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With the growth of global trade and technological progress, the shipping industry has become a key player in international cargo transport. However, its expansion has led to serious environmental concerns. In 2018, shipping accounted for 2.89% of global human-made emissions (IMO). Ships also emit large amounts of SOx and NOx during long port stays, contributing to seawater acidification. Without control measures, emissions could double by 2050 compared to 2007 levels. To address this, the IMO and governments have implemented various emission-reduction strategies.

Previous studies have analyzed how Emission Control Area (ECA) policies affect ship emissions. Wang et al. studied ships in the Port of Shanghai and found that emission reductions vary depending on ship type and size. Oil/chemical tankers and container ships had the largest reductions in SOx emissions. In addition, when ships use low-sulfur fuel while docked, SOx and PM10 emissions can be reduced by up to 94.4% and 78.3%, respectively. Weng et al. investigated how ECA policies influence ship routes and emissions. Their results show that stricter ECA policies reduced SOx emissions by 31.24%–42.67% for merchant ships. Some ships chose to sail outside ECA areas to avoid using expensive low-sulfur fuel. Moreover, when the fuel price difference is more than USD 450 per ton, most ships tend to avoid ECAs.

Currently, there are several ways to comply with ECA regulations, such as using LNG as fuel, switching to MDO, or installing scrubbers. Mohseni et al. found that LNG is the most cost-effective option. It performs better than MDO and scrubbers in terms of both shipowner costs and total supply chain costs. Their study also showed that switching from MDO to LNG can reduce total port emissions by about 76%, especially CO₂, SO₂, NOx, and PM. Zis et al. compared the use of MGO fuel with installing scrubbers to continue using HFO. Their results show that when the fuel price gap between MGO and HFO is large, installing scrubbers becomes more economically attractive and has a shorter payback period. If a ship operates for a long time and spends many days at sea, investing in scrubbers is more cost-efficient. This study will further explain the pros and cons of each alternative solution and conduct an economic analysis in Sections 2.3.2 and 2.3.3.

Conclusion:  
This study finds that installing a scrubber can effectively reduce fuel and maritime costs, resulting in a slight decrease of 0.206% in the overall supply chain cost. Although LNG offers strong environmental benefits, its high fuel price significantly increases the total cost, leading to an increase of up to 102% in the total cost per ship loop.

However, the findings of Mohseni et al. (2019) differ from those of this study. Their research suggests that, under conditions considering different routes (e.g., Asia–Europe, US–Europe), engine types, and future emission costs, LNG is the most economical option, with a total chain cost lower than that of using MDO or installing scrubbers. The study also points out that, in most cases, the scrubber option results in higher overall costs. This difference may be due to the assumptions made about fuel prices. In this study, LNG is assumed to be significantly more expensive than MDO and HFO, while Mohseni et al. considered several fuel price sensitivity scenarios, including cases where LNG prices are relatively lower.

While this study considers a fixed ETS cost per tonne of CO₂, future research could simulate varying carbon prices to assess the robustness of each alternative under carbon market volatility.