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RESEARCH PAPER

Impact of Arctic Sea Ice Changes on LNG Shipping in the Context of Rising Global Energy Demand

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Abstract

The need for and demand for energy rises quickly as the world's population grows and economic growth quickens as well. Given the rising need for energy worldwide, liquefied natural gas, or LNG, is playing a significant role in energy transportation. Russia has a lot of gas. Russia plays a significant role in the LNG trade. The Northern Sea Route has opened due to the melting of the Arctic Sea's ice due to global warming. There is great potential for LNG transportation in the area. EViews was employed in this study to ascertain the connection between Arctic Sea ice and LNG ship movement in the NSR. The data was prepared using the Vector Autoregressive Model and the Granger Causality Test. The outcome of the analysis was the correlation between Arctic Sea ice and LNG ship traffic. LNG ship traffic in the NSR in 2023, 2024, and 2025 was estimated using the Census X-12 Method, and the 5-year (2018–2022) dataset of LNG ships departing the Russian port of Sabetta was analyzed. According to this data, by 2025, an estimated 27.03% more LNG tankers will be visiting the Russian Arctic port of Sabetta.

Introduction

The world's climate is changing for many reasons. Humans play a leading role in this change (IPCC, 2018). Climate change brings many negative situations known as global warming; Droughts, unexpected rainfall, unpredictability of sea conditions and similar effects (Shukla et al., 2017). These changes also affect biodiversity and sea levels in the world (Parmesan, 2006). However, the arctic region is greatly affected by this situation (Ivanov, 2023). Temperatures in the Arctic are increasing much faster than in other parts of the world, causing the loss of glaciers and the rapid melting of sea ice (Bintanja and Linden, 2013). Studies show that Arctic Sea ice has decreased by approximately 13.4% in summer months since 1981 (Label et al., 2020). Global warming is not only causing the Arctic Sea ice to melt but is also causing new waterways in the Arctic Ocean that were previously difficult to access (Figure 1) (Vihma, 2019; Arctic Portal, 2023).

This shift has led to the emergence of new waterways, including the Northwest Passage (NWP) and the Northern Sea Route (NSR). The Northern Sea Route has seen nearly whole ice-free summers in recent year, particularly off the coast of Rusia (Koyama et al., 2020). The importance of the Arctic Sea routes for international trade has increased due to the disappearance of ice and the availability of new sea channels (Steinberg, 2006; King, 2021; Tiller et al., 2020). Interest in the Arctic has grown as a result of global warming, and between 2010 and 2020, the number of ships traversing the NSR increased significantly (Arctic Council, 2021). According

Figure 1. New waterways have opened in the Arctic Sea

to the Northern Sea Route Association, 4 ships passed through the NSR in 2010, 34 vessels in 2011, 46 in 2012, 71 in 2013, 31 in 2014, and 22 in 2015 (NSRA, 2016). While only 5 ships passed through the Northwest Passage in 2016, this number increased to 36 in 2020 (Government of Canada, 2021). These data show that Arctic Sea routes are becoming more accessible due to climate change, which, in turn, increases ship traffic.

LNG is increasingly considered a preferred fuel type and “clean” energy instead of traditional fossil fuels (Ampah et al., 2021; Radoushinsky et al., 2023). With the dramatically increasing demand for natural gas in recent years, LNG has become an important area in the global energy industry (IEA, 2020; Wolak, 2021). LNG circulation is carried out in two main processes around the world: firstly, by pipelines and secondly, by vessels. According to the analysis of total LNG exports from 2011 to 2021, Russia ranks first with 241.3 billion cubic meters of exports (BP Statistical Review of World Energy, 2022). Russia leads the world in LNG exports, with 241.3 billion cubic meters exported between 2011 and 2021 (BP Statistical Review of World Energy, 2022). The BP World Energy Statistics Report from 2022 states that while LNG shipments via pipelines have fluctuated, Russia's LNG exports via ships have been rising significantly in recent years. In 2011, Russia exported 14.3 billion cubic meters of LNG by ship; by 2021, that amount had risen to 39.6 billion cubic meters. LNG pipeline shipments fell from 210.6 billion cubic meters in 2011 to 201.7 billion cubic meters in 2021 over the same period (BP Statistical Review of World Energy, 2022). A report published by the Oxford Institute for Energy Studies in 2019 estimated that Russia would begin exporting 80 million tons of LNG annually via the Northern Sea Route (NSR) by 2035 (Henderson & Yermakov, 2019).

Russia has been investing in infrastructure services in the Arctic regions since the Soviet era (Dalaklis & Baxevani, 2017). The Arctic region is very suitable for LNG availability thanks to the large natural gas reserves in the Yamal Peninsula and its proximity to the Northern Sea Route. Compared to traditional routes such as the Suez Canal, the Northern Sea Route significantly reduces transit time and costs (Erokhin & Gao, 2021). Over time, Russia has continued to develop the oil and gas resources and infrastructure of the Arctic region in order to support its economic development (Østhagen, 2013; Huebert, 2017). The projects of Yamal LNG and Arctic LNG-1, which are being implemented by Novatek in the Sabetta harbour, are one of the most important projects achieved at this stage (Radoushinsky, 2023). Besides the two projects, Vostok Oil, Arctic LNG II, Sakhalin 2, and Oblong are all four of Russia's major projects (Schreiber, 2022). Accordingly, the LNG transportation of Russia's current and planned projects and the opening dates of the projects have been declared as follows: Arctic LNG-1 in Yamal region between 2027-2030, in Arkhangelsk region between Black LNG /Rosneft in 2030-2035, in the Republic of Sakha (Yakutia) /Khabarovsk region between Yakutsk LNG 2025-2026, in Yamal region Arctic LNG-2 in 2030, Start of production of Shtokman LNG in 2035 in the Murmansk region (Baudu & Lasserre, 2023; Suldin et al., 2021). With the construction of new LNG terminals and the development of LNG infrastructure in this region, an increase in LNG tanker traffic is expected.

