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A Study on Environmental Trends and Sustainability in the Ocean Economy Using Topic Modeling: South Korean News Articles

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Abstract: The ocean economy plays a critical role in global economic growth, yet it confronts substantial environmental risks. This study employs topic modeling of South Korean news articles to analyze the evolving trends of environmental risks and sustainability in ocean economy. A dataset comprising 50,213 articles from 2008 to 2022 is examined, revealing prevalent environmental concerns that have persisted over the years. The findings demonstrate an increasing emphasis on sustainability and marine environmental issues, as evidenced by prominent keywords related to construction, safety, plastic pollution, and ecosystem conservation. Through Latent Dirichlet Allocation (LDA) in topic modeling, 10 distinct themes are identified, encompassing sustainable fisheries management, accident and disaster response, polar environment, carbon neutrality, microplastic pollution, habitat ecosystems, cruise tourism development, nuclear power plant pollution, and infectious diseases. The outcomes highlight the necessity of collaborative efforts and international partnerships, underpinned by diplomatic cooperation, to effectively address transboundary environmental challenges encountered in the ocean-based industries.

Keywords: ocean economy; environmental trends; sustainability; topic modeling; text mining

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1. Introduction

According to the OECD, the ocean economy encompasses a wide range of industries, including shipping, fisheries, and ports, as well as offshore wind power generation, marine biotechnology, marine ecosystems, and marine tourism. It has the potential to contribute to the economic growth, employment, and innovation of various countries worldwide [1]. In 2010, the production value of the ocean economy accounted for 25% of the global gross value added (GVA), reaching $1.5 billion, and it is projected to more than double by 2030 [1]. Furthermore, according to the OECD [2], the six maritime economic activities, including marine fishing, aquaculture, fish processing, shipbuilding, maritime freight transport, and maritime passenger transport, accounted for 2% of the gross domestic product (GDP) of high-income countries, 11% of middle-income countries' GDP, and 20% of low-income and island countries' GDP [3]. The ocean economy is rapidly expanding due to factors such as population growth, economic and income level growth, climate and environmental changes, and technological advancements. It is expected to exceed the global economic growth rate in terms of value-added and employment in all aspects by 2030.

However, as the scale of the ocean economy grows worldwide, it is increasingly exposed to numerous risks and faces threats. The recent COVID-19 pandemic that has affected the entire world, coupled with the Russia–Ukraine conflict that erupted in early 2022, has acted as a continuous threat to the global supply chain. This has plunged the

world economy into a quagmire of stagflation, characterized by high inflation, high interest rates, unemployment, and economic downturn occurring simultaneously. The global economic growth rate due to COVID-19 decreased by more than 3.1% in 2020, and the world trade volume decreased by more than 8.2% [4]. The global economic situation has inflicted severe damage on the maritime and port industry, which is responsible for the majority of international trade.

Alongside these macroeconomic conditions, the ocean economy also faces significant threats due to the environmental risks associated with the specificity of the ocean. Sumaila et al. [5] stated, "A vibrant ocean economy depends on sustainable and healthy oceans, however, many aspects of current ocean resource use patterns make it unsustainable". Furthermore, Bennett et al. [6] compiled a list of ten risks that undermine the sustainable ocean economy, including such as "Dispossession, displacement and ocean grabbing", "Environmental justice concerns from pollution and waste", and "Environmental degradation and reduction of availability of ecosystem services". However, it was noted that awareness of these risks is still insufficient [6]. In particular, environmental issues such as accelerated global warming, the occurrence of super typhoons, increasing marine plastic pollution, and the radiation contamination of seafood from nuclear power plant effluents, as well as risks related to technological advancements, such as cyber vulnerabilities in ports, are growing concerns for the ocean economy [7].

The devastating earthquake that occurred in Japan in 2011 had a profound impact on the marine fisheries industry [8]. It led to the closure of 16 ports in Japan for one month, causing a collapse in the global supply chain network of port-utilizing enterprises. The resulting production disruptions in the automotive, electrical, and electronics manufacturing industries alone caused a minimum of $40 billion in damages to the port sector. Similarly, the grounding of the container ship Ever Given in the Suez Canal in March 2021 resulted in a six-day disruption to global east–west shipping routes, causing the suspension of over 200 vessels and approximately 17 million tons of cargo transportation [9]. This incident inflicted significant damage on shipping companies. The estimated damages to Egypt, which manages the Suez Canal, are believed to exceed $1 billion. These examples illustrate how the ocean economy can have significant ripple effects on the global economy when it suffers losses.

Furthermore, the economic effects of large-scale maritime accidents may be limited to the short term, but the damages resulting from environmental pollution are long-term and difficult to estimate in scale. The issue of contaminated water leakage from nuclear power plants following the Great East Japan Earthquake continues to have a significant impact on neighboring countries even after 12 years, and the International Atomic Energy Agency (IAEA) has published reports examining the safety of wastewater disposal. In the case of the Ever Given grounding incident, although the incident lasted for about a week, concentrations of sulfur dioxide (SO_2), a prominent pollutant, increased to up to five times the normal levels in the Mediterranean Sea as hundreds of vessels remained anchored for an extended period. Other ripple effects are still under investigation. Thus, ocean economy, as the foundation of various industries in many countries, has the potential to significantly impact both national industries and the global economy when it incurs damages. Among these, environmental damages are of particular concern due to their long-lasting and extensive consequences, highlighting the need for sustained attention.

Therefore, in this study, we aim to analyze the changing environmental risks that threaten the ocean economy from the past to the present and gain insights for the future direction. To achieve this, we collected 15 years of South Korean marine news text data and conducted an analysis using topic modeling.

South Korea's ocean economy ranks 14th out of 32 domestic industries in terms of total production (as of 2019). It accounts for 71.5% of the size of the Korean automobile industry and is about 2.5 times the size of the agriculture and forestry industry [10]. In particular, the maritime freight transportation volume in South Korea accounts for 99.8% of the national total (as of 2020), amounting to 1.276 billion tons, playing a crucial role

in the national economy [10]. Furthermore, the South Korean ocean economy has shown steady growth and maintains a highly competitive position globally. According to the report "The Leading Maritime Nations of the World" published by Menon Economics [11], which evaluates the maritime industry of each country and city using 24 indicators such as shipping, maritime finance and law, maritime technology, and ports and logistics, South Korea ranks 4th in the overall ranking along with Germany and Norway. Notably, it ranks 1st in the field of maritime technology, which has the highest competitiveness globally, and 4th in terms of volume handling [11].

Amidst the projected decrease in global economic growth rates by 0.5% to 0.9% compared to the previous year, the growth rate of South Korea's economy is predicted to be around 1.5% [12]. The value-added growth rate of the South Korean ocean-based industry is forecasted to be 3.2%, a decrease of 0.7% compared to 2022. While the fisheries, ports, marine leisure tourism, and shipbuilding industries are expected to experience moderate growth, the value-added of the shipping industry is expected to decline due to worsening supply chain conditions caused by geopolitical and economic tensions between countries, global economic slowdown, and the spread of inflation leading to weak consumer demand. Through this study, a systematic analysis of the environmental risks faced by ocean-based industries can provide valuable implications for guiding future development towards a sustainable maritime economy. By identifying and assessing these risks, policymakers, industry stakeholders, and researchers can gain insights into the areas that require attention and intervention.

The remaining sections of this paper are structured as follows. In Section 2, a review of previous studies applying topic modeling to text data related to the marine fisheries field is presented. Section 3 provides an explanation of the topic modeling methodology, while Section 4 describes the data used in this study. The analysis results are summarized in Section 5, and the discussion and conclusion, including the implications of the research, are presented in Section 6.

2. Literature Review

Existing studies that have applied topic modeling to text data in the marine fisheries field include the following.

