments: to scientifically contribute to the adoption of marine policies in Montenegro and recommend the governing bodies the on-time actions in the sustainable development of the BE.

3. Methodology

The available literature, books, scientific and professional articles obtained through bibliographic research served as a methodological starting point for preparing this paper. It is based on three research methods: document analysis, systematic review, and case study.

We begin with the empirical overview of the Montenegrin strategic documents in Section 4 (the document analysis method) specifying the engaged relevant bodies for the implementation of the BE activities that were provided in the Strategy for the development of the maritime industry for the period 2020–2030 (SDMI) [23] and National Strategy for Sustainable Development until 2030 (NSSD) [24] as a precondition for understanding the concept of the sustainable use of the Montenegrin coastal area. The qualitative observation of the relevant documents contains the most important implications in the BE sectors elaborated in the following method.

The rising question of identification of the BE sectors, an overview of the scientific and legal regime (where applicable), critical appraisal of sectors' development and trends, and data presentation were a subject of the systematic review method. Indeed, this is the first analysis that comprehends all Montenegrin BE sectors in one place providing the historical background, economic parameters, statistical data, and legal policies. Section 5 contains:

- the economic contribution of BE in Montenegro;
- the total investments in coastal tourism and tourists' achievements with its contribution of the total gross domestic product (GDP) and national employment level;
- realized and planned capital infrastructure projects that directly or indirectly impact the BE;
- the current initiatives to develop small shipyards for leisure boats, yachts, and megayachts, application of biotechnologies aiming at environmental protection;
- the scientific background of the fisheries sector especially the small coastal fishing and its impact on GDP and national employment, potentials of mariculture, and;
- the international negotiations in the exploration of oil and natural gas as a novel sector in the country giving the review of the adopted regulations.

The specific emphasis is on the maritime transport sector applying the case study method is presented in Section 6. It is distributed through the four directions:

- the review of importance of the maritime transport national and regional scientific investigations in the prism of its environmental sustainability in Montenegrin ports;
- the statistical background of economic activities achieved by cargo and passenger ships throughput and nautical tourism vessels;
- the overview of the global legal framework on the protection of the marine environment from pollution and the status of its adoption in Montenegrin legislation and;
- the relevant national regulations for maritime transport and ecologically sustainable use of the sea.

The research methods used in this paper aim to address the specific research question: Is there any gap between marine policy and practice, and what actions are needed?

4. Montenegrin Strategic Documents and Maritime Administration in the Context of BE

In this section, we provide an empirical and critical view on relevant strategic documents that have direct and indirect implications for the development of BE sectors in Montenegro in the context of sustainable use of the sea. Here we consider: National Strategy for Sustainable Development until 2030 (NSSD) [24]; National Strategy for Integrated Coastal Area Management from 2015–2030 (NSICAM) [25]; Strategy for the development of maritime industry for the period 2020–2030 (SDMI) [23] and Transport Development Strategy—Montenegro 2019–2035 (TRDS) [26].

As it is not the focus to go through a detailed analysis, we elaborated few strategies in the context of assessing the dedication of Montenegro in the direction of sustainable use of marine resources and the development of the BE. Indeed, NSICAM represents an integral part of NSSD such that both strategies deserve special attention. NSICAM is the umbrella and long-term development strategy of Montenegrin society. The adoption of NSICAM was preceded by another document—National Sustainable Development Strategy in 2007 (NSDS) [27] that included guidelines for Montenegrin sustainable development and recognizes the ecological vision as a key aspect for sustainable development. In 2016, Montenegro adopted the NSSD, which seeks to improve the policy of sustainable development and ensure effective control and prevention of pollution. The goal of the NSSD strategy is aimed at the sustainable development of Montenegrin society through the consideration of four types of resources: human, social, natural, and economic. The strategy recognizes the coastal area resources as a developed opportunity of the BE and adequate resources management, treating BE development as a strategic goal. The document identified the coastal ecosystem as one of the most endangered systems. The reasons for this are numerous pressures on the environment starting from excessive urbanization and infrastructure development in the coastal area, which leads to the conversion of natural habitats into built-up areas. The expansion of cruising tourism leads to a large increase in the number of visitors including accompanying maritime transport activities, which implies an increase in environmental pollution, such as the spread of invasive species resulting in higher ballast water discharges. Furthermore, the pollution control system and natural resources management are recognized as a big problem and are of great concern. The strategy correctly notes that there are not enough valid data on monitoring the effects of environmental pollution i.e., there is a lack of analysis of the impact of increased concentrations of certain pollutants on the local population, as well as estimates of total damage which threatens the economy due to environmental pollution. To overcome this and preserve the coastal area, the use of mechanisms and instruments for sustainable management of coastal resources is of key importance. In that sense, the specific emphasis is related to creating conditions for diversification of the economy in the coastal area and stopping uncontrolled urbanization.

The orientation towards the BE is evident in NSICAM, which defines a strategic framework for sustainable development of the Montenegrin coast through the integration of spatial and developed solutions aimed at advancing the economic, social, and environmental performances of the coastal area. Moreover, this strategy underlines the importance of integral and coherent management of Montenegrin coastal area resources including: natural (the sea, water, land, and space), economic (primarily in agriculture, fishery, maritime transport, and shipbuilding), social capital (interconnections and cooperation between social actors), and human resources (knowledge and abilities). Besides, in the sea, other economic activities are performed such as bathing and nautical tourism, maritime transport, shipbuilding, fishery, and mariculture. It is recognized that the sea offers possibilities for economic activities which are currently not developed in Montenegro—biotechnology, exploitation of living and inanimate components of the marine environment for pharmaceutical purposes, exploitation of minerals, and others.

In 2020, Montenegro adopted the SDMI document. The main aim of the Strategy is to define the directions of the maritime economy in Montenegro and adequately valorize the potentials of the sectors through the prism of the BE activities. The Strategy covers almost all economic activities related to the sea. The strategic goals of the document are related to increasing the contribution and growth of the economy, strengthening the capacity of the maritime administration, greater involvement of the civil sector, and the inclusion of the professionals as a precondition for a prosperous maritime economy. The Strategy foresees a Montenegrin maritime cluster establishment that would include all national bodies, public authorities, business actors, etc. Despite the positive assessment adopting this act (which is the first act of its kind in Montenegro), we believe that the Strategy has certain shortcomings. One of the high omissions is the very conceptual setting of this document, i.e., the broader approach during its formation. The broader approach leads to the perception of different segments of the maritime economy of Montenegro in a very restrictive, i.e., superficial way. Furthermore, the lack of measures or insufficient analysis to achieve strategic goals will be an aggravating factor for implementing the Strategy. In addition, we believe that much more attention should be paid to the examination of the economic and social aspects of the maritime economy, precisely aiming for its better development.

In the context of our research, we present a TRDS strategy that determines the situation in the field of transport, defines the goals of the development of the transport system that is realized through implementation plans. Ecological sustainability is envisaged as a strategic goal, which is observed through carbon dioxide emissions reduction and the impact on the natural, historical and socio-economic environment. The Strategy presents the maritime transport sector through an overview of the existing infrastructure and shipping fleet of Montenegro while neglecting the consideration of safety and protection of the marine environment as a dimension of sustainable maritime transport.

To conclude this part shortly, we single out three more strategies that converge to the BE sectors identified in the following section. The most important aspect of the Fisheries Strategy of Montenegro 2015–2020 [28] is related to the identification of the key steps for the integration of Montenegro in Common Fisheries Policy (CFP). The projected goal of the Tourism Development Strategy in Montenegro until 2020 [29] is to create a sustainable, high quality, and diverse tourism product that will enable the growth of income and the growth of the number of tourists, and through that create new jobs and increasing living standards. The Energy Development Strategy of Montenegro to 2030 specifies the plan for energy development within the regulations of the Energy Policy of Montenegro to 2030 adopted in 2011 [30].

Referring to the jurisdiction of relevant bodies responsible for the implementation of the BE activities, we specify three levels of Montenegrin maritime administration in Figure 1. The first level is related to the four ministries with a focus on the competencies of each body individually according to SDMI in 2020 [23]. The Ministry of Transport and Maritime Affairs is the umbrella institution for drafting laws and bylaws, systemic solutions, defining policies, and implementing maritime affairs. These activities are implemented through the Directorate of Maritime Economy and the Directorate of Maritime Transport and Inland Waterways (that represents the second level of competencies). The last one, through its four units, follows the implementation of maritime safety standards, standards for the sea pollution prevention and inland navigation, supervision in international and inland waterways transport, and harbors offices in Bar and Kotor (included in the third level of competencies). Also, the Administration for Maritime Safety and Port Management performs tasks related to the safety of navigation in the coastal area of Montenegro as well as other tasks assigned to its competence.

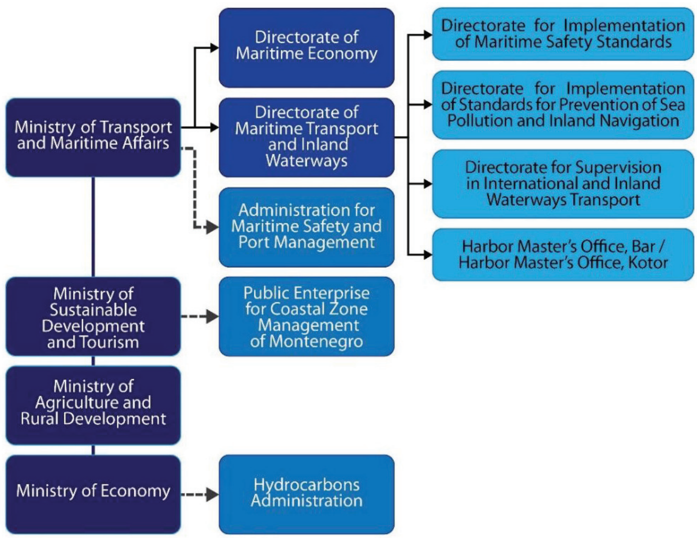

Figure 1. Montenegrin maritime administration in the context of the Blue Economy (BE) by 2020.

Within a Ministry of Sustainable Development and Tourism, there is a Public Enterprise for Coastal Zone Management of Montenegro (positioned at the second level) that manages all maritime infrastructure facilities (ports, docks, moorings, etc.). This body established the functional unit for the integral management of the maritime domain area and infrastructure facilities. The sustainability of the management system (protection, arrangement, and improvement), marine assets, and maritime infrastructure facilities, has been achieved by reinvesting the funds earned by the concession fee incomes.

The Ministry of Agriculture and Rural Development is responsible for the fisheries and mariculture sector. The Ministry of Economy founded the Hydrocarbons Administration (the second level) and delegated the responsibility for the implementation of the Energy Development Strategy of Montenegro to 2030 [30].

5. BE Sectors in Montenegro: Status and Trends

According to the published data in the SDMI [23], there were 488 active business entities registered in the field of BE in 2018. The growing number of business entities indicates a growing interest in this area. In contrast to that, the BE accounted for 0.6% of Montenegro's GDP, which is the lowest level in five years. Besides, the average number of employees was 1502 persons, which represent 0.8% of employees in the country. The mentioned trends are the result of the business of larger companies in this area. The overall economic contribution of the BE from 2014 to 2018 is given in Table 1 [23].

Table 1. Economic contribution of BE in Montenegro [23].

	2014	2015	2016	2017	2018
No. of business entities	336	379	390	417	488
Average no. of employees	1971	1778	1592	1481	1582
Gross Value Added (million €)	29.5	27.9	26.8	30.2	27.2
% in GDP	0.9	0.8	0.7	0.7	0.6

The importance of the sea waters is priceless for small countries such as Montenegro (with a total coast length of 289 km). Its geographic position provides some advantages compared to the countries that are not entering the sea and cannot use the potentials in maritime transport, coastal tourism, capital infrastructure projects and shipbuilding and repair, fisheries and mariculture, and offshore oil and natural gas for economic development.

In the following analysis, we identify Montenegrin BE sectors as well as the most important legislative framework and strategic documents. Regarding the maritime transport sector, a detailed overview will be provided in the next section.

5.1. Coastal Tourism

Coastal tourism includes tourism and beach recreation (e.g., swimming, surfing, etc.) and other recreational activities in coastal areas. According to statistical data, 85% of tourist arrivals and 95% of total overnight stays happened in coastal places [23]. The distribution of the number of tourists' statistics and the type of the region visited are given in Tables 2 and 3, respectively [31].

Table 2. Percentage of the increase in the number of tourists' arrivals and overnights for the period 2014–2019 [31].

	2015/2014	2016/2015	2017/2016	2018/2017	2019/2018
Tourists arrival	11.4	5.9	10.3	10.2	20.00
Overnights	13.6	1.8	6.3	8.2	11.8

Table 3. Percentage of the total number of tourists' arrival by the type of region [31].

	2015/2014	2016/2015	2017/2016	2018/2017	2019/2018
Coastal region	n/a	76	94.9	94.9	94.9
Other	n/a	24	5.1	5.1	5.1

The number of tourists' arrivals increased every year, i.e., from 1.5 million in 2014 to 2.6 million in 2019 [31]. Analogously, in 2014 there were a total of 9.5 million overnights while in 2019, it increased to 14.4 million overnights. From Table 3, it is evident that from 2017 almost 95% of the total number of tourists that are visiting Montenegro are located in the coastal region.

The total investment in tourism is approximately 30% of total financing every year [25]. The coastal tourism in Montenegro relies on mass swimming tourism with natural beaches and clean bathing water, while coastal transport represents a type of touristic service. The coastal transportation is active for touristic purposes (consisting of bathers and excursion tours) and taxi boat transport during the summer season on one side, and ferry transport in function of intercity traffic performed in a year. Besides the existing transportation along the coast in the previous period, Montenegro adopted regulations in 2019 followed by making changes and amendments to the Law on Maritime Navigation Safety [32].

Coastal tourism activity contributes 15% of the GDP of Montenegro, and it employs 27% of people in the country [33]. The operation goal within SDMI [23] is to build new marinas and modernize the existing ones. In the last ten years, the total number of international vessels increased by 67.8%. There is no official evidence for recreational tourism. The coastal area is the most economically developed part of Montenegro. Slightly higher activity rate (51.6%, which is 1.5% higher than the national average) and lower unemployment rate (8.4%, which is 11% lower than the national average) are correlated with a higher degree of economic development. The coastal area, known for its natural values and cultural heritage, is of special interest in the development of tourism. Over the past several years, more than 95% of the total tourist traffic in Montenegro (measured by realized overnight stays) took place in the coastal area [25,31].

5.2. Capital Infrastructure Projects and Shipbuilding and Repair

In terms of activities, the most significant growth was recorded in the construction sector with an increase in infrastructure works of 31.5%, while investments in fixed capital recorded an increase of 21.5%, as a result of infrastructure projects and projects in the fields of energy and tourism. The total estimated share of gross investment and exports of goods for 2018 is estimated at 73.4% of GDP (an increase from 62.2% in 2015). This shows that the goals of economic policy aimed at the growth of investments and exports of goods and services are being achieved [26].

If we observe the priority projects of the transportation infrastructure that directly or indirectly impact the BE sectors, the first place is related to the construction of the highway Bar-Boljare; the second place refers to the modernization of the rail infrastructure, and the third priority project is directed to the increase of the number of shipping lines. According to the Regional Development Strategy of Montenegro 2014-2020 (RDS) [34], almost 4 billion € was planned to be invested in nine projects: a touristic complex in Kumbor, the Plavi horizonti resort, the Montenegro-Italy submarine cable, Luštica bay resort, Porto Montenegro, Maoče coal mine, the second block of thermal power station Pljevlja, the Kotor-Lovćen-Cetinje cable car, and the first part of the Bar-Boljare highway.

Referring to the maritime transport and nautical tourism activities, there are some small ports, marinas, and resorts that are mostly built: Porto Montenegro as an exclusive yachting marina (invested approximately 550 million €), Porto Novi (invested approximately 545 million €), Marina Lazure (invested approximately 25 million €), Dukley Marina and other small ports in the Boka Kotorska Bay, partially reconstructed marina Bar, constructed Luštica Bay resort (until now approximately 26 million € have been invested).

Projected capital infrastructure projects from 2020 include a new container terminal in the Port of Bar, an extension of passenger and bulk cargo terminals in the Port of Bar, increasing the operational capacity in the Kotor cruise port and Marina Kotor, purchasing of new ships within "Barska plovidba AD" and "Crnogorska plovidba AD Kotor", renewal of the Ro-Ro line between Montenegro and Italy [23,35]. From the fisheries and mariculture sector, some constructions and equipping are projected for the fishing ports of Ulcinj, Bar, and Herceg Novi [23].

According to Petrick et al. [1], it is suggested that one of the promising marine and maritime activities in Montenegro is related to shipbuilding and ship repair. The history covers almost one hundred years of the ship repair activities of the biggest repair yard in the Southern Adriatic called "Bijela". But, following the trends and Montenegrin orientation towards nautical and coastal tourism, the shipyards are finding potential in relation to the construction and repair of leisure boats, yachts, and mega yachts.