Oksanen et al. (2020) reported that LNG tanker density in the Russian Arctic region has dramatically increased in recent years. LNG transportation via the Northern Sea Route (NSR) has dramatically increased in the last decade. The amount of cargo transported in 2021 reached 34.9 million tons. This is explained by advances in ship technology and the increase in global demand for Arctic LNG (Humpert, 2022). By routinely transporting LNG from the Port of Sabetta to Asia and Europe, the Yamal LNG Project, which was introduced in 2018, has enhanced traffic. The Arctic LNG 2 project is anticipated to enable the expansion of LNG transportation with an annual capacity of 19.8 million tons (Karpova & Sidorova, 2019). Koyama et al. (2021) emphasize in their study that the Northern Sea Route is increasingly an ideal route for LNG transportation. Zelenkov et al. (2022) stated that by 2030, the ice on this route will have melted for half of the year, making navigation much easier (Katysheva, 2023).

Seasonal data on LNG ships arriving at the ports of Prigorodnoye and Sabetta from 2018 to 2022 was analyzed in this study. Analysis was done on the connection between the two ports. During the same time frame, the connection between Arctic Sea ice and LNG tanker traffic in the Sabetta Port was examined. Lastly, the future of ship traffic in the area was evaluated, along with a projection of the amount of LNG tankers that will arrive at the Sabetta Port between 2023 and 2025.

Literature Review

The impacts of Arctic sea ice downfall on shipping and trade have been broadly studied in recent years. For instance, a report by the Clean Arctic Alliance (2024) reported a 37% increase in the number of ships operating in the Arctic waters between 2013 and 2023, which was attributed to mitigations in sea ice extent. Alike, Zhang et al. (2023) examined the risk factors leading to ship-ice collisions in Arctic waters and the significance of understanding sea ice dynamics for safe navigation. Furthermore, Li et al. (2021) enhanced a data-driven model using machine learning and causal analysis to predict short-term sea ice extent to improve navigation safety in the Arctic. However, there is inadequate research in the literature on the straight relationship between Arctic sea ice extent and LNG traffic patterns in strategic ports such as Sabetta port. Focusing on the Sabetta port, this study quantifies the extent to which changes in LNG tanker traffic in the port are due to Arctic sea ice fluctuations using Granger causality analysis, providing important insights into the future of transportation dynamics in the Arctic.

Materials and Methods

This study uses 5-year (2018–2022) Arctic sea ice expansion data from the National Oceanic and Atmospheric Administration (NOAA). Additionally, 5-year (2018–2022) LNG tanker ship traffic data from Sabetta and Prigorodnoye Ports of Russia obtained from Automatic Identification System (AIS) data providers provided by MarineTraffic are used. The NOAA and AIS data collected are organized into separate 60-month periods and cover all months. The selected time period of 2018–2022 reflects the recent trends in Arctic LNG transport and sea ice variability. Prigorodnoye and Sabetta ports were selected due to their strategic importance; Prigorodnoye serves as a major terminal for Sakhalin LNG exports, while Sabetta serves as a critical hub for Yamal LNG (Erokhin & Gao, 2021; Humpert, 2022). To apply the Granger Causality Test, the AIS and NOAA data used in this study were first stabilized using the Augmented Dickey-Fuller Test (Yamak & Erdem, 2017). The Granger Causality Test was implemented after the data reached the final stage of stationarity.

EViews was selected for this study due to its robust capabilities in processing time series data and its extensive application in econometric analysis. In particular, EViews ensures an effective framework for applying the Granger Causality Test, which is integral to studying the causal relationship between Arctic sea ice extent and LNG vessel traffic. The Granger Causality Test was selected because it is well suited to identify directional relationships between variables over time, which is critical for understanding how changes in sea ice extent affect LNG tanker traffic patterns in the Sabetta port.

The projections in this study are based on a 5-year dataset (2018-2022) from verified and authoritative platforms such as the Automatic Identification System (AIS) for vessel traffic data and the National Oceanic and Atmospheric Administration (NOAA) for Arctic sea ice data. These data sources are greatly distinguished for their accuracy and reliability. However, it is recognized that any projection carries inherent uncertainties, especially within the context of rapidly changing Arctic conditions. To reduce this, the Census X-12 method was used due to its robustness to seasonally adjusted time series data, ensuring the reliability of projections for LNG vessel traffic between 2023 and 2025.

Deadweight tonnages (DWT) of LNG tankers arriving at Sabetta and Prigorodnoye ports, the two main LNG tanker ports of Russia between 2018-2022, were examined monthly (60 months) and seasonal sub-series were created. By comparing the sub-series of the two ports on the basis of years and months, it has been determined which port in which seasons Russia's LNG exports are concentrated. It is known that LNG traffic in the NSR is caused by the seasonal variation of sea ice levels in the Arctic. In order to examine the causality relationship between the Arctic Sea ice and the LNG tankers arriving at the Sabetta port, the Granger Causality test was applied to determine the causality relationship between the two variables.

In order to perform the Granger Causality test, two different models have been applied. In the equations, Y_t represents the dependent variable at time t, while X_{t-i} denotes the lagged independent variable, where $t-i$ refers to the value of X at i time periods earlier. The coefficients γ_i and β_i indicate the influence of the lagged values of Y_t and X_{t-i}, respectively, on the current value of Y_t. Here, p represents the maximum number of lags considered in the model, reflecting the number of time periods included to capture temporal effects. The error term, ε_t accounts for the unexplained variation in the dependent variable, capturing random fluctuations not explained by the model. The summation symbol $\sum_{i=1}^{p}$ aggregates the effects of all lagged values from $i = 1 \; to \; p$, allowing the model to account for the cumulative impact of prior periods on the current value of Y_t.

