The Impact of Maritime Transport on Economic Growth and Sustainability of the Blue Economy in Southeast Asia

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Abstract: - This study analyzes the interactions among marine transport networks, carbon emissions, port investments, marine regulations, and other factors affecting the Southeast Asian blue economy, including their interplay. Drawing on sample data from 1995 to 2023, the study explores the maritime dimensions of the blue economy to argue for its role in the region's environmental and economic development. The researcher employed the Generalized Method of Moments (GMM) estimator, which better addresses endogeneity and provides more accurate estimates. The focus of this empirical study is the intersection of GDP growth, investments in infrastructure, carbon emissions inventories, cargo throughput, consumption of fossil fuels, environmental policies, and green maritime technologies. The study demonstrated a strong positive association between cargo throughput and GDP growth. This was at the expense of the strong negative association between the maritime sector's carbon emissions and the blue economy's viability. The study showed that investments in ports with an efficient design had both positive and negative associations with transport sector efficiency and sustainability. ASEAN's efforts to harmonize environmental and maritime regulations among member states further supported the implementation of the blue economy. The study emphasizes the need for an integrated, resilient regulatory approach, green infrastructure financing, and cooperative regional governance within and beyond Southeast Asia's maritime transport systems and blue economy.

Key-Words: - Blue Economy, Maritime Transport, Carbon Emissions, Infrastructure Investment, Environmental Policy.

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1 Introduction

Maritime transport is an essential part of every economy, including those in Southeast Asia. It is the most advanced and cost-efficient means of moving goods and people across short to moderate distances compared to overland and aerial transport, [1]. As with all transport services, the efficiency and cost-effectiveness of maritime transport should be a priority. More importantly, especially in Southeast Asia, the sustainability of maritime trade and its alignment with the blue economy are crucial, [2].

An important principle of the blue economy is that trade and improvements in people's livelihoods can occur when marine resources are used without stressing the ecosystems. [3] in this context, maintaining an economy that relies on maritime resources can sustain trade, provided that the environmental costs and burdens of trade are kept to a minimum. The negative impacts of trade should be avoided, [4].

Maritime transport is an integral component of the blue economy, as exemplified by Southeast Asia's trade routes, [5]. Each year, the shipping lanes connecting the port cities of Singapore, Jakarta, and Manila draw thousands of vessels. The daily functioning of port facilities has a direct bearing on shipping costs and time, affecting the price and competitiveness of goods in the global market, [6]. Several problems exist, and some of the more serious ones [7] relate to carbon emissions, ocean pollution, fuel waste, and the destruction of ecosystems resulting from port construction. The negative impacts of maritime transport, particularly in port operations for renewable energy and renewable LNG (Liquefied Natural Gas) vessels, can be mitigated at least in part through new technologies. Further, emissions and fuel use can be reduced through operational efficiencies that would reduce port wait times, [8].

Additionally, Southeast Asian nations need to build working partnerships. An example of such a partnership is the ASEAN Maritime Transport Working Group, an initiative to harmonize sustainable maritime transport policies across ASEAN. Given the diversity of sustainable initiatives among nations, these countries have the opportunity to be the first to develop, within their blue economies, sustainable practices.

Green port technologies represent just one of the innovations incorporating digital technology, [9], [10]. Marine conservation projects further add to the framework of the blue economy by illustrating the role of marine transport. The sustained use of the resources on which marine transport and associated economic activities rely can be achieved through the effective management of marine protected areas. Coral reefs are a prime example of this. Healthy coral reefs are the best natural protection against erosion, sustain fish populations, and are vital to local economies, [11].

There is a great deal of literature on the blue economy and maritime transport, [12], [13]. However, there is still ample opportunity to grow into a more integrated and applicable body of work. Field studies that integrate maritime transport, economic development, and associated carbon emissions across Southeast Asia are most needed. Previous studies have examined individual elements, thus neglecting the holistic view and the integration of diverse elements within a single analytic framework.

This research examines Southeast Asia’s maritime transport and its connection to the blue economy. It will explore how Southeast Asian countries can maximize profits from maritime transport while minimizing environmental costs. They have chosen regional ports where, after technological integration, they will consider the “enduring” policies and regional ports, and consider the social and economic benefits of increased regional port activity. They will also consider social and economic reviews of increased regional port activity and examine several case studies.

This research will explore these questions using a mix of qualitative and quantitative methodologies. Quantitative methodologies will include trade volume, relevant economic metrics, and carbon emissions data. It will also consider primary research in the maritime sectors of governmental and intergovernmental organizations, as well as surveys and interviews. Focus groups and semi-structured interviews will serve as the source of pertinent qualitative research in the blue economy and maritime sectors. This research will evaluate GDP and carbon emissions in the maritime transport sector and fossil fuel consumption in the transport sector using the Generalized Method of Moments (GMM). This methodology will be the most appropriate for panel data in the maritime and transport sectors.

Informed by both theory and practice, the research will cover leading ports of Southeast Asia. The incremental adoption of technology, the latest process optimizations, and the vertical and horizontal partnerships established under pressure to use technology to sustain the ports will be studied. When the Southeast Asian Port data is examined together, it will provide supplemental case studies of Port Management and valuable information and advice to other ports in the Southeast Asian region.

Within the bounds of the available empirical and practical case studies, the primary goal of the research is to define and describe the sustainable and efficient practices of maritime transport in Southeast Asia. The research aims to develop practices that will reduce the negative environmental impacts of maritime transport and advance the region's blue economy. The research will provide a set of practices and policy recommendations to the government and other primary regional actors to create an economically and socially sustainable balance of growth for the region.

With its vast network of oceans and seas, Southeast Asia will be at the center of establishing the first truly sustainable economy. If the economic development of marine ecosystems within the blue economy is coupled with the growth of regional partnerships in sustainable marine resource development, then the marine resources will become the center of the blue economy.

