RESEARCH ARTICLE

Unveiling the nexus between marine energy consumption, seaborne trade, and greenhouse gases emissions from international shipping

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Abstract

As a result of the globalization of production processes and the expansion of international trade, both water-based trade and the use of marine energy are expanding quickly. Marine energy consumption is rapidly increasing as a result of globalization. Despite being ignored for many decades, reducing marine emissions is today a top priority among European nations. Thus, the present study contributes to the existing literature by investigating the nexus between marine energy consumption, seaborne trade, and GHG emissions by employing time series data for eight Northern European nations from 2005 to 2017. The extended EKC model and three proxy variables for seaborne trade (i.e., container throughput, liner shipping connectivity index, and trade openness) are used to investigate the nexus between these variables. FMOLS and DOLS methods have been employed to control the problems of endogeneity and serial correlation. Only in Denmark, Norway, and Sweden did the data corroborate an inverted U-shaped relationship (the EKC curve) between maritime GHG emissions and economic development. The increase in energy utilization across all nations directly increased marine GHG emissions; however, the adverse effect of energy consumption on the environment is severe in Denmark, Norway, and Sweden. Container throughput, linear shipping connectivity index, and trade openness exhibit a positive impact on marine GHG emissions. The impact of seaborne proxy variables is severe in Denmark and Sweden. In order to have a robust assessment and to confirm the validity and uniformity of the results, Driscoll-Kraay standard errors (DKSE) and robust standard error (RSE) regression techniques are being employed.

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Introduction

The temperature rise caused by GHG emissions is seen as the biggest threat of the 21st century. Seaborne transport carries more than 90% of global merchandise trade by volume (Nævestada et al. 2019). Marine transport is regarded as the most efficient and clean form of transportation as compared to air and land transport; however, society has now become critical of the emissions it produces (Kilic and Deniz 2010; Grewal and Haugstetter 2007). According to the International Maritime Organization (IMO), seaborne trade has expanded by 400% in the last four decades, with a commensurate rise in marine greenhouse gas (GHG) emissions. International shipping contributes to global GHG emissions significantly, accounting for approximately 3.1% of annual global CO_2 emissions and 2.8% of annual GHG emissions from 2007 to 2012. This emission from shipping is just a slice, but it can grow up to 250% in 2050 if no measures has been taken (IMO 2014).

Currently, marine GHG emissions are dominating the agenda; however, it was neglected in the last few decades. The United Nations Framework Convention on Climate Change (UNFCCC) was the first climate change treaty, signed in 1992 and later expanded into the Kyoto Protocol in 1997. This was the first international treaty on global warming and climate change aiming to reduce greenhouse gas emissions (Akbar et al. 2022; Yuelan et al. 2019, 2021). However, marine and shipping emissions were not included in this treaty but were acknowledged as significant emitters (Sames and Kopke 2012). 196 countries signed the Paris Climate Agreement in 2015, pledging to keep the century's average temperature rise well below 2 degrees Celsius by cutting GHG emissions and avoiding the worst effects of global warming. However, the reduction of marine GHG emissions was not included (Yuelan et al. 2019; Shi 2016). This was the only major sector not included in the emission reduction agenda. However, in 2018, at the 72nd meeting of the Marine Environment Protection Committee (MEPC), the International Maritime Organization (IMO) adopted a resolution to reduce marine emissions by at least 50% and CO_2 emissions by at least 70% by 2050 (IMO 2018).

More than 90% of EU's international trade goes through the sea (Jonson et al. 2015), making marine transport an important industry in Europe. Over the past 20 years, preventive policies have been put in place in Europe to deal with other types of emissions sources (industrial, urban, etc.). This has made marine emissions a bigger part of GHG emissions overall (EEA 2013). According to the EU Commission report, marine CO_2 emissions have increased by 48% from 1990 to 2008 in Europe and are expected to rise beyond 86% by 2050. In 2011, the EU Commission published a white paper on transport, aiming to reduce transport emissions by 60% by 2050. Following up on the 2011 White Paper on Transport in the European Union. The EU approved a strategy for incorporating marine emissions into EU policies aimed at decreasing GHG emissions. In this context, the European Parliament adopted a regulation (EU) 2015/757 on the monitoring, reporting, and verification of CO_2 emissions from marine transport in 2015. The regulation is also known as the EU MRV regulation (EU Regulation 2015). The main points of EU MRV regulations are: 1) collecting verified CO_2 emissions data for all ships (5000+ GT) in the EU region. 2) Providing robust information and data for future policymaking decisions. 3) Using advanced technologies to make ships more environmentally friendly. In June 2019, the first report of EU MRV was published, which showed that shipping activities in the EU region emitted more than 130 million tons of CO_2 in 2018 (EU Regulation 2019).

European countries have a coastline of more than 65,000 km and having some of the busiest seaports in the world. Seaborne trade and marine transportation have been increasing due to globalization and industrialization (Marmer et al. 2009). According to the UNCTAD report, seaborne trade increased from 2,605 million tons in 1970 to 10,702 million tons in 2017, with a growth rate of 411%. Transportation of energy commodities (oil and gas) contributes the most to the overall seaborne trade (UNCTAD 2018). Figure 1 shows the liner shipping connectivity index (SCI) of northern European countries over the period of 2005–2017.

SCI measures how well countries are linked to global shipping networks. The higher value of the index means better connectivity to the global shipping network. Figure 2 displays time series data on container port traffic from 2005 to 2017. In twenty-foot equivalent units (TEUs), container