NSICAM [25] promotes the EU integrated maritime policy from 2008 dealing with sustainable maritime transport and shipbuilding, including short sea shipping, Ro-Ro transport, and local coastal transport. One of the measures and sub-measures is to emphasize the application of new materials and biotechnologies in the sense of protecting the environment caused by technological operations in shipbuilding, repairs, and yacht sustainability. The hot spot locations are proposed and comprised of current shipyards. Additionally, NSSD [24] in Montenegro defines the strategic goal SDG 9 (9.4, 9.5) that provides remediation of existing pollution and builds infrastructure for waste and wastewater treatment. It is referred to as shipyard "Bijela" and other small shipyards.

The use of small vessels is also present in Montenegrin coasts for leisure activities and daily charter, as well as taxi and excursion boats, etc. Currently, the most popular shipyards are a couple of small yards located in the Boka Kotorska Bay, and Bar. Some of them are traditional shipyards for the wooden boats used to improve environmental performances of coastal tourism and maritime transport [1]. Besides, the construction of hybrid solar vessels is also occurring at the shipyards, their building satisfies the environmental requirements providing easy maintenance especially in the Boka Kotorska Bay.

A strategic effort in research and innovation in green shipbuilding and energy-efficient ships should represent a significant part of the BE in Montenegro in the future. It will follow the recommendations described in Petrick et al. [1] and the EUSAIR document [22] that promotes a national strategy to develop potential synergies between shipbuilding and ship repair, yachting, and marinas [33]. Shipyards in Montenegro are oriented to vessels for sports and leisure activities, and the need to provide conditions for a regular and extraordinary overhaul of maritime inland waterway vessels in Montenegro is recognized [23].

5.3. Fisheries and Mariculture

This sector was scientifically treated and we present an overview on the actualities within fisheries and mariculture in Montenegrin waters beside others in the Adriatic. First, we emphasize the research work of Cobani et al. [36] that reported a study by the FAO AdriaMed Working Group on small-scale fisheries (SSFs), which has identified the gaps and priorities for the fisheries sector in the observed region. This research is followed up by the recent scientific work of Grati et al. [37] that considered the seasonal dynamics of the set gears. They observed regional small-scale fisheries including Montenegro and collected the data (landings, fishing effort, the composition of catches, and length-frequency distributions of target species and economic value of landings) on target species.

Rajović and Bulatović [38] analyzed some geographic aspects of fisheries of Montenegro emphasizing that the total catch of marine fish by species was 741 tons, while the catch of freshwater fish amounted to 838 tons representing a lack of potential development in this sector of Montenegro. Joksimović et al. [39] contributed to the literature in the reported area and reviewed the state of marine fisheries in Montenegro for the last 15 years. On the other hand, Matić-Skoko et al. [40] gave specific conclusions for the coastal resources in the SSFs domain in Croatia and Montenegro. The authors proposed additional measurements and the active management of the fisheries. Finally, they demonstrated some advances in collecting data methodology. Joksimović et al. [41] completed the study on the ecosystem risk identifying the concentration of individual metals and metalloids for the ten years at precise locations along the Montenegrin coast.

The fisheries sector is treated as an important economic activity that has the potential for development [23]. According to the analysis reported in FS [28], this sector is not developed at a satisfactory level while the dominant activity is related to the small coastal fishing. The fishing fleet accounts for up to 80% of small-scale coastal fishing vessels. According to the Statistical Office of Montenegro (MONSTAT) data for 2019, the fishing fleet consists of a total of 244 vessels which is a significant increase in the fishing fleet compared to 2016 when it consisted of a total of 135 vessels [35]. The share of the fisheries sector in Montenegro results in 0.5% of the GDP whereas the number of employees in the fisheries sector is 400; on the other hand, the total catch of fish along the Montenegrin coast is approximately 700 to 800 tons per year [24].

The fisheries sector has started to intensively follow the Montenegrin pre-accession negotiations with the EU in order to meet the requirements of the EU CFP. This is most evident through the adoption of legal instruments for the sustainable management of living marine resources and the regulation of overall fisheries policy, as well as through the foundation of an institutional framework for the fisheries sector. In that sense, the basic regulations in Montenegro that stipulate the sustainable management of biological resources, i.e., hunting, breeding, and protection of fish and other organisms in sea and freshwater based on the principles of sustainable development are: the Law on Marine Fisheries and Mariculture [42] and the Law on Freshwater Fisheries and Aquaculture [43]. In addition to the current situation in this sector, there are still a number of problems, primarily an outdated and inefficient fishing fleet, lack of adequate coastal infrastructure (fleet port, first landing sites, first sale sites), illegal fishing, and lack of appropriate market channels for the sale, etc [42].

Mariculture activities that have the potential for natural development, benefits, and cultivation but are not completely used are presented especially within the seaside of the Boka Kotorska Bay in Montenegro, as reported by the Institute of Marine Biology of the University of Montenegro. The cultivation of shellfish is also at a low level in relation to the natural potentials. At a total of 17 farms, which are also located in the Boka Kotorska Bay, the current annual production of mussels in 2017 was 197 tons, while the amount of oysters farmed is still negligibly small and yields about 17 tons [23]. One of the main reasons for the insufficient development of the mariculture sector is that there are no new breeding sites, especially those on the high seas. Therefore, it is necessary to improve the examination of the potential of the high seas from the aspect of strengthening fisheries and mariculture, and in the context of diversification of economies [24].

5.4. Offshore Oil and Natural Gas

Exploration of oil in the Montenegrin underwater area has been especially actualized from the 2010s. In 2011, Montenegro defined an area (blocks) for exploration and production of hydrocarbons, while in 2013 it published the first public call for the award of contracts for concessions for exploration and production of hydrocarbons. In 2014, the Ministry of Economy adopted the Energy Development Strategy of Montenegro to 2030. According to official data, Montenegro does not have oil and natural gas reserves [30]. From 2016, two concession agreements have been concluded for the production of hydrocarbons; the first one was signed in 2016 with a consortium consisting of the company Eni Montenegro BV and the company Novatek Montenegro BV. The second contract was signed a year later with the company Energean Montenegro LTD. The benefits of the research, which are one of the obligations of the concessionaire, are related to the fee payment for the concession area. The collected data on the payment concession fee for all three concessionaires benefited Montenegro with an income of 2.1 million € from 2016 to 2020 [44].

The Montenegro Hydrocarbon Administration of the Government of Montenegro represents the institution responsible for all affairs relevant to the exploration and production of hydrocarbons. It also supervises the execution of the concession contract for the production of hydrocarbons by the side of concessionaires [44]. The country adopted the regulations which ensure the successful implementation of research of the underwater area, without negative effects. The key Montenegrin laws of importance for the exploration and production of hydrocarbons are: the Law on Exploration and Production of Hydrocarbons [45] and the Law on Tax on Hydrocarbons [46]. The Draft Law on Safety Measures for Exploration and Production of Hydrocarbons in the underwater area is in the preparation phase which should implement Directive 2013/30/EU on the safety of underwater operations [47].

Regarding natural gas, in February 2020 there were media announcements of the potential communication between the American and Montenegrin companies in the field of storage and distribution of natural liquefied natural gas from the United States of America to Montenegro [48].

6. Analysis of Maritime Transport and Legislative Framework in Montenegro

6.1. Research Work on the Topic of Sustainable Maritime Activities

The overview on the research works dated since 2014 on the topic of providing the sustainable environmental maritime (transport, logistics, and other coastal) environment in Montenegro without mentioning the BE concept, served as an incentive for deeper analysis of its economic impact simultaneously providing ecological solutions and environmental preservation of the coastal region, having in mind the increased level of maritime traffic and other coastal activities.

The Montenegrin UNESCO protected site, the Boka Kotorska Bay, was a subject of numerous scientific investigations related to the environmental sustainability of maritime transport (cruise and ferry) in the last decade. The study on the Boka Kotorska Bay in the sense of air pollution implications has been done by Nikolić et al. [49]. The quantification of cruise ship exhaust emission at cruising, maneuvering, and hoteling regimes was reported. The results showed that more than 70% of the total emission from cruise ships was related to the hoteling mode while providing recommendations for its reduction. A comparative analysis in the level of emission from cruise ships and their externalities between Dubrovnik cruise port in Croatia and Kotor cruise port in Montenegro was reported in Dragović et al. [50]. The estimation of air pollution indicated the infrastructure solutions (such as an extension of the main berth's length) for reducing the emission inventories and the level of damage costs.

In the study of Nikčević [51], the author identifies the problems that Montenegro is facing on the pathway to achieve full membership within the Paris Memorandum of Understanding on Port State Control (Paris MoU), as a legal instrument that hugely contributes to the sustainable maritime transport in Montenegro. At the same time, the author gives guidelines on whether to improve the inspection supervision in the sea of Montenegro to become a full member of the Paris MoU. Moreover, observing the comprehensive legislative, administrative, technical, and financial resources, Nikčević [52] stipulated that the local authorities should pay more attention to avoid the possible intensive pollution and constitute sustainable tourism to the Kotor cruise port. The economic sustainability of passenger ferry transport in the case of the Boka Kotorska Bay in Montenegro is reported in Škurić et al. [53]. The study shows that with the appropriate assignment of the ferry fleet, the operator achieves increased profit. Also, the estimation of emission inventories of nitrogen oxides (NOx), particulate matter (PM), sulfur dioxide (SO_2), and carbon monoxide (CO) produced by passenger ferry services that are transporting tourists inside the Boka Kotorska Bay in Montenegro during a peak season was discussed. The proposals for emission reduction solutions are provided in Škurić et al. [54].

Ivanović and Bauk [55] developed a holistic multi-phase logistics model for six coastal towns in Montenegro while taking into account the specifics of centers of these towns, which are confined and with limited connectivity with the main road, real, sea transportation, and delivery channels. The simulation results provided in the analysis showed the possibility of achieving greater economic and environmental effects. Vitić-Ćetković and Bauk [56] positioned the Port of Kotor on the digital map of leading cruise ports in Europe and highlight online informative and transactional functions that should improve the Port of Kotor's visibility and approachability for the visitors through its website. Bauk et al. [57] dealt with port worker's occupational safety at the Port of Bar container terminal developing a model of advanced vehicle-to-everything (V2X) communication network at the physical and link layers, based on 5G technology to enhance workers traceability and avoid accidents within the port environment. It should contribute better positioning of Port of Bar among "safe" and "green" ports in the Mediterranean. Kapidani et al. [58] compared maritime business and safety info-communication systems available and used in Montenegro and other neighboring EU and non-EU countries. They highlighted the weaknesses of Montenegro's "fit-out" in this regard comparing with EU countries and proposed recommendations for improvements towards enhancing maritime sustainability.

6.2. The Sector of Maritime Transport

The total value of imported goods within maritime transport in 2018 amounted to 3.5 million € (compared to 2 million € in 2014; 3.3 million € in 2015 and 2017, respectively), while exports of goods achieved around 1.8 million €. The only deviation was recorded in 2017, when there was a surplus in the exchange of goods with foreign countries in the amount of more than 10 million €, as a result of the sale of the docks of the "Bijela" shipyard. In the structure of imports, the trade of yachts and other vessels for sports and leisure activities is the most represented [23].

Also, there is a surplus in maritime transport services. In 2018, the surplus based on the mentioned services amounted to 40.5 million €. The total revenues from maritime transport services amounted to 60.1 million €, while expenditures amounted to 19.6 million €. In the total revenues of maritime transport, other transport activities account for 88.4% of the revenues, freight transport 11.5%, while revenues from passenger transport are negligible with only 0.1%. On the other hand, in the structure of expenditures of maritime transport, the largest share of 52.8% belongs to other transport activities and 46.1% is related to freight transport, while expenditures based on passenger transport counted 1.1% [23].

Looking back to the 1980s, Montenegro was one of the republics within Yugoslavia where maritime transport benefits played an important role. At the time as Lloyd reported, the Yugoslav shipping trade fleet ranked 27th in the world. This result is achieved by two Yugoslav shipping companies located in Montenegro "Prekookeanska plovidba" from Bar and "Jugooceanija" from Kotor and included 44 ships in their fleet in 1988 that provided huge incomes for the state and Montenegro. It provided a profit of about 100.000 million $ realizing the transport of 900,000 ship gross tonnages [59].

The political situation in the 1990s implied the disintegration of Yugoslavia and the national shipping companies did not operate and remained without the income of the shipping fleet. The result of this situation was indeed unfavorable for the country and shipping companies from Montenegro went bankrupt. From 2006 when Montenegro claimed independence, the intention was to revitalize maritime transport through the establishment of two shipping companies in Bar and Kotor ("Barska plovidba AD" and "Crnogorska plovidba AD Kotor") for operating with bulk cargo.

With reference to maritime activities, there are six ports in Montenegro included for international transport: Bar, Kotor, Zelenika, Budva (only in the summer season), Tivat, and Risan. The biggest port in the country is the Port of Bar, and the second phase of the port area was constructed in 1971. It was projected to realize the throughput of 5 million tons per year. From 2009, the Port of Bar completed the restructuring process and was divided into two companies: Container Terminal and General Cargo AD—from 2013 Port of Adria AD as a multipurpose port with dedicated terminals for container ships, general cargo ships, Ro-Ro, and cruise ships [60], and Port of Bar AD [61]. The total realized throughput of goods in Montenegrin ports observing the period 2014–2019 is given in Table 4.

Table 4. The statistics of achieved throughput in Montenegrin ports [31].

Year	Throughput in Ports in Tons	Transshipped Tons in Ports	Manipulated Tons in Ports
2014	1,241,431	1,787,101	2,760,042
2015	1,488,399	1,650,776	3,369,942
2016	1,645,797	1,617,518	3,696,210
2017	2,096,122	2,324,336	3,673,312
2018	1,963,204	1,989,023	3,293,338
2019	2,050,869	2,023,183	4,032,266

As evident, there was an increase in 2017 and 2019 of cargo throughput with more than 2 million tons, respectively. Regarding the transshipped tons of goods for the same period, certain transshipment is presented for 2014, 2015, 2016, and 2018. Finally, the maximum level of manipulated tons was reached in 2019 [31]. On the other hand, Ro-Ro passenger throughput at the ferry line between Bar (Montenegro) and Bari (Italy) was: in 2014 the traffic volume reached 42,489 passengers, during 2015 the indicator was 39,198 passengers and in 2016, a total of 35,925 passengers were transported [31]. From 2017 the official Montenegrin operator canceled the line and afterward, the Croatian Ro-Ro ship was chartered only during the summer season.

The share of profit achieved by the Port of Bar AD in 2016 was 1.3 million €; 0.94 million € in 2017; 0.3 million € in 2018, and 0.93 million € in 2019 indicating the fluctuations in the business activities of the port. It included the income from the combination of port services, fishing, shipping, cruise tourism, and other activities [62].

The cruising sector is experiencing high yearly growth in the last decade. Kotor cruise port is the third port after Venice and Dubrovnik in the Adriatic Sea regarding the number of port calls achieved in a year [63]. However, the region is recognized as an attractive cruise destination. The statistics on the number of port call and passengers (pax) on-board cruise ships is given in Figure 2. As can be seen, the number of port calls faced an increase until 2016 while there was a slight decrease in the number of port callings from 2017 to 2019. On the other hand, the enhanced throughput of passengers was predominant every year except in 2018 when there was an unusual decrease in the number of tourists that came to Kotor by cruise ships [31]. According to the official financial reports of the Port of Kotor, the achieved profit in 2016 was 0.912 million €; 0.927 million € in 2017; 0.795 million € in 2018, and 1.1 million € in 2019 [64].

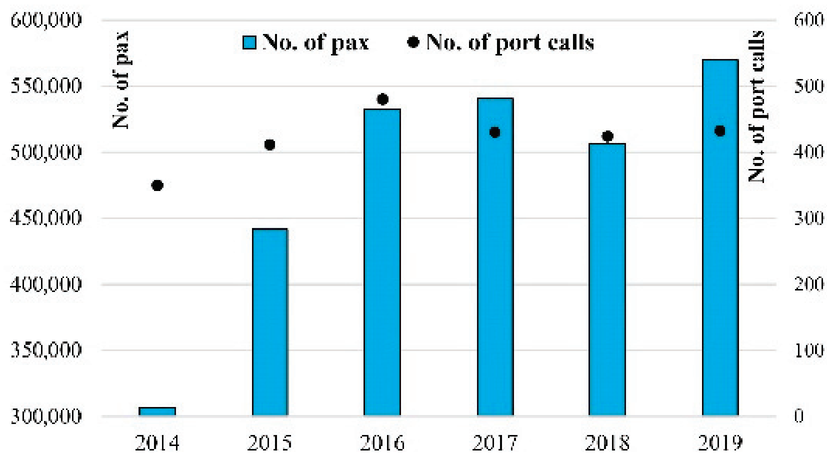

Figure 2. The cruise ships' throughput statistics [31].