Rezende and Moretti [13] analyzed research on microplastics in marine and freshwater habitats using topic modeling. A total of 1681 research articles published between January 2010 and May 2021 were collected from the Scopus and Web of Science databases and 15 topics were identified. These topics include "effects on behavior and development of aquatic biota, pollution in freshwater, toxicity tests, ingestion and trophic transfer, adsorption capacity, pollution in urban waters, bioaccumulation in mussels, biofilm colonization, toxicity on aquatic biota, pollution in marine habitats, presence in biotic and abiotic compartments, isolation and quantification protocols, assessment of marine litter, occurrence and removal from wastewater, and transport and sinking behavior" [13].

Hay Mele et al. [14] conducted a study in which they categorized topics encompassing ecological and economic aspects in marine science. They grouped these topics within fields relevant to integrated coastal management (ICM) and examined the flow of knowledge between these fields using an information-flow network. The dataset they utilized included 583 papers from Isi-WoS and 5459 papers from Scopus. The identified representative topics comprised coastal resilience, ecological economics, integrated coastal management, marine ecology, marine/maritime economy, socio-ecological systems, network science, and topic modeling.

In a separate study, Otero et al. [15] employed Twitter data analysis to evaluate public interest in the impact of marine plastic pollution. They scraped a dataset of approximately 140,000 tweets specifically related to marine plastic pollution from Twitter. Their objective was to gain insights into the characteristics of users who tweet about this topic and examine how and when they engage in discussions. The researchers identified six optimal topics,

including the impact on wildlife, microplastics and water pollution, estimates and reports, legislation and protection, and recycling and cleaning initiatives.

Tomojiri et al. [16] used topic modeling to analyze 2172 articles, published between 1975 and 2021, on anthropogenic marine debris (AMD). The study identified 50 topics, including "plastic pollution, spatiotemporal dynamics and distribution patterns of marine debris, and interdisciplinary or transdisciplinary research areas". Keller and Wyles [17] conducted a study that examined the newspaper coverage of marine plastic pollution in four prominent online newspapers in the UK. Using structural topic modeling, the researchers analyzed 943 news articles published in 2019 that discussed marine plastics. These articles were categorized into 36 topics. The identified representative topics included plastic pollution, devices for cleaning the ocean and rivers, plastic straws, plastic bags, and the impact of microplastics on humans and animals. In another study, Yan et al. [18] developed a content-aware corpus-based model to analyze marine accidents. They utilized a dataset consisting of 207 investigation reports of ship collision accidents, which were published by the Maritime Safety Administration of China. For the purpose of topic modeling, they selected 40 topics, including hazards, causes of accidents, and accident scenarios.

Zhou et al. [19] used a text-mining approach to analyze sustainability disclosure for container shipping. The authors applied a hierarchical unsupervised text-mining method to 33 sustainability reports published between 2016 and 2019 from 12 listed container shipping companies. As a result, an integrated framework with three primary dimensions was developed: employee training and management, sustainable business management, and sustainable transportation operations. Each of these primary dimensions was further divided into three secondary sub-dimensions. Shin et al. [20] further explored issues related to sustainability issues in the maritime industry. The authors outlined their data collection and analysis process, which includes selecting 155 papers from SCI and SSCI indexed journals published between 1993 and 2017. They preprocessed the text data, generated a document-term matrix, applied a Latent Dirichlet Allocation (LDA) model to uncover hidden topics and patterns, and conducted a bibliometric analysis to visualize the landscape of sustainability research.

Hwang et al. [21] explored research trends and key issues in marine spatial planning (MSP) using topic modeling and bibliometric analysis. The authors analyzed 1726 articles related to MSP published between 2010 and 2020, identifying 29 topics that represent the intellectual structure of the literature. Additionally, the paper applied the policy readiness level (PRL) framework to examine changes in the core themes of MSP research over time. Jiang et al. [22] conducted a topic modeling analysis of 1726 papers related to hydropower. The authors examined studies published between 1994 and 2013 and established 29 topic models. A topic modeling study related to maritime leisure was also conducted. Sánchez-Franco and Rey-Moreno [23] applied a service and feature-oriented approach to explore the subjective experiences shared by Airbnb guests in their public reviews. Their processed dataset contains 73,557 reviews of Airbnb stays in both coastal and urban destinations between 2017 and 2020. In this study, community #10, which includes topics such as beaches, landscapes, litter, islands, and climate change, is related to maritime areas and is characterized by conservation and a focus on the future of the local community.

Others include maritime transport [24], mobility patterns from ship trajectories [25], ship motion patterns [26], COVID-19 [27], etc. Although there are several studies that have conducted topic modeling analyses of the environment in the marine fisheries sector, most of them are oriented to specific keywords such as microplastics and marine accidents, and there are not many studies that analyze overall trends in the marine environment. To understand the sustainability of the ocean economy, it is necessary to analyze trends and issues from a macro perspective.

According to Ortiz et al. [28], newspaper data are relatively easy to collect and are sometimes the only continuously available source of event data. While there are methods such as surveys or opinion polls to understand public opinions on social issues, they often require significant time and cost, and conducting them repeatedly over a period of time

can make time series analysis difficult. On the other hand, news data are convenient for handling historical data and are suitable for research purposes due to their ability to provide objective and independent information based on specialized knowledge.

3. Topic Modeling

Topic modeling is a text mining technique that aims to discover abstract semantic "topics" within a collection of documents [29]. Essentially, it involves grouping words that are likely to belong to the same topic and assigning a topic based on the meaning of these word clusters. The underlying assumption is that words within a document have a high probability of being associated with the same topic, assuming each document has a single topic. This allows for determining the probability of a word belonging to a specific topic and the percentage of that topic within a document.

Various techniques can be used for topic modeling, including Latent Dirichlet Allocation (LDA), Latent Semantic Analysis (LSA), probabilistic LSA (pLSA), and Dirichlet Multinomial Regression (DMR) [29]. LSA constructs a semantic space based on a corpus and uses it to cluster words, sentences, paragraphs, and documents by comparing their similarities [30–33]. While LSA clusters based on word frequency, pLSA is a probabilistic model that considers the probability of word occurrence. It only relies on the document-term matrix and does not take into account the distribution of topics within a document. On the other hand, LDA considers both the distribution of topics across documents and the distribution of terms within topics. LDA is a Bayesian version of pLSA and employs a Dirichlet distribution with a conjugate prior [34]. DMR, an extension of LSA, incorporates the assumption that the hyperparameter α can vary based on document metadata, such as author, department, or region [35,36].

Currently, LDA is the most widely used topic modeling method in many studies. While some studies have compared LSA and LDA, no clear dominance of one method over the other has been established. LSA offers the advantage of intuitive analysis results based on term frequency, while LDA, as a probability-based model, can reveal new associations that may not be apparent from frequency alone. Given that this study aims to identify environmental and sustainability issues and trends in the marine fisheries sector, the LDA model was employed. The DMR model was excluded as the deviation of information from metadata is not substantial in the case of news data.

The LDA technique is illustrated in Figure 1.

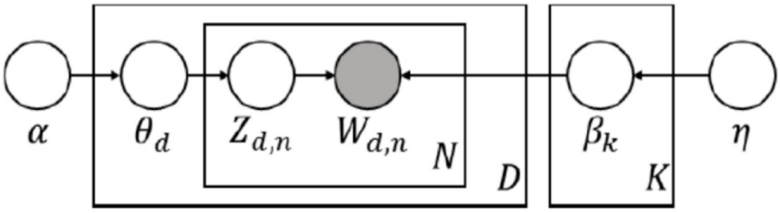

Figure 1. Schematic of the topic modeling algorithm. K: number of topics; α: Dirichlet prior weight of topic k by document, the parameter which determines the value of θ; η: Dirichlet prior weight of word w by document, the parameter which determines the value of β; θ_d: the ratio of topics by document; β_k: the probability that word w will be generated by topic; $Z_{d,n}$: the topic of the nth word in document d (index); $W_{d,n}$: the nth word in document d (variable observed in document, index).