This model shall be referred to as Equation (1) and Equation (2) as follows (Yamak & Erdem, 2017):

$$Equation\ (1): Y_t = \sum_{i=1}^{p} \gamma_i Y_{t-i} + \sum_{i=1}^{p} \beta_i X_{t-i} + \varepsilon_{1t}$$

$$Equation\ (2): Y_t = \sum_{i=1}^{p} \gamma_i Y_{t-i} + \sum_{i=1}^{p} \beta_i X_{t-i} + \varepsilon_{2t}$$

As a result of these equations, which Granger created in his study in 1986, it was revealed that there can be four different results in the causality relationship between the variables by applying the Granger Causality Test (Granger, 1986). These results are as follows;

- There is a one-way causality relationship between the variables. For equation (1), β_1's are non-zero. For equation (2), the γ_i's are no different from zero. X is the cause of Y. Y is the result of X.
- There is a one-way causality relationship between the variables. For equation (1), β_1' s are no different from zero. For equation (2), the γ_i's are non-zero. Y is the cause of X. X is the result of Y.
- There is a two-way causality relationship between the variables. For equation (1), For equation (1), β_1' s are non-zero. For equation (2), the γ_i's are non-zero too.
- There is no causal relationship between the variables. For equation (1), β_1' s are no different from zero. For equation (2), the γ_i's are no different from zero too. Y is the cause of X, but X is not the result of Y, or X is the cause of Y, but Y is not the result of X.

Sabetta Port series was accepted as the dependent variable, and Arctic Sea Ice was accepted as the independent variable from the application of the Granger Causality Test. As a dependency variable, the Sabetta Port series has been selected as an independent variable by means of Granger Causality Tests, and Arctic Sea ice has been chosen as an independent variable. The H_0 and H_α Hypotheses for the first stage are as follows:

- Hypothesis H_0: The number of LNG ships arriving at Sabetta Port is not the cause of the seasonal extent of Arctic Sea Ice.
- Hypothesis H_α: The number of LNG ships arriving at Sabetta Port is the cause of the seasonal extent of Arctic Sea Ice.

The H_0 and H_α Hypotheses for the second stage are as follows:

- Hypothesis H_0: The seasonal extent of Arctic Sea Ice is not the cause of the number of LNG ships arriving at Sabetta Port.
- Hypothesis H_α: The seasonal extent of Arctic Sea Ice is the cause of the number of LNG ships arriving at Sabetta Port.

In the last stage, as a result of applying the Census X-12 Method to the 60-month (between 2018-2022) data set of LNG ships arriving at the Sabetta port of Russia, it has been estimated how many LNG ships of average size will arrive at the Sabetta Port in 2023, 2024 and 2025. The Census X-12 method, widely used for time series analysis and seasonal adjustments, is particularly valuable in addressing seasonal fluctuations. However, its application in Arctic contexts requires caution due to the region’s rapidly changing environmental conditions, which may introduce additional uncertainties into the projections. The three steps required for the Census X-12 ARIMA Method are shown in Figure 2, Figure 3, and Figure 4, respectively.

Findings and Discussion

Prigorodnoye port, which is a part of the Sahkalin II project and located on the Russian island of Sahkalin, and the port of Sabetta, located on the Yamal Peninsula, are located in different regions of Russia and are two important ports for LNG export. In view of the fact that the port of Sabetta is located in the Arctic region of Russia, it is not possible to actively use it throughout the year with the same efficiency. Prigorodnoye Port and Sabetta Port have distinct roles in Arctic LNG transport. While Prigorodnoye benefits from milder ice conditions in the Sakhalin region, allowing relatively consistent year-round operations, Sabetta faces harsher seasonal ice coverage in the Arctic. This necessitates specialized ice-class LNG carriers and icebreakers to maintain year-round functionality, underlining the geographical and operational differences between the two ports. For this reason, it is necessary to resolve whether the port of Prigorodnoye may be a substitute for the Sabetta in some months of the year. In this study, seasonal sub-series of LNG tankers arriving at Prigorodnoye and Sabetta ports between 2018-2022 were evaluated. When the seasonal sub-series created were evaluated, it was determined that there was no regular distribution between the years 2018-2022 (Figure 5-14). LNG arriving via pipelines was delivered to both ports during all months of the year and was exported from these ports via ships. When the seasonal sub-series between the Sabetta port in the Kara Sea and the Prigorodnoye ports in the Sea of Okhotsk are examined, it is determined that there is no seasonal connection between these two ports in ship traffic. The observed irregularity in seasonal ship traffic between 2018 and 2022 can be attributed to the unpredictable variability of Arctic sea ice, fluctuations in global LNG demand, and the limited availability of ice-class LNG tankers during peak winter months. n the last stage, as a result of applying the Census X-12 Method to the 60-month