Nautical tourism activities are recognized as very attractive ones along the coast of Montenegro. The expansion of marinas is related to leisure activities and a lot of yachts and other touristic vessels are coming to small nautical ports such as Porto Montenegro, Porto Novi, Marina Bar, Marina Budva, Marina Škver, Marina Kotor, etc. Montenegro adopted the Law on Yachts in 2007 [65] which in one place, using the best international legal solutions, regulates the nationality, identification, registration, navigation, yachts stay, and rental conditions in the Montenegrin waters. This law establishes a special yacht register—the Montenegro Yachts Register. Every yacht can be entered in this register, regardless of whether it is owned by a foreign or domestic citizen (yacht owner) [66]. Speaking of the impact of nautical tourism activities in Montenegro, from Figure 3 there is an evident constant increase both in the total number of vessels that visited Montenegrin territorial waters and the number of passengers on-board those vessels. The coast region of Montenegro is on the nautical map of these activities and often represents a favorite destination during the summer. For example, an average of 5.9% of the yearly increase happened in the case of the number of vessels. In the case of passengers, there is a higher increase on an average of 12.4% every year [31].

Assuming the inconceivable consequences that unsafe maritime transport would have in the coastal area for all sectors of the BE, as well as for the entire state of Montenegro, and beyond, we opted for a more detailed review of the legislative framework of maritime transport considering regulations related to the environmental sustainability.

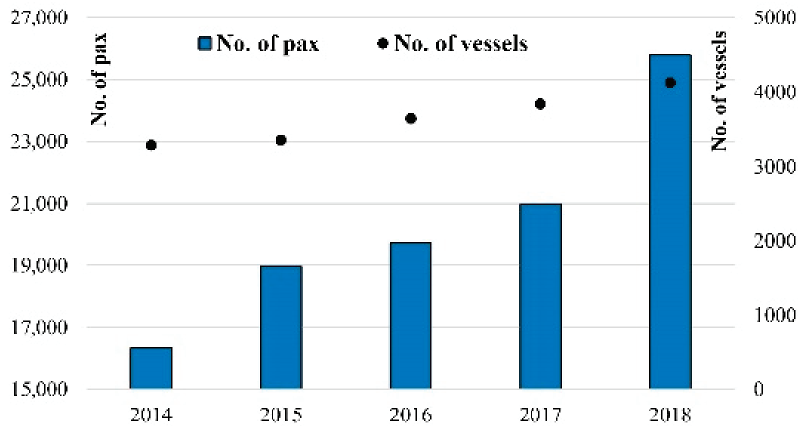

Figure 3. The statistics of nautical tourism vessels and passengers [31].

In order to obtain a sustainable development of maritime transport, it must not have an adverse impact on the marine environment, i.e., its negative impacts should be minimized. Consequently, in compliance with regulations related to maritime safety and protection of sea pollution from vessels represent a prerequisite and imperative for sustainable maritime transport. In this section, first, we identify the international regulations that represent the global framework for the protection of the sea and Montenegro's adoption status. Afterward, the Montenegrin regulations are important for maritime transport and ecologically sustainable use of the sea.

6.3. International Regulations

The protection of the marine environment from pollution has, for many years, been placed under the priority activities of several international organizations. This section emphasizes the activities in the direction of the implementation of legal regulations.

The UN Convention on the Law of the Sea—UNCLOS, represents the "umbrella treaty" considering the legal framework governing the rights and responsibilities of nations in their use of ocean space. Part XII of UNCLOS (Articles 192 to 237) regulates the protection and preservation of the marine environment including the area that stipulates the right of innocent passage through the territorial sea, sea areas, settlement of disputes, etc. Although the primary responsibility of the flag state for ships flying its flag is to control the pollution, the Convention also foresees certain powers for coastal states and port states to protect the marine environment. In addition to the UNCLOS, there are numerous international conventions on the protection of the marine environment adopted under the auspices of the IMO.

The global legal framework divided into three criteria (prevention from sea pollution, legal framework to eliminate and reduce harmful consequences, and legal framework related to liability and compensation for marine pollution damage) is presented in Table 5. Precisely, the first criterion diversifies prevention of maritime accidents and sea pollution and prevention of sea pollution from/to ships by the type of pollution. The first level comprises international regulations aimed at preventing maritime accidents (including marine pollution). The second level refers to marine pollution prevention according to certain types of pollution from/to ships.

Table 5. Global legal framework and adoption status of Montenegro.

Relevant Regulations	Name	Adoption Status
Global	The United Nations Convention on the Law of the Sea, UNCLOS 1982	Ratified
	Relevant regulations by criteria I, II, and III	
	I Prevention	
Prevention of maritime accidents and sea pollution	The International Convention for the Safety of Life at Sea, SOLAS 1974	Ratified
	The International Convention for the Prevention of Pollution from Ships, MARPOL 1973/1978	Ratified
	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, STCW 1978	Ratified
	The International Convention on Load Lines, LL 1966. Protocol of 1988	Ratified
	The International Convention on Tonnage Measurement of Ships, TONNAGE 1969	Ratified
	The International Convention for Safe Containers, CSC 1972	Ratified
	The Convention on the International Regulations for Preventing Collisions at Sea, COLREG 1972	Ratified
	The Convention on Facilitation of International Maritime Traffic, FAL 1965	Ratified
	The Convention on the International Maritime Satellite Organization, INMARSAT 1976	Not ratified
Prevention of sea pollution from/to ships by the type of pollution	The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, LC 1972	Ratified
	The International Convention on the Control of Harmful Anti-fouling Systems on Ships, AFS 2001	Ratified
	The International Convention for the Control and Management of Ships' Ballast Water and Sediments, BWM 2004	Ratified
	The International Convention for the Safe and Environmentally Sound Recycling of Ships, HONG KONG Convention, 2009	Not ratified
	II Legal framework to eliminate and reduce harmful consequences	
	The International Convention on Maritime Search and Rescue, SAR 1979	Ratified
	The International Convention on Salvage, SALVAGE 1989	Ratified
	The International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties, INTERVENTION 1969	Ratified
	Protocol relating to Intervention on the High Seas in Cases of Pollution by Substances Other Than Oil, INTERVENTION PROT 1973	Ratified
	The International Convention on Oil Pollution Preparedness, Response and Cooperation, OPRC 1990	Not ratified
	Protocol of Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances, OPRC/HNS 2000	Not ratified
	III Legal framework related to liability and compensation for marine pollution damage	

Table 5. *Cont.*

Relevant Regulations	Name	Adoption Status
	The International Convention on Civil Liability for Oil Pollution Damage, CLC 1969, CLC Protocols 1976 CLC Protocol 1992	Not ratified Ratified
	The International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage, FUND 1971, FUND Protocols 1976 FUND Protocol 1992 and FUND Protocol 2003	Not ratified Ratified
	The Convention relating to Civil Liability in the Field of Maritime Carriage of Nuclear Material, NUCLEAR 1971	Not ratified
	The Convention on Limitation of Liability for Maritime Claims, LLMC 1976, Protocol 1996	Not ratified
	The Athens Convention relating to the Carriage of Passengers and their Luggage by Sea, PAL 1974, PAL Protocols, 1976, PAL Protocol 1990 PAL Protocol 2002	Not ratified Ratified
	The International Convention on Liability and Compensation for Damage in connection with the Carriage of Hazardous and Noxious Substances by Sea, HNS 1996, Protocol, 2010	Not ratified
	The International Convention on Civil Liability for Bunker Oil Pollution Damage, BUNKERS 2001	Ratified
	The International Convention on the Removal of Wrecks, WRC 2007	Not ratified
Regional instruments	The Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean, Barcelona Convention, 1995	Ratified
	The Paris Memorandum of Understanding on Port State Control, Paris MoU 1982	Ratified

The second criterion contains international regulations already adopted to eliminate and reduce the harmful consequences of maritime accidents that have already occurred. The third criterion reports the legal framework for determining liability and compensation for marine pollution damage at the international level. In addition to the global legal framework, Table 5 also recognizes two regional instruments by whose regional cooperation is realized for resolving specific issues in marine protection. It also shows the status of Montenegro concerning international conventions.

Although the subject of this paper does not allow the closer analysis of the global legal framework, in the next section we opted for a more detailed presentation of the provisions of national legislation in the field of marine protection. We believe that any domestic legislation, including Montenegro, represents an important component contributing to the global legal regime and its environmental protection.

6.4. National Regulations

This section presents the Montenegrin legal framework on the protection of the sea from pollution from ships. Legal regulations are divided according to the three criteria starting with laws that deal with marine environment protection issues. Second are laws that treat different relations in the maritime sector, but in certain parts also regulate the protection of the sea from pollution. Last are laws that are directly related to the prevention of marine pollution. The Montenegrin legal framework is shown in Table 6.

Table 6. Legal framework in Montenegro.

National Regulations by Criteria I, II, and III	
I Marine protection	
Laws related to nature and environmental protection	Law on Nature Protection, 2016
	Law on Environment, 2016
Laws on maritime transport	Law of the Sea, 2007
	Law on Ports, 2008
	Law on Yachts, 2007
II Indirect impact on marine protection	Law on Maritime Navigation Safety, 2013
III Specialized regulation for marine protection caused by pollution from vessels	Law on the Prevention of Sea Pollution from Vessels, 2011
	National Plan for Emergent Reaction in the Event of Sea Pollution from Vessels, 2011

The Law on Nature Protection [67] and the Law on Environment [68] refer to the protection and preservation of nature, and the environment, respectively. The marine environment is treated as a part of nature or the environment. These regulations have a general approach when formulating legal provisions concerning the protection of the marine environment. It is expected to have in mind their general character and the main objective related to environmental protection.

The Law on Nature Protection [67] protects marine habitats by a general provision, in the manner that prohibits the performance of actions and activities for destroying them (Article 19 of the Law). The need for the adoption of the Strategy on Marine Environmental Protection following Article 29 of the Law and providing the protection of the sea and coastal area by systematic monitoring of marine and coastal ecosystems including the implementation of specific measures are foreseen in the Law on Environment (Article 18 of the Law) [68].

The Law of the Sea, Law on Ports, Law on Yachts, and the Law on the Exploration and Production of Hydrocarbons belong to the maritime transport regulations which in certain parts regulate the protection of the sea from pollution [69]. In that sense, the Law of the Sea stipulates the duty for Montenegro to protect, preserve and improve the marine environment (Article 2 paragraph 3 of the Law). The Law envisages and encourages the cooperation of Montenegro with neighboring countries and countries in the region to prevent and reduce marine pollution as provided in Article 2, paragraphs 4 and 5 of the Law. Observing the Law of the Sea, it can be noticed that the provisions on the protection of the sea from pollution are contained in specific articles, which regulate the right of innocent passage and certain maritime zones [69].

Law on Ports and Law on Yachts represent the general laws that deal with the marine environment protection throughout several provisions thereof. According to Article 26 of the Law on Ports, to prevent pollution of the sea or the port area, the port beneficiary is obliged to adequately equip the port with facilities for receiving and handling waste. When natural persons or legal entities pollute the sea, the competent authorities shall inform them to terminate the pollution by removing the harmful effects.

According to Article 33 of the Law on Yachts [65], besides the nationality, identification, registration, and other issues, the article also regulates the provisions on marine pollution prevention from yachts. Article 28 stipulates the obligation for the master or yacht manager to immediately notify the administrative body about the eventual discharge of oil and oily water, waste, garbage, and other polluting substances including the exact position of the yacht.

The Law on Maritime Navigation Safety [32] is classified as a second criterion of the legal regime for marine protection in Montenegro. Its regulations indirectly impact the marine protection environment. The Law comprises all the aspects of maritime safety besides contributing to avoiding maritime accidents and related pollution of the sea. Concerning the protection of the sea from pollution, the provisions on Port State Control given in Part XIV, Articles 183 to 198 of the Law, are particularly significant.

The third criterion includes regulations on sea pollution protection from vessels, including those on pollution prevention [69]. These are the Law on the Prevention of Sea Pollution from Vessels [70] and the National Plan for Emergent Reaction in the Event of Sea Pollution from Vessels [71]. For the first time in the national framework, the Law regulates the segments of sea pollution protection from vessels. Its adoption aims to prevent, reduce and eliminate sea pollution as much as possible. The law regulates the sea pollution protection from vessels that navigate or are located in the inland waterways and the territorial sea of Montenegro. While observing, the lawmaker, when formulating its provisions, tries to implement the international obligations from numerous international conventions.

The Law includes: Part I (General Provisions), Part II (Pollution from the vessels), Part III (Ship for the transport of oil as load or as a fuel), Part IV (Ship for the transport of harmful liquids in bulk), Part V (Ship for the transport of harmful substances in the packaged form), Part VI (Fecal waste), Part VII (Communal waste), Part VIII (The emission of harmful substances into the air), Part IX (Ballast waters), Part X (System anti-fouling ship plating), Part XI (International dumping of the waste), Part XII (Reception and handling of waste, waste oil, cargo residues and sediment from ballast tanks in ports), and Part XIII (Responsibility and compensation in case of marine pollution from the vessels).

In April 2011 the Government of Montenegro brought the National Plan for Emergent Reaction in the Event of Sea Pollution from Vessels [71]. The Plan determines the main principles of actions, tasks, and obligations, together with measures to prevent, minimize or remove the consequence of the vessel-sourced marine pollution. The main goal of the Plan is to provide a prompt and efficient response to accidents of sea pollution from vessels at the national level. The Plan will be applicable in a maritime accident that has caused or could have caused pollution in the sea areas, both on the seabed or under the seabed including internal waters and territorial sea. The general aim of the Plan is to adequately react and provide an initial and efficient response in the case of oil spills, and discharge of harmful substances that adversely affect or could negatively impact the marine environment of Montenegro and its coasts, as well as to ensure the national and international cooperation in the Adriatic and Mediterranean Seas.

7. Conclusions and Recommendations

The concept of the BE is relatively new and appears as a "pillar of protection" for the unsustainable use of marine resources. Its relevance is mostly conditioned by the geographical position of the country and by the availability of marine and coastal potentials. The geographical position of Montenegro implies that the marine resources and potentials for Blue Growth represent its development opportunity. The question is, what is the approach of Montenegro towards BE, and does it observe marine resources as a potential for its growth and development?

Reviewed studies, likewise strategic documents and legislation in this area, address certain issues within BE. Numerous relevant documents indicated the lack of identified sectors, institutional structures, databases relevant for reviewing the current situation in the BE sectors, and scientific monitoring of marine resources management.

This research indicates that Montenegro is more oriented declarative to the sustainable development of marine resources and the BE concept progress. Although certain problems have been identified in the strategic documents, it is clear that the analysis for overcoming the problems in the sense of proposing concrete measures and solutions is missing. In our opinion, this will be especially evident during the realization of strategic goals. Although strategic documents identified certain problems, it is clear that the directions for solving the issues (i.e., proposing concrete measures) are missing. Nevertheless, this will be especially evident during the realization of strategic goals. However, we notice that implementation is still pending (given the recent adoption of these strategies), so deeper economic analysis will be the subject of another research.

Based on the conducted research in this paper, we give some general directions in order to provide more efficient marine resources monitoring in the country:

- Initiating a comprehensive survey in the manner of assessing the existing capacities of individual marine resources and determining their optimal level and intensity of exploitation;
- Establish coordinated cross-sectoral management in BE and maximum public involvement;
- Provide the efficient and effective implementation of legal regulations within the sector of maritime transport and further implementation of international instruments, especially in the part of the protection of the marine environment would avoid degradation of marine areas and the visual appearance of the coast;
- Forming an electronic database system relevant to the BE sectors and thinking in the direction of adopting a strategic document, e.g., Strategy on sustainable use of marine resources that would define and in detail describe all issues important for the Montenegrin BE development;
- Detailed economic analysis on determining the profit from the exploitation of marine resources and their participation in GDP and;
- Popularization of the BE concept through strengthening human resources in the context of higher education, vocational training, and raising public awareness.

All mentioned with the existence of a stable political environment oriented towards the development of the BE and favoring the importance of marine resources for the economic and general development of Montenegrin society, hopefully, represents a core basis for creating an environment focused on sustainably using marine resources and reducing the environmental impact of their use.

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Impact of Demographic Structure on Economic Development of Ukrainian Coastal Regions

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Abstract: The main aim of our paper is to study peculiarities of two periods, i.e., the pre-conflict period (2004–2013) and conflict period (2014–2018), in the context of the impact of the demographic structure of the population on the economic growth and development of coastal regions of Ukraine. In the first step of the analysis, we investigate the relationship between the demographic shifts and selected economic indicators, using the Pearson's correlation coefficient. In the next step of the analysis, we focus on the quantification of the impact of demographic indicators on the economic variables, based on the panel model with fixed effects. The received results confirm that the influence of the demographic stricture on the economic state of coastal regions changed significantly in the conflict period in comparison with the pre-conflict period, especially concerning income, unemployment, and the openness of the economy. Additionally, our findings show that while economic differences existed between the Azov Sea regions and the Black Sea regions in the pre-conflict period, they disappeared due to the economic deterioration of the Azov Sea regions during the conflict period. It is concluded that war affects adversely the population's demographic structure, which inhibits the growth and economic development of Ukrainian coastal regions.