Fig. 1 Liner Shipping Connectivity Index
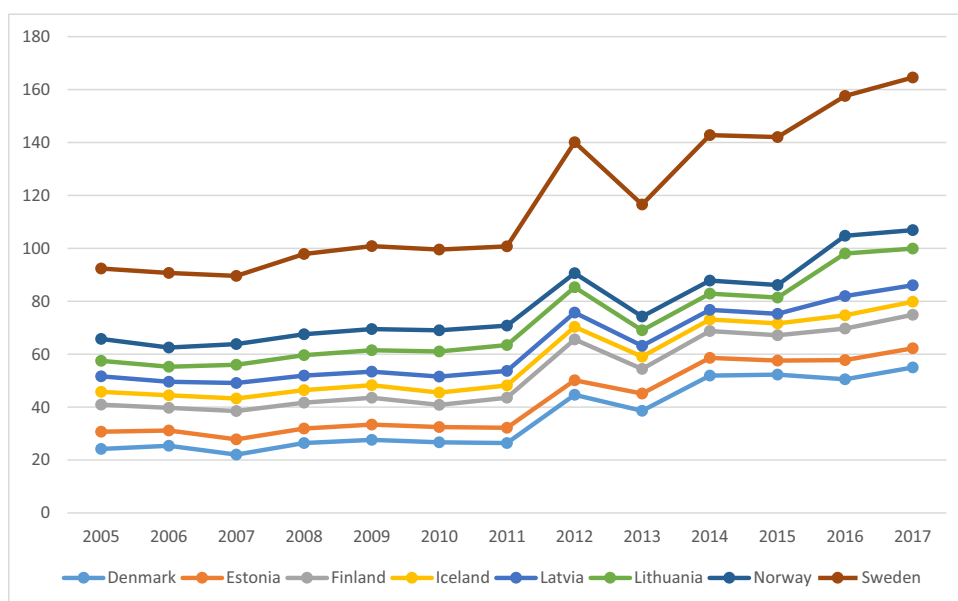
Fig. 2 Container Port Traffic (container throughput)
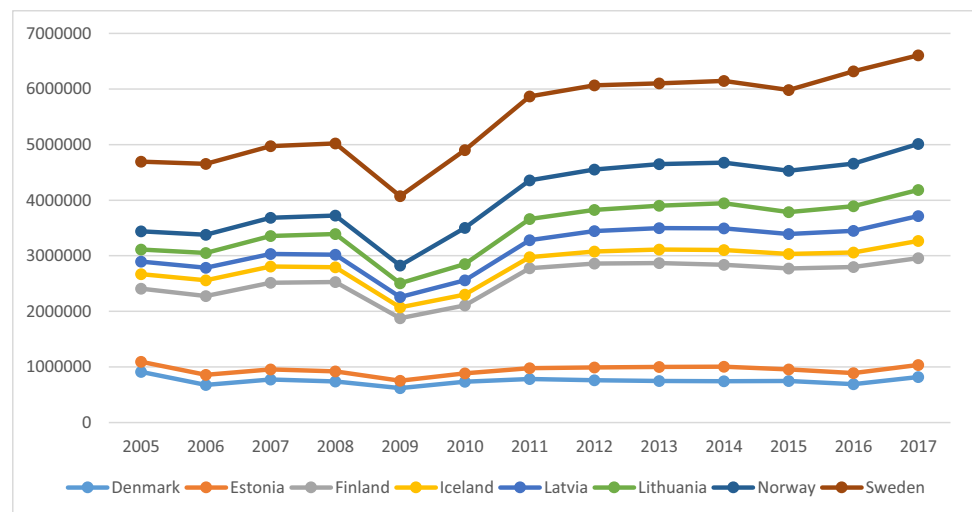
port traffic tracks the flow of containers from land to maritime transport modes and vice versa. From the figure, it can clearly be seen that there was a sharp decline in container flow during 2008–2009 due to the global financial crisis.

Because of the expansion in global trade, shipping emissions are currently increasing and will most likely continue to do so in the future. Nearly 70% of ship emissions happen within 400 km of the coast (Andersson et al. 2009), which is bad for the air quality in coastal areas. Ship emissions also hurt the marine environment. Conventional air pollutants in shipping emissions include carbon dioxide (CO_2), sulfur oxide (SO_x), nitrogen oxide (NO_x), methane (CH_4), nitrous oxide (N_2O), particular matter with a diameter less than 10 μm ($PM10$, $PM2.5$), volatile organic components (VOCs), carbon monoxide (CO), and black carbon (Eyring et al. 2010; Zhong et al. 2022; Akbar et al. 2021). Shipping emissions contributed approximately 15% of global NO_x and 5–8% of global SO_x emissions (Corbett et al. 2007). High amounts of SO_x and NO_x irritate the lungs and raise ocean acidity (Walker 2016). Lung cancer and heart disease are caused by $PM2.5$ emissions (USEPA 2016). Other air pollutants, such as ozone, which is produced when NO_x and VOCs react in the presence of sunshine, can irritate the lungs (Cullinane and Cullinane 2013).

In recent years, several studies have looked at the link between marine GHG emissions and various economic indices. Chang used time series data from eight nations from 1990 to 2006 to investigate the relationship between marine GHG emissions, economic growth, and marine energy use (Chang 2012). The author found that marine energy consumption and economic growth lead to an increase in marine GHG emissions. Andersen et al. (2010), estimated the shipping emissions of China's exported goods for the year 2008 and found that overall shipping emissions for goods exported reached 55 million tons. Chen et al. (2017), used an econometric approach to investigate the relationship between marine pollution and marine economic

growth, and found N-shaped relationship between the two variables. To and Lee, (2018), estimated the GHG emissions associated with China's seaborne trade from 1980 to 2015 and found that total GHG emissions increased from 2.6 million tons in 1980 to 39.9 million tons in 2015. Jiang et al. (2014) studied the contribution of China's marine economy to GDP and found that the contribution of the Chinese marine economy to overall GDP increased from 6.4% in 2000 to 13.8% in 2011. Fitzgerald et al. (2011) calculated the marine GHG emissions of New Zealand's seaborne export and import in 2017 and discovered that total GHG emissions associated with seaborne trade are 8.02 million tons. Al-Mulali and Ozturk, (2016), used the panel of 27 high-income countries and found that energy consumption contributes to environmental pollution. Environmental innovation, renewable energy, and energy transition have a substantial negative connection with ecological footprint, according to Bashir et al (2023). On the other hand, urbanization, economic expansion, and financial development all contribute to environmental degradation. In their research, Bashir et al. (2022) found that export diversification increases greenhouse gas emissions while having a negative impact on carbon emissions. Similar to institutional quality, economic growth, financial development, and economic expansion, economic growth increases greenhouse gas emissions while reducing carbon emissions. Comparatively, trade openness has a favorable impact on carbon emissions but a detrimental effect on greenhouse gas emissions. In addition, urbanization is one of the main causes of environmental deterioration. The use of keyword and co-occurrence analysis, according to Lei et al. (2022) and Shahbaz et al (2021), reveals that board diversity has a substantial influence on the performance, environmental performance, and CSR of the businesses. The three primary dominant research issues, according to Bashir (2022), were the Pollution Haven Hypothesis and Economic Growth Nexus, Trade, Pollution Haven and Developing Economies, FDI, Carbon Emissions, and Pollution Haven Nexus. According to an analysis by Bashir et al. (2022b,