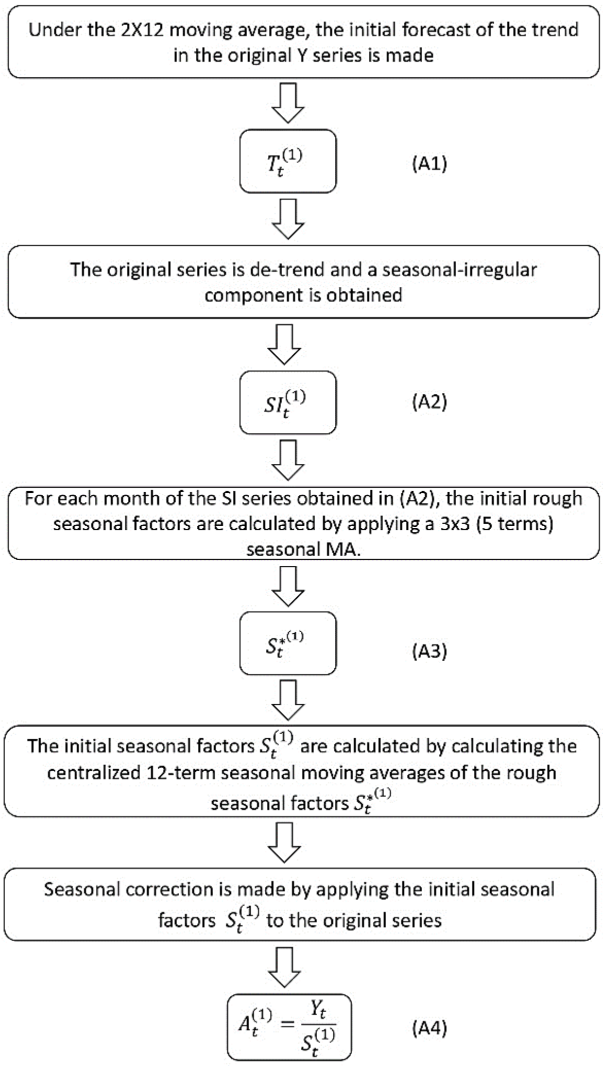

Figure 2. Census X-12 ARIMA Method Phase 1: Initial Estimation.

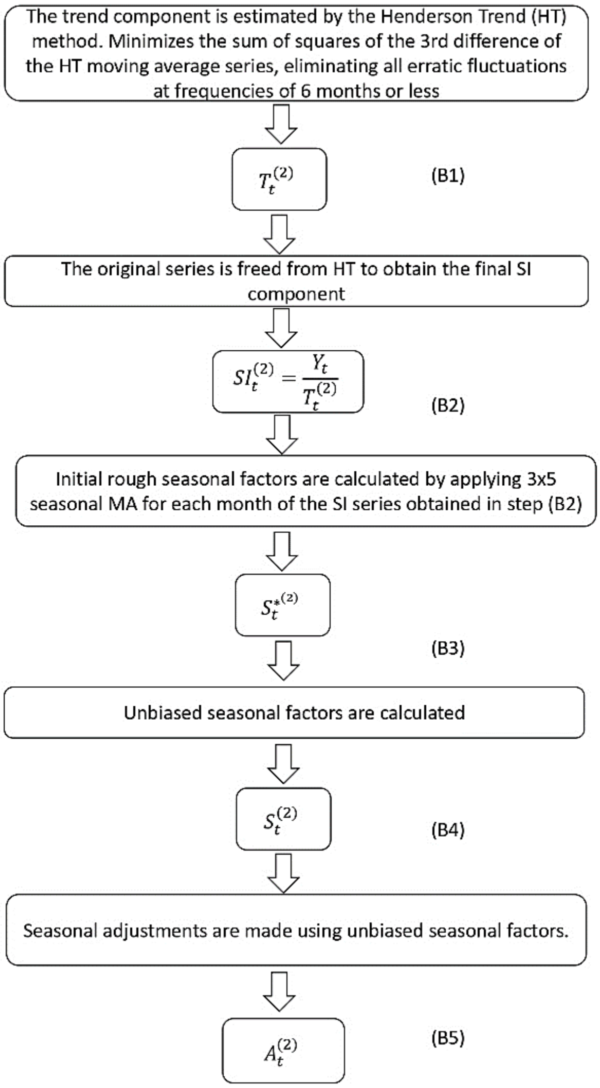

Figure 3. Census X-12 ARIMA Method Phase 2: Calculation of Seasonal Factors and Seasonal Adjustment.

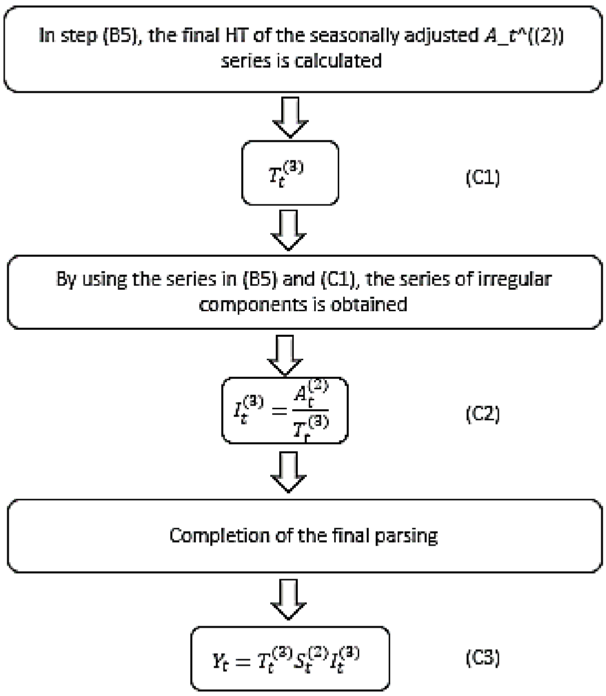

Figure 4. Census X-12 ARIMA Method Stage 3: Detection of Final HT and Irregular Components

(between 2018-2022) data set of LNG ships arriving at the Sabetta port of Russia, it has been estimated how many LNG ships of average size will arrive at the Sabetta Port in 2023, 2024, and 2025. In the analysis carried out, it is revealed that both ports are not an alternative to each other, and they cannot be replaced by another. It has been observed that these two LNG terminals carry LNG from different sources to different regions, and at the same time, they will not affect each other in terms of carrying capacity due to the lack of pipeline connection. Pototskaya et al. (2016) determined Russia's geopolitically important main pipelines in their study and showed parallel results with our study.