The LDA algorithm employs a process of inferring hidden variables from observed variables in a document to uncover concealed topics [29]. In Figure 1, the observed variable corresponds to a word ($W_{d,n}$). Then, there are hyper parameters α and η, and hidden parameter β_k, which are used to extract the word. Finally, there are hidden variables $Z_{d,n}$ and $W_{d,n}$ that are not directly observed in the document and that we want to infer through the LDA model. In the LDA model, $Z_{d,n}$ is generated from θ_d, which is the ratio of topics by document whose value follows the Dirichlet prior weight determined by the value α. Similarly, β_k, representing the probability of a word being generated by a topic, is

determined by the parameter η. The Dirichlet prior distribution of β_k is shaped by η. The word $W_{d,\,n}$ is consequently identified through the combination of $Z_{d,n}$, which indicates the topic assignment for each word, and β_k, representing the word-topic ratio.

The LDA algorithm is summarized as follows (Table 1). In this study, 10 topics were selected and analyzed.

Table 1. Simplified procedure for performing topic modeling.

1. Decide how many topics you want to categorize.
2. Analyze topic modeling.
   2.1 Randomly assign each word to a topic—for example, say the word 'A' is assigned to topic 1.
   2.2 Determine which topic 'A' belongs to based on two criteria.
      2.2.1 What is the percentage of the word 'A' in topic 1?
      2.2.2 What percentage of the document is currently occupied by topic 1?
   2.3 Assign word 'A' to a new topic based on the above criteria.
   2.4 Repeat 2.2 and 2.3 for all words.
3. Give each topic a topic name.

4. Data Description

The news text data utilized in this study were collected through the BigKinds news big data analysis service [37]. BigKinds evolved from the Korea Integrated News Database System (KINDS), a service that allows storage and retrieval of news from broadcasts and major daily newspapers since 1990. It has incorporated big data analysis technology since April 2016. BigKinds offers a database capable of storing, searching, and processing over 10 million news articles from 54 media outlets in South Korea, including 11 national dailies, 8 economic dailies, 28 regional dailies, 5 broadcasting stations, and 2 professional magazines. Additionally, it provides features such as data clustering, keyword analysis, word cloud and network visualization, and information extraction capabilities [38,39].

For this study, we collected and analyzed 50,213 news articles from the 11 national daily newspapers provided by BigKinds over the past 15 years (from 1 January 2008 to 31 December 2022). According to the research objective of analyzing the ocean economy at the national level and focusing on broader issues instead of specific regional concerns, only the aforementioned 11 national daily newspapers were included in the analysis to ensure the homogeneity of the text data. The representative keywords, to search and collect news data, used in the field of marine and fisheries, are: 'Ocean, Maritime, Fishery, Port, Shipping'. These search terms were selected based on the organizational classification system of the Ministry of Oceans and Fisheries of South Korea, which includes the Marine Policy Office, Fisheries Policy Office, Shipping and Logistics Bureau, and Ports and Harbours Bureau. To search for news data related to the ocean environment, the following terms were utilized: 'Environment, Biology, Resource, Ecosystem, Climate, Carbon, Mortality, Epidemic, Infection, Hygiene, Trash, Microplastic, Disease, Contaminator, Habitat, Wastewater, Noise'. These terms were selected by extracting general nouns from 215 text-based reports (from 2008 to 2023) related to marine policy and then identifying the top words based on term frequency that are relevant to the environment. The selection of search terms was conducted by researchers affiliated with the Korea Maritime Institute (KMI), a government-funded research institution established for the purpose of formulating marine and fisheries policies.

The number of collected news articles by year is shown in Figure 2. As can be seen from the figure, environmental issues in the marine and fisheries sector have shown a steady increase since 2008 and have experienced significant growth, particularly after 2017. This trend is interpreted to be attributable to the multitude of policies and plans related to the ocean environment announced by the International Maritime Organization (IMO) and the Ministry of Ocean and Fisheries of South Korea since 2017. In 2018, the IMO unveiled the Initial IMO GHG Strategy on the reduction of GHG (greenhouse gas) emissions from ships, setting out a vision which confirms IMO's commitment to reducing GHG emissions from international shipping and to phasing them out as soon as possible. Likewise, the

South Korean government also released the 1st Climate Change Response Plan in December 2016, followed by the 2030 Greenhouse Gas Reduction Roadmap in 2018, both serving as foundational elements for their climate change mitigation efforts. With the establishment of these mid-to-long-term environmental policies, a noticeable surge in interest in the ocean environment has been observed.

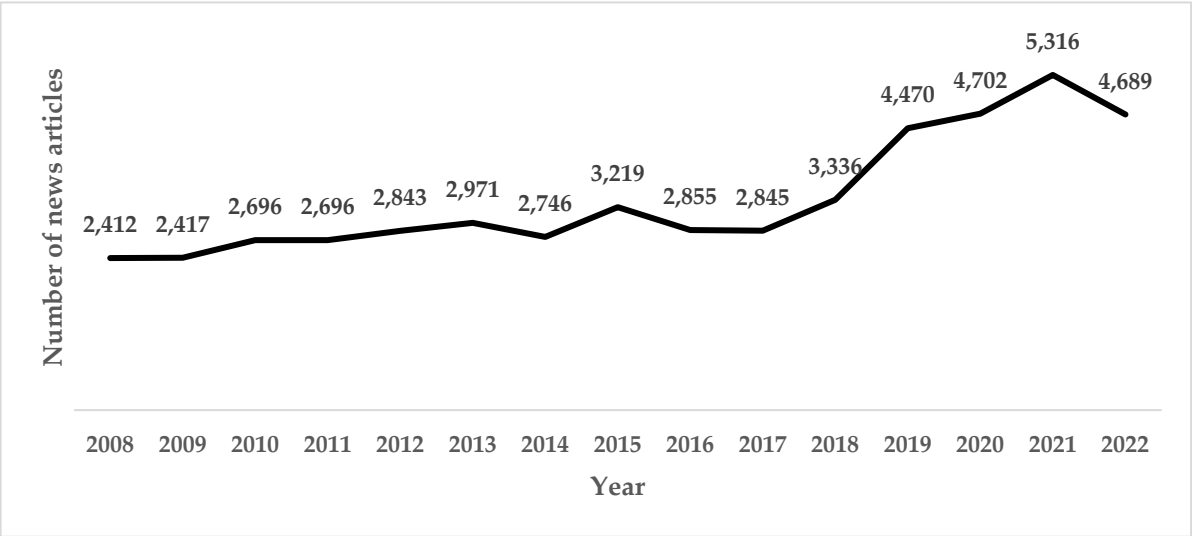

Figure 2. Number of news articles by year.

Subsequently, the preprocessing steps were performed on the collected data. Following the typical text data preprocessing steps, we first conducted tokenization based on whitespace as the delimiter. Next, part-of-speech analysis was performed to extract only the words corresponding to common nouns. During this process, we applied normalization techniques such as stemming and lemmatization. Subsequently, we removed words with a length of one character or less, as well as specific local names, personal names, positions, titles, and other words that excessively possess generic meanings (e.g., world, people, process, start, manage). Additionally, since it is self-evident that the keywords used for data collection (Ocean, Marine, Maritime, Fishery, Port, Shipping) would frequently appear and contribute little to the interpretation of the results, we also removed these words from the dataset.

5. Results

5.1. Results of Word Clouds

Figure 3 presents word cloud images based on term frequency, organized by year. The word clouds depict the 15-year period from 2008 to 2022, encompassing the entire data collection phase. By observing these visual representations, a general overview of the prevalent environmental issues in the marine and fisheries sector can be obtained.