a) and Zia et al (2022), the global energy industry is one of the most adversely impacted businesses since energy demand, supply, and pricing mechanisms have all displayed significant unpredictability as a result of these extraordinary economic and social shifts. Economic complexity, renewable energy, and energy innovation, according to Bashir et al. (2022b, a), are effective ways to lessen environmental damage. Urbanization and financial growth both have a negative effect on the environment. The influencing mechanism of different variables used in this study is illustrated in Table 1.

In existing literature, researchers mostly focused on the estimation of GHG emissions associated with seaborne trade. While few researchers also explored the nexus between marine GHG emissions and different economic indicators like the marine economy or marine energy consumption. However, according to the author's best knowledge, none of the studies explored the interacting effects between marine GHG emissions, marine energy consumption, and seaborne trade. To fill this gap, this study used the time series data of eight Northern European countries from 2005–2017 to investigate the impact of marine energy consumption and seaborne on marine GHG emissions.

The following are the additions this study makes to the existing body of research: Utilizing time series data ranging from 2005 to 2017, the study first investigated the impact that marine energy consumption and seaborne commerce have on marine greenhouse gas emissions. Second, it utilized three proxy variables for seaborne trade, such as container throughput, liner shipping connectivity index, and trade openness, in order to conduct an in-depth investigation into the nexus between marine GHG emissions and seaborne trade. This was done in order to gain a comprehensive understanding of the relationship between the two. Thirdly, it investigated the combined and interactive influence of container throughput (also known as container port traffic) and the linear shipping connectivity index on maritime greenhouse gas emissions. In the end, it used fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS) econometric methodologies in order to address the problems of endogeneity, serial correlation, and a limited sample size. The remaining portions of this article are organized as shown below. The approach and the materials are presented in the second portion, the findings and the discussion are shown in the third section, and the conclusion is presented in the fourth section.

Data and methodology

Data description

Time series data from eight Northern European countries (Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, Norway, and Sweden) is used from 2005 to 2017. Marine GHG emissions are measured in kilotons (kt). The unit of GDP per capita is the US dollar. Marine energy consumption is the total energy consumed by the marine sector in one year, measured in kg of oil equivalent. Container throughput (CTP) is the measure of the number of containers handled in one year in a port, measured in TEU (twenty-foot equivalent unit). The liner shipping connectivity index (SCI) is the measure of how well countries are connected to global shipping networks. The higher value of the index means better connectivity to the global shipping network. Trade openness (TRO) is the sum of export (US$) plus imports (US$), taken in the US dollar. All US dollar values are taken into constant 2010. A summary of variables and descriptive statistics of data is shown in (Tables 2) and (3) respectively.

Model specifications

Our research is based on the EKC (Environmental Kuznets Curve) conceptual framework, which is a well-known

Table 1 Influencing mechanism of variables

Variables	Influencing Mechanism	GHGs	Source
Marine energy consumption	Combustion products manufacturing → Increase in water and solid waste → Affects environment	↑	(Perera 2017)
Economic Growth (Environmental Kuznets curve theory)	Early stages of growth → greater emphasis on development and industrialization → environmental damage is overlooked	↑	(Grossman and Krueger 1991)
	Developed phase → emphasis on the environment → stringent government rules, and public awareness	↓	
Container port traffic	Increase in container port traffic → Increase transportation activities → consume more energy	↑	(Wilmsmeier and Spengler 2016)
Linear shipping connectivity index (SCI)	High value of SCI → better connectivity to global shipping network → Increase shipping frequencies	↑	(Wilmsmeier and Spengler 2016)

Table 2 Variables description

Symbol	Variable description	Source
GHG	Marine greenhouse gases emissions (kiloton)	UNFCCC[1]
PGDP	GDP per capita (Constant 2010 US dollar)	World Bank
EC	Marine energy consumption (kg of oil equivalent)	IEA[2]
CTP	Container throughput (TEU)	UNCTAD[3]
SCI	Liner shipping connectivity index	UNCTAD[3]
TRO	Trade openness (Constant 2010 US dollar)	World Bank

[1]United Nations Framework Convention on Climate Change. [2]International Energy Agency n.d. [3]United Nations Conference on Trade and Development

conceptual framework. Simon Kuznets first proposed it in 1955 (Kuznets 1955), and Grossman and Krueger used it for the first time to discuss the environment in 1991. (Grossman and Krueger 1991). The Environmental Kuznets Curve (EKC) refers to the inverted U-shaped relationship between economic growth and environmental pollution. According to this concept, pollution rises throughout the early phases of growth, but the trend reverses after a certain level of income is reached (known as the income turning point). That is, economic expansion leads to environmental improvement and pollution reduction at higher income levels. In general terms, the Environmental Kuznets curve can be expressed as follow:

$$Y = \alpha + \beta_1 X + \beta_2 X^2 + \mu \qquad (1)$$

where Y represents environmental degradation, while X represents economic growth. We extend the existing EKC model by adding control variables and proxy variables for seaborne trade as follows:

Table 3 Descriptive statistics

Country	Variable	GHG	PGDP	EC	CTP	SCI	TRO
Denmark	Mean	2068.04	59,682.56	5,022,103,250.6	753,637.5	43.28	61,376.88
	Std. dev	307.25	1545.74	1,592,648.4	38,058.9	11.50	4248.28
	Min	1594.08	58,041.41	4,295,363,216.9	689,000	26.41	54,616.96
	Max	2352.19	62,356.75	6,633,623,189.5	821,100	54.98	67,691.38
Estonia	Mean	932.91	17,095.66	264,132,526.8	214,780.9	6.22	28,668.77
	Std. dev	246.11	1463.41	261,548.9	34,154.07	0.79	3559.69
	Min	579.16	14,638.60	204,141,987.3	152,000	5.30	21,050.34
	Max	1290.99	19,257.48	366,427,929.1	260,293	7.30	32,459.35
Finland	Mean	651.21	46,240.01	4,984,153,861.7	1,779,285	11.09	36,951.04
	Std. dev	305.96	826.17	2,656,347.1	228,704.6	2.27	1490.27
	Min	272.99	45,239.37	4,013,493,516.3	1,223,702	8.36	35,155.32
	Max	1107.19	47,558.89	5,329,851,354.8	1,920,800	15.51	40,055.55
Iceland	Mean	94.59	46,363.45	45,842,630.6	243,556.3	4.695	48,751.08
	Std. dev	73.92	3040.81	456,323.4	38,086.34	0.22	7562.95
	Min	0.25	43,024.93	25,731,060.6	193,000	4.41	40,482.6
	Max	194.81	51,281.99	65,952,695.7	308,100	5.01	61,359.14
Latvia	Mean	842.93	13,523.89	217,677,288.9	362,756.5	5.21	16,566.52
	Std. dev	105.85	1355.48	548,306.6	58,460.62	1.32	2381.32
	Min	720.14	11,326.22	118,659,284.4	256,000	3.62	12,321.68
	Max	1070.90	15,532.22	309,626,828.9	448,533	7.27	20,118.82
Lithuania	Mean	366.57	14,508.15	285,146,630.8	402,462.5	9.61	22,980.58
	Std. dev	172.20	1595.18	106,548.1	55,158.63	3.73	4495.74
	Min	35.74	11,984.87	161,142,651.1	295,000	5.84	15,887.36
	Max	559.84	16,838.54	345,424,892.2	472,000	16.04	30,158.75
Norway	Mean	1095.36	89,217.61	4,262,133,617.2	735,632.3	6.14	498,566.5
	Std. dev	503.78	1367.15	2,645,138.5	52,070.8	1.21	23,821.7
	Min	488.33	87,481.15	3,556,643,649.5	646,900	4.75	451,418.4
	Max	1620.54	91,451.35	5,089,189,697.7	826,500	7.93	526,492.6
Sweden	Mean	6372.79	54,057.74	5,893,563,587.3	1,506,122	46.71	49,583.33
	Std. dev	747.29	1753.71	4,648,036.9	84,117.55	11.18	3075.56
	Min	5538.98	52,132.92	4,782,983,552.7	1,399,574	30.02	45,255.75
	Max	7841.16	56,610.68	7,011,893,029.8	1,659,557	57.71	54,222

$$lnGHG_t = \alpha + \beta_1 lnPGDP_t + \beta_2 \left(lnPGDP_t\right)^2 + \beta_3 lnEC_t$$
$$+ \beta_4 lnCTP_t + \beta_5 lnCTP_t + \beta_6 lnTRO_t + \mu_t \quad (2)$$

where GHG stands for marine greenhouse gas. PGDP stands for gross domestic output per capita and GHG emissions., EC denotes marine energy consumption, CTP denotes container throughput (container port traffic), SCI denotes liner shipping connectivity index, and TRO denotes trade openness. All variables are taken into natural logarithm form. To check the robustness of Eq. 1, we incorporate the interaction variable between container throughput and liner shipping connectivity index (CTP*SCI) in order to test the combined interacting effect of CTP and SCI on marine GHG emissions. Hence, rewriting Eq. (2) as follow:

$$lnGHG_t = \alpha + \beta_1 lnPGDP_t + \beta_2 \left(lnPGDP_t\right)^2$$
$$+ \beta_3 lnEC_t + \beta_4 ln\left(CTP^*SCI_t + \mu_t\right) \quad (3)$$

In Eq. (3) (CTP*SCI) is used as a combined proxy variable for seaborne trade in northern European countries.

The fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS) estimation approaches were used in this investigation. In 2001, Pedroni proposed the FMOLS system (Pedroni 2001). When cointegrated variables are present, FMOLS is a residual-based test that delivers correct results. FMOLS can also work with small sample sizes while minimizing endogeneity and serial correlation concerns (Hamit-Haggar 2012). DOLS was proposed by Stock and Watson in 1993 (Stock and Watson 1993). The Granger Causality Test was also used to check the causal links between marine GHG emission and its determinants.

Furthermore, we also used Driscoll-Kraay standard error (DKSE) and Robust Standard Error (RSE) regression techniques to confirm the validity of our results. DK standard error and resilient standard error were introduced for the first time by (Driscoll and Kraay 1998). Unlike other regression procedures, these methods produce effective and consistent findings even when cross-sectional dependence exists, and the standard errors obtained are robust (Sarkodie and Strezov 2019). The Driscoll-Kraay technique also has the benefit of providing missing values and is suitable for both balanced and unbalanced data sets. Furthermore, when the time dimensions get bigger, the Driscoll-Kraay standard error provides a non-parametric technique that is flexible and unrestricted. The methodological framework of this paper is shown in Fig. 3.

Empirical results and discussion

Unit root and cointegration analysis

The data's stationarity and cointegration often affect whether or not a regression result is good and which regression model to use. The result may be spurious if the data is non-stationary. Hence, in the first step, we performed a unit root test. Data stationarity is typically checked at the level and using the first-order difference. Because each test has its own flaws, we ran tests to acquire better and more acceptable findings. The stationarity of our variables was checked using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. Dickey and Fuller proposed the ADF test in 1979, with the null hypothesis that the series has a unit root, implying that the data is non-stationary (Dickey and Fuller 1979). Phillips and Perron proposed the PP test in 1988, and it has the same null hypothesis as the ADF test, namely that the series has a unit root (data is non-stationary) (Phillips and Perron 1988).

The results of the ADF and PP unit root tests are displayed in the table below (Table 4). The majority of the variables are non-stationary at level, but when the first-order difference is taken into account, they all become stationary for each country. As a result, we conclude that the sequence of variables is non-stationary at level. The sequence becomes stationary after extracting first-order difference variables.

