Mapping Freight Transportâ€“Related CO_2 Emissions in Supply Chain Networks: An Application of Freight Transport Modal Shifts in Japan

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Author: Mami Matsuse
Co-Authors: Ai Nagata, Shigemi KAGAWA

In 2022, the transport sector accounted for 18.5% of Japanâ€™s total COâ‚‚ emissions, with trucks responsible for 38% of transport-related emissions. The government aims to reduce transport-sector COâ‚‚ emissions by 35% by 2030 relative to 2013 levels, underscoring the need for mitigation in freight transport. Emissions per ton-kilometer are 208 g-COâ‚‚ for commercial trucks, compared with 43 g-COâ‚‚ for ships and 20 g-COâ‚‚ for rail, highlighting modal shift from road to maritime and rail as a key strategy.
This study makes two key contributions. First, it develops a new approach to mapping freight transportâ€“related CO_2 emissions in supply chain networks. Discussions of emission reduction in the transport sector often focus on improving the energy efficiency of individual modes. However, transport demand is directly and indirectly induced by final demand; therefore, freight transportâ€“related COâ‚‚ emissions should be attributed not only to final demand but also to the intermediate demand it generates. Multi-regional inputâ€“output (MRIO) analysis is well suited to capturing linkages between economic activity and transport demand.
Several previous studies (e.g., Yu et al., 2021; Liu et al., 2022; Egilmez and Park, 2014; Li et al., 2025; Park et al., 2015) have applied IO frameworks to analyze transport-related environmental burdens. However, many rely on single-region inputâ€“output (SRIO) models that treat a country as a single production system. Because modal shift policies target long-distance interregional transport, SRIO models that ignore regional heterogeneity and originâ€“destination structures cannot assess reduction potential. In contrast, MRIO models capture interregional emission transfers and spatial dependencies in freight transport. Because modal shift feasibility and effectiveness depend on interregional distance and infrastructure connectivity, a spatially explicit MRIO approach is essential.

Second, this study advances environmentally extended inputâ€“output (EEIO) analysis by incorporating transport activity (ton-km) into COâ‚‚ emission factor estimation. Conventional IO studies typically use monetary emission intensities (t-COâ‚‚ per unit of output). However, high-value, low-weight commodities and low-value, high-weight commodities impose different transport burdens per monetary unit, potentially biasing modal shift estimates. Recent studies propose hybrid models separating monetary and transport-based emissions (Weber and Matthews, 2015) and life-cycle approaches using physical emission intensities (Facanha and Horvath, 2007). Building on these approaches, this study integrates ton-kmâ€“based emission factors into an MRIO-based EEIO framework, linking macroeconomic ripple effects with logistics realities.
Full mitigation potential and spillover of modal shift require: (1) an economy-wide supply chain view, (2) an MRIO framework for interregional freight, and (3) ton-km logistics data. Few studies integrate all three , making this approach unique.
In this study, using the available 2015 single-region inputâ€“output tables for Japanâ€™s 47 prefectures and inter-prefectural freight flow survey data, we constructed an MRIO table covering 47 prefectures and 81 sectors. Based on this database, we estimated the modal shift CO_2 reduction potential in inter-prefectural transport. The results show that shifting all truck transport over 500 km to maritime transport would reduce total CO_2 emissions by about 13% (âˆ’9 Mt CO_2). Corridor analysis shows that, under a complete truck-to-ship modal shift, the top three prefecturesâ€”Saitama (19%), Tokyo (10%), and Osaka (6%)â€”account for 35% of the total COâ‚‚ reduction. By sector, machinery and equipment (17%), building construction (12%), and medical services (10%) contribute 40% of the reduction. These prefectures and sectors thus represent priority targets for modal shift.

The above results estimate mitigation potential assuming the commonly used 500 km threshold for modal shift. However, the Japanese government does not specify a clear distance criterion. To address this, the study incorporates transport distance into the EEIO framework and examines priority ranges by varying the minimum distance threshold. Mitigation potential depends on this threshold: although reductions generally increase as it decreases, the relationship is nonlinear. Notably, 350â€“400 km appears to be a structural turning point where modal shift effectiveness changes markedly.

From a policy perspective, the results suggest prioritizing high-emission prefectures and sectors and providing incentives, such as subsidies, to promote a more efficient modal shift toward decarbonization. In addition, setting an appropriate minimum distance thresholdâ€”particularly around the 350â€“400 km turning pointâ€”would enhance policy effectiveness by targeting transport flows with the greatest mitigation potential.