From 2009 to 2012, keywords such as 'Construction, Facility, Inspection, Creation, Energy' were prominently identified. This period was characterized by extensive efforts to construct large-scale facilities and complexes related with 'tourism, R&D, fishery processing, logistics warehouses'. It was a time before the establishment of a clear national policy focusing on marine environmental issues. Particularly noteworthy is the steady increase in the number of foreign tourists, from 6.89 million in 2008 to 11.14 million in 2012, which fueled the demand for the development of tourism resources, including 'Ecological Experiences and Cruises' [40]. Furthermore, the increase in per capita annual seafood consumption from 36.7 kg in the early 2000 s to 54.2 kg in 2012 reflects the growth in infrastructure facilities for seafood production, processing, and distribution [41].

Figure 3. Word clouds by year.

From 2013 to 2017, the keyword 'Safety' dominated as a key term. This can be attributed to the aftermath of the 2011 Great East Japan Earthquake (Fukushima nuclear accident) and the Sewol ferry disaster in 2014. When searching for keywords such as 'Fukushima' and 'Marine, Fisheries, Port, Shipping', it was found that the number of news

articles reported was 293 in 2011, followed by 43 articles in 2012, 361 articles in 2013, 81 articles in 2014, 69 articles in 2015, and 39 articles in 2016. In other words, more news coverage was observed in 2013 compared to the year of the accidents in 2011. This can be attributed to the release of reports such as the UNSCEAR 2013 Report [42] investigating the cause and impact of the accidents, which brought them back into the spotlight as social issues in neighboring countries. Particularly, in 2013, the official report confirming the leakage of contaminated water from the Fukushima Daiichi Nuclear Power Plant's cooling water tank into the ocean had a significant impact. Furthermore, the Sewol ferry sinking on 16 April 2014, which resulted in the deaths of 304 passengers, was a major tragedy in South Korean history and led to a surge in public interest in marine safety accidents for a prolonged period. Since the Sewol incident, there has been increased media exposure and attention to both significant and minor maritime incidents and accidents that previously received less attention. This trend can be interpreted as a reflection of the increased media coverage and public awareness of maritime safety issues following the Sewol incident.

Starting from 2018, keywords such as 'Trash, Plastic, Contaminator, Discharge' became prominent. This period marked a time when South Korea, following international trends, became increasingly interested in creating a sustainable marine environment and formulating relevant policies. This can be observed in the Korean-Sustainable Development Goals (K-SDGs) developed in 2019, which were based on the United Nations' Sustainable Development Goals (SDGs) announced in 2015 [43]. The SDGs encompass 17 goals to be achieved by 2030 for global sustainable development, and the 14th goal specifically expresses the intent to 'Conserve and sustainably use the oceans, seas, and marine resources for sustainable development'. The five sub-tasks under this goal include 'Plastic/Marine Pollution, Over-fishing, Acidification, Eutrophication, Ocean Warming'. The K-SDGs align with these objectives and establish seven goals, including 'Establish marine pollution management system, Manage ecological environment and fishery resources habitat, Minimize marine acidification, Sustainable fishery resources and its use, Designate coastal and marine protection areas, Expand R&D efforts on marine science' [44].

Lastly, in 2022, keywords such as 'Ecosystem, Cooperation, Establishment' indicate a shift from directly addressing factors that pose immediate threats to the environment, such as 'Trash, Plastic, Contaminator', towards emphasizing intergovernmental and intercorporate cooperation for the sustainable conservation of marine ecosystems.

5.2. Results of Topic Modeling

Table 2 below presents the titles and descriptions of the 10 topics identified in the topic modeling analysis. The distribution of topic proportions is shown in Figure 4, where Topic 4 (Carbon Neutral, Hydrogen Energy) has the highest share of 18%, followed by Topic 7 (Cruise Tourism Development and Smartization) in second place, and Topics 5 (Micro Plastic, Climate Change) and 10 (Diplomatic Cooperation Between Countries) with proportions of 13% each.

Topic 4 has the largest proportion, which can be interpreted as a result of the increasing interest in marine environment as time goes by. Recent news articles have a relatively higher proportion in the overall dataset, and among them, carbon neutrality and hydrogen energy emerge as the main issues. In particular, greenhouse gas emissions from large vessels have been recognized as a serious problem, reaching approximately 1.1 billion tons annually. In response to this, the International Maritime Organization (IMO) has set a goal to reduce ship carbon emissions by 50% compared to 2008 levels by 2050, with the motto "safe, secure and efficient shipping on clean oceans". It is expected that this goal will be further revised upwards to 100% at the 80th Marine Environment Protection Committee (MEPC) meeting in July 2023. Consequently, countries worldwide are making efforts to introduce environmentally friendly ships using hydrogen, ammonia fuel cells, and other technologies, or to develop new technologies in this field.

Table 3 presents the probabilistic distribution of words associated with each topic. Topic modeling provides a set of keywords with a high probability of being grouped

together within the same topic, as well as the proportion of topics within the documents. Therefore, to interpret the results and derive implications, an additional exploration of the specific content related to each topic in the news articles was conducted.

Table 2. Titles and descriptions of the topics.

Topic Number	Topic Title	Description
1	Sustainable Fisheries and Aquaculture Management	Damage to Coastal Fisheries and Aquaculture due to Environmental Pollution
2	Accident, Calamity, Disaster Response	Damage and Countermeasures Caused by Oil Leaks, Typhoons, and Earthquakes
3	Polar Environment	Polar Environment Damage
4	Carbon Neutral, Hydrogen Energy	Development and Side Effects of Marine Renewable Energy to Reduce Carbon Emissions
5	Micro Plastic, Climate Change	Influence and Measures on Climate Change such as Microplastic Waste Problems and Global Warming
6	Tidal Flats, Habitat Ecosystems	Ecosystem Destruction and Disturbance, Habitat Damage
7	Cruise Tourism Development and Smartization	Environmental Pollution by Tourism Resource Development, Development and Utilization of Smart Technology in the Marine Fisheries Sector
8	Japanese Nuclear Power Plant Pollution	Radioactive Contamination due to the Release of Japanese Nuclear Power Plant Pollution
9	COVID-19	Global Supply Chain Paralysis due to Infectious Diseases, Establishing a Prevention System
10	Diplomatic Cooperation Between Countries	Diplomatic Cooperation to Achieve Carbon Neutral and ESG Management, Disputes of Maritime Law and Fishing Rights Between Countries

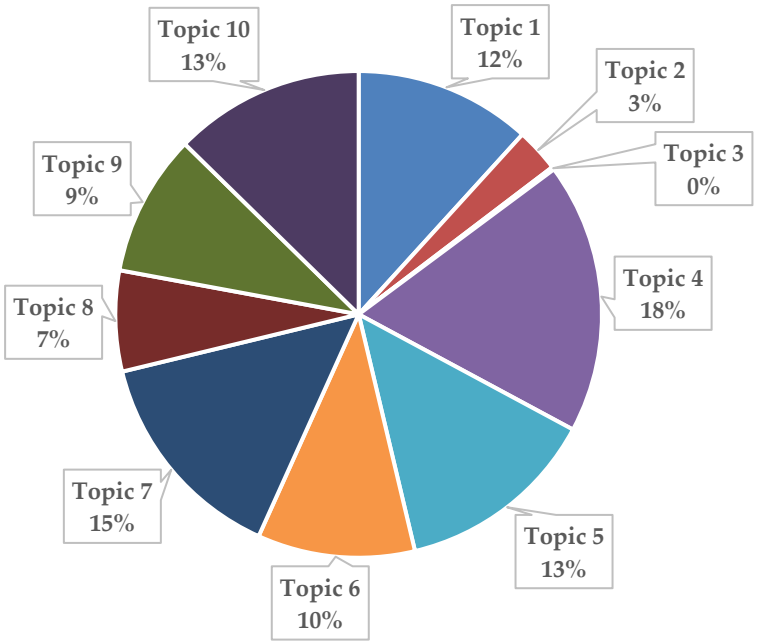

Figure 4. Ratios by topic.