The Gregory–Hansen test for cointegration was used to figure out how our variables have been linked over time. Gregory and Hansen developed the Gregory–Hansen cointegration test in 1996. (Gregory and Hansen 1996). The Gregory–Hansen cointegration test is more powerful and efficient than other residual-based cointegration tests (Shahbaz et al. 2012). This test has a null hypothesis of no cointegration. The results of the Gregory–Hansen test for cointegration are shown in (Table 5). Results show that the null hypothesis of no cointegration is rejected for all variables. Hence, we conclude that our variables have a long-run association for all countries. As cointegration is confirmed among all variables, thus we can proceed to perform a regression analysis.

Regression estimates of DOLS and FMOLS

Regression results of FMOLS and DOLS are shown in (Table 6). The results confirmed the existence of the EKC curve in Denmark, Norway, and Sweden, as the coefficient of PGDP square is negative in these countries. However, the EKC curve cannot be confirmed in Estonia, Finland, Iceland, Latvia, and Lithuania. According to the EKC theory, economic expansion increases environmental pollution in the early stages of development, but after reaching a certain degree of development, it tends to decrease environmental pollution through technological improvement and tight environmental controls. As a result, we find that only Denmark, Norway, and Sweden have met the criterion for reducing pollution through economic expansion. While other countries must still catch up, as economic growth in these countries increases both short- and long-term marine

Fig3 Methodological frame-
work of the study
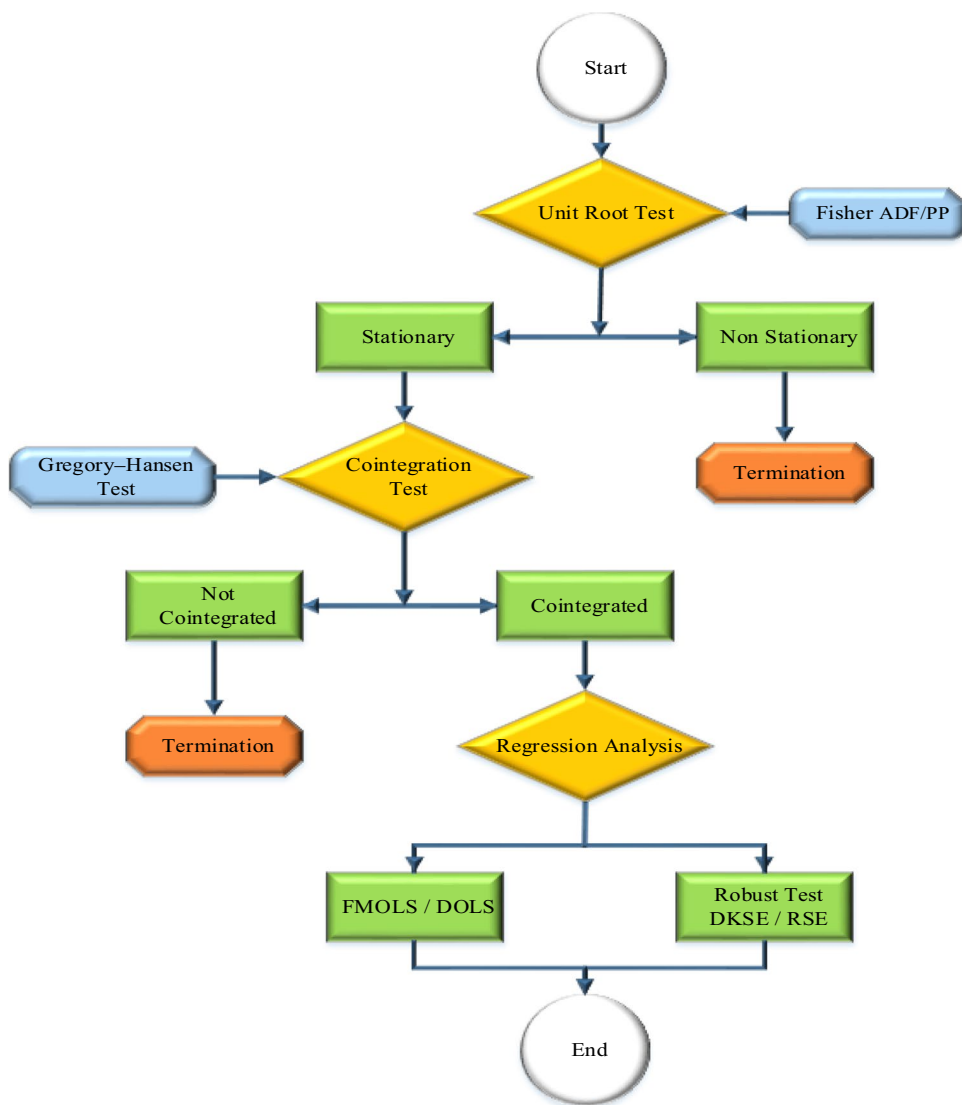
GHG emissions. The results of FMOLS and DOLS are consistent for PGDP and PGDP2 across all countries.

The results about marine energy consumption (EC) show that EC increases GHG emissions in all countries.EC is positively significant at 1% across all countries and contributes to increased environmental pollution. The impact of marine energy consumption on GHG emissions is highest in Denmark, Norway, and Sweden. These countries have the most developed economies, largest populations, and best trade networks in northern Europe, which results in higher GHG emissions.

The results of CTP (container throughput) show that CTP is positive and increases marine GHG emissions in all countries.CTP is positively significant at 1%, 5%, and 10% across different countries. The impact of CTP on marine GHG emissions is highest in Sweden, where a 1% increase in CTP leads to an increase in marine GHG emissions by 81% (FMOLS) and 96% (DOLS). Sweden is the largest country in Northern Europe, and Swedish ports handle the highest number of containers in Northern Europe. Hence, more container ships visiting Swedish ports result in higher emissions. On the other hand, the impact of CTP on marine GHG emissions is lowest in Iceland, which is due to the lower seaborne trade activities of Iceland as compared to other countries.

