POPULAR SCIENTIFIC ABSTRACT

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[Towards sustainable road transportation systems: fleet dynamics, resource constraints, and emission pathways]

The transportation sector is critical in global climate change mitigation as it contributes to approximately one-quarter of global fuel-related carbon emissions. This share will be even higher when its embodied emissions of supportive material systems and energy systems are considered. The road transportation system, in particular, plays a significant role in providing essential mobility services to people and in reducing anthropogenic carbon emissions. A sustainable transition of the road transportation system requires high-quality mobility services with minimal resource and environmental impacts. The past few decades have seen a growing body of literature, from both demand- and technology-oriented aspects, that have been proposed, evaluated, and implemented to address such challenges. However, a systemic approach would still be needed to analyze the material and emission implications associated with fleet dynamics and various strategies to avoid burden shifting.

This thesis aims to address these challenges and has developed a dynamic, high resolution, fleet-based, and integrated modeling framework that links the vehicle's full life cycle with the material demand, energy use, and greenhouse gas emissions under different scenarios and pathways. I have used this modeling framework in four case studies involving bikes, passenger cars, and buses to demonstrate the interaction among fleet dynamics, resource constraints, and emission pathways in a sustainable road transportation transition.

In the first case study, I portrayed the first dynamic picture of car and bike stock development in 60 countries from 1962 to 2015. The results showed that both per capita bike and car ownership would increase with increasing per capita income, but they show different patterns, following largely an S-shaped curve with the increasing social-economic levels. Further, I discussed the bike use patterns and potential influence factors and explored their consequent carbon and health benefits if the global short-distance car use was shifted to bikes following the Danish and Dutch patterns.

The sharing mobility, which aims to improve fleet efficiency, has gained increasing attention in recent years. In the second case study, the sharing mobility has been explored in bike systems for over five decades, from government-dominated white bikes in Amsterdam to company-dominated dockless sharing bikes (DSBs) popping up in China. Results from characterizing stocks and flows of DSBs development in the context of regular bikes in China showed that, if well regulated, DSBs could improve stock efficiency, reduce carbon emissions, and drive the bike industry's resurgence in the future.

Widely adopted electric vehicles worldwide will help get rid of lock-in internal combustion engine vehicles and curb operational emissions, but this could lead to potential resource constraints problems. In the third case study, I employed an improved dynamic material flow analysis to characterize historical and prospective cobalt inflows and outflows in the anthropogenic cobalt cycle, and discussed the impact of battery technology development and circular economy strategies on the global and regional (e.g., China, Japan, EU, USA, the rest of the world) cobalt demand-supply balance from 1998 to 2050. Results show that battery technology advancement (e.g., with less or no cobalt) and improved cobalt recycling could mitigate the supply pressure in the near term, but inevitable cobalt supply crises will still occur before cobalt-free technologies commercialize and penetrate the market. This alerts the short window of opportunity for battery technology development and potential cobalt resource constraints in future electric vehicle diffusion.

In the last case study, I further explored China's passenger car transition from multiple dimensions and its implications on materials and operational and embodied emissions. Results showed that demand-oriented mitigation could be an effective way to reduce total emissions in the short run. Technological innovation could, on the contrary, reduce the operational and total emissions dramatically in the long run, while this may shift partial burdens to the industry and energy sectors with increasing embodied emissions. Therefore, compatible decarbonization in the industry and energy sectors could further reduce the whole transportation system emissions in the future. I conclude that neither demand- nor technology-oriented efforts alone can meet the climate target, and realizing an ambitious emission reduction requires both efforts.
In summary, this thesis highlighted the importance of demand- and technology-oriented strategies on fleet dynamics and associated materials and emissions in the short and long term using various case studies and scenarios. These results could help policymakers in different countries and sectors to prioritize their mitigation strategies, considering the local context and temporal dynamics.