A novel combined energy-material flow hybrid model under the Multifactor EEIOA Framework to study circularity and decarbonizing challenges of UK passenger transport

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The transport sector plays a vital role in socioeconomic development, enabling the vast movement of people and goods. For example, energy flows, material flows, and material stock in the form of fuels, vehicles, and infrastructure, are required for motorized mobility. In addition, 28% of the UK energy-related CO2 emissions are caused by transport, which makes this sector the more significant emitter in the country; in comparison, the industry, which is responsible for material production, accounts for 19% of all UK territorial emissions. To achieve the national targets set out by the Paris Agreement, knowledge about the generation mechanisms of CO2 emissions within the value chain of transport services is needed. However, there is still a gap in understanding the complex interplay between factors of transport-related CO2 emissions as fuel combustion during the vehicle's operations is not only responsible for them; instead, other factors such as energy conversion, material stock turnover, and service delivery also contribute.

The present study aims to identify circularity and decarbonizing challenges for passenger transport services in the UK from the understanding of the trends in resource consumption of energy and materials in 1960-2015. To do so, we develop a novel exergy input-output model of energy and materials of the value chain of transportation services, which is constructed under the Multifactor Environmentally-Extended Input-Output Framework by Guevara and Domingos (2017).In addition, we apply a Structural Decomposition Analysis approach to this model to identify the driving factors of life-cycle CO2, energy and material trends across the value chain of transport services.

This model represents better the energy and material flows and the physical transformation processes that these experience across the value chain of transport services than any other available models. Moreover, it provides a comprehensive and detailed analysis of factor decomposition effects as it characterizes the energy and material exergy trends by an integrated model of 40 factors. For comparison, other conventional input-output models have less than five factors representing the whole value chain of goods and services. In most cases, two independent models are needed to account for energy and material flows. Another innovation of the model is that it includes the useful stage of energy conversion in the economy, while conventional analysis only considers the primary and final conversion stages. The latter allows a high level of detail in structural decomposition analysis, which is highly desirable for policy design, evaluation, and improvement. The model is built with energy use data from the Energy Balances and Statistics of the International Energy Agency and material balances data from Carmona et al. (2021) and Rodrigues et al. (2022).

The results reveal that the rapid increase in carbon emissions since 1960 is primarily attributable to the increasing prevalence of automobile use and the rising demand for services (measured in passenger-kilometer). However, energy efficiency (primary-to-final and final-to-useful) for both the energy conversion chain and the material transformation chain had somewhat attenuated the relative increase in CO2 emissions related to car ownership and transport demand. Moreover, the reduction of the embodied carbon intensity of materials is also an inhibiting factor that limited CO2 emissions. In addition, the energy and material conversion processes within the Iron & Steel industry had the most significant influence on the overall CO2 emission trends of transport services compared to other industries involved. Finally, this study provides information on country-specific energy policy guidelines toward UK energy and emissions targets.