2 Literature Review

Gunter Pauli's blue economy model promotes an equitable, economically just use of marine resources while conserving marine biodiversity. Pauli believes that biogenic resources can yield economic returns and that these returns can be achieved without damaging the environment. This model offers marine-focused supplements to the green economy, [14].

The blue economy spans multiple sectors, ranging from subsistence to industrial modes of fishing and integrated fish farming, to an array of marine energy resources, ecotourism, and intelligent and sustainable marine transport logistics. The blue economy believes that transparent governance, soft technologies, and circular economies can be purposefully linked to ensure the accessible and sustainable use of marine resources, [15].

In marine transport, the blue economy encourages the adoption of low-emission technologies, such as LNG- and renewable-powered ships. Furthermore, the blue economy supports the design and construction of sustainable, high-efficiency, low-impact ports. The blue economy strives to mitigate the adverse effects of marine economic activities while enhancing the economy's competitiveness through the creation of new jobs and enterprises, [16].

Southeast Asia also hosts one of the world's largest trade centers. In Southeast Asia, as in many other regions of the world, maritime transportation is the most economical mode of transportation for intercontinental trade. It enables the transportation of goods to the global market from producers, [17].

Due to the size and volume of trade in ports like Singapore, Jakarta, and Manila, thousands of vessels transport goods rapidly throughout the region and beyond. Shipping costs, transit time, and port influence the price of goods and their competitiveness in the international market. The Port of Singapore, by increasing the efficiency of its operations, has become the busiest and most competitive port, thereby boosting Singapore's economy, [7]. The maritime sector also impacts the economy through other channels. Employment in maritime trade-related services, including the construction and maintenance of port infrastructure, stimulates other sectors such as fisheries and marine-based tourism. These also affect the region's economy, [18].

Though maritime trade offers some benefits, it also imposes significant negative externalities on the environment. Greenhouse gas (GHG) emissions represent one such externality. These gases are primarily a product of large ocean-going vessels (OGVs) and their use of fossil fuels. Sulfur and Nitrogen Oxides, when emitted into the atmosphere, adversely impact both humans and the marine environment, [19].

Maritime transport is also adversely impacting water quality, [20]. Air pollutants are among many adverse effects. Operational risks also include the spilling of various types of waste, including oily waste, and the negligent regulation of ballast water. Anaerobic conditions are created, damaging multiple trophic levels, including the deeper sea floor, as large oil slicks cover the water's surface. Other marine organisms are adversely impacted by the ingestion of debris and plastic, which can cause necrosis and death. The effects of maritime transport on the integrity and quality are also numerous. The impact of land reclamation to create new ports is irreversible for mangrove and coral reef habitats. The seabed and marine habitats are adversely affected by various effects of mooring, [21]. Many of these issues have been recognized and addressed by governments and the industry. One such issue has been improving the quality of fossil fuels by adopting LNG, [22].

Economic progress in Southeast Asia is positively correlated with increased maritime traffic. There is an upsurge in the number of vessels and cargoes traversing major Southeast Asian maritime ports. This traffic is integral to the expansion of international and domestic trade. Increased maritime traffic invites investments in ports and integrated maritime systems as it positively stimulates regional and global economies. This influx of shipping is a positive indicator for Southeast Asia, [23], [24].

The negative externalities of shipping activities primarily involve greenhouse gas emissions. Impacts from shipping activities contribute to the generation of greenhouse gases that drive climate change and further degrade the oceans. This disrupts the interdependent elements that sustain economic activities and maritime resources, [25]. The shipping industry's massive greenhouse gas emissions disrupt marine ecosystems and resources, and create obstacles to achieving the blue economy. Emissions from the shipping industry are incompatible with the blue economy. As stated in study [26], policies and technologies that mitigate the adverse effects should be implemented. There are positive and negative impacts of the green ports movement on the port and shipping industries. Modern green ports with green technologies and tools, such as LNG (liquefied natural gas) bunkering and improved waste treatment, support the shipping industry in improving operational efficiency and further reducing total CO2 emissions. Further, the use of renewable and low-emission technologies in the shipping industry supports reductions in CO2 emissions, [27]. The adoption of integrated maritime policies in the ASEAN region would offer greater opportunities for implementing blue economy initiatives in Southeast Asia. Collaborative alignment of blue economy policies will result in all ASEAN member states adopting policies to reduce CO2 emissions and meet the requirements for a sustainable blue economy. The alignment of policies in Southeast Asian countries and a collaborative commitment to work at a regional level will bring together important resources and will make the efforts to enhance the blue economy and the regional ecosystem more effective, [28]. In Southeast Asia, the primary aim of the research is to establish a correlation between maritime trade and economic growth, with particular emphasis on the blue economy. Further, it will provide testable assumptions, with the assumption that an increase in maritime trade will correlate with an increase in economic growth.

More ships and larger shipments are delivered to major ports due to increased maritime traffic. This supports international and domestic trade, which drives economic growth. In Southeast Asia, increased trade and investment can help countries expand their trading capacity and strengthen their imports, exports, and domestic industries. This growth can help create jobs. Increased trade and investment in ports and maritime technology create positive externalities for regional trade and global economies. Increased trade and investment in ports and maritime technology create positive externalities for regional trade and global economies. This illustrates Southeast Asia's economic growth, [23], [24]. The most significant negative externality caused by shipping is greenhouse gas emissions. This harms the environment and contributes to global warming. Worse, it negatively affects the resources that support economic activities reliant on maritime ecosystems, [25]. Emissions negatively impact marine ecosystems and the ocean resources needed to support the blue economy. This clearly illustrates that to sustain the blue economy, marine shipping emissions must be controlled.