LNG ships arriving at the Sabetta port in the Arctic region of Russia were evaluated between 2018 and 2022. As shown in Figures 5 to 14, the rows represent the months of each year (January to December), while the columns represent the deadweight tonnage (DWT) of LNG ships arriving at Sabetta and Prigorodnoye Ports. As a consequence of these evaluations, it was observed that the number of ships arriving at Sabetta port decreased due to challenges in navigation after the widening of Arctic Sea ice in the winter months. Studies show that result of the rough weather conditions and changes in sea ice in the Arctic region, there is a risk of traffic congestion for any type of ship in the passage of

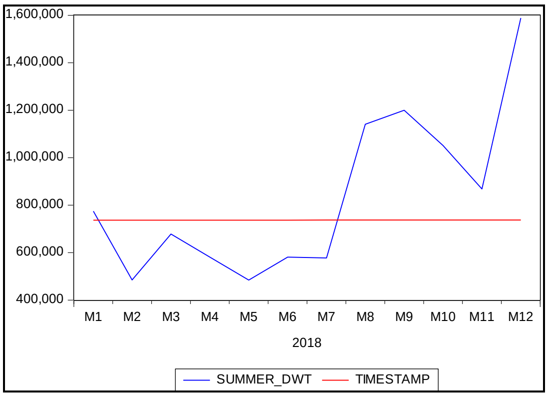

Figure 5. Sabetta Port Seasonal Sub-series, 2018.

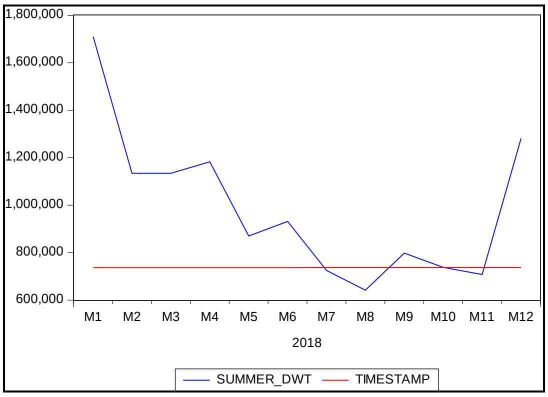

Figure 6. Prigorodnoye Port Seasonal Sub-series, 2018.

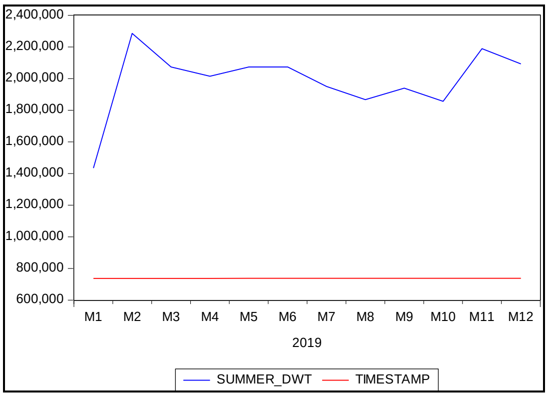

Figure 7. Sabetta Port Seasonal Sub-series, 2019.

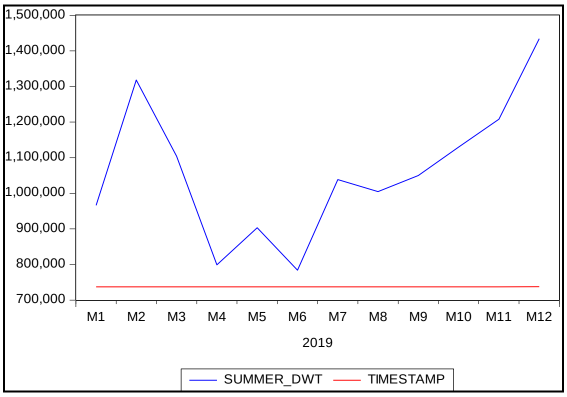

Figure 8. Prigorodnoye Port Seasonal Sub-series, 2019.

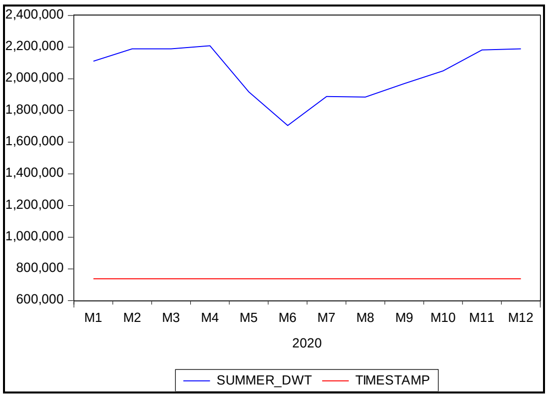

Figure 9. Sabetta Port Seasonal Sub-series, 2020.