Keywords: Ukraine; coastal regions; demographic structure; regional economic performance

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1. Introduction

Coastal regions play an essential role in the country's economic performance and sustainable development due to available diversified resources and multifunctionality. However, it is necessary to pay attention that disparities between these regions could constrain the country's economic growth [1,2]. Therefore, it is necessary to analyze comprehensively different factors affecting the economic state of coastal regions. Based on this analysis, it is possible to work out the regions' strategies, aimed at ensuring their dynamic and effective functioning in the country, taking into account tendencies and peculiarities of international economic processes.

Ukrainian coastal regions include Donetsk, Kherson, Mykolayiv, Odesa, and Zaporizhzhya oblasts, Autonomous Republic of Crimea, and Sevastopol (city). Odesa and Mykolayiv oblasts and Sevastopol (city) border with to the Black Sea, and the Donetsk and Zaporizhzhya oblasts have access to the Azov Sea. The Kherson oblast and Autonomous Republic of Crimea border with both the Black and Azov seas. The coastal regions make a special contribution to Ukraine's international trade, industry, and recreation and tourist activities. In these regions, seaports are situated that have strategic importance for the country. The value of the regions is also determined by the fact that their coastal shelf contains large reserves of mineral resources, including oil and gas.

It should be noted that Russia used to be one of the major political and economic partners of Ukraine. Though, the situation changed significantly at the beginning of

2014. Prolonged protests took place in the country when the Ukrainian president Viktor Yanukovych rejected to sign the Association Agreement between Ukraine and the European Union. Pro-European political forces came to power in the country, aiming at the conclusion of this Agreement. Russia annexed the Crimean peninsula and occupied significant parts of the Donetsk and Luhansk regions in violation of international treaties. Nowadays, economic and trade ties between the countries are limited. In Ukraine, the substantial decline of the country's economy, the deterioration of the population's living standards, and the intensification of internal and external migration are observed.

Taking into consideration that the effects of demographic processes on the economic growth of Ukraine and its regions are investigated to a limited extent (particularly, in regards to Ukrainian coastal regions), we decided to select this research direction. The main aim of our article is to study peculiarities of two periods, i.e., the pre-conflict period (2004–2013) and conflict period (2014–2018), in the context of the impact of the demographic structure of the population on the economic growth and development of coastal regions of Ukraine. Moreover, demographic and economic differences between the Black Sea and Azov Sea regions were explored during the above-mentioned periods. The overarching research hypothesis of the article was that war affects adversely the demographic structure of the population, which inhibits the growth and economic development of Ukrainian coastal regions.

The paper is organized as follows: Section 2 provides a brief overview of publications on the impact of demographic changes on the economic performance of countries and regions. In Section 3, research assumptions are presented. Section 4 includes the description of data, methods, and the research process. In Section 5, research results concerning the effect of demographic composition on the economic state of Ukrainian coastal regions are presented. Section 6 contains a discussion and possible directions for future research. The main conclusions are given in Section 7.

2. Literature Review

Moosa [3] considers war as a state of armed conflict among countries, governments, societies, and factions. It can also take place within the country as the civil or revolutionary war. Reasons, tendencies, and consequences of war economics have been studied for a long time. For instance, historical features and theoretical foundations of this economics are investigated in detail by Robinson [4]. As stated by the researcher, the cause of war is the law of decreasing returns. This economic principle is the driving force that pushes countries to war activities.

Taking into account different war and conflict origins, Kimbrough et al. [5] identify the following war/conflict economic models:

- Contest models;
- War of attrition games;
- Colonel Blotto games;
- Guns versus butter models;
- Spatial conflict models.

Anderton and Carter [6] point out that conflict and economics are linked as follows:

- Conflict is a choice, which is similar to economics;
- Conflict has an impact on economic outcomes (production, trade, capital and labor migration, growth, etc.);
- Economic variables influence conflict;
- Conflict is a way of wealth acquisition.

It is important to understand the real impact of war on economic development. Based on the U.S. data, the Institute for Economics and Peace [7] analyses the macroeconomic effects of five war periods on the country's economic performance. It is found that military spending has only a temporal positive influence on the country's economy. Regardless of used financial sources, its consequent macroeconomic impact is negative because of higher taxes, the larger budget deficit, growing inflation, etc.

The influence of demographic factors on the development of different countries is widely considered in publications. For example, Wei et al. [8] forecast the influence of population aging on various economic processes in China in 2050, applying the global computable general equilibrium model. Their findings testify that, due to the aging, the country will have a decline in consumption and labor supply, as well as investments. As a result, the predicted value of GDP is expected to be lower by nearly 10%.

Lee et al. [9] make predictive calculations about the link between demographic changes and fiscal sustainability in Asian countries up to 2050. Based on the simple stylized model, the researchers identify that population aging could have a strong negative impact on the fiscal health of these economies. They argue that the drastic increase of the old age population might cause the rise in public spending and the contraction in revenue to a significant extent even in the case of the existing demographic structure.

Uddin et al. [10] examine the peculiarities of the effect of the population age structure on Australia's economic development. Employing several statistical approaches (including dynamic ordinary least squares, fully modified ordinary least squares, and the vector error correction model), it is determined that the dependency ratio has an unfavorable influence on the gross domestic product (GDP) per capita. Accordingly, the population in the working-age affects positively the county's economic state.

Mierau and Turnovsky [11] work out the extended single-sector endogenous growth model to better understand how demographic shifts are associated with economic development and wealth inequality. The researchers note that the impact of the population growth rate on countries' economic performance might be different, depending on the character of demographic changes. As an example, they investigate the effect of demographic changes (the growth of life expectancy and the decline of the birth rate) on the US economy. The received results show that the mentioned evolution of birth and life expectancy rates are positively linked with the country's economic growth in the long-term. Moreover, these demographic tendencies have offsetting effects on the degree of wealth inequality.

Sánchez-Romero et al. [12] explore the impact of demographic changes on wealth inequality in the US based on the elaborated small-open economy model with overlapping generations. It is revealed that, while the decrease in fertility causes the growth of wealth inequality, it has the reverse effect on this inequality at the population level. Additionally, it is identified that the rise of life expectancy affects wealth inequality non-monotonically.

Heijdra and Mierau [13] use the demographic macroeconomic model to assess the impact of aging on the Netherlands' economic growth. The research results indicate that population aging has a positive influence on the country's economic performance. At the same time, the findings show that the increase in the retirement age hurts the economy as a consequence of a longevity shock.

Sánchez-Romero et al. [14] examine how long-term demographic trends affect the income growth of Spain. Using the overlapping generations model, they found that around 17% of the per-capita income rise is connected with demographic changes: 14.5% and 6.4% because of contraction infertility and the growth in longevity, respectively. The researchers argue that, after productivity, the demographic component is the most influential factor of the country's income growth.

Based on the multi-country overlapping generations model, Kolasa and Rubaszek [15] present a prognosis of the impact of aging on the economic situation in the selected European countries: Germany, France, Italy, and Spain. The obtained results confirm that the expected growth of the old-dependency ratio can cause substantial external and internal imbalances in these European economies.

Lindh and Malmberg [16] explore the effect of the age structure on the economic situation in the EU-15 countries. The results confirm that there is a link between the increasing portions of dependent age groups and the shrinking GDP growth rates. It is also expected the existence of the negative influence of population aging on the countries' economic growth in the long-term, though related to various time horizons.

Dolls et al. [17] investigate the expected influence of population aging and upskilling on the income distribution of the EU-27 countries by 2030. The use of reweighting and microsimulation techniques allow the researchers to determine that, while population aging will likely lead to income inequality growth, the estimated impact of increasing educational attainment will be more ambiguous.

Cruz and Ahmed [18] study the impact of changes in the population age structure on the economic development of selected countries, applying several approaches (the first-difference estimation, panel fixed effects estimation, and system-GMM estimation). It is found that the increase of the portion of the working-age population and reduction of the child-depending ratio is positively linked with the growth of GDP per capita and the decrease of the poverty level of analyzed countries.

Kuhn and Prettner [19] consider specific features of the influence of the population age structure on the economic growth and consumption level in chosen countries. The obtained results indicate that there are significant cross-country differences concerning the impact of the generational turnover effect on the countries' economic development. Its positive influence is identified in countries with a young population, while its negative effect is observed in aging economies. It is argued that these differences are due to the peculiarities of the consumption age profile. It is also noted that consumption growth per capita tends to be lower in economies with high levels of mortality and fertility.

Wietzke [20] explores the relationship between demographic changes and the poverty level, analyzing data for 140 countries. Based on the poverty–growth regression, it is found that the fertility decline positively impacts countries' poverty rates. Moreover, it is determined that it has a more pronounced effect in countries that are in the early stage of demographic transition.

Several studies are conducted to assess the impact of the population age structure on regional economic development. For instance, Wei and Hao [21] examine the effect of demographic structure on the economic growth of China's provinces based on the panel data approach. Their findings show that the demographic change (particularly, the effect of fertility decline on the contraction of youth dependency) is positively associated with the long-term country's growth. The reverse impact of the economic growth on investigated demographic indicators is also revealed.

Applying fixed-effect estimations, Zhang et al. [22] find that the various demographic groups impact substantially the economic state of Chinese provinces. The changes in the population composition cause the growth of GDP per capita by one-fifth at the regional level. Attention is also given to the fact that the size and demographic structure of the working-age population have at least the same influence as dependency ratios.

Benassi and Salvati [23] study how migration and demographic changes affect the economic performance of Greek regions, employing the multi-temporal principal component analysis and diachronic analysis. The findings confirm that there is a significant influence of the structure of the regional population on expansions and recessions of the country's economy. The received results also show the substantial impact of migration, demographic changes, and the population structure on the regional polarization. Moreover, it is identified that there is a short-term influence of aging on the population structure, which could unfavorably affect the ability of Greece's economic revival in the post-crisis period.

The results received by Brunow and Hirte [24] indicate a significant effect of the demographic structure on the economic performance of EU-15 NUTS2 regions (namely, on GDP per capita). Using four specifications (the basic OLS regression, the spatial error approach, the spatial lag specification, and the spatial regressive specification), the most substantial positive impact is identified for the working cohorts that are younger than 45. While the positive influence is also found for the 45–59 age group, the effect of the young population on the regional economic development is rather limited.

Different aspects of demographic changes and their influence on the countries' economic development are also explored in the publications [25–31]. Moreover, some authors argue that demographic shifts can have a changeable impact on economic growth, depending on the situation in countries and/or regions. For example, Taketoshi [32] analyzes the influence of the demographic dividend on the economic growth of China. In this study, particular attention is given to:

- the "labor effect", which is connected with an expanding working-age population and, consequently, the country benefits from a larger young labor force;
- the "capital effect", that is related to the declining dependency ratio and its positive impact on total savings, which are mainly used for investment in physical capital.

Until the 2010s, the "capital effect" has affected China's economy to a greater extent than the "labor effect". However, in the 2010s, the situation changed completely, and the "capital effect" was not the substantial driving force of the country's economic development anymore.

Macunovich [33] assesses the impact of the demographic structure on the main economic indicators of selected countries, employing the Fair–Dominguez method. The findings show that the population aged 15–24 has the strongest effect on the countries' economic development. Though, while this young population group positively affects GDP, it hurts both the current account balance and gross capital formation.

It should be noted that there are many papers published on general demographic trends and problems in Ukraine. However, only a few studies are dedicated to the assessment of the impact of demographic changes on the economic state of the country and its regions. First of all, we would like to draw attention to the article written by Maksymenko [34], in which ways of interaction between declining fertility and the state of the Ukrainian economy are examined. Based on a multi-variable vector autoregression model, it is found that there will be the short- and long-term reactions of fertility on unemployment, money holdings, and the country's economic growth. In the short-term, policies in regards to decreasing fertility could be suitable. Though, in the long-term, opposite approaches and policies should be implemented to promote the country's economic performance. We can also mention several other publications [35–37], in which some aspects of demographic and economic interaction in Ukraine are explored.

3. Research Assumptions

According to the main aim of the paper, research hypotheses were formulated. The overarching research hypothesis of the paper was that war affects adversely the demographic structure of the population, which inhibits the growth and economic development of Ukrainian coastal regions. The verification of this hypothesis was split into three parts to assess the validity of three main and several partial research assumptions.

The first analytical part of the paper was focused on the verification of the hypothesis that the war conflict influenced significantly the relationship between demographic and economic indicators. The hypothesis was investigated using correlation analysis. This analysis was employed to examine four partial assumptions:

- relationship between the demographic and economic indicators in coastal regions differed substantially from the rest of Ukraine;
- relationship between the demographic structure and economic indicators in the war period differed significantly from the peace period;
- gross regional product and income were not influenced by the demographic structure in the war period;
- unemployment in the conflict period was more affected by the age structure than in the pre-conflict period.

The second part of the analysis was aimed at the verification of the hypothesis that demographic development has a significant impact on the economic performance of regions. The hypothesis was checked using the panel data model with fixed effects. In this part of the paper, the following research assumptions were formulated:

- war inhibited the regional economic performance;

- income and the openness of the economy was significantly influenced by the war conflict;
- young working population played the most important role in the economic development of regions.

The third part of the analysis was devoted to the Black Sea and Azov regions and the verification of the research hypothesis that war accelerates population aging and its unfavorable impact is more significant on the economic performance of Azov Sea regions due to their proximity to the conflict zone. This hypothesis was tested based on the comparative analysis, applying the statistical inference.

In this part, three partial research assumptions were also verified:

- the war conflict accelerated population aging;
- differences between the Azov and Black sea regions on the age structure in the peace period persisted in the conflict period;
- differences between the Azov and Black sea regions on their economic performance disappeared during the war period.

4. Materials and Methods

We used data and publications of the State Statistics Service of Ukraine (www.ukrstat.gov.ua (accessed on 14 December 2020), database.ukrcensus.gov.ua/MULT/Dialog/statfile_c.asp (accessed on 14 December 2020)). Data were collected for 5 coastal Ukrainian regions (Donetsk, Kherson, Mykolayiv, Odesa, and Zaporizhzhya oblasts) for 2004–2018. Regarding the Donetsk region, data for 2014–2018 were available for enterprises, institutions and organizations which submitted reports to the state statistics bodies. Since 2014, data for the Autonomous Republic of Crimea and Sevastopol (city) were not accessible due to Russia's annexation, and that is why they were not included in this study.

The coastal regions were investigated in the pre-conflict period (2004–2013) and the conflict period (2014–2018). Overall data for Ukraine were used as a benchmark in some comparisons. Data were employed in the form of a panel, including time series with 15 periods and 5 cross-section units; thus, there were 75 observations in total. The analysis included the following economic indicators:

- Gross regional product (GRP) per capita;
- Total export of goods per capita;
- Total import of goods per capita;
- Openness of the economy: (export + import)/GRP;
- Disposable income per capita;
- Unemployed population, %.

The values of GRP and disposable income per capita were recalculated from Ukrainian hryvnias into US dollars, based on the annual average official exchange rate of the National Bank of Ukraine. The trade indicators, i.e., total export of goods per capita and total import of goods per capita, were available in US dollars.

Several demographic indicators, related to the age structure, were investigated in terms of their impact on the above-mentioned economic indicators:

- Under14: population aged 0–14 years;
- Workingp: working population (15–65 years);
- Youngwork: young working population (15–34 years);
- Primework: prime working population (35–54 years);
- Oldwork: old working population (55–65 years);
- Elderly: population aged 65 years and over.

All variables in panel models, except unemployment, were included in the form of the natural logarithm. In the case of demographic indicators, the logarithm of the number of people in each category was used to avoid collinearity problems that would occur with an investigation of data expressed as a population share. In correlation analysis and descriptive statistics, demographic indicators were expressed as the population share (population aged 0–14 years, working population, and elderly) and the share of working people (young working population, prime working population, and old working population) to make them comparable across the regions.

The analysis also explored the influence of the war conflict in Ukraine on the relationship between investigated variables. It was conducted by including a conflict dummy variable into the performed analysis, which was equal to 0 for the pre-conflict period and 1 for the conflict period.

In the first analytical part of the paper, special attention was given to the verification of the hypothesis that the war conflict influenced significantly the relationship between demographic and economic indicators. This hypothesis was checked using the correlation analysis, which measures the strength of the relationship between analyzed variables. For this purpose, the Pearson's correlation coefficient was used:

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}} \quad (1)$$

where x_i is the ith value of variable x, y_i is the ith value of variable y, $\overline{x}$ means the value of x and $\overline{y}$ means the value of y; the r value close to 1 refers to the strong positive correlation, and the value close to -1 refers to the strong negative relationship. A value close to 0 means a weak or no relationship between variables. This analysis was conducted on data for the whole analyzed period and separately for the periods before the conflict and during it. The analysis included only correlations between demographic and economic variables. In the analysis, economic indicators were employed as regional values of indicators per capita in USD, and demographic indicators were included as the share of the population in each category.