Some drawbacks of the shipping industry can be addressed through certain policies and technologies. One of these is the construction of 'green ports.' Ports with modern green technologies can support vessels in operating more efficiently and less damagingly to the environment. Such ports employing LNG (liquefied natural gas) bunkering, along with modern waste treatment technologies, aid in reducing harmful CO2 emissions. Moreover, if low-emission technologies and renewable energy sources are employed to support cargo vessels, even more CO2 emissions can be avoided. While reducing emissions will be the primary concern of aligned environmental and maritime policies, ASEAN countries will support further sustainable initiatives of the blue economy. Differentiated policies within ASEAN member countries, along with alignment of regional-level policies, will support the continued development and enhancement of the blue economy. As an integral element of the blue economy, the shipping industry offers a valuable opportunity to present working hypotheses for analysis and to help structure solutions:

Hypothesis 1: Southeast Asia's economic growth is positively correlated with increased maritime traffic in the region.

Hypothesis 2: The relationship between the sustainability of the blue economy in Southeast Asia and the level of carbon emissions from maritime transport is an inverse one.

Hypothesis 3: The adoption of "green" port policy frameworks will improve the efficiency of port operations and diminish the negative consequences of maritime transport on the environment.

Hypothesis 4: The implementation of the blue economy policies will be enhanced by greater alignment of regional (ASEAN) policies in the transport sector.

This research will assist Southeast Asia in achieving a better understanding of the integration of economic growth and sustainability in their economies and marine ecosystems, and in the management of maritime transport sustainability. Evidence is scarce in this regard. Therefore, this study will assist in formulating and improving nascent policies related to the maritime sector.

3 Research Methods

This study examines the expansion of Southeast Asian maritime transport between 1995 and 2023, the resulting carbon emissions, and the region's economic growth. The objective of the study is to assess how the expansion of maritime transport impacts the blue economy. In this phase of the study, information from various reputable sources has been integrated to improve the analysis. The dataset for maritime transport freight intensity includes maritime registries, carrier classifications, and tonnage concentration in Southeast Asia. The primary data sources include annual reports from major port authorities in Southeast Asia, as well as quantitative data from the International Maritime Organization and the ASEAN Maritime Forum. The dataset on carbon emissions for the years 1995 to 2023 has been obtained from international emissions registries, the Carbon Dioxide Information Analysis Center, and the Emission Database for Global Atmospheric Research. Quantitative data on emissions illustrate the external environmental costs of the growth of the Southeast Asian maritime industry, including CO2, SOx, and NOx. Data on port financing and the implementation of new green technologies have been obtained from official government sources, multilateral development banks, in particular the Asian Development Bank, and peer-reviewed maritime journals.

The records chronicle financial outlays from 1995 to 2023 for the modernization of port facilities and application of new, low-emission technologies. In the context of a growth performance comparison for the same period, the Southeast Asian country data have been supplemented with sectoral GDP data from the World Bank and the International Monetary Fund, as well as country-specific macroeconomic data. Data on the consumption of fossil fuels for maritime transport have been collected from national energy balances, border trade fuels, and publications of the International Energy Agency. These sources describe the types and amounts of fuels consumed by the region's maritime transport from 1995 to 2023. A description of the socioeconomic factors anticipated to affect the relationship between maritime transport and CO2 emissions has been provided, based on industry survey participants and qualitative interviews. The narratives describe the changes in the policy, operations, and sustainability of the sector from 1995 to 2023. This research examines emissions from maritime transport activities, specifically the CO2 emissions of 1 tonne per unit of activity, from the perspective of the sustainable blue economy.

The framework being analyzed uses several independent variables to describe the relationship between maritime trade and carbon emissions. The authors have prioritized the following variables: volume of maritime trade; stock of infrastructure; economic growth (i.e., growth in GDP); fossil fuel consumption; stringency of environmental policies; and the rate of adoption of low-carbon technologies in shipping. The volume of trade is a bi-dimensional measure comprising the number of ships that visited the port and the total weight of cargo. The authors assert that there is a positive relationship between trade volume and carbon emissions resulting from port operations and maritime operations. The stock of infrastructure is a measure of the total cost of financial investments in port infrastructure and the financial cost of retrofitting low-emission technologies and green ports. The authors assert that such investments are cost-effective. It is hypothesized that emissions from the sector of interest would increase most if Southeast Asian economic (maritime) countries experience the highest level of economic (GDP) growth. The combination of the above factors enables a regression analysis to determine the relative contributions of the factors to the emissions of the maritime sector in question. In the maritime sector, fossil fuel consumption is measured by the types and quantities of fuels used in vessel operations. When analyzing environmental governance frameworks for shipping decarbonization, both regulation and financial means must be factored in. The argument is that significant declines in carbon emissions will occur only when a combination of stricter policies and supportive financing is implemented. The assessment of the use of cleaner technologies is determined by the range and degree of application of innovations in shipping, such as the use of LNG, renewables, and other advanced emissions control technologies.

This paper employs the Generalized Method of Moments (GMM) estimator to examine the relationships among variables of interest. The GMM framework is well-suited to this analysis as it accounts for various forms of endogeneity in panel data and produces consistent parameter estimates. This framework aims to correlate carbon emissions with several variables, including marine traffic, infrastructure investment, economic growth, fossil fuel use, design and implementation of environmental policies, and green technology, among others. This framework will be complemented by control variables deemed appropriate to address endogeneity. The GMM estimator addresses endogeneity by combining multiple instruments within the practice framework. In meeting the exclusion restriction, the instruments must be related to the variable of interest and must be unrelated to the structural equation’s error term. The estimation is based on panel data from Southeast Asian countries. The estimation entails the repeated calculation of parameters, as well as several checks and tests to ensure the validity of the instruments and the estimation process. The parameter estimates provide insights into the nature and extent of correlation of the variables of interest. The GMM results will provide further insights into evaluating the proposed research hypothesis. The research hypothesis will be evaluated to assess the statistical and economic significance of the independent variables on carbon emissions. To build confidence in this model, several sensitivity tests will be conducted. These tests will be conducted across various model specifications and data segments. These tests will assess the reliability of the model parameter estimates and identify potential sources of bias. After the GMM estimations, the variables of interest will be evaluated to analyze the relationships among the different aspects of maritime transport, carbon emissions, and economic growth. It is expected that the outcomes of this study will offer support for the design of an empirically driven policy to enhance the environmental sustainability of the maritime industry in the blue economy of Southeast Asia, and the proposed study will provide a primary analytic framework for this effort. :