The results demonstrate that the liner shipping connectivity index (SCI) is positively significant at 1% across all nations and increases marine GHG emissions. Results of both tests (FMOLS and DOLS) indicate that an increase in SCI leads to an increase in marine GHG emissions. SCI is generated from five components, i.e., the number of ships, the container carrying capacity of those ships, ship size, the number of container companies working in a country's port, and the number of services those companies provide (UNCTAD 2018). SCI is the measure of how well a country is connected to the global shipping network. The better the

Table 4 Results of ADF and PP unit-root tests

Country	Order	Variables											
		Augmented Dicky-Fuller (ADF)						Phillips-Perron (PP)					
		lnGHG	lnPGDP	lnEC	lnCTP	lnSCI	lnTRO	lnGHG	lnPGDP	lnEC	lnCTP	lnSCI	lnTRO
Denmark	Level	-16.88	-19.88[c]	-55.59	-0.68	-3.67	-55.13[b]	696.53	165.90	4.80	38.97	7.61	761.25
	First diff	-14.31[a]	-18.10[a]	-89.28[b]	-0.03[c]	8.86[b]	-14.08[c]	827.13[a]	177.71[b]	11.25[b]	78.53[c]	15.71[b]	789.44[b]
Estonia	Level	-12.46	-21.57	-15.98	-0.42	-3.87	-56.63	586.82[b]	158.33	5.60	32.36	4.89	455.56
	First diff	-8.36[a]	-19.01[a]	-78.14[c]	1.59[b]	6.59[a]	-16.35[a]	625.36[a]	198.14[c]	13.70[c]	68.88[a]	8.10[b]	605.90[a]
Finland	Level	-15.77	-25.56	-61.80	-0.68	-4.11	-61.64	621.58[b]	218.32	6.93	39.18	5.14	562.48[c]
	First diff	-13.12[a]	-23.67[a]	-67.80[a]	0.21[a]	8.42[a]	-22.59[a]	771.89[a]	266.50[a]	13.06[c]	76.35[c]	11.29[b]	956.65[a]
Iceland	Level	-6.09	-14.90[a]	-26.97	-0.36[b]	-2.90	-38.56	256.36	111.59	3.67	14.46	3.99	336.23
	First diff	-2.36[a]	-14.11[a]	-96.53[c]	2.30[c]	7.63[c]	-12.86[b]	424.42[a]	136.17[a]	8.86[b]	15.81[b]	5.51[a]	425.74[c]
Latvia	Level	-9.68	-17.45[b]	-35.36	-0.39	-3.32	-44.94	369.12[b]	184.13	3.87	31.55[a]	4.45	441.14
	First diff	-8.05[a]	-15.49[a]	-46.88[a]	2.89[b]	6.88[a]	-14.37[a]	502.59[a]	220.69[a]	6.59[a]	51.09[a]	10.60[b]	826.26[a]
Lithuania	Level	-11.27	-19.01	-26.18	-0.58	-3.98	-48.19	456.02	212.36	4.11	35.59	4.80	645.93[c]
	First diff	-4.69[a]	-15.60[a]	-98.35[c]	0.12[b]	5.55[b]	-17.99[a]	597.78[a]	299.11[a]	8.42[a]	66.28[b]	11.25[b]	699.15[a]
Norway	Level	-17.89	-29.98[c]	-21.55[a]	-0.78	-4.79	-65.12	683.51	161.96	2.90	39.98	5.60	961.29
	First diff	-15.32[a]	-28.20[a]	-46.09[a]	-0.13[c]	9.56[b]	-24.07[a]	812.11[a]	174.74[b]	7.63[c]	79.14[c]	13.70[c]	989.48[b]
Sweden	Level	-17.11[c]	-28.11	-63.59	-0.71	-4.91	-68.78	712.36	178.36	3.32	44.80	6.93	862.61
	First diff	-16.28[a]	-24.33[c]	-56.28[b]	-0.36[b]	7.26[a]	-25.61[a]	866.46[a]	246.36[a]	6.88[a]	80.80[a]	13.06[c]	912.38[a]

H_0: series contain unit root, a: Rejection of the null hypothesis at 1% ($P < 0.01$), b: At 5%, the null hypothesis is rejected ($P < 0.05$), c: At 10%, the null hypothesis is rejected ($P < 0.10$)

Table 5 Results of Gregory–Hansen test for cointegration

Country	ADF t-statistics	Probability	Conclusion
Denmark	-11.359***	0.000	Cointegration exists
Estonia	-4.585***	0.000	Cointegration exists
Finland	-5.598**	0.035	Cointegration exists
Iceland	-2.443*	0.081	Cointegration exists
Latvia	-4.268***	0.000	Cointegration exists
Lithuania	-3.331**	0.029	Cointegration exists
Norway	-8.917***	0.000	Cointegration exists
Sweden	-6.662***	0.000	Cointegration exists

H_0: no cointegration; *** Rejection of the null hypothesis at 1% ($P < 0.01$), ** At 5%, the null hypothesis is rejected ($P < 0.05$), * At 10%, the null hypothesis is rejected ($P < 0.10$)

country is connected to a global shipping network; the more shipping activities will occur in the country's coastal areas. Thus, more shipping-related GHG emissions will be emitted.

Trade openness (TRO) has a positive impact on marine GHG emissions across all countries except Iceland. When trade opens up more, greenhouse gas (GHG) emissions from the ocean go up in Denmark, Estonia, Finland, Latvia, Lithuania, Norway, and Sweden. Regarding Iceland, the results of the FMOLS showed that the impact of trade openness is insignificant on marine GHG emissions, while the results of the DOLS suggest that trade openness has a negative impact on marine GHG emissions. The impact of trade openness on marine GHG emissions is severe in Sweden. Sweden has the biggest trade volume of any Northern European country, with seaborne trade accounting for 90% of total trade. As a result, increased trade leads to increased port and maritime activity, which increases pollution and marine emissions.

The Driscoll-Kraay Standard Errors (DKSE) and Robust Standard Error (RSE) regression approaches were used to ensure that our findings were accurate and consistent. To study the combined interacting effect of container through-put (CTP) and liner shipping connection index (SCI), we used Eq. (2) for a robust test. The results of robust tests are shown below in Table 7. In Denmark, Finland, Norway, and Sweden, the relationship between economic growth and marine GHG emissions was like an upside-down U. However, the EKC hypothesis is rejected in Estonia, Iceland, Latvia, and Lithuania. Energy consumption increases GHG emissions in all countries. Seaborne trade (CTP*SCI) is a proxy variable that is positively significant at 1% across all nations and increases marine GHG emissions. This shows that container port traffic and the linear shipping connectivity index increase seaborne trade activities, which pollute the environment by emitting more GHG emissions.