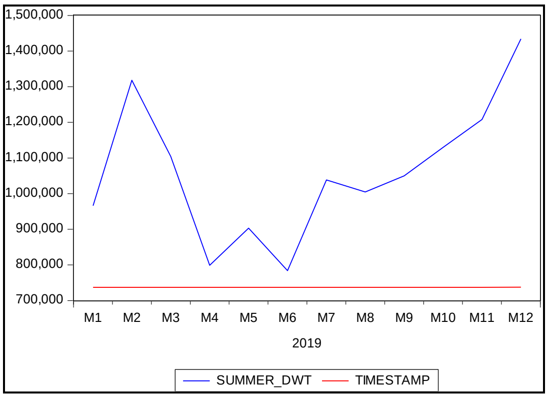

Figure 10. Prigorodnoye Port Seasonal Sub-series, 2020.

ships in this region and that traffic is related to the climatic conditions of this region (Cheaitou et al., 2019; McDonald, 2018; Khan et al., 2018; Christensen et al., 2019). Karahalil et al. (2021) emphasized the importance of the Polar Code in addressing the unique challenges of polar navigation, especially in ensuring safety and mitigating environmental risks in the Arctic and Antarctic regions. In the period 2018-2022, an analysis of Granger causality was conducted in this study. When its prob. value is evaluated at a 10% significance level, the Arctic Sea Ice series is accepted as the dependent variable, and as a result of the Granger causality Test performed for the Arctic Sea Ice series, H_0: The Arctic Sea Ice series is accepted as not the cause of the Sabetta Port series. H_α: Arctic Sea Ice series has been considered to be the cause of the Sabetta Port series. As a result, between 2018-2022, the H_0 hypothesis was rejected, while the H_α hypothesis was accepted (Table 1-5). In other words, it has been determined that there is a causal relationship between the LNG tankers arriving at the Sabetta port and the Arctic Sea Ice. Boylan (2021), in his study, revealed that the Arctic Sea ice melting in the Arctic summer opened the way for sea transportation and increased ship traffic in this region. Aksenov et al. (2017) stated that the predictions at this point are that navigation could be possible without the escort of ships breaking ice in the Arctic during the Arctic summer in the early 2030s. On the other hand, Khon et al. (2010) stated

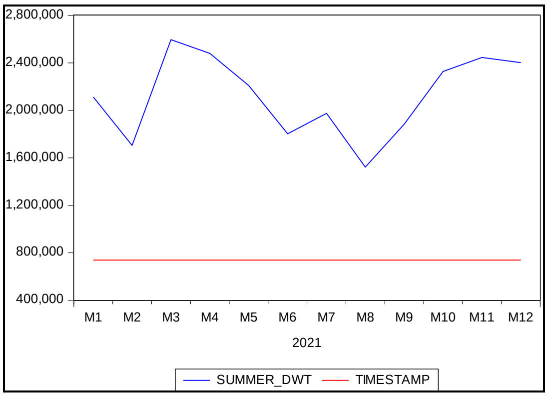

Figure 11. Sabetta Port Seasonal Sub-series, 2021.

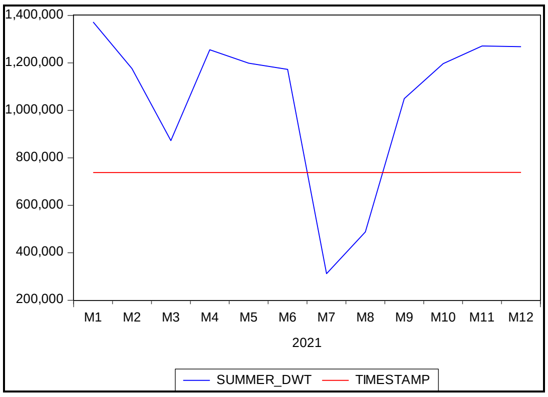

Figure 12. Prigorodnoye Port Seasonal Sub-series, 2021.

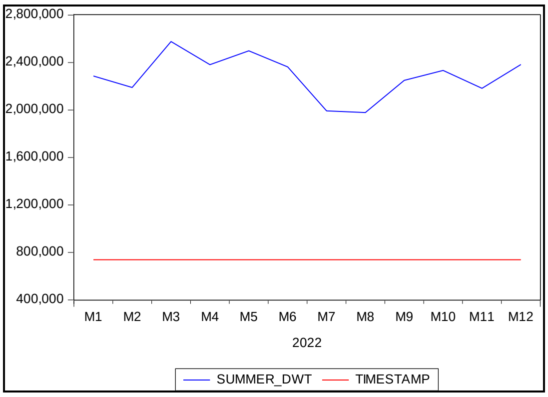

Figure 13. Sabetta Port Seasonal Sub-series, 2022.

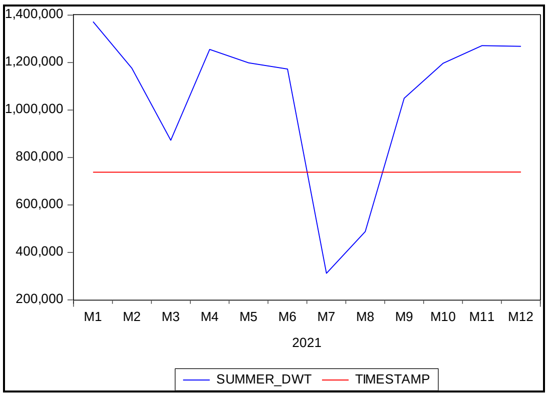

Figure 14. Prigorodnoye Port Seasonal Sub-series, 2022.

Table 1. Granger Causality Test 2018

VAR Granger Causality/Block Exogeneity Wald Tests			
Date: 04/23/23 Time: 18:05			
Sample: 2018M01 2018M12			
Included observations: 9			
Dependent variable: SABETTA			
Excluded	Chi-sq	df	Prob.
SEA_ICE	11.00769	3	0.0117
All	11.00769	3	0.0117
Dependent variable: SEA_ICE			
Excluded	Chi-sq	df	Prob.
SABETTA	83.03569	3	0.0000
All	83.03569	3	0.0000

Table 2. Granger Causality Test 2019

VAR Granger Causality/Block Exogeneity Wald Tests			
Date: 04/22/23 Time: 19:03			
Sample: 1 12			
Included observations: 9			
Dependent variable: SABETTA			
Excluded	Chi-sq	df	Prob.
SEA_ICE	9.586290	3	0.0224
All	9.586290	3	0.0224
Dependent variable: SEA_ICE			
Excluded	Chi-sq	df	Prob.
SABETTA	120.8251	3	0.0000
All	120.8251	3	0.0000

