***HOW CAN TRANSPORT SECTOR CONTRIBUTE TO CHINA’S CARBON NEUTRALITY GOAL BY 2060?***

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## Overview

As the world’s largest emitter of CO2, China has made a commitment to become carbon neutral by 2060 and to begin cutting its CO2 emissions within the coming decades. China’s ambitious plan to reach carbon neutrality before 2060 requires a set of actions across all sectors of the economy, such as electricity generation from zero-emission sources, expansion of clean power, and the deployment of carbon capture and storage. Because the transport sector represents a significant source of China’s CO2 emissions, developing strategies to work toward the deep decarbonization of the transport sector are critical to meet the goal of carbon neutrality before 2060. However, rapid urbanization, economic development, and growing private vehicle ownership are driving dramatic increases in passenger and freight transport activities in China, which will counteract the national efforts to decarbonize the transport sector. Moreover, because the transport sector is currently reliant on fossil fuels, the reduction of CO2 emissions from transport will be more challenging than in other sectors. Therefore, it is necessary to depict long-term pathways toward transport decarbonization, leading to the achievement of China’s carbon neutral goal. The main purpose of this study is to explore the potential role of transport sector in reducing CO2 emissions and to investigate how transport sector would contribute to the achievement of carbon neutrality in China by 2060, by using a provincial transport energy model under multiple scenarios, with varying policy assumptions.

## Methods

## To represent the regional characteristics of transport energy use instead of an aggregated overview at the national level, we developed a provincial transport energy model to project the future energy consumption and emissions of China’s ground transport sector in 31 provinces by integrating a transport demand model and an energy system model. The transport demand model was established to offer spatial flexible and temporally dynamic simulations of transport demand and modal choices. For the transport demand forecasting, panel data were employed to predict the future transport demand for passenger and freight activities at the provincial level, which contains an elaborate representation of socioeconomic driving factors like GDP, population, transport infrastructure supply such as road network, land use, and generalized transport cost. Next, the total transport demand will be split to different modes by choice model considering detailed transport behavioral and technological descriptions such as mode preference, vehicle speed, travel time, load factor, device cost, and fuel cost.

## The transport demand model was coupled with an energy system model to detect the optimal technology and energy mix, and the corresponding emissions in transport sector. A bottom-up optimization model with detailed technology selection framework associate with a technology database will be employed for describing the energy system. Technology database includes the information on lifetime, initial costs, Operation and Maintenance (O&M) costs, energy efficiency and emission factors. To satisfy a given amount of energy service demand, technology selection was modeled as a linear optimization problem with some constraints to minimize the total system costs. The transport demand model passes the mode-specific service demand to energy system model for estimating future technology mix transition, energy consumption, and CO2 emissions, while the technology mix and costs will feedback to the transport demand model for re-calculating the generalized transport cost with updated technology mix. An iterative algorithm was used to achieve the convergence of coupled transport-energy system model. This feedback loop continues until a self-consistent solution is obtained that technology mix and generalized transport cost remain constant in successive iterations. The study considered the time span of 45 years from 2015 to 2060 at 1-year intervals.

## A set of scenarios were created to project the long-term (up to 2060) trends of transport demand, modal choices, energy use and emission profiles according to the Avoid-Shift-Improve (A-S-I) framework. The A-S-I approach serves as a way to structure policy measures to reduce the environmental impact of transport sector. “Avoid” refers to the need to improve the efficiency of the transport system as a whole. Through transport-oriented and compact development of cities, the need for motorized travel and the trip length can be reduced. “Shift” refers the modal shift from the most energy consuming transport mode towards more environmentally friendly modes. “Improve” focuses on vehicle and fuel efficiency such as introducing renewable energy sources into the transport sector. According to this A-S-I approach, scenarios for representing compact city, public transport development, vehicle occupancy rate, electric vehicle promotion, and biofuel penetration were structured to predict the impacts of policy interventions on transport demand, modal shares, energy use, and emission profiles. Also, a business-as-usual scenario, which presumed the continuation of technological improvement at the current pace and the maintenance of the existing transport and energy policies, was designed to explore the potential for energy transition and emission reduction in China’s transport sector.

## Results

## To integrate the merits of transport demand model and energy system model, the numerical computation was conducted using the iterative algorithm to achieve the convergence between two models. The results showed that the discrepancies for each iteration to compare the region and mode specific cost, technology mix, and transport demand between two models decreased gradually with more iterations and were less than 10-7 after ten iterations, indicating that the model integration can achieve a convergence. After the convergence of model coupling, the technology mix transition can be captured and reflected by the transport demand model, because the transport demand and modal shares estimated by the transport demand model have been updated with the feedbacks from energy system model.

## Scenario simulation results showed that the deep decarbonization of China’s transport sector can be achieved by implementing policy interventions such as compact city, public transport development, increasing the vehicle occupancy rate, electric vehicle promotion, and the penetration of biofuel. The stringent adoption of electric vehicles presented the most significant emission reduction potential, with more than 60% of the CO2 emissions in the BaU scenario being reduced due to the EV policy, while the lowest reduction was attributed to the compact city scenario in which the CO2 emissions only can be reduced less than 10%. Moreover, the maximum emission reduction potential further increased to more than 80% compared with the BaU level by combining all scenarios, implying that the implementation of policies proposed according to the A-S-I framework can contribute to achieving the target of carbon neutrality in China. In addition, the impacts of policy measures varied spatially across 31 provinces in China, implying that the regional disparities in the policy effectiveness deserve careful attention when making transport policy and planning decisions.

## Conclusions

## This study developed a provincial transport energy model containing an elaborate transport demand model and a technology bottom-up model that considered provincial differences in socioeconomic development, population, land use, infrastructure, transport cost, and technological improvements to provide an assessment tool for estimating the future energy consumption and emissions of China’s ground transport sector. A set of scenarios was established to investigate what impacts on energy consumption and emissions at the provincial level would emerge following transport policies and how transport sector would contribute to China’s carbon neutral target by 2060. Scenario simulations indicated that the “Improvement” is the most effective way to stimulate an energy transition away from fossil fuels and reduce CO2 emissions from transport, while policies designed according to “Avoid” and “Shift” would moderately influence the energy mix and emission profiles. Province-specific policy actions might be needed to effectively promote the deep decarbonization of transport sector for achieving the carbon neutrality by 2060 because policy impacts significantly differ across 31 provinces in China.