The initial topic, namely "Sustainable Fisheries and Aquaculture Management", encompasses instances of abandoned fishing grounds, volatile supply and demand of fishery products, fluctuations in production and prices of fishery products, hygiene concerns regarding fishery products, biofouling, and the aging of fishing grounds and vessels. The second topic, labeled "Accident, Calamity, Disaster Response", incorporates instances of ship-based oil spills, underwater earthquakes and typhoons, damage to logistics infrastructure, and disruptions in supply chains due to natural disasters. Topic 3, referred to as "Polar Environment", addresses issues related to environmental degradation in polar regions and transformations in the Arctic shipping environment, while Topic 4, denoted as "Carbon Neutral, Hydrogen Energy", focuses on matters concerning carbon emissions stemming from ship operations, the development of marine energy sources, and policies aimed at curtailing carbon emissions.

Table 3. Probability distribution of words by topic.

Topic 1		**Topic 2**		**Topic 3**		**Topic 4**		**Topic 5**	
Fishery	0.0197	Accident	0.0270	Antarctica	0.0755	Energy	0.0116	Plastic	0.0175
Aquaculture	0.0143	Calamity	0.0260	North Pole	0.0356	Carbon	0.0110	Micro	0.0158
Aquatic products	0.0121	Disaster	0.0215	Ice	0.0192	Hydrogen	0.0095	Climate	0.0146
Sea area	0.0112	Respond	0.0172	Glacier	0.0181	Global	0.0082	Change	0.0104
Fishing	0.0112	Oil	0.0147	Penguin	0.0161	Invest	0.0076	Effect	0.0086
Resource	0.0091	Outflow	0.0145	Polar region	0.0146	Market	0.0062	Weather change	0.0081
Coast	0.0080	Maritime Police	0.0137	Sea ice	0.0134	Wind force	0.0058	Rise	0.0068
Damage	0.0077	IAEA	0.0133	Ice shelf	0.0101	LNG	0.0057	Earth	0.0067
Water temperature	0.0074	Inspection	0.0124	Antarctic Sea	0.0098	Generation	0.0049	Biology	0.0064
Fish species	0.0073	Nuclear power	0.0114	Arctic Ocean	0.0097	Export	0.0048	Observation	0.0062
Topic 6		**Topic 7**		**Topic 8**		**Topic 9**		**Topic 10**	
Foreshore	0.0167	Tourism	0.0174	Japan	0.0473	COVID-19	0.0197	Cooperation	0.0091
Ecosystem	0.0163	Attracting	0.0122	Contaminator	0.0391	Corona	0.0143	Nation	0.0085
Habitat	0.0117	Market	0.0118	Nuclear power plant	0.0287	Virus	0.0112	Diplomacy	0.0085
Marsh	0.0117	Growth	0.0113	Discharge	0.0250	Occurrence	0.0080	Meeting	0.0079
Inspection	0.0113	Job	0.0094	Fukushima	0.0225	Standard	0.0075	Summit	0.0070
Area	0.0109	Development	0.0078	Decision	0.0130	Prevention	0.0065	Respond	0.0065
Protect	0.0090	Cruise	0.0072	Radiation	0.0128	Infection	0.0065	Emphasis	0.0062
Facility	0.0088	Smart	0.0069	Emission	0.0123	Diffusion	0.0059	USA	0.0059
Development	0.0082	Future	0.0064	Material	0.0121	Respond	0.0058	Politics	0.0057
Disturbance	0.0075	Application	0.0057	Process	0.0114	Damage	0.0058	Congress	0.0056

The subsequent topic, designated as "Microplastic, Climate Change (Topic 5)", encompasses diverse concerns pertaining to the escalation of microplastic waste, global warming, ocean acidification resulting in pH reduction, detrimental effects on fisheries due to climate change, and corresponding response measures. "Tidal Flats, Habitat Ecosystems (Topic 6)" encompasses content related to the destruction and disruption of ecosystems, habitat damage, and the introduction of non-indigenous marine species. The seventh topic, known as "Cruise Tourism Development and Smartization", addresses issues such as ecosystem damage resulting from tourism infrastructure development, decline in cruise tourism, and job loss due to the implementation of smart technologies.

The eighth topic, titled "Japanese Nuclear Power Plant Pollution", predominantly explores the issue of pollution arising from Japanese nuclear power plants and its particular relevance to Korea's geographical characteristics. It includes problems of marine pollution resulting from various wastewater sources. The ninth topic highlights the damages incurred by infectious diseases, with COVID-19 being a representative case. It verifies the emergence of marine economic risks, such as port closures or reduced operations, and alterations in consumption patterns attributable to infectious diseases. Lastly, "Diplomatic Cooperation Between Countries" reflects concerns surrounding carbon reduction, international cooperation for environmental, social, and governance (ESG) management, and conflicts between nations over fishing rights or territorial sovereignty. This underscores the necessity of global collaborative endeavors through diplomatic cooperation to foster the growth of the marine economy, surpassing the limitations of individual national efforts.

5.3. Analysis of Yearly Trends

Following the topic modeling results, a trend analysis was conducted over time. Firstly, the overall trend was assessed by visualizing the data using graphs for the entire period. Subsequently, a quantitative analysis was performed using a linear regression model. In their work, Sun and Yin [45] collected transportation research data from 1991 to 2015 and analyzed it through topic modeling. Sun and Yin [45] defined an index r_k using the proportion of topic k in each journal article, denoted as θ_k^t. Based on this, if the value of r_k was less than 1, it was considered a "hot topic", whereas if it was greater than 1, it was considered a "cold topic".

$$r_k = \frac{\sum_{t=1991}^{1995} \theta_k^t}{\sum_{t=2011}^{2015} \theta_k^t} \quad (1)$$

However, using a simple arithmetic mean, such as r_k, for analysis has limitations in reflecting the overall trend of the research. Therefore, in this study, a linear regression model was constructed using the method proposed by Griffiths and Steyvers [46] to classify hot and cold topics based on significant regression coefficients. The independent variables were divided into a total of 15 intervals from 2008 to 2022, and the dependent variable was set as the proportion of each topic based on the corresponding year (Figure 5). Significant topics were selected at a p-value of 0.5% and categorized as hot topics if the regression coefficient was positive (+) or cold topics if it was negative (−) (Table 4).

According to the trend analysis conducted using the linear regression model, six topics were classified as hot topics due to their significant increasing trends: 1. Sustainable Fisheries and Aquaculture Management; 4. Carbon Neutral, Hydrogen Energy; 5. Microplastic, Climate Change; 7. Cruise Tourism Development and Smartization; 9. COVID-19; and 10. Diplomatic Cooperation Between Countries. Only one topic, 2. Accident, Calamity, Disaster Response, was classified as a cold topic. This indicates a decline in interest regarding accidents, calamities, and disasters, while environmental issues such as microplastic pollution, carbon reduction, and climate change, as well as diplomatic cooperation between countries, have emerged as global trends.

In particular, in the case of Korea, the lack of large-scale oil spill incidents since the Taean oil spill in 2007, the relatively small scale of recent oil spill accidents, the absence of major maritime accidents since the Sewol ferry disaster in 2014, and the scarcity of natural disasters related to the sea have contributed to the decreased interest in Topic 2 (Accident,

Calamity, Disaster Response). However, globally, the frequency of natural disasters and disasters caused by climate change is increasing, emphasizing the need for continuous attention and measures to address these issues.