Tablo 3. Granger Causality Test 2020

VAR Granger Causality/Block Exogeneity Wald Tests			
Date: 04/22/23 Time: 18:44			
Sample: 2020M01 2020M12			
Included observations: 9			
Dependent variable: SABETTA			
Excluded	Chi-sq	df	Prob.
SEA_ICE	1.910075	3	0.5913
All	1.910075	3	0.5913
Dependent variable: SEA_ICE			
Excluded	Chi-sq	df	Prob.
SABETTA	7.720477	3	0.0499
All	7.720477	3	0.0499

Tablo 4. Granger Causality Test 2021

VAR Granger Causality/Block Exogeneity Wald Tests			
Date: 04/22/23 Time: 18:49			
Sample: 2021M01 2021M12			
Included observations: 9			
Dependent variable: SABETTA			
Excluded	Chi-sq	df	Prob.
SEA_ICE	4.642662	3	0.1999
All	4.642662	3	0.1999
Dependent variable: SEA_ICE			
Excluded	Chi-sq	df	Prob.
SABETTA	6.899218	3	0.0752
All	6.899218	3	0.0752

Tablo 5. Granger Causality Test 2022

VAR Granger Causality/Block Exogeneity Wald Tests			
Date: 04/22/23 Time: 18:53			
Sample: 2022M01 2022M12			
Included observations: 9			
Dependent variable: SABETTA			
Excluded	Chi-sq	df	Prob.
SEA_ICE	1.948052	3	0.5833
All	1.948052	3	0.5833
Dependent variable: SEA_ICE			
Excluded	Chi-sq	df	Prob.
SABETTA	11.49810	3	0.0093
All	11.49810	3	0.0093

that according to the trend of Arctic Sea ice between 1979 and 2012, they expect the entire Arctic Ocean to offer ice-free navigation for September before 2050.

It has been determined that the operation was carried out with a total of 37 LNG ships with an average capacity of 50.000 DWT between 2018 and 2022 at the port of Sabetta. The DWT amounts of LNG tankers arriving at Sabetta Port between 2018-2022 are shown in Table 6, and the number of LNG tankers that will arrive at Sabetta Port between 2023-2025 with the Census X-12 method is assumed to be an average of 50000 DWT, and the number of them is estimated. When evaluated according to years, it is seen that the highest increase was in April with 35.14%, and the lowest increase was in December with 18.60% (Table 7). According to the applied Census X-12 method, 47 ships in 2023, 45 ships in 2024, and 49 ships in 2025 are expected to arrive at Sabetta port (Table 8). In making these estimates, an account is taken of LNG vessel traffic in the period from 2018 to 2022. Besides political and economic events likely to alter this estimate, there could also be a change in the estimated number of ships due

Table 6. 2018-2022 Sabetta Port Incoming LNG DWT Amounts

	2018	2019	2020	2021	2022
January	774591	1433689	2111092	2111294	2285700
February	484373	2285652	2189175	1704730	2188809
March	677937	2072638	2188846	2595404	2576320
April	581038	2014436	2208119	2479574	2382286
May	484145	2072718	1917418	2207868	2498874
June	581098	2072811	1704862	1801773	2363176
July	577525	1949602	1887737	1974536	1991759
August	1140900	1866828	1884546	1521256	1977773
September	1199426	1939116	1969453	1882525	2249333
October	1051257	1855999	2050044	2326855	2333418
November	868355	2188684	2181928	2445964	2181963
December	1588594	2092057	2189031	2401890	2382551

Table 7. Estimated LNG DWT Amounts Arrived at Sabetta Port 2023, 2024 and 2025

	2023	2024	2025
January	2317521.1	2187126.30	2361561.0
February	2257566.1	2162206.92	2366797.9
March	2626752.1	2484873.70	2648321.0
April	2508788.1	2379102.05	2552039.4
May	2440316.3	2297444.05	2461929.2
June	2260315.6	2135642.15	2317908.3
July	2169579.3	2072259.06	2274211.1
August	2090897.6	2045053.19	2270051.2
September	2315297.3	2187164.24	2411706.9
October	2449884.6	2263145.66	2477348.9
November	2459752.4	2288002.15	2515625.7
December	2581908.5	2389416.22	2640885.6

Table 8. Average Number of Incoming Ships by Years (2018-2022) and Average Number of Estimated Incoming Ships (2023-2025)

Months	Average Number of Incoming Ships (2018-2022)	Average Number of Estimated Incoming Ships (2023-2025)
January	34,865464	45,774722
February	35,410956	45,24380613
March	40,44458	51,73297867
April	38,661812	49,59953033
May	36,724092	47,99793033
June	34,09488	44,759107
July	33,524636	43,44032973
August	33,565212	42,70667993
September	36,959412	46,09445627
October	38,470292	47,93586107
November	39,467576	48,422535
December	42,616492	50,7480688
Total	37,067117	47,03800044

to natural disasters. On the other hand, Russia has put forward some projects to increase LNG terminals in this region in order to export LNG from the Arctic region, where ship traffic will become safer and easier. Recent studies have highlighted the significant impact of geopolitical events, such as the Russia-Ukraine conflict, on Arctic shipping logistics and LNG export dynamics, further emphasizing the strategic importance of infrastructure development in this region (Erol, 2024). The new LNG terminals planned to be opened by Russia will allow the LNG transported by pipeline to be transported by sea. When the new LNG terminals planned to be opened by Russia are also taken into consideration, it is estimated that there will be a greater increase in the transportation of LNG by sea than the result reached in this study.