The second part of the analysis was the quantification of the influence of demographic indicators and the effect of conflict on economic variables. For this purpose, the panel model with fixed effects was applied. This type of model was selected due to the nature of the long panel (the small number of cross-sections and the higher number of periods). Each model also includes the F-test for no fixed effects, which verifies the suitability of the fixed-effect model (H0 should be rejected for the suitable fixed-effect model). Models were estimated in the form:

$$Y_{it} = b_0 + b_1 LnUnder14_{it} + b_2 LnYoungwork_{it} + b_3 LnPrimeWork_{it} + b_4 LnOldwork_{it} + b_5 LnElderly_{it} + b_6 conflict_{it} + u_{it} \quad (2)$$

where y_{it} is the economic dependent variable. All variables were used in the form of the natural logarithm, except unemployment measured in %. b_0 to b_6 are parameters of the model. b_0 is the intercept and b_1–b_6 are the estimated effects of explanatory variables on the dependent variable and u_{it} is a random error in the estimated fixed-effect model. Demographic variables were expressed as the logarithm from the number of people in each category.

Conflict is the dummy variable, which was equal to 0 for the pre-conflict period and 1 for the conflict period. Models were estimated for each dependent variable in the same form separately. The final model was estimated using the method of stepwise backward elimination. Results include only the final model for each dependent variable, including parameters significant at least at alpha = 0.1.

The last part of the analysis included the comparison of regions with access to the Azov and Black seas before and during the conflict period. It was conducted using the *t*-test (for variables with normal distribution) or Mann–Whitney test (for variables that were not normally distributed). The distribution of data was verified by application of the Shapiro–Wilk test of normality. The analysis was performed in SAS 9.04.

5. Results

Characteristics of analyzed variables can be found in Table 1. They include basic descriptive statistics for the analyzed group of regions in the upper part of the table and

Ukraine in its bottom part. In the case of economic variables, the high variability of data measured by the coefficient of variation is seen. On the other side, from a demographic perspective, data are expressed by the small variability measured by the coefficient of variation. The demographic indicators in the analyzed group of regions are very similar to the overall demographic variables in Ukraine. The average value of the working ratio is 70% with 41% share of young people, 41% of people in prime-age and 18% of old people in this category. The average share of elderly people is equal to 16%.

Table 1. Descriptive statistics of analyzed variables for five coastal regions and Ukraine.

Descriptive Statistics	Variable	Mean	Median	Standard Deviation	Variance	Coefficient of Variation	Min	Max	Skewness	Kurtosis
Analyzed group of regions—Demographic indicators	under14p	0.14	0.15	0.01	0.00	9.8	0.12	0.17	−0.25	−0.88
	workingp	0.70	0.70	0.01	0.00	1.26	0.68	0.71	−1.10	0.32
	elderlyp	0.16	0.15	0.01	0.00	8.52	0.14	0.20	0.94	0.52
	youngw	0.41	0.41	0.02	0.00	5.44	0.35	0.44	−0.64	−0.33
	primew	0.41	0.41	0.01	0.00	1.84	0.40	0.43	0.37	−0.55
	oldw	0.18	0.18	0.02	0.00	13.19	0.15	0.23	0.23	−1.20
Analyzed group of regions—Economic indicators	GRP	2433.23	2336.00	1025.55	1,051,753.56	42.15	616.00	4942.00	0.53	−0.21
	Income	1966.01	1875.00	739.87	547,402.96	37.63	713.00	3885.00	0.48	−0.26
	unemployment	8.33	8.30	2.18	4.73	26.13	4.40	14.60	0.74	0.84
	export	1261.08	1167.00	873.57	763,128.02	69.27	197.00	3917.00	0.79	0.13
	Import	692.37	633.00	448.52	201,169.40	64.78	68.00	2000.00	1.2	1.5
	openness	0.80	0.80	0.39	0.15	48.40	0.19	1.91	0.55	0.24
Ukraine—Demographic indicators	under14p	0.15	0.15	0.01	0.00	3.54	0.14	0.15	0.15	−1.66
	workingp	0.69	0.69	0.01	0.00	1.16	0.68	0.70	−0.60	−0.39
	elderlyp	0.16	0.16	0.00	0.00	3.4	0.15	0.17	0.18	−1.03
	youngw	0.41	0.41	0.02	0.00	5.44	0.37	0.44	−0.56	−0.92
	primew	0.41	0.41	0.01	0.00	1.23	0.41	0.42	0.66	−0.26
	oldw	0.18	0.18	0.02	0.00	12.68	0.15	0.21	−0.00	−1.64
Ukraine—Economic indicators	GDP	2741.31	2807.50	929.21	863,422.23	33.90	959.00	4188.00	−0.21	−0.52
	Income	2046.53	2005.00	706.52	499,171.41	34.52	840.00	3343.00	0.28	−0.46
	unemployment	8.6	8.10	1.9	1.18	13.48	6.40	9.50	−0.24	−1.42
	export	1090.40	1067.00	282.61	79,869.54	25.92	694.00	1517.00	0.27	−1.29
	Import	1257.13	1273.00	407.53	166,078.70	32.42	616.00	1867.00	0.25	−1.07
	openness	0.86	0.96	0.32	0.10	37.39	0.00	1.37	−1.28	2.39

Source: Authors' calculations based on data from the State Statistics Service of Ukraine.

From an economic perspective, these regions have lower levels of GRP per capita and income, compared to the national level. On the other hand, the coastal regions have a smaller unemployment rate (8.33%) compared to Ukraine in total (8.6%). Export per capita in the regions is higher than on average for Ukraine, and import per capita is almost half of overall Ukraine's average level. The regions' openness of the economy is smaller in comparison with the average level in Ukraine.

A graphic comparison of the development of demographic indicators over time in the analyzed group of regions and Ukraine is presented in Figures 1–3. These figures are used to show the influence of the war conflict on the analyzed demographic indicators. The share of the population between 0 and 14 years varied between 12% and 17% in the considered period. The smaller portion of this category over the analyzed period was recorded in the Donetsk region, where, after the small increase in 2015, this indicator continued to have a declining trend. The indicator grew in 2010 after its initial fall in other regions and at the country's level. At the beginning of the analyzed period, its highest portion was observed in the Kherson oblast. Though, since 2011, the highest share of the youngest category has been observed in the Odesa region, reaching its maximum (17%) in 2018.

The development of the working-age population is shown in Figure 2. This figure is divided into four panels. Panel (a) shows the share of the working-age population in the total number of people in each region and Ukraine. The share of this category in the analyzed regions was similar and varied from 67% to 71%. The level of this indicator in the presented regions was higher than its average in Ukraine at the beginning of the research period. In 2004, the highest value was observed in the Odesa oblast, while its smallest number was seen in the Kherson oblast. After reaching the maximum level in 2011, this indicator started to drop in the majority of the considered regions. In 2018, its smallest value was found in the Donetsk region. Panels (b), (c) and (d) show the portions of the young age, prime-age, and old age working population. The share of young people in the working-age population varied from 35% to 44%. The initial increase was followed by a continuous decline for almost the whole analyzed period. In 2018, the smallest value of this indicator was found in the Donetsk region.

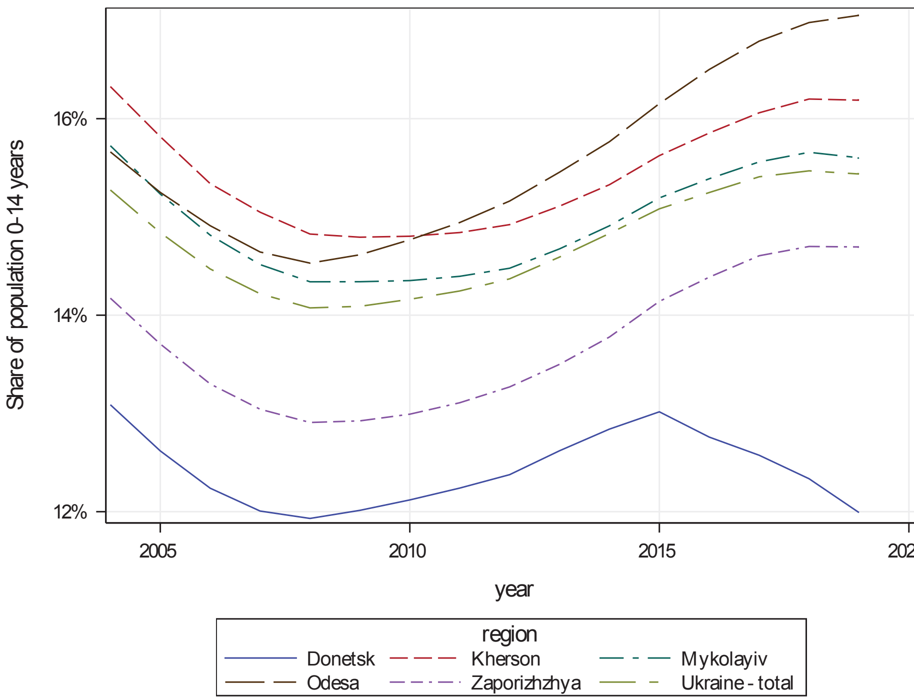

Figure 1. Share of population 0–14 years, %. Source: Authors' calculations based on data from the State Statistics Service of Ukraine.

The share of the prime-age population in the working-age category was between 40% and 43% during the analyzed period. This means the small variability in the presented group of regions with its smallest value in the Odesa oblast at the beginning of the given period and in the Kherson oblast at the end of the considered period. Panel (d) shows the development of the old category share in the working population. The indicator continuously increased from its smallest value in 2014 in all analyzed regions, following by its overall trend in the country. The highest share of the old population in the working-age category at the end of the presented period was in the Donetsk region. The growth of the old age category in the working-age population corresponded to the development of the share of elderly people (65+) shown in Figure 3, which had a similar trend in all considered regions. This share varied between 15% and 23%. During the analyzed period, its highest value was in the Donetsk region, and the smallest value of the indicator was in the Odesa region. After its initial increase, this indicator continuously decreased from 2007 to 2013. Then, the indicator has started its further increase until the end of the given period. Based on this trend, it can be expected that it will continue to rise in the short-term.

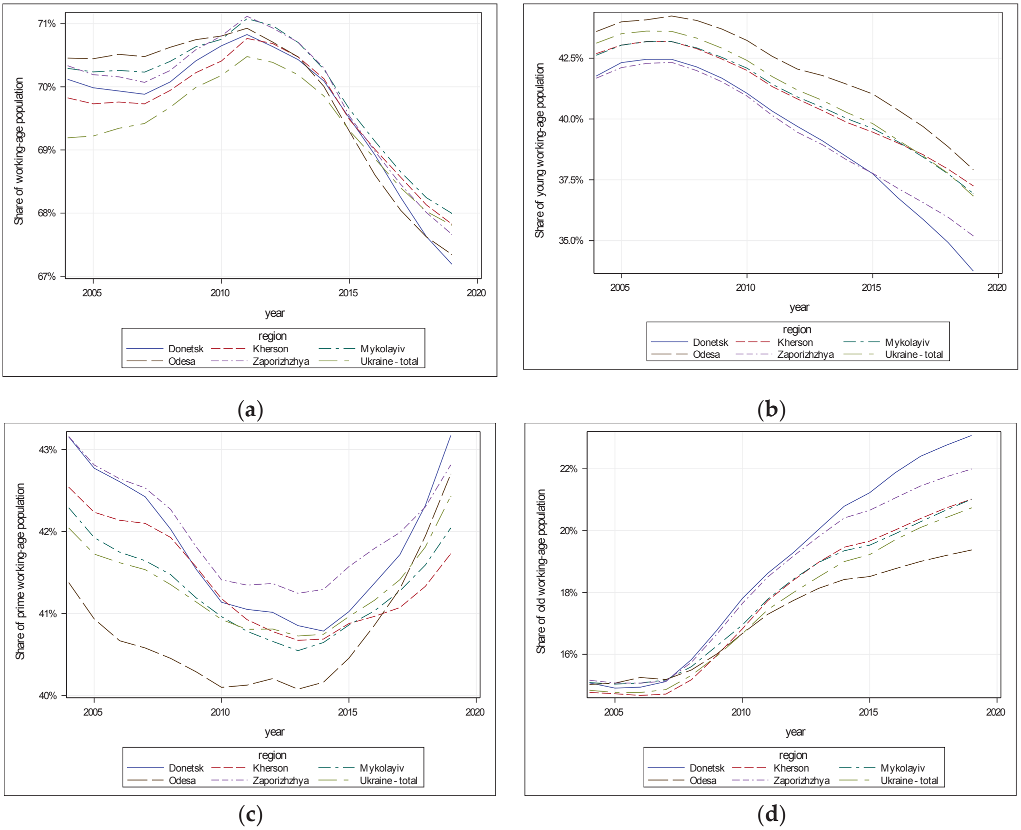

Figure 2. Share of the working-age population (15–64 years), by group, %. This figure contains four panels: (**a**) Share of the working-age population, (**b**) Share of young age population in the working-age category, (**c**) Share of prime-age population in the working-age category, (**d**) Share of old population in the working-age category. Source: Authors' calculations based on data from the State Statistics Service of Ukraine.

From an economical point of view, the most important indicator is the gross regional product. Its development is shown in Figure 4. At the beginning of the analyzed period, the Donetsk region had the highest value of this indicator. At the end of the considered period (after the beginning of the war conflict), a substantial drop in the indicator can be seen. The economic situation deteriorated for the Donetsk region to a significant extent, and, at the end of the analyzed period, this oblast had the smallest value of GRP per capita among the presented regions. It is also worth noting that, at the end of the given period, GRP in almost all examined regions (except the Zaporizhzhya oblast) was lower in comparison with its country's level.

It is expected that the war conflict has a significant impact on the development of the chosen regions. In Table 2, descriptive statistics for the analyzed regions, divided into the period before the conflict, which covers years 2004–2013, and the conflict period starting from 2014, are shown. The average value of all economic indicators got worse during the war period. The average per capita values of GRP, export, and import declined by 118 USD, 239 USD, and 261 USD, respectively. The rate of unemployment increased by 2.61%, and the openness of the economy contracted by 0.15. The most significant change was observed in the case of disposable income per capita, which decreased almost by 433 USD.

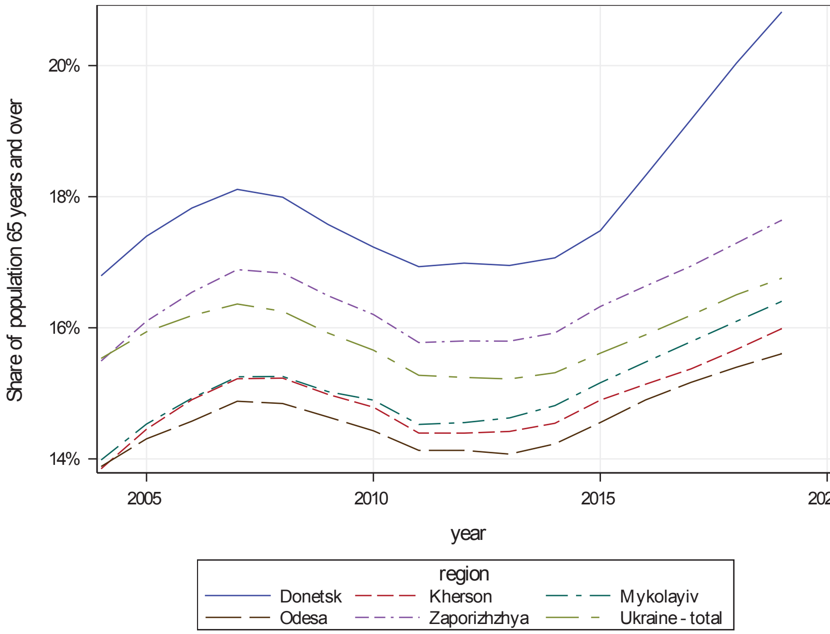

Figure 3. Share of population aged 65 and over, %. Source: Authors' calculations based on data from the State Statistics Service of Ukraine.