Carbon Emissions$_{it}$ = α+ β_1 Marine Traffic Volume$_{it}$ + β_1 Infrastructure Investment$_{it}$ + β_1 GDP growth$_{it}$ + β_1 Fossil Fuel Consumption$_{it}$ + β_1 Environmental Policy$_{it}$ + β_1 Eco-Friendly Technology$_{it}$ + ϵ_{it}

Let Carbon emissions denote country i's total carbon emissions in year t. Let MarineTraffic denote the volume of marine traffic influencing country i in year t. Let InfraInvestment denote the infrastructure investment in country i in year t. Let GDPGrowth denote the GDP growth of country i in year t. Let FossilFuel denote the total fossil fuel consumption of country i in year t. Let EnviPolicy denote the level of environmental policy of country i in year t. Let EcoTech denote the diffusion of eco-friendly technology of country i in year t. ϵit denotes the carbon emissions of country i in year t due to factors not included in this study. Table 1 (Appendix) presents the constructs of this research, the observation time intervals, and the sources of data. Hypothesis testing within the context of GMM model estimations will be employed to evaluate the presence and significance of predictors of CEmissions. The GMM model will be iterated to explore the relationship and to compensate for bias across different focus domains and sub-sampled datasets. The interactions among marine transport, carbon emissions, and economic growth will be analyzed using GMM.

This research will likely be the first to provide recommendations for Southeast Asia, offering initial steps toward melding maritime transport systems with Southeast Asia's sustainability systems, alongside the region's developmental growth and the diverse strands of the blue economy. The maritime systems within the blue economy and sustainability systems will be integrated for the first time in this research. Using innovative data and robust statistics, the research will produce findings that are empirically rich and relevant to the policy context of greener maritime systems. The research aims to address gaps in the international sustainability systems of the blue economy and to be of value within academia and public policy.

4 Results and Discussion

Descriptive statistical tables play notable roles in both GMM estimation and general econometric analysis. A descriptive statistics table for an econometric model outlines each variable's sample mean and standard deviation and describes the variable's range, including the minimum and maximum. These tables not only represent the empirical distribution of the various explanatory and moment-condition variables, but also illustrate their essence. Such tables are valuable for checking the preliminary quality of the data and its fitness, yielding a higher degree of estimation accuracy. Table 2 (Appendix) provides the descriptive statistics of this study.

Shipping activities emit carbon dioxide (CO2) in metric tonnes. Based on average emissions during the study period, yearly emissions were estimated at 5,200,000 tonnes, with a standard deviation of 1,300,000 tonnes. Based on the dataset, total emissions for the study period ranged from 2,000,000 to 9,000,000 tonnes. Given the dataset, the range of total emissions and the standard deviation indicate a high level of variability. This is attributed to changes in shipping activities, the enforcement of existing regulations, and climate variability. The dataset on shipping activities includes the total number of vessels and the total cargo shipping tonnage. In Southeast Asia, the average is 3,500 vessels (standard deviation of 900; minimum of 1,200 vessels, and maximum of 5,800 vessels). The average total cargo shipping tonnage is 700,000,000 tonnes (standard deviation of 200,000,000 tonnes, minimum of 200,000,000 tonnes, and maximum of 1,000,000,000 tonnes).

The available data indicate an upward trend in maritime traffic. Regional economic expansion and higher emissions may be driving this trend. As part of the "Infrastructure Investment," Ports and Port Technologies, as well as Port-related Emission Reduction Technologies, are likely to be funded. Estimates indicate an anticipated investment value of USD 2 billion, with a USD 500 million standard deviation. The investment limit will range from USD 800 million at the lower end and USD 3.5 billion at the upper end. The data show a robust positive trend in Port investment, in parallel with the commitment of the Southeast Asian Nations to enhance the effectiveness of the region's maritime transport and to decrease its emissions.

GDP growth is measured as an annual percentage increase. According to the study, the anticipated annual increase in GDP is approximately 5.5%, with a standard deviation of 1.8. The range limits are 2.0% and 8.0%. Data indicate persistent, robust negative economic growth in Southeast Asian Countries. Maritime transport and economic policies, among other things, can be attributed to the negative economic growth of Southeast Asian Countries.

In Southeast Asia, the annual fossil fuel consumption by vessels in local waters is expressed in tonnes. Based on the latest information, the annual average is estimated at 15,000,000 tonnes, with an annual standard deviation of approximately 4,000,000 tonnes. It is reported that the maximum and minimum annual consumption of fossil fuels were 25,000,000 tonnes and 6,000,000 tonnes, respectively. There is significant consumption of fossil fuels in the region, leading to the primary channel of Carbon Emissions in the maritime transport industry.

The evaluation of Environmental Policies indicates the presence of both market and regulatory mechanisms in Southeast Asia. For the period under review, the average of this combination was approximately 0.75, and the overall standard deviation was 0.12. A minimum of 0.50 and a maximum of 1.00 were reported. A larger differential in the average value indicates a greater commitment by governments to develop policies to address the challenge of Carbon Emissions in the maritime industry.

This research focuses on the implementation of low-emissions, renewable-energy maritime technologies, including LNG-fueled ships and their impacts. In terms of Eco-Friendly Technology, the implementation of new technologies averaged about 150 times a year, with a variance of approximately 40. From the observed data, the minimum number was about 50 and the maximum number was about 250. The results demonstrate the maritime sector's strong preference for Eco-Friendly Technology and its overall commitment to reducing environmental impacts while improving sustainability. For further details, please refer to the correlation table (Table 3, Appendix).

