An Integrated SBMâ€“Meta-Frontier DEA and Environmentally Extended Inputâ€“Output Analysis of Fuel Inefficiency in Japanâ€™s Fisheries

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Japanâ€™s fisheries production has declined markedly since its peak of 12.82 million tons in 1984, falling to approximately 3.63 million tons in 2022. This decline has been widely attributed to the overexploitation of fishery resources and persistent excessive fishing capacity. Although the number of fishing entities has decreased substantially since the late 1980s, productivity improvements have remained limited, indicating persistent structural inefficiencies that have yet to be systematically evaluated at the national level.

As resources decline, competition for remaining stocks intensifies, leading fishing entities to expand capital investment and fishing effort to secure catches. This response increases fuel consumption and operating costs, amplifying both economic vulnerability and environmental pressure. Meanwhile, greenhouse gas emissions from fisheries have risen despite stagnant production, underscoring the need to decouple fisheries production from carbon emissions through efficiency-oriented management.

In Japan, more than 90% of fishing entities operate in coastal fisheries and are predominantly individually managed. Because these operators face financial constraints, limited technological access, and high exposure to fuel price fluctuations, inefficient fuel use directly threatens both economic viability and environmental sustainability. Improving fuel-use efficiency has therefore become a critical policy issue.

The novelty of this study lies in three aspects. First, it constructs an integrated analytical framework that enables nationwide comparison across major fishery types and coastal regions using micro-level data. Second, by applying a Slack-Based Measure (SBM) Data Envelopment Analysis, it identifies input-specific sources of inefficiency, clarifying the structure of excessive fuel and resource use. Third, by employing a meta-frontier DEA approach, it decomposes total inefficiency into inter-regional and intra-regional components, allowing assessment of whether inefficiencies stem primarily from structural conditions or managerial performance.

This study addresses three research questions: (i) how efficiency levels and input inefficiencies differ across fishery types and regions; (ii) whether excessive input use reflects regional environmental constraints or managerial and technological factors; and (iii) how embodied carbon emission reduction can be achieved through energy efficiency improvements without reducing output.

The analysis uses micro-level data from the 2018 Census of Fisheries: Individual Entity Data conducted by the Ministry of Agriculture, Forestry and Fisheries of Japan. The sample consists of 250 coastal fishing entities engaged in active, passive, and hook-and-line fisheries. Vessel gross tonnage, fishing days, fuel costs, and crew size are used as inputs, and total sales as output. Entities are grouped into major coastal regions to account for environmental and structural heterogeneity.

SBM-DEA estimates overall and input-specific inefficiencies, where values closer to one indicate higher inefficiency. A meta-frontier framework then decomposes inefficiency into regional and managerial components. Environmental impacts are evaluated using the Embodied Energy and

Emission Intensity Data for Japan (3EID) within an environmental-extended inputâ€“output framework (Nansai, 2019). DEA-based fuel inefficiency is converted into potential fuel savings and corresponding COâ‚‚ reduction potentials. A bootstrap procedure is employed to account for sampling variability, and results are extrapolated to the national level using 2023 entity counts.

The results reveal substantial regional and fishery-type disparities in efficiency. Average total inefficiency scores are 0.44 for active fisheries, 0.27 for passive fisheries, and 0.44 for hook-and-line fisheries. Fuel costs represent the dominant source of inefficiency across all fishery types.

Meta-frontier results indicate that the relative importance of structural and managerial inefficiencies varies across regions, suggesting that uniform policy measures are unlikely to be effective.

When extrapolated to the national level, approximately 180 kt-COâ‚‚ (39.8%) could be reduced in active fisheries, 8 kt-COâ‚‚ (31.6%) in passive fisheries, and 383 kt-COâ‚‚ (35.9%) in hook-and-line fisheries. These findings indicate that roughly one-third of emissions could be mitigated through improvements in fuel-use efficiency alone, without reducing output.

Overall, integrating DEA-based productivity analysis with environmental inputâ€“output modeling provides an empirical basis for designing differentiated fisheries policies that enhance economic sustainability while contributing to climate mitigation.