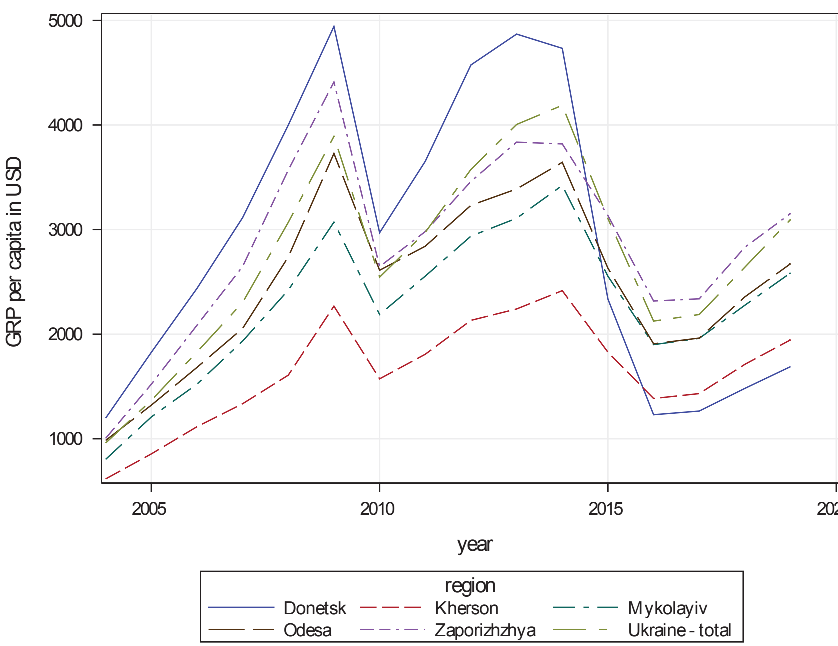

Figure 4. Gross regional product (GRP) per capita, USD. Source: Authors' calculations based on data from the State Statistics Service of Ukraine.

Table 2. Descriptive statistics in the pre-conflict and conflict periods.

Period	Variable	Mean	Median	Standard Deviation	Variance	Coefficient of Variation	Min	Max	Skewness	Kurtosis
Pre-conflict period	under14p	0.14	0.14	0.01	0.00	16,285	0.12	0.16	−0.38	−1.02
	workingp	0.70	0.70	0.00	0.00	0.51	0.70	0.71	−0.20	−0.69
	elderlyp	0.15	0.15	0.01	0.00	33,055	0.14	0.18	0.66	−0.81
	youngw	0.42	0.42	0.01	0.00	44,077	0.39	0.44	−0.55	−0.12
	primew	0.41	0.41	0.01	0.00	43,923	0.40	0.43	0.23	−0.88
	oldw	0.16	0.16	0.02	0.00	29,465	0.15	0.20	0.64	−0.95
	GRP	2472.38	2429.00	1103.12	1,216,871.87	44.62	616.00	4942.00	0.38	−0.50
	export	1340.70	1276.00	974.04	948,760.26	72.65	197.00	3917.00	0.71	−0.34
	import	779.26	744.50	502.79	252,801.09	64.52	68.00	2000.00	0.70	0.08
	disp income	2110.16	2138.00	812.54	660,223.28	38.51	713.00	3885.00	0.20	−0.72
	unemployment	7.49	7.85	1.52	2.31	20.30	4.40	10.70	−0.09	−0.60
	opennes	0.85	0.84	0.41	0.17	48.14	0.19	33,239	0.55	0.19
Conflict period	under14p	0.15	0.15	0.01	0.00	44,440	0.12	0.17	−0.55	−0.77
	workingp	0.69	0.69	0.01	0.00	43,831	0.68	0.70	0.07	−1.09
	elderlyp	0.16	0.16	0.01	0.00	43,709	0.14	0.20	43,101	43,862
	youngw	0.38	0.38	0.02	0.00	45,017	0.35	0.41	−0.25	−0.28
	primew	0.41	0.41	0.01	0.00	12,785	0.40	0.42	0.26	−0.39
	oldw	0.20	0.20	0.01	0.00	28,976	0.18	0.23	0.26	−0.56
	GRP	2354.92	2317.00	865.38	748,878.91	36.75	1230.00	4733.00	43,891	43,922
	export	1101.84	1059.00	613.44	376,304.97	55.67	225.00	2113.00	0.06	−1.31
	import	518.60	541.00	238.65	56,953.67	46.02	133.00	1034.00	0.14	−0.36
	disp income	1677.72	1701.00	458.26	210,005.79	27.31	819.00	2539.00	−0.02	−0.63
	unemployment	10.1	9.90	2.34	5.47	23.37	6.40	14.60	0.36	−0.20
	opennes	0.70	0.70	0.33	0.11	46.26	0.20	44,562	0.12	−1.20

Source: Authors' calculations based on data from the State Statistics Service of Ukraine.

The change in the demographic structure was not so substantial. The notable shift was only in regards to the share of young people in the working population: it reduced by 4%, i.e., the same increased value as for the old category of the working population. The average share of the working population in the total population went down only by 1%, and the average portion of elderly people grew by 1%. In general, it can be concluded that the conflict did not have a strong effect on the demographic structure in the selected oblasts, but it impacted the regions' economic performance to a significant extent.

To verify the hypothesis that the war conflict influenced substantially the relationship between demographic and economic indicators, a correlation analysis was employed. Table 3 includes information about the correlation between the economic variables and demographic structure. This analysis was used to examine three partial assumptions. The analysis was performed on pooled data of the chosen regions, and it was compared with results for Ukraine.

Table 3. Correlation between the economic variables and demographic structure in the analyzed regions and Ukraine.

Correlation Coefficients		Under14p	Workingp	Elderlyp	Youngw	Primew	Oldw
Analyzed regions	GRP	−0.47 ***	0.34 ***	0.24 **	−0.12	−0.36 ***	0.24 **
	income	−0.33 ***	0.38 ***	0.07	−0.08	−0.33 ***	0.18
	unemployment	−0.01	−0.50 ***	0.34 ***	−0.67 ***	0.13	0.59 ***
	export	−0.73 ***	0.19	0.59 ***	−0.22 *	0.20 *	0.14
	import	−0.31 ***	0.31 ***	0.1	0.16	−0.16	−0.1
	openness	–0.50 ***	0.04	0.46 ***	-0.04	0.49	–0.13
Ukraine in total	GDP	−0.32	0.39	−0.31	−0.26	−0.59 **	0.40
	income	−0.50 *	0.58 **	−0.38	−0.12	−0.68 ***	0.25
	unemployment	0.65 ***	−0.37	−0.16	−0.71 ***	−0.12	0.69 ***
	export	−0.44	0.53 **	−0.37	−0.14	−0.63 **	0.26
	import	−0.51 *	0.50 *	−0.23	−0.07	−0.55 **	0.18
	openness	−0.20	0.28	−0.25	0.56 **	−0.08	−0.55 **

*** significant at alpha = 0.01 ** significant at alpha = 0.05 * significant at alpha = 0.1. Source: Authors' calculations based on data from the State Statistics Service of Ukraine.

Only a weak correlation was observed between GRP and demographic indicators. It was significantly correlated with the share of the working population. Within the category of working people, it was strongly correlated with the group of old people only. There was a significant moderate correlation between GRP and the share of young people aged 0–14 years. A similar result was also found in regards to income per capita and demographic indicators.

In the case of unemployment, the different results were found in the analyzed regions and Ukraine in total. Regarding the examined regions, unemployment was positively correlated with the old working population and elderly people. Additionally, it correlated negatively with the working population and young working population within this category. At the same time, this indicator did not correlate with the age group between 0 and 14 years. On the other hand, a strong positive correlation was found between unemployment and young people aged 0–14 years old and the elderly population category in Ukraine. Moreover, a very strong negative correlation was identified between unemployment and the young working population.

Different results were determined on export and import. Concerning Ukraine, they were substantially correlated with the share of the working population. In the analyzed regions, export was significantly positively correlated with the elderly population, and it had a negative correlation with a young population under 14 years. In the case of import, only the weak positive correlation with the working population and the weak negative correlation with a young population between 0 and 14 years old were identified. The openness of the economy in Ukraine was significantly positively correlated with the young working population and negatively with the old working population. On the other side, we found a significant positive correlation between the openness of the economy and elderly people and the negative correlation among this economic indicator and population aged 0–14 years old in the selected regions. The results presented in Table 3 show that the relationship between economic and demographic indicators in coastal regions differed substantially from the rest of Ukraine.

More detailed results can be found in Table 4. In this case, the analysis was done for the periods before and during the conflict separately. In the pre-conflict period, GRP was correlated positively with the working, old working, and elderly population. All correlations were moderate. Its negative correlations were identified with the 0–14-year age group, young working population and prime working population. A similar result was also received concerning income. While it was moderately correlated with the working population, the indicator's correlation was especially strong with the old working population. Its negative correlation was determined in cases of the population under 14 years and prime working population, while the strong negative correlation was revealed for the young working population. Unemployment was not significantly correlated in the pre-conflict period with any of the considered demographic indicators. Export was significantly positively correlated with the elderly population during the pre-conflict period. It is worth noting that a strong negative correlation was found between export and the 0–14-year age group. Significant correlations with export were also found with a young working population (the moderate negative correlation) and an old working population (the weak positive correlation). Regarding import, only weak correlations with demographic indicators were obtained in the pre-conflict period. Significant correlations were determined in the case of the population between 0 and 14 years old, prime working population (the negative correlation) and working population (the positive correlation). The openness of the economy was significantly correlated with the elderly population, prime working population (the positive correlation) and population under 14 years (the moderate negative correlation).

Table 4. Correlation between demographic and economic indicators in the pre-conflict and conflict periods in the analyzed regions.

Correlation Coefficients		Under14p	Workingp	Elderlyp	Youngw	Primew	Oldw
Analyzed regions—pre-conflict period	GRP	−0.64 ***	0.45 ***	0.49 ***	−0.54 ***	−0.39 ***	0.64 ***
	income	−0.47 ***	0.51 ***	0.30 **	−0.73 ***	−0.48 ***	0.84 ***
	unemployment	0.25 *	−0.11	−0.21	−0.19	0.22	0.04
	export	−0.88 ***	0.20	0.80 ***	−0.59 ***	0.15	0.40 ***
	import	−0.32 **	0.37 **	0.20	−0.07	−0.30 **	0.21
	openness	−0.52 ***	0.03	0.49 ***	−0.13	0.44 ***	−0.12
Analyzed regions—conflict period	GRP	−0.13	0.63 ***	−0.24	0.30	−0.30	−0.26
	income	0.31	0.06	−0.32	0.14	0.12	−0.25
	unemployment	−0.77 ***	−0.15	0.80 ***	−0.74 ***	0.36 *	0.85 ***
	export	−0.42 **	0.13	0.31	−0.36 *	0.35 *	0.33
	import	−0.03	−0.12	0.09	−0.16	0.36	0.05
	openness	−0.41 **	−0.42 **	0.61 ***	−0.63 ***	0.64 ***	0.57 ***

*** significant at alpha = 0.01 ** significant at alpha = 0.05 * significant at alpha = 0.1. Source: Authors' calculations based on data from the State Statistics Service of Ukraine.

The results of correlation analysis in the conflict period were substantially different in comparison with the pre-conflict period, which confirmed our hypothesis. In the case of GRP, only one significant positive correlation with a working population (the moderate correlation) was recorded. Income was not substantially correlated with any of the investigated demographic indicators during the conflict period. This was also in accordance with the hypothesis that the gross regional product and income in the war period were not influenced by the demographic structure. The situation also changed for unemployment. While this indicator was not correlated with demographic variables in the pre-conflict period, its strong correlations with the elderly population, old working population (the positive correlation, which means that these categories mostly caused the increase of unemployment) were identified in the conflict period. Strong negative correlations were found between unemployment and the young working-age category and the 0–14-year age group. These results confirmed our hypothesis that unemployment in the conflict period was more impacted by the age structure than in the peace period. Regarding export, only one weak, but significant negative correlation with a population between 0 and 14 years old was identified at significance level alpha = 0.05 in the conflict period. In the case of imports, any significant correlation was not found during this period. On the other hand, the openness of the economy was significantly correlated with all demographic variables. It was positively correlated with the prime working population, old working population, and elderly population (category 65+) in the war period. At the same time, this indicator was negatively correlated with a population under 14 years, working population and young working population. The correlation analysis proved the research assumption, that the war conflict affected the significant relationship between the demographic and economic indicators.

To check the research hypothesis about the significant impact of the demographic development on economic performance, the panel model with fixed effects was applied. Table 5 shows estimated panel models with fixed effects for each economic indicator. The dependent variable in each model can be found in the heading. In these models, we estimated the effects of demographic indicators, which are labeled in the first column of the table. Almost all variables were used in the form of the logarithm (except unemployment), which means that estimated coefficients can be interpreted as elasticity (the average percentage change of dependent variable in case of 1% change of the independent variable). Regarding unemployment, coefficients should be interpreted as lin-log semi-elasticity. The variable denoted as conflict is the dummy variable equal to 0 in the period before conflict and 1 in the period of conflict. The significance of this variable means the substantial difference in the dependent variable between the two considered periods. This was confirmed in the case of income, unemployment, and the openness of the economy that deteriorated substantially during the war period. The average values of all analyzed economic indicators were worse in the conflict period compared to the pre-conflict period, but in the case of GRP and export, the significance of this difference was not confirmed. The significance of the variable "conflict" confirmed the hypothesis that war inhibited economic performance. This was proved especially in the case of income and the openness of the economy (the decrease of the indicators), which was in accordance with our assumption. Regarding import, the difference between these two periods was significant only at 0.1 level of significance. All models explained a significant proportion of variability with good prediction ability measured by R squared. In all panel models, significant differences were found between the investigated regions (according to the f test for no fixed effect), which makes the fixed effect model suitable for the performed analysis. The variable expressing the overall share of the working population could not be included in the model due to perfect collinearity with three categories of working people (young working population, prime working population, and old working population), which were present in it.

Table 5. Estimated parameters of the panel model with fixed effects.

	Dependent Variable					
	Ln GRP	**Ln Income**	**Unemployment**	**Ln Export**	**Ln Import**	**Ln Openness**
const	−175.89 ***	−222.42 ***	10,002 ***	−243.73 ***	72.08	8.51
Lnunder14	-	3.75 **	−13.8 *	-	−5.25 ***	-
lnyoungwork	13.83 ***	11.71 ***	−46.45 ***	9.39 ***	16.45 **	−5.86 ***
lnprimework	−14.55 ***	−16.18 ***	39.29 *	−4.5 *	-	6.75 ***
lnoldwork	7.42 ***	8.38 ***	−21.86 ***	6.98 ***	-	−1.65 **
lnelderly	8.08 ***	11.11 ***	−36.68 ***	8.07 ***	-	-
conflict	-	−0.83 ***	1.72 **	-	−0.17 *	−0.38 ***
R Squared	0.73	0.67	0.77	0.89	0.81	0.82
F test for no fixed effect pvalue	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

*** significant at alpha = 0.01 ** significant at alpha = 0.05 * significant at alpha = 0.1. Source: Authors' calculations based on data from the State Statistics Service of Ukraine.

In the case of GRP, the most significant influence was found regarding the young working population. The substantial impact was also determined in the case of the old working population and the category of elderly people. Surprisingly, the working population in prime-age had a negative effect on GRP. This can be probably caused by the positive correlation of this category with unemployment. This table includes only significant parameters, which means that GRP was significantly influenced by all analyzed demographic indicators (except the population category 0–14 years). A similar result was also found in the case of income, which was significantly impacted by all demographic variables. The largest effect was identified in the case of young (0–14 years old) and elderly people. Similar to GRP, income was also negatively affected by the number of working people in the prime age.

Regarding unemployment, a very strong negative impact (causing a decrease in unemployment) of the young working population and elderly people was found. The prime working category influenced unemployment positively, but it was confirmed only at a 0.1 level of significance. This implicates that most of the employed people in the analyzed regions probably belonged to the young working and old working population groups, as well as to the elderly category. The increase in the category of young working people by 1% will decrease unemployment by 0.46%. Export was also substantially influenced by the young working and old working population groups and the elderly population category. The effect of the young working category was the most significant. The increase in this category by 1% will lead to an average increase of export by 9.39%. The impacts of people aged 0–14 years and prime working-age people were not significant at alpha = 0.05. On the other side, the import was significantly influenced only by the category of young people between 0 and 14 years old and young working category, with the negative effect of the youngest category and the positive impact of working people.

The openness of the economy was significantly positively affected only by the prime working category, and it was negatively impacted by the young working and old working population categories. Based on these results, it can be confirmed that the young working category played a very important role in economic development. Old people (the old working group and the elderly category) still played a significant role in the regions' economic performance. Surprisingly, the role of the prime-age working category was not as important as expected. The carried out analysis also confirmed the hypothesis about the important role of the young working population, which was significant in all estimated equations.

The hypothesis that the war conflict accelerated population aging and its unfavorable impact was more substantial on the economic performance of Azov Sea regions due to their proximity to the war zone was verified by the comparative analysis (*t*-test or Mann–Whitney test according to the distribution of data). The comparison of regions with access to the Black and Azov seas is shown in Table 6, taking into consideration the location of their seaports. It was performed separately for the periods before the war conflict and after its beginning. The table includes average values of indicators for the above-mentioned groups of regions in both periods. From the demographic point of view, the significant difference was determined in the period before conflict on the share of the population aged 0–14 years, young working population, the working population in the prime age, and elderly population. A small change was found in comparison with the period of the war conflict when the difference between these two regional groups became significant in the case of the share of elderly people.

Table 6. Comparison of regions with access to Black and Azov seas in the pre-conflict and conflict periods.