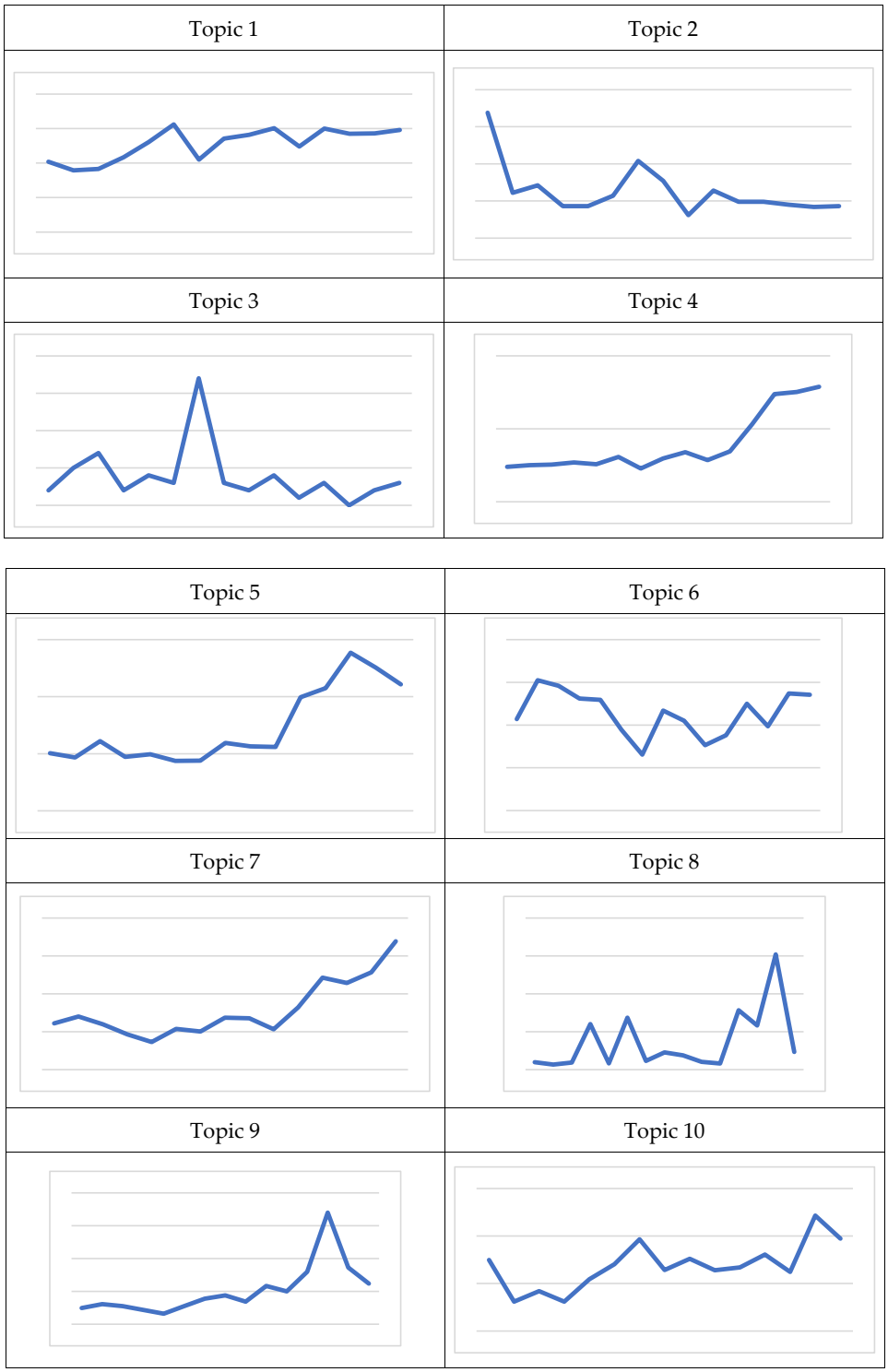

Figure 5. Topical research trends by year.

It Is important to note that the classification of hot and cold topics based on trend analysis does not imply the complete disappearance or lack of importance of certain topics. Rather, it reflects the shifting focus and increasing prominence of specific issues over time.

Table 4. Hot/cold topics.

Topic No.	Coefficient	*p*-Value	Hot/Cold
1	7.639	0.001	hot
2	−4.082	0.042	cold
3	−0.229	0.358	
4	38.014	0.000	hot
5	24.425	0.000	hot
6	−1.971	0.543	
7	26.168	0.001	hot
8	16.771	0.083	
9	24.268	0.004	hot
10	14.346	0.008	hot

5.4. Text Network Analysis

To obtain additional implications, network analysis was conducted. Text network analysis is a technique that constructs and analyzes networks based on the relationships between words appearing in texts, drawing on social network analysis [47]. Social network analysis encompasses the process of quantifying, statistically analyzing, and visualizing relationships among individual actors, such as individuals, organizations, companies, and groups, in a network, using nodes and edges [48]. In text network analysis, the co-occurrence matrix of keywords serves as an adjacency matrix to build the network.

In text network analysis, various centrality measures, such as degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality, can be applied to the constructed network for analysis. Eigenvector centrality, in particular, defines the centrality value of each node as the corresponding elements of the eigenvector that corresponds to the largest eigenvalue of the adjacency matrix when representing the network [49]. In this study, utilizing the results of the topic modeling analysis conducted earlier, a network was generated, and eigenvector centrality was measured. Among the top three keywords extracted for each topic, a total of 30 keywords (nodes) were selected (excluding 'cooperation', 'nation', and 'Japan' due to their overly general meanings). The weight of the edge was determined by the number of newspapers in which two different keywords co-occurred. To compare differences based on time periods, the entire data period of 15 years (2008–2023) was divided into three groups of five years each for analysis. The results of eigenvector centrality analysis are presented in Table 5, and the network adjacency matrix is included in the Appendix A.

The analysis results show that the keywords 'Contaminator, Accident, Fishery, Foreshore, Energy' consistently had high centrality throughout the entire period. These keywords are among the most central and highly related to various issues and topics related to the marine economy. Their continued presence over the past 15 years suggests the need for sustained attention to ensure the sustainability of the marine economy. Particularly, the keyword 'Accident' showed a decrease in centrality ranking from second to seventh place in the most recent period of 2018–2022. This decrease can be attributed to a decrease in the number of major marine accidents. However, policies and financial support for continuous accident prevention and safety measures should still be maintained.

Furthermore, in the period of 2008–2012, the keyword 'Climate', which was highly ranked in centrality measures, was replaced by 'Aquatic products' in the period of 2013–2017. In the subsequent period of 2018–2022, 'Climate' and 'Carbon' entered the top ranks instead of 'Aquatic products' and 'Tourism'. These results align with the yearly trend analysis conducted in the previous topic modeling analysis. The emergence of 'Aquatic products' reflects the impact of reports on the Fukushima nuclear accident and subsequent issues related to the release of contaminated water, which have been ongoing since 2013, two years after the earthquake in Japan in 2011. The inclusion of 'Climate' and 'Carbon' keywords in the top

ranks demonstrates the increasing importance of greenhouse gas-induced climate change and carbon neutrality goals, particularly among various environmental issues related to the ocean. This trend is expected to continue to develop as a significant topic.

Table 5. Results of text network analysis.