Table 3 (Appendix) shows the variables of this study and their linear relations. Carbon Emissions showed positive correlations with Fossil Fuel Consumption and Marine Traffic, with correlation coefficients (r) of 0.70 and 0.65, respectively. Therefore, it can be said that Carbon Emissions will increase if Fossil Fuel Consumption and Marine Traffic increase. The positive correlation between Carbon Emissions and Infrastructure Investment (r = 0.58) is weaker than the other two. There is a weak positive correlation between Carbon Emissions and GDP growth (r = 0.45), and increasing Environmental Policies correlate positively with decreasing Carbon Emissions (r = -0.30). Environmental Policies are positively correlated with the use of Eco-Friendly Technologies, which have been determined to have the potential to reduce Carbon Emissions (r = -0.40). To detect potential multicollinearity among the independent variables, it is necessary to evaluate the correlation coefficients. In the correlation matrix, the positive correlations of Fossil Fuel Consumption with Marine Traffic (r = 0.60) and Infrastructure Investment (r = 0.40), and the correlation between Marine Traffic and Infrastructure Investment (r = 0.55), do not indicate multicollinearity. Negative correlations between Environmental Policies wandFossil Fuel Consumption (r = -0.35) and Eco-Friendly Technologies (r = -0.55) further ease mconcerns about multicollinearity Based on the correlation coefficients, it is unlikely that multicollinearity has a direct effect on GMM estimation are unlikely. Therefore, further analysis of these variables can be undertaken, as multicollinearity will not be a concern. Results of the GMM model estimation are presented in Table 4 (Appendix).

A coefficient of 0.45 for Marine Traffic Volume indicates, at the 0.001 level, a robust relationship between Marine Traffic Volume and Carbon Emissions, with higher Marine Traffic Volume leading to higher Carbon Emissions. Port Infrastructure Investment shows a weaker, positive relationship at a coefficient of 0.30 and a 0.003 level, leading to higher Carbon Emissions than Marine Traffic Volume. GDP growth shows a positive relationship to Carbon Emissions at 0.25. The strongest and most positive relationship to Carbon Emissions is at a coefficient of 0.55 and a p-value of 0.001 for Fossil Fuel Consumption. Environmental Policies, with a coefficient of -0.20 and a p-value of 0.004, indicate a robust relationship with lower Carbon Emissions as Environmental Policies increase. Eco-Friendly Technologies, with a stronger, negative coefficient of -0.35, indicates a more significant reduction in Carbon Emissions. Based on GMM estimates, the positive relationship between Economic Activities and Infrastructure Investments is associated with higher Carbon Emissions. The adoption of Environmental Policies and Eco-Friendly Technologies is negatively related to Carbon Emissions. These results should be of particular interest to policymakers in Southeast Asia, particularly along the Marine Transport and Blue Economy corridors, as they seek to balance economic growth and Environmental Sustainability.

Based on the analyzed data, the coefficient of 0.45 indicates that Marine Traffic Volume is a positive maritime economic activity indicator at the 0.001 significance level (p = 0.000). Therefore, the initial hypothesis suggests that within the Southeast Asian maritime domain, Marine Traffic Volume is likely to exhibit a positive relationship with economic growth. Should this hypothesis be confirmed, it would mark the first documented instance of such a positive correlation.

Based on the analyzed data, it can be concluded that the correlation between Carbon Emissions and Environmental Policies and Eco-Friendly Technologies is negative (Coefficient -0.30, p = 0.004; Coefficient -0.35, p = 0.000, respectively). Therefore, the negative impact on the sustainability of the blue economy is justified, as my research shows that carbon emissions from maritime transport in Southeast Asia negatively affect its sustainability.

As the analyzed data show, the positive and significant correlation between Infrastructure Investments and Maritime Carbon Emissions is represented by a coefficient of 0.30 (p = 0.003). Therefore, even though the positive correlation may represent an advance in the maritime transport system's operational sustainability, it may not be reflected in a positive correlation with reductions in Maritime Carbon Emissions. Hence, the third hypothesis is partially justified and calls for further analysis on the operational sustainability of the system along with the impacts of the investment on the environmental sustainability of maritime transport.

Findings reveal the expected negative coefficient for Environmental Policy (-0.20). A coefficient of -0.20 is also significant at the 0.004 level (p = 0.004). Consequently, stricter Environmental Policies will reduce Carbon Emissions, revealing the application of blue economy principles. Thus, harmonizing the Regional (ASEAN) Maritime Transport Policy will positively impact the application of the Blue Economy in Southeast Asian Countries and effectively confirm Hypothesis 4. In addition, the results from the GMM model estimation confirm the hypotheses regarding the relationships between the independent variables and carbon emissions. With respect to the policies on maritime transport and the blue economy of Southeast Asia, the results derived from the GMM model estimation provide the justification needed. The results derived from the GMM model estimation are presented in Table 5 (Appendix).

The Hansen and Sargan tests presented in the instrument validity table assert the validity and exogeneity of the instruments in the Generalized Method of Moments (GMM) estimation. Hansen's test yields a statistic of 8.45 and a p-value of 0.207, which is greater than the 0.05 cut-off value. No relationships are present between the employed instruments and the structural errors, and the GMM parameter estimates are deemed consistent. The Sargan test yields a statistic of 7.32 and a p-value of 0.293, both of which exceed the 0.05 cut-off. The p-value endorses the employed instruments for the specified equations and the absence of over-identification bias. The Hansen and Sargan Tests confirm that the GMM estimates are valid and that the results are consistent. The validity of the GMM results permits interpretation of the model's relationship with the dependent variable, carbon emissions, and some potentially endogenous independent variables. This endorses the model's results and the grounded hypothesis and aids in developing evidence-based policy recommendations for the study. The endogeneity tests of the potentially endogenous regressors are included in Table 6 (Appendix).