Figure 4 presents the regression distribution of marine GHG emissions and seaborne trade (CTP*SCI). The solid line shows a linear trend of marine GHG emissions, while the dots represent the combined interacting effect of container throughput and linear shipping connectivity index (CTP*SCI). The linear trend of marine GHG emissions

Table 6 FMOLS and DOLS results

Country	FMOLS						DOLS					
	$lnPGDP$	$lnPGDP^2$	$lnEC$	$lnCTP$	$lnSCI$	$lnTRO$	$lnPGDP$	$lnPGDP^2$	$lnEC$	$lnCTP$	$lnSCI$	$lnTRO$
Denmark	0.051*** (0.598)	-0.104*** (0.249)	0.487*** (0.916)	0.718*** (0.012)	0.342*** (0.511)	0.163*** (0.005)	0.431*** (0.879)	-0.098*** (0.098)	0.874*** (0.801)	0.770** (0.098)	0.415*** (0.340)	0.074*** (0.505)
Estonia	0.514*** (0.062)	0.126*** (0.716)	0.258*** (0.103)	0.225*** (0.209)	0.319*** (0.879)	0.517* (0.249)	0.771*** (0.505)	0.010** (0.137)	0.511*** (0.012)	0.195*** (0.249)	0.333*** (0.615)	0.733*** (0.351)
Finland	0.325*** (0.879)	0.511*** (0.298)	0.306*** (0.065)	0.487** (0.109)	0.879*** (0.023)	0.316*** (0.307)	0.449*** (0.023)	0.281* (0.090)	0.626*** (0.800)	0.597*** (0.098)	0.688*** (0.430)	0.471*** (0.137)
Iceland	0.302*** (0.168)	0.358*** (0.493)	0.161*** (0.137)	0.147*** (0.406)	0.517*** (0.004)	0.518 (0.098)	0.443*** (0.059)	0.279*** (0.901)	0.213*** (0.307)	0.951*** (0.701)	0.136*** (0.293)	-0.754** (0.023)
Latvia	0.644*** (0.004)	0.509*** (0.105)	0.222*** (0.307)	0.768*** (0.203)	0.821*** (0.009)	0.411*** (0.004)	0.469*** (0.249)	0.854*** (0.505)	0.358*** (0.303)	0.949*** (0.098)	0.549*** (0.879)	0.117*** (0.745)
Lithuania	0.599** (0.265)	0.443*** (0.059)	0.459*** (0.219)	0.218** (0.107)	0.070*** (0.193)	0.393*** (0.879)	0.260*** (0.003)	0.022*** (0.946)	0.404*** (0.249)	0.245*** (0.098)	0.716*** (0.777)	0.217*** (0.012)
Norway	0.551*** (0.618)	-0.714*** (0.098)	0.511*** (0.519)	0.178*** (0.501)	0.727*** (0.012)	0.676*** (0.022)	0.134*** (0.023)	-0.001*** (0.404)	0.598*** (0.098)	0.710*** (0.307)	0.145*** (0.137)	0.176*** (0.001)
Sweden	0.521*** (0.505)	-0.108*** (0.179)	0.674*** (0.219)	0.814** (0.002)	0.798*** (0.883)	0.878*** (0.137)	0.994*** (0.111)	-0.821*** (0.098)	0.631*** (0.307)	0.965* (0.795)	0.118*** (0.321)	0.773*** (0.004)

a: The standard deviations are shown in parentheses, b: The statistical significance at the 1%, 5%, and 10% levels is shown by ***, **, and *, respectively

Table 7 Robust analysis

Country	Driscoll-Kraay Standard Errors (DKSE)				Robust Standard Error (RSE)			
	lnPGDP	lnPGDP^2	lnEC	lnCTP*SCI	lnPGDP	lnPGDP^2	lnEC	lnCTP*SCI
Denmark	0.216*** (0.541)	-0.015*** (0.158)	0.301*** (0.736)	0.770*** (0.005)	0.131*** (0.102)	-0.054*** (0.415)	0.186*** (0.742)	0.143*** (0.315)
Estonia	0.315** (0.015)	0.701 (0.234)	0.221*** (0.036)	0.403*** (0.157)	0.514*** (0.010)	0.004*** (0.749)	0.610*** (0.715)	0.300*** (0.310)
Finland	0.610*** (0.740)	-0.010** (0.057)	0.574*** (0.200)	0.912*** (0.047)	0.050*** (0.547)	-0.301* (0.095)	0.011** (0.841)	0.304*** (0.004)
Iceland	0.131*** (0.212)	0.651*** (0.547)	0.020** (0.158)	0.351*** (0.091)	0.187*** (0.711)	0.004*** (0.030)	0.201*** (0.001)	0.385*** (0.504)
Latvia	0.001*** (0.098)	0.542*** (0.493)	0.362*** (0.057)	0.754*** (0.883)	0.921*** (0.137)	0.370*** (0.095)	0.216*** (0.800)	0.087*** (0.315)
Lithuania	0.145** (0.234)	0.268*** (0.315)	0.065*** (0.009)	0.512*** (0.736)	0.304*** (0.095)	0.280*** (0.057)	0.058** (0.234)	0.214* (0.098)
Norway	0.248*** (0.736)	-0.254*** (0.493)	0.857*** (0.095)	0.015*** (0.098)	0.098*** (0.808)	-0.782*** (0.736)	0.348*** (0.883)	0.487*** (0.137)
Sweden	0.578** (0.057)	-0.048*** (0.883)	0.254*** (0.800)	0.278*** (0.234)	0.136*** (0.137)	-0.714*** (0.493)	0.047*** (0.300)	0.782*** (0.315)