Kapsar et al. (2023), in their study conducted in 2023, examined ship traffic in ice-covered waters according to different ship types in the Pacific Arctic region and revealed that there is a relationship between ship traffic and sea ice. In their study, they concluded that there was an increase in ship traffic due to the decrease in sea ice in the Arctic region, in parallel with this study (As shown in Figure 15, the rows represent the years analyzed 2018 to 2025, while the columns represent the average number of LNG ships arriving at Sabetta Port during this period). In the results we obtained in this study, it was determined that while the average number of LNG tanker ships arriving at Sabetta port was 37 between 2018 and 2022, it will be 47 by 2025 (Table 8). Accordingly, it has been determined that the traffic in this region will increase, and the results show parallelism with this study.

Conclusions

When the seasonal sub-series created were evaluated, it was determined that there was no regular distribution between the years 2018-2022. LNG arriving via pipelines was delivered to both ports during all months of the year and was exported from these ports via ships. As a result of the evaluations, it was observed that the number of ships arriving at Sabetta port decreased due to the difficulties in navigation after the expansion of the Arctic Sea ice in the winter months. When the connection between Sabetta port and Arctic Sea Ice was evaluated at a 10% significance level between 2018-2022, the H_0 hypothesis was rejected between 2018-2022, while the H_α hypothesis was accepted. This suggests that the decreases in Arctic sea ice extent are causally linked to the increased LNG tanker traffic in the port of Sabetta. On the contrary, the relationship also implies that climatic conditions such as ice extent can significantly restrict or enable maritime operations in the Arctic region. In another saying, a causal relationship has been established between LNG tanker arrivals in the Sabetta port and Arctic Sea Ice. In the final stage, it is estimated that 47 LNG vessels with an average of 50,000 DWT will be operated between 2023 and 2025. While these projections highlight a positive trend in LNG traffic, external factors such as further climate change, policy changes or infrastructural developments such as improved port facilities and ice-class tankers may significantly affect these projections. At this point, it is envisaged that there will be an average increase of 27.03% in the number of LNG ship arrivals in the Sabetta port by 2025. This study determined that

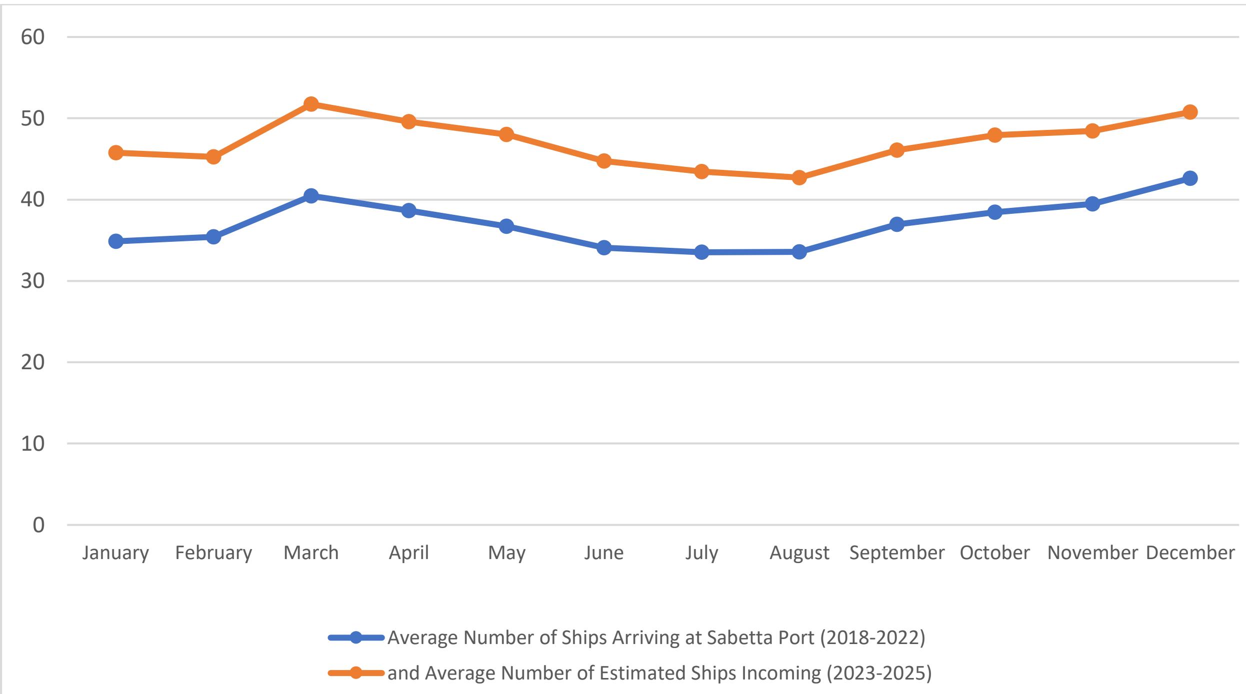

Figure 15. Average Number of Ships Arriving at Sabetta Port (2018-2022) and Average Number of Estimated Ships Arriving at Sabetta Port (2023-2025)

there will be an increase in LNG ship arrivals to the Sabetta port by 2023, thus increasing LNG ship traffic in this region. These findings highlight the need for strategic planning to address logistics challenges and seize oncoming opportunities. Policymakers and industry stakeholders should give priority to investments in Arctic infrastructure, navigation technologies, and sustainable practices to enlarge the advantages of increased LNG traffic while reducing potential environmental impacts.

Ethical Statement

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Author Contribution

First Author: contributed to Conceptualization, Writing -review, and editing, Data Curation, Formal Analysis, Investigation, Methodology, Visualization, and Writing -original draft.

Second Author: contributed to Conceptualization, Writing -review, Formal Analysis, Investigation, Methodology, and Writing -original draft; and Supervision.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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