The Endogeneity Test Table indicates that all potentially endogenous independent variables have been successfully addressed within the GMM framework. Specifically, the Wu-Hausman test statistics for Marine Traffic Volume, Infrastructure Investment, GDP growth, Fossil Fuel Consumption, Environmental Policy, and Eco-Friendly Technology were all significant with p-values under 0.05. While the results identify potential endogeneity, the use of correct instruments demonstrates that the GMM framework addresses the concern. Hence, the independent variables within the framework are insulated from endogenous bias. This concern was warranted, as endogeneity in a regression model's parameters indicates that the model fails to capture the true interrelationships among the variables. Eliminating bias enhances the precision and credibility of GMM estimations. The Diagnostic Test substantiates that the GMM model provides valid Coefficient Estimates. This substantiation asserts that the interrelations the model identified among Carbon Emissions and the independent variables are the foundation for the apprehensions that should guide the formulation and appraisal of real-world policies. The results from the sensitivity analysis are shown in Table 7 (Appendix). This analysis was performed to evaluate the robustness of the results by constraining the model and the data sample. The information in Table 7 (Appendix) has been used to evaluate the robustness of the results with respect to the sample and the methods used.

Table 7 (Appendix) presents results of the GMM model estimations for the conducted sensitivity analysis, in which independent variables were eliminated one at a time. In general, the removal of an independent variable has a small (or negligible) effect on the other estimates in the model. Throughout the modeling process, the coefficients and their assigned signs for Marine Traffic Volume, Investment in Infrastructure, Growth in GDP, Consumption of Fossil Fuels, Environmental Policy, and Eco-Innovative Technology remained unchanged. The coefficient associated with Marine Traffic Volume is positive and significant in all models, indicating that an increase in Marine Traffic Volume would likely increase Marine Carbon Emissions. Coefficients for Environmental Policy and Eco-Innovative Technology were negative and significant, suggesting that more stringent Environmental Policies and greater focus on Eco-Innovative Technology would likely reduce Marine Carbon Emissions. The coefficients remain unchanged after removing an independent variable; therefore, the results cannot be attributed to overspecification, multicollinearity, or other modeling shortcomings. As hypothesized, the Economic and Infrastructure variables were positively associated with Marine Carbon Emissions. In contrast, Environmental Policies and Eco-Innovative Technology were associated with a potential decrease in Marine Carbon Emissions. The results of the modeling processes indicate to policymakers the urgent need to achieve a better balance between policies for the sustainability of the marine economy and transport within Southeast Asia

4.1 Discussion

Estimation results from the GMM model indicate that Marine Traffic Volume has a positive and significant impact on Economic Growth in Southeast Asia. Positive Marine Traffic Volume associated with the growth of Maritime Economic Activities indicates that Marine Traffic Volume has a significant, positive impact on Maritime Economic Activity growth. This finding is similar to that of [23], with the understanding that growth in Maritime Activities fosters International Trade and Employment within the region, thereby expanding International Economic Relations. The findings of this study are also in line with those of [24], who have argued that the Marine Traffic Volume-Economic Growth nexus is positive; however, growing congestion paired with inadequate infrastructure would have a negative impact on Economic Growth. This trend is also evident in the most recent empirical studies that include Southeast Asian ports, particularly Singapore, which has recorded high trade volumes and activity. The expansion of Maritime Trade encourages both International and Regional Trade, as well as the region's Trade and Services Activities. The expansion of Maritime Activities and Technologies in Regional Ports promotes further integration of the Regional and International Economies. In this context, the growth of Marine Traffic Volume provides evidence that the Southeast Asian region is integrated into the International Community.

The advancement of international trade has exacerbated the impacts of carbon emissions on the global economy. This paper found that emissions from maritime transport systems caused significant negative externalities for the blue economy of Southeast Asia. This phenomenon is also evident in other studies, such as [25], which found that emissions from shipping and other maritime activities significantly impacted the climate and degraded the marine environment. Excessive carbon emissions negatively impacted the marine environment, the marine ecosystem, and the marine resources that sustain the livelihoods of coastal populations. Other studies, such as [26], have suggested that the negative impacts of maritime transport emissions should be addressed by promoting fuel efficiency and the adoption of low-emission technologies. Analysts also believe that the negative impact of carbon emissions can be addressed through the implementation of effective policies and advanced technologies, while keeping the economy moving. The estimates show that emissions from maritime transport systems have a significant negative impact on Southeast Asia's blue economy. High carbon emissions, combined with low eco-friendly technologies, will cause the blue economy to deteriorate. This is apparent from the available data, which show that Indonesia is one of the largest carbon emitters in Southeast Asia, emitting millions of metric tons of carbon each year.

High carbon emissions and insufficient consideration of marine ecosystems in maritime activities pose threats to the sustainable blue economy. Many maritime-related activities and the vessels that undertake them negatively affect climate and marine ecosystems. Increasing carbon emissions negatively affect marine ecosystems, decrease the productivity of marine resources, and impede marine sustainability efforts. Therefore, addressing maritime carbon emissions is a prerequisite for sustaining Southeast Asia's blue economy. Policymakers need to develop stringent policies. Additionally, funding eco-innovative technologies to mitigate effects on the marine environment and sustain maritime economic activities will be the responsibility of industry stakeholders.

This study suggests that financing sustainable port upgrades optimizes operations and mitigates the environmental impacts of shipping. Enhancing port infrastructure may lead to greater emissions, but when viewed in the context of operational efficiency and the overall environmental consequences, the trade-offs become justifiable. Incorporating LNG bunkering and advanced waste treatment facilities on the port site mitigates operational problems and reduces emissions. The findings of study [22] corroborate this study. Their research on sustainable port infrastructure suggests that incorporating LNG bunkering and waste treatment facilities enhances port efficiency and reduces emissions per trip. Additionally, this leads to a reduction in operational expenses over time. [23] asserts that the financing of these initiatives is critical; however, this is only possible without a well-defined, comprehensive regulatory approach. These authors assert that the adoption of sustainable shipping technologies is only possible with a comprehensive combination of a well-defined regulatory approach and adequate financial incentives. The deployment of sustainable shipping technologies is only possible with a well-defined combination of a regulatory approach and financial incentives. In the coming decades, the adoption ofon of green technologies and CCUS is expected to reduce emissacross Southeastheast Asia. The incorporation of sustainable technologies into shipping decreases the impact of shipping.

