Comprehensive Structural Decomposition Analysis of CO2 Emissions from Vessels: Case Study of Japan

Topic: Structural Change and Dynamics
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Maritime transport is the backbone of global economy, accounting for more than 80% of world goods trade. However, CO2 emissions from international shipping are increasing, reaching approximately 3% of global anthropogenic emissions. In response to the global need for emission reductions across industries, the International Maritime Organization has set ambitious greenhouse gas reduction targets for international shipping, aiming for a more than 70% reduction by 2040 compared to 2008 levels, and carbon neutrality by 2050. These targets have brought attention to zero-emission vessels, which creates a significant need for comprehensive life cycle assessment (LCA) studies to evaluate their environmental impacts.

While previous studies employed LCA to assess the environmental performance of zero-emission vessels, there is a research gap in evaluating the impacts of lifespan changes with those of other CO2 reduction measures. Specifically, few studies have compared CO2 reduction effects through the lifespan changes with those resulting from other factors, such as fuel efficiency improvements and vessel size optimization.

To address this gap, this study investigates the impact of changes in the average lifespan of vessels on CO2 emissions, using Japanese domestic maritime transport as a case study. Two key analyses were conducted. First, this study estimates CO2 emissions of Japanese domestic maritime transport from 2005 to 2022 under varying vessel lifespans, comprehensively considering the vessel life cycle. This estimation examines the relationship between lifespan changes and emissions, incorporating vessel repair into the estimation model for the first time. Second, this study develops an LCA-specific structural decomposition analysis (SDA) and applies it to the emissions across different lifespan scenarios. This SDA decomposes CO2 emissions into 12 factors across four vessel life cycle stages: production, consumption, repair, and activity. This approach reveals stakeholdersâ€™ contributions in each vessel life cycle stage to changes in emissions, providing more concrete policy implications for each stakeholder. Furthermore, the SDA identifies the main drivers of emission changes both within and across the different lifespan scenarios, allowing comparisons of environmental impacts of lifespan changes with those of other factors.

The results revealed that extending vessel lifespans by five years led to a cumulative reduction of approximately 1.7 Mt-CO2 compared to the baseline, despite the increased demand for vessel repairs. Additionally, the SDA results under the baseline lifespan scenario demonstrated that supply chain management by shipyards and vessel stock restructuring (i.e., reducing the total number of vessels and travel distances) by shipping companies significantly contributed to the emission reduction. These findings suggest the need for policies that not only target shipyards to improve their supply chain management but also encourage shipping companies to optimize their operations, complementing current policies aimed at enhancing energy efficiency. The comparison of the SDA results across different average lifespan scenarios further indicated that the lifespan changes were the third-largest contributor to CO2 reduction, following reductions in vessel stock and travel distances. Therefore, these findings indicated that the impact of lifespan changes is indeed substantial, suggesting the importance of integrating current CO2 reduction measures with strategies for extending vessel lifespans to achieve greater environmental benefits.

This study made three novel contributions. First, this study incorporated vessel repairs into the CO2 estimation model, shedding light on the environmental trade-offs between extending the average lifespan and subsequently increasing vessel repair demand. Second, this study developed a novel SDA framework capable of comprehensively decomposing the estimated CO2 emissions across vessel life cycle stages. Applying SDA provided deeper insights into stakeholder contributions at each stage of the vessel life cycle. Third, the SDA framework facilitated a quantitative comparison of lifespan changes with other mitigation measures by applying it across various average lifespan scenarios, enhancing discussions on effective CO2 reduction strategies.