[a]The standard deviations are shown in parentheses. [b]The statistical significance at the 1%, 5%, and 10% levels is shown by ***, **, and *, respectively
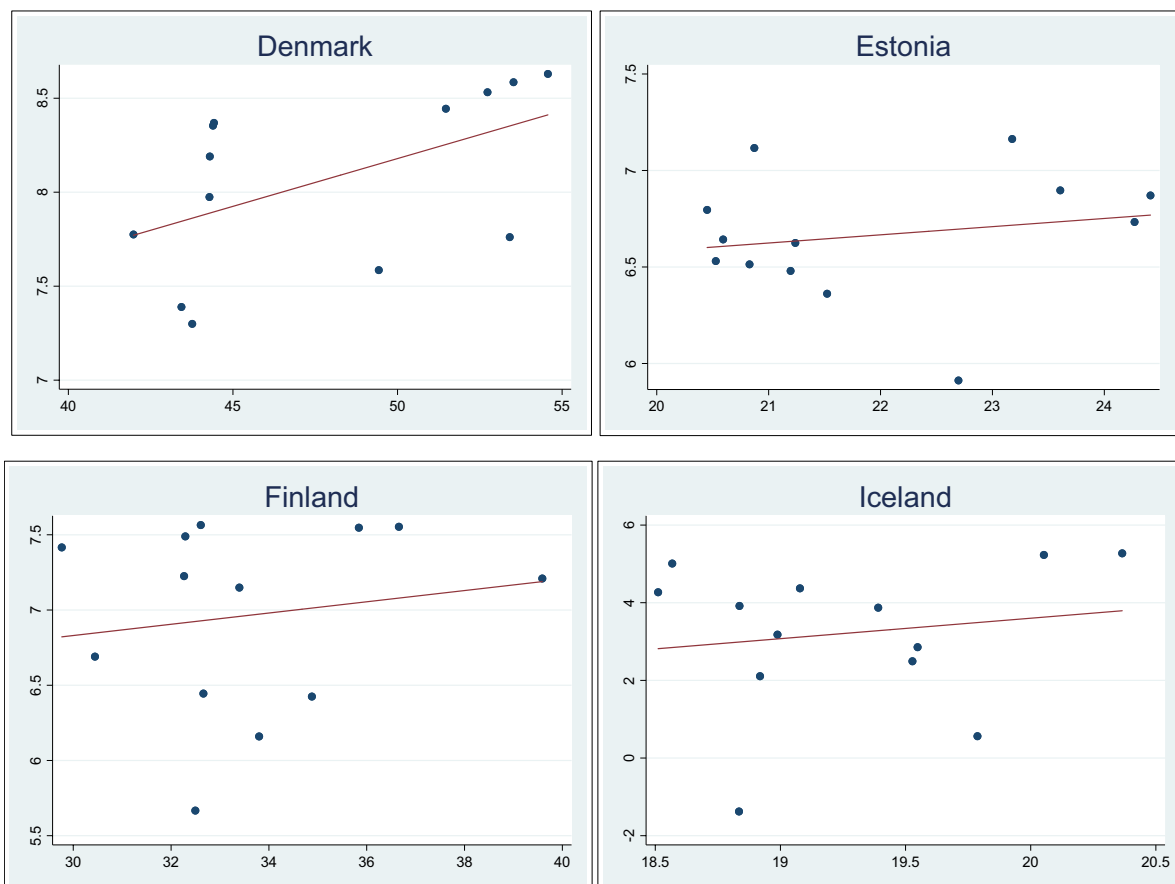
Fig. 4 Graphical distribution of marine GHG emissions and seaborne trade. Note: Solid line denotes the linear trend of marine GHG emissions. Dots represent the regressions distributions of (CTP*SCI)

shows a sharp increase in Denmark, Norway, and Sweden, while it shows a steady increase in Estonia and Iceland. Figure 2 also indicates a sharp escalation in seaborne trade activities in Denmark, Iceland, and Sweden in recent years.

Conclusion and policy implications

Using time series data from eight Northern European nations from 2005 to 2017, this article sheds fresh light on the link between marine GHG emissions and seaborne trade. The extended EKC model and three proxy variables for seaborne trade (i.e., container throughput, liner shipping connectivity index, and trade openness) are used to investigate the nexus between marine GHG emissions and seaborne trade. Furthermore, to overcome the concerns of endogeneity, serial correlation, and limited sample size, fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS) econometric techniques are used. Driscoll-Kraay standard errors (DKSE) and robust standard error (RSE) estimation techniques are also employed to check the robustness of the results.

In Denmark, Norway, and Sweden, economic growth (PGDP) has an inverted U-shaped relationship with marine greenhouse gas emissions (GHG). This signifies that these countries have met the criteria for reducing emissions through development. However, the inverted U-shape relationship (EKC curve) is not confirmed in Estonia, Finland, Iceland, Latvia, and Lithuania. Marine energy consumption has a positive effect on GHG emissions and contributes to polluting the environment in all countries. Energy consumption increases GHG emissions across all countries; however, the adverse effect of energy consumption on the environment is severe in Denmark, Norway, and Sweden.

Regarding trade variables, it was found that container throughput has a positive impact on marine GHG emissions across all countries and leads to increased emissions. The impact of container throughput on marine GHG emissions is highest in Sweden, due to the highest number of containers handled by Swedish ports. The liner shipping connectivity index also has a positive impact on marine GHG emissions and leads to increased emissions across all countries. Except for Iceland, trade openness (TRO) has a favorable impact on maritime GHG emissions. In Sweden, the impact of trade openness on marine GHG emissions is enormous. The trade volume of Sweden is the highest among all Northern European countries, 90% of which is seaborne trade. Hence, an increase in trade leads to an increase in port and shipping activities, which ultimately increases environmental pollution and marine emissions. Governments should exercise effective planning to promote "green ports" in their respective countries. Green and advanced technologies should be implemented in the shipping industry to reduce the emissions of ships. Governments should tighten environmental policies and increase environmental awareness to combat environmental pollution.

There are also some limitations and future gaps of the current study, the empirical analysis of the study sheds light on the link between marine GHG emissions and seaborne trade. First of all, in this study we could not consider the whole European region because of the data availability, but in future research this gap can be fulfilled. Moreover, role of fiscal policy in this matter is very important, so in coming research, it is recommended that role of contractionary and expansionary fiscal policy can be analyzed for marine GHG emissions. On the same pattern, sectoral or disaggregated data analyses can also be performed in the future.

Declarations

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