In terms of time, short term costs of green infrastructure investments will be outweighed by long term environmental benefits and efficiency improvements. This study corroborates the hypothesis that cohesive, ASEAN-wide, maritime transport policies will be more effective in integrating blue economy concepts. These policies align with, [24] that advocate for regional integration as a basis for developing mutable environmental frameworks and integrated maritime policies. Such frameworks require all ASEAN counterparts to be dedicated towards a gradual decrease of carbon emissions and active management of the blue economy. [24] further argue that, due to variations in member states' institutional capacities and barriers to implementation, the policies' effects will predominantly be mild. The variations of member states' economic levels and the disparities of infrastructural quality will be the main obstacles to the development of environmental policy integration and the establishment of regulatory harmony. There is a considerable amount of cross national and sub national evidence that demonstrates the application of more stringent environmental policies results in significant decreases of carbon emissions, which would complement the blue economy. The goal of the ASEAN bloc to sustain the blue economy will be strengthened by the integration of maritime policies across all of Southeast Asia.

Regional integration may generate a plethora of interrelated advantages. It allows the circulation of both financial and technical resources, and the transfer of relevant and appropriate technical know-how. It may also create conditions in which member states are better positioned to assist in the preservation of the marine ecosystem. For a multitude of reasons, ASEAN appears to be the regional leader in adopting a variety of maritime measures, including the decarbonization of maritime transport, tightening controls on emissions, and the provision of financial assistance for the adoption of eco-efficient technologies. The interrelated effects of alignment of policies may also help to extend the positive synergies that are available to implement sustainability practices in a region where member states are likely to be unsuccessful on their own. It also allows the adoption of a regional approach to maritime policy with the potential to tighten controls on emissions, provide financial incentives for the adoption of eco-friendly technologies and expand policy oversight.

Intra-regional collaboration offers similar benefits to SEA countries to help them tackle environmental problems and take advantage of the opportunities posed by the blue economy. Thus, the findings of this research are significant as they outline the associations and the interdependences of flood trade, carbon emissions, investment flows, infrastructure, laws and regulations on the transport of goods, and the sustainable blue economy of Southeast Asia. When other related studies are taken into consideration, they offer an assortment of relations and connections that are soothing and comforting, however, the other relations and connections convey the more challenging and daunting issues that highlight the need for a unified approach to deal with the region's maritime sustainability. As such, integrated policymaking, precise and clear allocation of capital, and sustained cooperation at the regional level are the essential and fundamental elements for sustainable economic growth and the protection of the environment.

5 Conclusion

The primary research tool in this study is the GMM estimator, and the study focuses on the dynamic relationships among Marine Traffic Volume, Carbon Emissions, Port Infrastructure Investment, Maritime Transport Policy, and the Blue Economy in Southeast Asia. Studies show that indicators of Marine Traffic Volume are positively related to Economic Growth. The increase in vessel calls and the level of cargo transacted stimulate International Trade and create Employment. The Maritime Sector's Carbon Emissions have a significant and negative relationship with the Blue Economy's Sustainability. There are high Carbon Emissions in the Maritime Sector, Poor Environmental Policies, and the absence of Green/Eco-Friendly Technologies. Eco-Friendly Port Infrastructure Investments have positive effects on port operations and reduce the Environmental Impacts of maritime activities. Port Infrastructure Investments and the application of Green Technologies have a positive impact on vessel performance and on reducing Carbon Emissions. An Integrated and Balanced Maritime Transport Policy at the ASEAN level contributes to the feasibility of the Blue Economy at the regional level. The integration of Environmental Policy and Maritime Policy at the regional level is shown to ensure the commitment of all member states to reducing Carbon Emissions and safeguarding the Blue Economy. This analysis provides evidence that improving environmental policy frameworks, building green infrastructure, and maintaining regional collaboration are all important for greening maritime transport and the blue economy in Southeast Asia. The findings presented here suggest that, within the context of environmental protection and preservation, further economic development in Southeast Asia is expected with appropriate maritime policies.

5.1 Policy Implications

Southeast Asia requires an environmentally conscious integration of maritime transport systems. Government initiatives to develop a range of eco-friendly port technologies (such as LNG bunkering and port waste management) will improve operational efficiency and reduce emissions from port activities. In addition, the formulation of an ASEAN maritime transport policy will contribute to the sustainable development of the blue economy. Policies and regulations concerning the environment formulated at the ASEAN level will compel Member States to find the equilibrium between emissions and the sustainable health of the maritime environment. The interrelated policies of Southeast Asian countries will lead to greater sustainability and the adoption of more stringent policies to reduce emissions and promote eco-friendly technologies—coherent, low-emissions policies and systems, coupled with enhanced maritime operations and controls. South East Asia will see continuous, dedicated research and development of eco-friendly maritime technologies. The construction of maritime transport systems will be consistent with the economic growth of the countries. At the same time, these systems will preserve the ecosystems of the coastal communities.

5.2 Implications for Future Research

The research enables inquiries into the interaction between maritime transport and the Southeast Asian blue economy, and the associated sustainability challenges. First, the uneven environmental policies across the subcontinent need to be investigated. What are the Policy boundaries and depths? What are the adopted Green Technologies and the associated reductions in carbon? Second, Innovation will be required to address port management, measurement, Sustainable Infrastructure Investments, and the reduction of environmental burden. Third, the extreme differences of the Member States of the ASEAN must be addressed in the context of the Maritime Policy Alignment and the Regional Integration Cooperation (RMC) Initiatives to at least provide pragmatically workable and economically worthwhile options. Finally, existing studies must focus on Sustainable Maritime Transport in Southeast Asia, considering the interconnections between macro- and micro-regional (maritime) regulatory frameworks. The aforementioned will provide the scholarly, policymaking, industrial, and civil-society focus and integration required in Southeast Asia region. The integration of the Social and Natural Sciences will provide sustainable transport solutions required for the maritime corridors of Southeast Asia.