2008~2012		2013~2017		2018~2022	
Keywords	**Centrality**	**Keywords**	**Centrality**	**Keywords**	**Centrality**
Contaminator	0.408	Fishery	0.471	Contaminator	0.355
Accident	0.374	Accident	0.386	Fishery	0.353
Fishery	0.373	Contaminator	0.379	Energy	0.324
Foreshore	0.349	Foreshore	0.291	Climate	0.322
Energy	0.325	Aquatic products	0.271	Carbon	0.255
Climate	0.276	Tourism	0.227	Foreshore	0.236
Tourism	0.254	Energy	0.225	Accident	0.236
Aquatic products	0.199	Aquaculture	0.222	Plastic	0.222
Aquaculture	0.192	Nuclear power plant	0.182	Aquatic products	0.197
Ecosystem	0.168	Climate	0.170	Nuclear power plant	0.194
Nuclear power plant	0.165	Calamity	0.169	Tourism	0.189
Diplomacy	0.114	Disaster	0.159	Ecosystem	0.170
Calamity	0.105	Ecosystem	0.127	Smart	0.164
Carbon	0.086	Diplomacy	0.114	Micro	0.163
Habitat	0.079	Habitat	0.080	Aquaculture	0.163
North Pole	0.066	Micro	0.065	Diplomacy	0.137
Antarctica	0.061	Smart	0.060	Corona	0.124
Glacier	0.046	Plastic	0.056	Calamity	0.116
Cruise	0.038	North Pole	0.056	Hydrogen	0.113
Micro	0.037	Carbon	0.050	Habitat	0.104
Plastic	0.037	Antarctica	0.047	Virus	0.084
Smart	0.033	Cruise	0.040	Infection	0.073
Hydrogen	0.027	Infection	0.040	North Pole	0.065
Disaster	0.022	Virus	0.031	Glacier	0.052
Virus	0.022	Glacier	0.028	Antarctica	0.048
Infection	0.018	Hydrogen	0.013	Disaster	0.024
Corona	0.001	Corona	0.001	Cruise	0.022

Lastly, the keywords 'Smart, Micro, Plastic' demonstrate a consistent upward trend, despite being positioned in the lower to middle ranks of centrality measures. This observation indicates a growing interest in introducing smart technologies to address the environmental issues of microplastics and micro-dust in the ocean economy. Smartization is rapidly progressing across various sectors of the ocean-based industry, including the intelligent transformation of maritime transportation and logistics services, the establishment of sustainable and eco-friendly smart fisheries management systems, the implementation of smart monitoring and response systems for disaster and safety management, and the adoption of IoT devices to facilitate ocean environmental management systems. Particularly, microplastics are identified as a major cause of ocean environmental pollution, driving vigorous technological developments for detection, prevention of inflow, collection, treatment, and hazard assessment. As such, it is anticipated that these efforts will continue to expand in the future.

6. Discussion and Conclusions

In this study, news text data were collected using keywords related to ocean economy as well as the environment. The data were then analyzed using the LDA (Latent Dirichlet Allocation) technique, one of the topic modeling methods, to examine the keyword trends over time based on term frequency. Furthermore, for the 10 resulting topics, significant increasing or decreasing trends over time were identified. Text network analysis was conducted based on the co-occurrence frequency of keywords within each topic to measure the centrality of keywords. Through this research, a systematic analysis of the environmental risks faced by ocean-based industries was carried out, and implications for the future development of sustainable marine economy were obtained.

The topics of Aquaculture, Carbon Neutrality, Microplastic, and Climate Change highlight the environmental issues that span the entire marine economy. Resolving environmental risks is crucial for the future development of the marine economy. Topics such as Climate Change and Carbon Neutrality are shared challenges for all industries based on the ocean, including fisheries, shipping, and ports. Microplastic and Aquaculture represent tasks that must be pursued for sustainable fisheries. Moreover, these topics align with the Sustainable Development Goals (SDGs) announced by the United Nations and the specific items of Korea-SDGs. Carbon Neutrality, in particular, is a prominent keyword in Korea's marine economy policy, leading to various carbon neutrality measures such as the development of low-carbon and zero-carbon ship technologies in the shipping and logistics sector, the transition from aging fishing vessels to low-carbon vessels, the introduction of low-carbon certification for aquaculture products, and the reduction of greenhouse gas emissions through the recycling of marine waste.

Another hot topic, Cruise Tourism Development and Smartization, represents the cruise industry as a key sector in marine tourism and the trend of smartization in the shipping and port sectors. The cruise industry has consistently shown growth as a prominent industry in the marine economy before the COVID-19 pandemic. However, the significant decrease in global cruise tourists from 29.67 million in 2019 to 5.77 million in 2020 indicates that the cruise industry was severely impacted during the COVID-19 period [50]. The selection of Cruise Tourism Development as a hot topic emphasizes the necessity of rebuilding the cruise industry for the continued growth of the marine economy. Smartization, on the other hand, is a crucial topic in the shipping and port industry, encompassing the automation and digitization of ship operations and port handling processes, as well as environmentally friendly practices through carbon neutrality and fuel conversion. While job reduction is a noted drawback of smartization, it is considered a necessary topic for securing the sustainability of the marine economy in the future.

The final hot topic, "Diplomatic Cooperation Between Countries", demonstrates that global, cross-border cooperation is essential for achieving goals of environmental protection and sustainable growth. It also highlights that such cooperation is the most effective and only viable approach to addressing environmental issues in the marine and fisheries sector. The topics derived from this study indicate that in order to promote the development of the marine economy, responding to environmental issues and ensuring sustainability are paramount across various ocean-based industries such as fisheries, shipping, and ports. Carbon neutrality, which emerged as a crucial keyword, is not only important for South Korea but for all countries with a significant stake in the marine economy.

As mentioned in the introduction, the marine economy holds great importance, not only for the national economy of South Korea, but also in the global economy. However, recent events such as the COVID-19 pandemic, the Ukraine–Russia conflict, and trade frictions in the era of the new Cold War have posed significant risks to the sustainability of the marine economy. These risks include disruptions in global supply chains, increased volatility in water traffic, congestion and delays, rising shipping costs, and prolonged inflation. Notably, the global economic growth rate decreased by over 3.1% in 2020, and world trade volume declined by over 8.2% compared to the previous year (IMF, 2022).

These low-probability, high-impact problems can only be addressed through short-term response measures and events such as vaccine development or conflict resolution.

While predicting the occurrence of such events is practically impossible, strengthening proactive prediction capabilities and formulating response strategies can minimize the adverse effects of extreme events and enhance the resilience of future societies in the face of uncertainties. Particularly, the COVID-19 pandemic has revealed significant challenges in global pandemic response capacities. Pandemics not only affect the health of living organisms but also cause extensive damage across all sectors of the marine economy, including seafood production, the cruise industry, port logistics, and maritime transportation. As the pandemic is being declared under control, it is necessary to reevaluate and thoroughly examine pandemic response measures spanning the entire ocean-based industry.

Furthermore, accidents and natural disasters at sea, such as oil spills, earthquakes, and typhoons, are difficult to predict, but efforts must be continually made to minimize damages. According to the results of this study, topics related to accidents, disasters, and hazards exhibited a continuous declining trend, except during the years when these events occurred. Although the volume of oil spills has decreased, the number of oil spill incidents remains at a similar level each year, and the frequency of natural disasters continues to rise steadily. In light of these findings, proactive preventive measures, system establishment, and regular inspections are necessary to prevent large-scale accidents and disasters.

In addition, environmental issues such as microplastic pollution, climate change, and carbon neutrality pose challenges that cannot be easily resolved without sustained execution of solutions through diplomatic cooperation between nations, despite their immediate impacts not being significant. The Korean government has implemented various policies for achieving carbon neutrality in the marine economy. However, due to the nature of the marine economy, the efforts of a single country alone may not yield substantial results. Hence, international environmental problems with transnational and interconnected characteristics require collaborative efforts from members of the international community, including governments, local authorities, and NGOs. It is necessary to share policies and establish unified policies among all countries with a significant stake in the marine economy.

The data analyzed in this study are confined to "South Korea" and "news", which presents certain limitations. As mentioned in the introduction, the scale and technological capabilities of South Korea's marine economy place it as one of the top five globally, making it a suitable research subject. However, there is a limitation in not being able to comprehensively analyze global news data due to language constraints. Considering the nature of the marine economy, it would be beneficial to conduct research targeting the global environment using expanded data sources in the future. Additionally, the study did not consider the diverse media platforms available through various social networking services such as YouTube, Facebook, and Instagram. These social platforms contain data that are more public-friendly compared to news data. Therefore, they can be utilized for research focusing on ideas development and direction setting for addressing environmental issues faced at the individual or small-scale community level, rather than macro-level and national policymaking. In particular, YouTube data, when combined with quantitative and statistical analysis involving metrics such as views, subscribers, number of videos, and video length, hold promise for conducting comprehensive research.