Average/Significance of the Difference	Pre-Conflict Period			Conflict Period		
Variable	**Azov Sea Regions**	**Black Sea Regions**	**Significance**	**Azov Sea Regions**	**Black Sea Regions**	**Significance**
under 14	0.1281	0.1493	<0.0001 ***	0.1351	0.1558	<0.0001 ***
workingp	0.7041	0.7035	0.6818	0.6897	0.6913	0.6685
youngwork	0.4122	0.4222	0.0063 ***	0.3695	0.3897	0.0002 ***
primework	0.4196	0.4146	0.0320 **	0.4162	0.4103	0.0059 ***
oldwork	0.1682	0.1632	0.3600	0.2144	0.2000	<0.0001 ***
elderly	0.1679	0.1471	<0.0001 ***	0.1752	0.1530	0.0003 ***
GRP	3087.1	1864.9	0.0004 ***	2548.5	2088.6	0.2716
income	2432.6	1876.6	0.0325 **	1653.0	1615.3	0.8657
unemployment	7.1000	8.50	<0.0001 ***	11.00	10.0300	0.0594 *
import	956.4	387.6	<0.0001 ***	596.2	395.2	0.0717 *
export	2288.4	762.4	<0.0001 ***	1468.3	928.2	0.1053
openness	1.1682	0.5873	<0.0001 ***	0.8730	0.6098	0.0942 *

*** significant at alpha = 0.01 ** significant at alpha = 0.05 * significant at alpha = 0.1. Source: Authors' calculations based on data from the State Statistics Service of Ukraine.

It should be mentioned that strongly significant differences between the Azov Sea and the Black Sea regions were identified for all investigated economic indicators in the pre-conflict period. In contrast, substantial differences were not determined for the majority of the presented indicators between the Azov Sea and the Black Sea regions at alpha = 0.05 and at alpha 0.1 during the conflict period. They were only found in case of unemployment, import and the openness of the economy. Thus, it can be seen that significant differences existed between these two compared regional groups in the pre-conflict period that disappeared during the conflict period, which confirmed our research hypothesis. On the other side, differences in the age structure between regions persisted. Table 6 also shows the substantial increase in the share of the old working and elderly population. This was also in accordance with our research assumptions.

So, the results of the conducted analysis show that the relationship between economic indicators and demographic structure differed substantially in Ukrainian coastal regions, compared to the whole country. This relationship was significantly influenced by the war conflict, in particular regarding income, unemployment, and the openness of the economy. The performed analysis also compared the pre-conflict and conflict situations in regions with access to Azov and Black Seas. Our findings confirm that while there were clear differences in the economic development among these two regional groups in the pre-conflict period, they disappeared during the conflict period because of the economic deterioration of the Azov Sea regions.

In general, it can be concluded that the results of the conducted analysis confirmed our basic hypothesis that war adversely affected the demographic structure and inhibited the growth and economic development of Ukrainian coastal regions.

6. Discussion

In this article, we investigated peculiarities of two periods, i.e., the pre-conflict period and conflict period, in the context of the influence of the population's demographic structure on the economic growth and development of Ukrainian coastal regions. The received results proved the overarching research hypothesis of the paper that the military conflict impacts adversely the demographic structure of the population, which inhibits the growth and economic development of Ukrainian coastal regions.

The findings confirmed the hypothesis that the military conflict influences significantly the relationship between demographic and economic indicators, which is in accordance with Anderton and Carter [6]. The unfavorable impact of the war on the economic performance of Ukraine and its coastal regions should be understood in the following way. On the one hand, while Russia realized its war plans regarding Ukraine to a certain extent, Ukraine had negative outcomes of the conflict situation. That is why the positive economic effects of the war were observed for Russia, and the negative influences of the military conflict were determined for Ukraine. So, the study of the Institute for Economics and Peace [7] is in line with our results. On the other hand, Ukraine with the support of the international community managed to prevent Russia's plans to occupy other parts of the Ukrainian territory. The sanctions imposed by the European Union, USA, and other countries weakened Russia's economy and reduced the intensity of the country's military activities against Ukraine.

Our research also showed that GRP and income were not affected by the demographic structure during the military conflict, and this result differed from Wei and Hao [21], Zhang et al. [22], and Benassi and Salvati [23]. At the same time, unemployment was impacted by this structure more substantially in the conflict period, compared with the pre-conflict period.

The obtained results proved the hypothesis that demographic development has a substantial influence on the regions' economic performance. This was particularly related to income, which is similar to Sánchez-Romero et al. [14], as well as to the openness of the economy. It was also confirmed that the young working population played the most significant role in economic development, which coincided with findings obtained by Macunovich [33]. However, our result on the young population was different in comparison with Brunow and Hirte [24].

Also, the hypothesis was positively verified that war accelerates population aging and its unfavorable impact is more substantial on the economic performance of Azov Sea regions due to their proximity to the conflict zone. It was revealed that while demographic differences occurred between the Azov Sea regions and the Black Sea regions before and during the military conflict, economic differences disappeared between these regions in the conflict period, in contrast to the pre-conflict period. Thus, the proximity to the conflict zone had a larger negative impact on the economic performance of the regions, compared with their demographic structure.

In future publications, attention could be given to the evaluation of the influence of demographic changes on the economic development of all Ukrainian regions, as well as regional disparity.

7. Conclusions

The main conclusion of our paper is that the war affects adversely the population's demographic structure, which inhibits the growth and economic development of Ukrainian coastal regions. This study allows us to discover some important aspects for a better understanding of processes in the regions, connected with the military conflict.

Firstly, it was identified that the war had a negative impact on the economic performance of the coastal regions. Thus, it can be stated that this substantial shift will hamper the further economic development of the regions.

Secondly, while the overall effect of the military conflict was negative, the degree of its influence was different. This was seen when we compared demographic and economic variables before and during the military conflict, particularly for the Azov Sea regions and the Black Sea regions.

It should be also mentioned that Ukraine made the choice in favor of the European democratic model, which is being implemented in the country with the support of the EU member states. At the same time, Russia defends its imperialist position, since the cause of the war was the conclusion of the Association Agreement between Ukraine and the European Union. Russia uses this conflict to seize new territories, expand its political and economic influence in the post-Soviet area, and reorient Ukraine to the authoritarian model.

The war conflict had a negative impact on various economic and social aspects of Ukraine's development. At the same time, it led to the economic shift of Ukraine toward the EU countries, which was possible owing to the Ukraine–EU Association Agreement.

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Review

Blue Gold: Advancing Blue Economy Governance in Africa

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Abstract: In Agenda 2063, the African Union focused on making the use of ocean resources a priority in the new frontier of its blue economy. However, most African countries are still lagging in taking the initial steps of identifying and prioritising blue economy sectors and understanding the risk to sea and ocean health. Many have not developed integrated blue economy strategies and road maps, and this delays the progress and vision for an African blue economy envisaged by Agenda 2063 and 2050 Africa's Integrated Maritime Strategy. For Africa, however, the blue economy offers greater opportunity beyond the economy and the environment. It presents Africa with a unique opportunity to achieve its national objectives, to improve regional integration, and to exert influence in the global setting. In this review, we agree with Schot and Steinmueller (2018) that we need to develop new framings and begin to experiment with new policy practices to address social and environmental challenges. Furthermore, we maintain that existing theories and knowledge based on innovation studies in Africa may be significant for designing and implementing policies towards climate change mitigation, blue economy governance, and sustainability transitions. Finally, we conclude by highlighting how experimentation is the key feature of transformative innovation policy that Africa has to employ in its blue economy while emphasizing how Africa (and the Global South generally) are in a unique position to develop their own transformation models that are different from those of the Global North.

Keywords: blue economy; ocean governance; policy development; transformation

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1. Introduction

The definition of the "blue economy", in the Charter on Maritime Security and Safety and Development in Africa (Lomé Charter), includes aquatic and marine spaces (seas, coasts, lakes, wetlands, floodplains, rivers, and underground water) while also covering a variety of production sectors like fishing, aquaculture, tourism, shipbuilding, underwater mining, transport, bioprospecting, and related activities [1]. Africa has embraced the concept of the blue economy and adopted the blue economy narrative; however, understanding the developments of the continent's blue economy requires an understanding of the blue growth agenda [2]. African governments are progressively implementing a blue or ocean-based economy as an approach for generating economic growth to better improve social welfare and equity and to reduce environmental and ecological concerns on the continent [3].

Thirty-eight of the 54 states in Africa are coastal and they fall under maritime zones under African jurisdiction [4]. In addition, its estimated that the lake zones on the continent cover approximately 240,000 sq. km, while 64% of the continent land area is covered by transboundary river basins [5]. The continent is rich in natural living and non-living resources such as water, flora and fauna, wildlife, fish, minerals, and hydrocarbons. In addition, Africa has a potential to further develop its blue economy. Over 90% of Africa's imports and exports are transported by water, which emphasizes the great geographical position the continent has to advance regional and international trade [6]. The presence of vast ocean and lake resources creates sufficient opportunity for African countries to diversify their economies [5]. However, despite Africa's abundant natural resources and blue economy, the continent is plagued with poverty (46% of the population lives in extreme poverty). The high levels of poverty increase the vulnerability to climate change and environmental degradation [7]. The majority of the African population is poor, and they are the most vulnerable to environmental degradation and the least able to survive. The result of prolonged human-induced degradation of ocean and aquatic resources is deteriorating human welfare and health. These environmental hazards are responsible for approximately 28% of the disease burden in Africa [8].

The concept of the blue economy originated in 1992 during the Earth Summit in Rio and was later featured in the international agenda at the 2012 Rio+20 Summit in Brazil [8]. Decades later, the African Union's (AU) Agenda 2063—the main policy framework towards transforming Africa's socio-economic development—referenced the concept in 2014 [2]. The African Union defines the blue or ocean economy as "sustainable economic development of oceans using such technics as regional development to integrate the use of seas and oceans, coasts, lakes, rivers and underground water for economic purposes, including, but without being limited to fisheries, mining, energy, aquaculture and maritime transport, while protecting the sea to improve social well-being" [9]. This definition emphasizes the features that characterize the blue or ocean economy as one that is local and more resilient to better reduce the likely impacts such as economic or environmental instabilities developing into regional or even global crises, as is the case currently [10].

The direction Africa has taken in adopting blue economy approaches reveals a broader awareness of its importance at the global level. This creates avenues to establish international, regional, and bilateral cooperation and partnerships, including public, private, and public–private partnerships (PPPs) [6]. However, Africa needs to coordinate policy and chart its own path identifying, defining, and understanding what prosperity and progress is for the continent, while encouraging innovative thinking and practices that will enhance human and ecological growth [11]. While doing the above in connection with the AU Agenda 2063, there is an opportunity for Africa to develop a blue economy narrative that is best suited for the continent and the development goals, co-operations, and societal needs that are important to move further into the 21st century. Weber and Rohracher (2012) claim that policy transformation change only starts when policies for transformative change begin to acknowledgement these four type of failures: "directionality, policy coordination, demand-articulation, and reflexivity" [12]. This is a particularly useful concept which we would like to draw upon in this review, mainly focusing on policy coordination [13]. Because of the limitation of this being a desktop study, the authors contribute an overview of the current African blue economy. Our attention to the blue economy in this review briefly highlights the challenges that exist on the continent while discussing opportunities that exist. This review aimed to raise awareness and provide a basis for further research. Further in-depth analysis using case studies would help contribute to ongoing research in this area.

This review focuses on the role of ocean governance policies in the context of opportunities and challenges created by the blue economy. The first part provides an overview of the blue economy in Africa and the potential of advancing the blue economy on the continent. The second part covers a review of dominant policies regarding the challenges in advancing the blue economy. We further investigate how policies must be employed to maximize opportunities and benefits provided by the blue economy and to eliminate/decrease the challenges it faces. Our research draws mainly on the concept of transformation defined by Schot and Steinmuelle (2018) [13]. The results of the discussion reveal that the African Union will need to focus on experimentation to embrace its innovation policy.

2. Methodology

To fully address the aims of this review, various pieces of accessible "grey" literature were explored using a content analysis. This primary method of data collection included analysing documents that made reference to the "blue economy", the "blue agenda", or "ocean governance". This method was adapted from Bueger (2015), who used a three-tier approach to examine a governance "buzzword". This process entailed the examination of three crucial aspects of the blue economy: the way the term is seen and used in comparison to other concepts (blue economy as an ideology), what is considered as a component of the blue economy (determining the scope of the blue economy), and best practices in the blue economy (adopting the blue economy) [14]. The majority of the literature that was analysed consisted of policy documents, conference proceedings, position papers, academic articles, and governmental reports, which were derived from two primary methods:

1. A broad web search for scholarly literature using the terms "blue economy" and "blue agenda."
2. A targeted web search of known agencies, organizations, and non-government organizations actively involved in blue activities (e.g., the African Union, the United Nations Economic Commission of Africa, etc.).

Nonetheless, this is not the complete list but an attempt to show the ongoing dialogues in the blue economy grey literature from Africa. In total, 43 policy documents from the AU blue economy were used in this analysis. To better address the identified gaps in this review, the findings were further supported by examining published scholarly literature from academics researching the development of the blue economy in other regions of the world. The different ways that the term "blue economy" is utilized and understood in different scholarly literature was examined by means of a content analysis. This process involved repeat coding and grouping recurring themes or concepts found within abstracts and introductions of each document [8]. A preliminary thematic analysis identified five common themes found across various grey literature, which were previously identified by Keen et al. (2017), as fundamental for the blue economy: "economic, environmental, social, innovation and technical capacity, and governance tools or approaches" [15].

3. Results and Discussion

3.1. Potential for Blue Economy

The blue economy is one of the main focuses for AU Agenda 2063 and 2050 Africa's Integrated Maritime Strategy (2050 AIM Strategy). In Agenda 2063, it is viewed as the catalyst towards achieving socio-economic change. In the 2050 AIM Strategy, the blue economy is mentioned in the Africa's Integrated Maritime Strategy and is prioritised as the "new frontier of African Renaissance" [16]. By adopting the 2050 AIM Strategy in 2014, the AU were committing to a shared continental vision and strategy to guide relevant responses to maritime insecurity [17]. These initiatives direct and advance efforts towards the continent achieving an integrated and multidimensional blue or ocean economy. The African Union has identified the blue economy as the engine of the structural transformation for Africa on many fronts. For instance, the International Energy Agency estimates that, in Africa, the ocean renewable energy power potential can provide up to 400% of current global energy demand [18]. In 2010, it was estimated that the total annual economic value of maritime-related activities reached 1.5 trillion Euro. In 2020 the predicted economic value was 2.5 trillion euro per year. In 2030, the estimated total annual economic value will reach EUR 3 trillion per year [19].

The 26,000 km African coastline is important for industrial, environmental, developmental, and security purposes. There are approximately 100 ports in Africa, and 52 of them handle containers and transnational trade, which is important for the continent's maritime economy [19]. It is estimated that the output of these African ports will increase from 265 million tons in 2009 to 2 billion tons in 2040. The maritime industry is approximately valued at USD 1 trillion a year. By having just and effective economic policies, the value of the industry could triple in just two years [4]. With 90% of Africa's imports and exports being transported by sea, the growth potential of Africa is dependent on improving ocean–land connections, which are currently lagging in other regions [20]. The majority of the countries in Africa rely on the ocean economy, and it could be an engine for economic growth if fostered well.

In the past decade, there have been new emerging industries within the blue economy, namely, "aquaculture; marine renewable energy technologies for wind, wave, and tidal energy; bioproducts (pharmaceutical and agrichemical); blue or ocean carbon (carbon storage in mangroves, seagrass, and saltmarsh); and desalination" [3]. This further highlights the various opportunities that exist for industrialization and economic development. Over 200 million African people depend on fresh water and marine fish for food security, and about 10 million people derive an income from these sources. According to the African Union (2014), the approximate first-sale value of African fisheries (marine, inland, and aquaculture) was USD 19.7 billion per annum. They also forecasted that an additional USD 2 billion would be available annually for African economies if there is sustainable management of the fisheries sector (AUC, 2015). These are some of the main reasons Africa requires holistic and comprehensive approaches to harness this potential and opportunities [5].

3.2. *Governance of Africa's Oceans to Advance a Sustainable Blue or Ocean Economy*

Garland et al. (2018) explain the importance of governance, politics, and governments in mitigating and managing the repercussions of failing or rising industries and the wider effects it has on the regions, employees, and owners based on any system change resulting from transitioning to low-carbon or to the development of marine cluster economies [20]. Consequently, for years now we have seen the growing need for governments to acknowledge the importance of aligning social and environmental problems with innovation objectives. Schot et al. (2018) assert that climate change, the eradication of poverty and pollution, and increasing inequality "have been transformed into challenges and opportunities for science, technology and innovation policy." For example, through African initiatives like the AU Agenda 2063, the AU envisions innovation to address the most pressing societal challenges and transition to a low-carbon and inclusive economy [13]. Governance in Africa greatly influences the management and coordination of natural resource wealth. To a degree, good ocean governance could unleash the full potential of the oceans towards reaching the desired outcomes in a sustainable blue economy [4]. However, the AU need to identify gaps in existing frameworks for ocean governance to support the path towards achieving a blue economy.