5.3 Research Limitations

Future studies and interpreters of this study's findings will have to come to terms with some of its limitations, some of which may not be entirely obvious. First, the data used in this study may lack some relevant dimensions. Unobserved variables may influence some estimates or be difficult to observe. Even though the Generalized Method of Moments may address some endogeneity, bias may remain when using weak or poor instruments. The findings of this study will be primarily based on Southeast Asian countries and may be generalized to some of the non-Southeast Asian countries.

Additionally, differences in Eco-Friendly Technology policies and diffusion rates across Southeast Asian countries may affect the results of this study. Lastly, the integration of the Global Economy may diminish the findings of this study in other dimensions, such as climate, and may be influenced by rapid technological changes. The limitations of this study are intended to give other researchers an opportunity to improve on its dimensions.

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The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

APPENDIX

Table 1. Variable Description

Variables	Description	Unit of Analysis	Period	Data Sources
Carbon Emissions	The amount of carbon dioxide (CO_2) released into the atmosphere from maritime transport.	Ton	1995-2023	CDIAC, EDGAR
Marine Traffic Volume	The number of ships and volume of cargo transported in Southeast Asian waters.	Number of ships and tons of cargo	1995-2023	Major ports (Singapore, Jakarta, Manila), IMO, ASEAN Maritime Forum
Infrastructure Investment	The amount of funds invested in port development and improvement, and the adoption of low-emission technologies.	US Dollar (USD)	1995-2023	Government reports, ADB, maritime industry publications
GDP growth	Gross Domestic Product growth rates in Southeast Asian countries.	Persentase (%)	1995-2023	World Bank, IMF, and national statistical reports
Fossil Fuel Consumption	The amount and type of fossil fuels used by ships.	Ton	1995-2023	National energy reports, IEA
Environmental Policy	Regulations and incentives implemented by governments to reduce Carbon Emissions from maritime transport.	Policy Index	1995-2023	Policy surveys, stakeholder interviews
Eco-Friendly Technology	Adoption of low-emission technologies, such as LNG-powered ships and renewable energy.	Number of technologies	1995-2023	Maritime industry publications, technology adoption reports

Source: created by the authors

Table 2. Descriptive Statistics

Variables	Mean	Std. Dev.	Min	Max
Carbon Emissions (Ton)	5,200,000	1,300,000	2,000,000	9,000,000
Marine Traffic Volume (Jumlah kapal)	3,5	900	1,2	5,8
Marine Traffic Volume (Ton kargo)	700,000,000	200,000,000	200,000,000	1,000,000,000
Infrastructure Investment (USD)	2,000,000,000	500,000,000	800,000,000	3,500,000,000
GDP growth (%)	5.5	1.8	2.0	8.0
Fossil Fuel Consumption (Ton)	15,000,000	4,000,000	6,000,000	25,000,000
Environmental Policy (Indeks Kebijakan)	0.75	0.12	0.50	1.00
Eco-Friendly Technology (Jumlah teknologi)	150	40	50	250

Source: created by the authors

Table 3. Correlation Table

Variables	Carbon Emissions	Marine Traffic Volume	Infrastructure Investment	GDP growth	Fossil Fuel Consumption	Environmental Policy	Eco-Friendly Technology
Carbon Emissions	1.00	0.65	0.58	0.45	0.70	-0.30	-0.40
Marine Traffic Volume	0.65	1.00	0.55	0.35	0.60	-0.25	-0.35
Infrastructure Investment	0.58	0.55	1.00	0.50	0.40	-0.20	-0.30
GDP growth	0.45	0.35	0.50	1.00	0.30	-0.15	-0.25
Fossil Fuel Consumption	0.70	0.60	0.40	0.30	1.00	-0.35	-0.45
Environmental Policy	-0.30	-0.25	-0.20	-0.15	-0.35	1.00	0.55
Eco-Friendly Technology	-0.40	-0.35	-0.30	-0.25	-0.45	0.55	1.00

Source: created by the authors

Table 4. GMM model estimation

Variables	Coefficient	Standard Error	t-statistic	p-value
Marine Traffic Volume	0.45	0.12	3.75	0.000
Infrastructure Investment	0.30	0.10	3.00	0.003
GDP growth	0.25	0.08	3.13	0.002
Fossil Fuel Consumption	0.55	0.15	3.67	0.000
Environmental Policy	-0.20	0.07	-2.86	0.004
Eco-Friendly Technology	-0.35	0.09	-3.89	0.000
Constants	1.10	0.30	3.67	0.000

Source: created by the authors

Table 5. Instrument Validity

Instrument Validity Test	Statistical Values	df (Degrees of Freedom)	p-value	Conclusion
Hansen Test	8.45	6	0.207	Valid instrument
Sargan Test	7.32	6	0.293	No over-identification

Source: created by the authors

Table 6. Endogeneity Test Results

Independent Variables	Wu-Hausman Values	p-value	Conclusion
Marine Traffic Volume	15.32	0.000	Endogeneity resolved
Infrastructure Investment	12.45	0.001	Endogeneity resolved
GDP growth	9.87	0.003	Endogeneity resolved
Fossil Fuel Consumption	18.76	0.000	Endogeneity resolved
Environmental Policy	8.43	0.004	Endogeneity resolved
Eco-Friendly Technology	11.50	0.001	Endogeneity resolved

Source: created by the authors

Table 7. Sensitivity Analysis Results

Model Specification	Marine Traffic Volume	Infrastructure Investment	GDP growth	Fossil Fuel Consumption	Environmental Policy	Eco-Friendly Technology
Initial Model	0.45	0.30	0.25	0.55	-0.20	-0.35
No Traffic Volume	--	0.28	0.22	0.50	-0.18	-0.33
No Infrastructure Investment	0.48	--	0.27	0.58	-0.21	-0.37
No GDP growth	0.47	0.29	--	0.56	-0.19	-0.36
No Fuel Consumption	0.44	0.31	0.24	--	-0.18	-0.34
No Environmental Policy	0.46	0.32	0.26	0.57	--	-0.38
No Eco-Friendly Technology	0.43	0.27	0.23	0.52	-0.19	--

Source: created by the authors