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Appendix A

Table A1. Co-occurrence matrix of keywords between 2008–2012.

Keywords		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27
W1	Fishery		328	296	184	62	4	19	9	10	218	14	4	25	14	175	309	86	70	245	11	22	221	47	0	25	29	117
W2	Aquaculture			137	65	12	2	5	5	5	61	10	1	8	9	45	130	29	30	66	3	7	91	15	0	18	12	17
W3	Aquatic products				117	25	1	8	3	3	42	5	3	9	5	26	82	32	17	69	4	2	153	60	0	7	3	17
W4	Accident					114	29	30	27	13	144	19	8	9	16	95	224	109	18	81	9	13	664	205	0	6	4	43
W5	Calamity						15	4	3	8	60	6	1	2	2	45	43	23	1	63	1	9	63	27	0	2	2	26
W6	Disaster							1	0	2	10	2	0	2	2	4	9	10	0	4	2	0	21	12	0	0	0	6
W7	Antarctica								97	57	57	14	2	2	6	84	25	34	11	10	1	2	23	6	0	1	1	7
W8	North Pole									67	58	13	1	5	13	90	46	28	12	11	2	0	33	11	0	1	2	8
W9	Glacier										36	17	1	2	11	75	26	12	8	6	4	0	21	0	0	0	1	9
W10	Energy											167	67	33	48	365	184	78	21	238	24	39	197	114	1	6	4	119
W11	Carbon												17	5	2	90	30	25	10	40	7	16	39	10	0	4	0	20
W12	Hydrogen													7	2	19	5	3	0	10	2	2	11	11	0	0	0	1
W13	Plastic														16	10	23	17	4	12	1	2	34	8	0	1	2	2
W14	Micro															20	17	13	4	9	1	1	29	5	0	3	4	5
W15	Climate																232	73	34	169	30	22	109	44	1	5	5	64
W16	Foreshore																	140	72	186	26	8	277	60	0	3	5	44
W17	Ecosystem																		71	75	3	4	149	15	0	10	5	24
W18	Habitat																			46	7	2	53	3	0	5	2	3
W19	Tourism																				83	31	109	13	1	5	4	71
W20	Cruise																					4	12	3	0	0	0	5
W21	Smart																						14	8	0	4	1	7
W22	Contaminator																							201	0	24	13	48
W23	Nuclear power plant																								0	1	1	27
W24	Corona																									0	0	0
W25	Virus																										54	1
W26	Infection																											5
W27	Diplomacy																											

Table A2. Co-occurrence matrix of keywords between 2013–2017.

Keywords		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27
W1	Fishery		524	507	423	166	155	40	50	8	281	23	4	52	44	200	501	136	114	405	48	76	386	104	0	46	72	181
W2	Aquaculture			204	59	20	17	9	13	3	74	5	1	21	20	54	191	39	24	80	7	31	97	31	0	21	26	13
W3	Aquatic products				189	14	29	14	16	3	52	4	2	18	13	41	150	49	30	106	10	20	268	147	0	16	22	32
W4	Accident					301	363	23	29	10	154	24	6	36	39	68	220	74	31	109	26	35	672	298	2	18	16	81
W5	Calamity						176	5	3	5	112	5	1	3	24	67	46	17	0	106	6	35	119	55	0	3	10	49
W6	Disaster							6	7	1	53	6	3	5	12	17	47	11	2	46	21	3	105	43	1	3	6	42
W7	Antarctica								79	62	46	14	6	6	16	83	39	41	18	10	1	2	35	5	0	1	3	12
W8	North Pole									58	58	14	4	11	13	91	45	30	28	15	3	1	45	4	0	2	2	21
W9	Glacier										41	12	4	5	8	75	28	24	8	13	5	1	18	1	0	2	2	5
W10	Energy											121	34	34	66	261	92	84	22	201	25	101	157	94	1	4	5	124
W11	Carbon												13	8	24	88	23	38	12	42	2	19	34	14	0	3	1	12
W12	Hydrogen													6	8	14	5	5	1	7	1	5	13	9	0	1	1	3
W13	Plastic														59	15	32	40	10	11	0	7	103	8	0	5	3	4
W14	Micro															45	25	39	3	13	1	4	118	15	1	1	1	8
W15	Climate																112	89	43	127	15	31	110	31	0	17	11	101
W16	Foreshore																	117	117	143	28	15	263	59	1	8	14	33
W17	Ecosystem																		76	76	9	11	139	13	0	10	13	16
W18	Habitat																			47	5	0	61	8	0	16	16	3
W19	Tourism																				99	58	114	39	1	9	16	88
W20	Cruise																					4	13	3	0	1	2	11
W21	Smart																						26	24	0	2	2	18
W22	Contaminator																							296	1	33	37	51
W23	Nuclear power plant																								0	5	2	35
W24	Corona																									1	1	0
W25	Virus																										97	4
W26	Infection																											7
W27	Diplomacy																											

Table A3. Co-occurrence matrix of keywords between 2018–2022.

Keywords		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27
W1	Fishery	0	771	779	375	211	30	45	61	25	413	235	89	222	174	438	672	212	215	497	42	401	475	179	179	182	193	218
W2	Aquaculture	0	0	355	61	44	7	10	18	10	118	48	23	72	40	129	196	66	57	126	12	232	168	30	40	36	29	18
W3	Aquatic products	0	0	0	226	30	15	7	13	4	74	60	31	94	46	96	219	74	47	134	10	122	347	334	81	57	62	84
W4	Accident	0	0	0	0	204	110	19	31	15	199	101	71	135	89	170	295	143	56	101	18	109	775	612	68	50	61	216
W5	Calamity	0	0	0	0	0	38	21	26	24	187	94	33	45	113	231	58	43	15	125	4	102	157	52	94	51	53	66
W6	Disaster	0	0	0	0	0	0	0	1	4	19	5	4	13	0	28	28	13	1	15	4	7	44	24	6	7	5	21
W7	Antarctica	0	0	0	0	0	0	0	135	128	60	51	2	41	28	168	48	86	69	23	1	4	53	2	10	11	7	12
W8	North Pole	0	0	0	0	0	0	0	0	133	113	66	4	53	51	235	52	71	46	22	10	10	78	6	11	18	18	26
W9	Glacier	0	0	0	0	0	0	0	0	0	81	82	7	32	25	223	49	66	33	15	4	3	49	8	21	16	10	7
W10	Energy	0	0	0	0	0	0	0	0	0	0	807	431	311	231	835	181	235	90	380	28	383	389	234	194	82	41	189
W11	Carbon	0	0	0	0	0	0	0	0	0	0	0	302	267	115	746	175	189	78	165	8	193	283	142	152	39	21	87
W12	Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	41	67	125	41	50	3	106	8	168	110	100	37	4	6	28
W13	Plastic	0	0	0	0	0	0	0	0	0	0	0	0	0	400	314	218	224	92	53	4	70	791	27	133	79	63	32
W14	Micro	0	0	0	0	0	0	0	0	0	0	0	0	0	0	213	103	110	15	86	9	98	551	44	66	58	23	34
W15	Climate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	287	349	203	251	21	166	410	191	199	90	60	253
W16	Foreshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	197	248	209	29	86	463	171	35	24	28	80
W17	Ecosystem	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200	159	11	71	292	103	68	55	30	42
W18	Habitat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	117	7	12	151	7	32	28	24	7
W19	Tourism	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	101	313	134	54	183	40	53	126
W20	Cruise	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	18	7	18	6	16	11
W21	Smart	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	110	60	112	33	22	58
W22	Contaminator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	577	155	135	114	272
W23	Nuclear power plant	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	7	10	324
W24	Corona	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	329	267	81
W25	Virus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	423	37
W26	Infection	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41
W27	Diplomacy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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