The blue economy in Africa is aligned and directly linked to United Nations Sustainable Development Goals (UN SDGs), specifically SDG 14, which promotes the "sustainable use [of] oceans, seas and marine resources for sustainable development" (UNECA 2016: 9). Understanding the blue economy within the African perspective is fundamental for developing policy. There is a growing need to link Africa's blue economy to the continent as a "global powerhouse of the future" narrative, where the blue economy is perceived to have a major influence towards the growth and transformation of the continent [6]. The former executive secretary of United Nations Economic Commission for Africa (UNECA), Carlos Lopes, reiterates this idea by saying that the blue economy "is a timely contribution to help the continent harness its 'new frontier'" (UNECA 2016: xii). However, such notions of "frontiers" and "progress" require a thorough interrogation into blue economy governance (e.g., how blue economy "resources" create new governable spaces and support certain ways of governing). The narrative of the African blue economy provides the impression of a homogenous continent, which is not the reality [6].

The Global South, which, in this context, is Africa, should be able to experiment instead of following transformation models from the Global North [13]. South Africa, Mauritius, and the Seychelles are the top countries in terms of implementing national blue economy strategies [21]. These countries are in a position to achieve best practices that other African countries can emulate. Countries like Ghana, Nigeria, and Kenya are also making progress towards developing their blue economy [22]. Following Schot and Steinmueller (2018), this review also calls for transformative change to address the current global social and environmental challenges such as the AU Agenda 2063 and SDGs, where transformation is defined as “socio-technical system change”, which is used mainly in the sustainability transitions literature [13]. The AU needs to explore different transformative innovation policy options towards making the use of ocean resources a priority in the new frontier of its blue economy [17]. Experimenting is a key feature in achieving any level of transformation, and it is a concept that is supported by different sustainability transition scholars (Kemp et al., 1998; Schot and Geels, 2008) [13].

Currently, the AU has the task of driving the region towards successful economic development with its various institutions and organisations being important for the advancement of the blue economy. However, the existing frameworks and approaches fail to highlight the importance of the continent’s coastal and marine resources for trade and economic development [23]. In this context, transformative change needs to address policy coordination failure by including integrative coordination in the initial stages of transformative change development. Attention should be on development and multi-faceted coordination in a process of working together towards transformative change [24]. The concept of tentative governance advanced by Kuhlmann and Rip (2014) describes this framework. It is understood as an “approach which is provisional, revisable, dynamic, and open and includes experimentation, learning, reflexivity, and reversibility” [25].

3.3. Building on Existing Policy

In policy development, experiments are recognised as short-term spaces used by various actors to collaborate on different possible avenues [26]. This includes policy actors, scholars, business owners, community members, and private donors. This is defined as strategic niche management, which is able to combine policy development and action with transformative governance. Ensuring that these spaces do not become pilots projects that employ traditional (top-down approaches) requires experimentation [24]. Challenging goals like Agenda 2063 require that actors understand that this process is unpredictable and that failure is a learning curve [26]. The goal should be on sharing new common prospects and ideas, forming new bonds and networks, and influencing new markets (niches) that will compete with existing mainstream markets and institutions [27]. However, the biggest challenge for transformative innovation policy in Africa is how it encounters significant uncertainty, quid pro quo, and corruption to serve interests and visions of certain factions both regional and international [28].

Global initiatives like the Paris climate agreement set ambitious goals to reduce greenhouse gas emissions to limit the increase of global temperatures in this century, and the United Nations (2015) formulated 17 SDGs that are interlinked to promote a balance between economic, social, and environmental needs, which allows sustainable ways of economic growth. The question of how important innovation is for creating a better world is based on the assumption that science, technology, and innovation contribute to the betterment of the world [24]. Innovation policy focuses on advancing research development and building national systems of innovation. Consequently, it is assumed that these policies can result in green growth where governments can invest in clean technology, reduce pollution, and clean up the environment. Furthermore, assumptions are made about how these policies will reduce inequality through creating employment opportunities resulting from growth and income distribution. These assumptions can only be a reality if nation states, despite globalization, have enough resources to invest in clean technology for longer periods of time, address tax avoidance, and are not plagued by corruption or captured by other interests to distribute and direct investment in certain directions [28]. Schot et al (2018) pose a fundamental question about whether states are in the position to deliver on this. As the discussion in this review shows, in Africa, there is evident erosion of the power of nation states, but even if there was the presence of a strong state, the more challenging issue is how externalities like climate change can be regulated using clean technology and distributional measures [24].

Public policies are generated from identifying past experiences and actions, reflecting on existing challenges, and predicting future potentials for action (Table 1). The African Union policy scholars and practitioners have, over recent decades, drawn from past, present, and future experiences (mainly from the Global North's development paradigms) to guide analysis and action [24]. Table 1 summarizes a non-exhaustive list of linkages between the blue economy development and the SDGs and Agenda 2063 aspirations that mention the blue economy [6].

Table 1. Linkages between development of the blue economy and SDGs and AU Agenda 2063 aspirations.

Potential POSITIVES of Proper Development of the Blue Economy	UN SDGs	AU Agenda 2063: Aspirations	Potential NEGATIVES of Improper Development of the Blue Economy
Transition to low-carbon economies Resilience to uncertain climate future	13 Climate change	7 Environmentally sustainable and climate-resilient economies and communities	Increased carbon intensity Coastal degradation leading to climate vulnerability
Enhanced health of aquatic and marine ecosystems Increased stock abundance supporting sustainable fisheries	14 Life below water	6 Blue/ocean economy for accelerated growth	Overexploitation of aquatic and marine resources Environmental degradation
Increased water security Enhanced sustainable transboundary water sharing	15 Life on land	7 Environmentally sustainable and climate-resilient economies and communities	Nutrient pollution Biodiversity loss
Improved governance Promotion of continental peace and security	16 Life on land	12 Capable institutions and transformative leadership in place	Resource conflict Failure to implement and enforce laws and regulation Dutch disease and resource curse

Adapted from UNECA, 2016 and AU Agenda 2063.

The economic growth of the blue economy in Africa, like in other parts of the globe, is characterised by industrial mass production and mass consumption that relies on fossil fuels, is energy- and resource-intensive, and produces large amounts of waste. The growing economic crises and inequality on the continent highlights how existing socio-technical systems employed to meet basic human needs are unsustainable [29]. These socio-technical systems in place need new policy framings to guide and manage the negative impacts and contributions of these systems. Science and technology framings that have evolved since World War II contribute very little to finding solutions to the socio-technical system of modern economic growth, which they are integral to and have contributed to [24].

3.4. Approach Transformation

Sustainability transitions scholars have highlighted the challenge towards providing good models for how policy can support the mobilization of transition towards sustainability. To deal with the challenges in blue economy in Africa, innovation and policy are key to addressing the existing issues of poverty, inequality, and exploitation of natural resources [28]. Like in many parts of the globe, the traditional supply-orientation of research and innovation policies is the most utilised in Africa. This linear approach needs to make way for more comprehensive and holistic approaches that use a wide range of policy instruments and that emphasise the important role of the demand for innovation [30].

Innovation policy making is dependent on having a holistic outlook and considering every factor that influences innovation; by doing this, the aims of the policy will be achieved [28]. The desired blue economy framework (Figure 1) illustrates the opportunities that exist when the system creates inclusive, holistic, intersectoral-linked development spaces where economic growth is not the sole measure of development but where environmental, social equity, and governance/transparency are equally important [6]. This proposed blue economy framework promotes an "integrated, systemic, dynamic, inclusive, participatory, and ecosystem-based approach where sectoral barriers are reduced at the activity and governance level, and environmental, social, and economic factors are incorporated and achieved for all blue economy activities" [6]. Effective innovation towards achieving sustainable economic system relies on the active engagement of different stakeholders in various sectors, levels of society, and parts of the world [28].

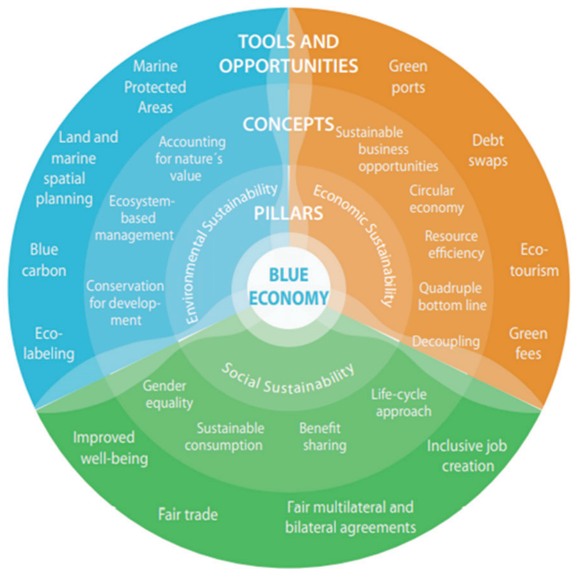

Figure 1. Tools, concepts, and pillars of the blue economy (adapted from UNECA, 2016) [31].

In the African context, there is ample talent, knowledge, and resources to achieve successful transformation within the blue economy [32]. In Africa, if the countries would embrace the potential offered by the renewable energy revolution, it would enable policy makers to promote green innovation, boost productivity, create new employment, and speed up the transition to a sustainable economic system [28]. As mentioned before, Africa has enormous renewable energy resources that are untapped (including wind, tidal, and wave energy). Energy development is one challenge in blue economy development in Africa. In 2020, about 592 million Africans had no access to electricity, thus Africa needs to explore options to meet the UN's target of electricity for all by 2030 [33]. The energy development potential from the sea and ocean is greatly unacknowledged, planned for, or mirrored in existing policies related to sectors such as transport and tourism. Thirty countries in African have developed policies that reflect the potential to integrate nuclear energy into the future energy mix [34]. Currently, only South Africa has an operational nuclear plant, while Egypt is expected to construct a 4.8 GW power plant. Other Africa countries are expected to be ready by 2030, and these include Alegria, Kenya, Ghana, Morocco, Nigeria, Sudan, and Tunisia [5].

Establishing a multisectoral and land–sea holistic approach would lead to the awareness of countless opportunism in the blue space. Knowledge and awareness of blue economy development policy is inadequate, and this needs greater awareness and knowledge-broadening attempts at the policy scale. A well-planned and integrative framework demands an innovative method of formulating new sources of development opportunities. This further highlights the importance of fostering transformative policy thinking and promoting creative and workable policy instruments. The traditional linear top-down approaches restrict stakeholder participation and community-level and context-specific responses. This makes this approach the least favourable towards a sustainable transition and awareness creation [24].

In UNECA (2016), it is explicitly stated that "criminal activities such as Illegal, Unreported and Unregulated (IUU) fishing; piracy and armed robbery at sea; illicit trafficking of goods and people; and environmental crimes also pose an acute threat to the sustainable use of blue economy resources and have a negative impact on security, social development, and economic growth of the continent" [35]. As illustrated in Figure 2, West Africa has the highest and most frequent number of piracy and armed robbery incidences globally. In 2018 and 2019, there were 112 and 98, respectively, of such incidents in West African waters largely because those countries on the west coast are oil rich. There has been a gradual decline in piracy and robberies in East Africa since 2011. This is largely because of multi-national initiatives to increase security and patrol these waters to reduce piracy. In addition, building strong legal capacity to prosecute criminals has helped reduce the numbers. However, policy development in the region has been focused more on security policies than on the economy. The AU member states need to find a balance to achieve the goals set out in 2050 Africa's Integrated Maritime Strategy [36].

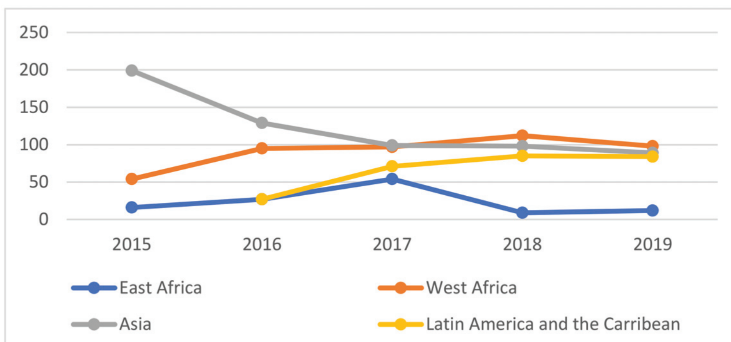

Figure 2. Worldwide piracy and armed robbery at sea incidences (2015–2019). Source: The state of Maritime Piracy, One Earth Future. * Data for 2015 only counted incidents in Southeast Asia.

As seen in East Africa, enhanced security could then serve as a catalyst to attract high investment and develop new business opportunities in key sectors to boost the blue economy forward. Greater rapid economic progress could create employment opportunities for the 200 million youths in Africa. This would benefit national security and decrease economic migration [31].

Transformative change is characterized by its multifaceted approach to transforming various systems thus leading to the transformation of the structure of the economy and society, while coordinating with other cross-cutting policies, including tax policy, economic policy, social policy. Finally, Schot et al. (2018) adds that there are "multi-level policy coordination failures to overcome between local, regional, national, and international policy" [24]. For example, the majority of regional economic communities succeed at achieving resource management and environmental sustainability; however, they fail to develop systems to advance the blue or ocean economy [36]. Transformative change requires a holistic integrative regional approach; however, this approach is likely to encounter bureaucracy, high costs, and corruption by different interest groups that benefit from dominant socio-technical systems [24]. The analysis above raises questions about the usefulness of national research and innovation councils in Africa to support transformation if their coordination efforts are undermined.

4. Conclusions and Recommendations

The blue spaces in Africa are experiencing a high level of degradation, overexploitation, and decreasing human activity because of global warming, pollution, overpopulation, oil spills, and mining activities, which damage ecosystem habitats. The management of these water spaces has been gradually fragmented, abandoned, and often overlooked, especially in regions where transboundary spaces are shared by millions of people in different countries [17]. The blue economy is a highly multifaceted and interdependent economy, thus making it difficult to manage and monitor. The different sector activities of the ocean economy are interdependent, which results in various effects throughout the supply chain when one sector impacts other industries [37]. The transition to sustainability needs both innovations in the economy and governance.

The analysis above demonstrates the importance of setting a road map and vision for sustainable development of the ocean economy [27]; the need to establish a regulatory framework; and different institutional science, technology, and innovation (STI) approaches for the blue economy, including setting up a ministry for the blue economy, coordination of the blue economy at a high office level, such as the office of the president, prime minister, or the creation of an inter-ministerial coordination mechanism. The discussion also highlights the importance of institutional planning, monitoring, and evaluation for the blue economy [31], exploring ways that new higher education strategies could create opportunities for a sustainable blue economy for decades to come [22]. This initiative could drive the launch of innovative programs to attract students from various educational and social backgrounds to foster a new generation of blue economy leaders [20]. Regional economic communities, intergovernmental organizations, and state's partnerships should be strengthened within the framework of AU Agenda 2063 and the AU 2050 AIMS. The success of these partnerships should result in a wider knowledge base, multifaceted socioeconomic and political integration, and possibly the establishment of a new geopolitical space [38], developing an African-grown paradigm incorporating all sustainable development dimensions.

Furthermore, we agree with the assertion by Schot et al. (2018) that it is mutually beneficial if both the Global South and the Global North use their unique geographical and political settings to experiment. This would result in transformative change that is more impactful. However, as mentioned before, this transformation framing should create alternative and new pathways that support local generation and experimentation. Most important should be the willingness to embrace and adapt to the complex system changes that will advance transformation. Wide-scale regional change will require more than STI policies, it will be a combination of various other policies. This highlights the importance of existing actors in actively engaging in this multifaceted historical process. Transformation innovation policy will lead to an effective blue ocean governance if policy makers and governments respond to "what is happening in and to the contemporary world in transition" [24].

Lastly, this review highlights the need for further research in emphasizing how informal institutions and policy can regulate human behaviour in the new philosophy of the blue economy. Such research will further explore practical dimensions to better implement environmental and people-centred policies driven by continental universities, think tanks, private companies, civil society organizations, and communities. These studies will focus on existing blue economy practices and will build on these. Achieving this provides opportunity for better implementation of policies that impact the wider society. We believe the aim of the blue economy should be to protect blue spaces while creating a good quality life for the African population.

In conclusion, the challenges outlined in the SGDs and in Agenda 2063 affect people every day on the continent, and this reiterates the need for policy makers and researchers in this area to develop new frameworks and to pursue experimentation with alternative policy practices [24]. This review recommends that Africa prioritise the generation of homegrown innovations in the economy and governance because only then can Africa address the social and environmental challenges that are crippling the blue ocean governance and start a journey towards a smooth and low-cost transition to new socio-technical systems.

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