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科研費
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研究課題名（和文）Exploring the pathways to deep decarbonization of transport sector in the post-COVID's new normal

研究課題名（英文）Exploring the pathways to deep decarbonization of transport sector in the post-COVID's new normal

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研究成果の概要（和文）：本研究は、ポストコロナの世界における交通需要、エネルギー消費、CO2排出の動態を描くために、交通モデルとエネルギーシステムモデルを組み合わせる統合的な手法を開発することを目的とした。シナリオシミュレーションは、パンデミック後の新常態における運輸部門の脱炭素化に向けた長期的な道筋を探るために行われた。シミュレーションの結果、ライフスタイルの変化によりCO2排出量が大幅に削減される一方で、交通行動の変化から生じるマイナス効果でその削減効果が部分的に相殺されることが示された。また、排出削減ポテンシャルには地域格差があり、交通運輸の脱炭素化には地域固有の政策パッケージが必要であることが示唆された。

研究成果の学術的意義や社会的意義
本研究の学術的意義はポストコロナの新常態から生じる前例のない課題と機会を考慮しつつ、エネルギーに焦点を当てた交通動態の分析方法を開発することにある。本研究の貢献は、理論的、方法論的、応用的な発展を提供するために、交通、エネルギー、気候変動という複数の研究分野に基づく学際的な研究枠組みを構築することである。さらに、研究成果は、政策立案者に対し、長期的な影響の全体像をより精緻に提供するとともに、コロナ危機がもたらす機会を活用し、運輸部門の脱炭素化に向けた動きを促すものである。

研究成果の概要（英文）：This study is aimed at developing an integrated methodology to couple a transport model with an energy system model to depict the dynamics of transport demand, energy consumption, and CO2 emissions in the post-COVID world. Scenario simulations were conducted to explore long-term pathways toward a deep decarbonization of the transport sector in the context of the post-pandemic new normal. The simulation results showed that CO2 emissions could be significantly reduced by lifestyle changes in a post-pandemic world, while the reduction potential would be partially offset by the negative effects stemming from travel behavioral changes. Moreover, regional disparities in the emission reduction potentials imply that transport decarbonization requires region-specific policy packages.

研究分野：環境学、土木計画学・交通工学

キーワード：transport sector　decarbonization　post-COVID　new normal　pathway　transport model　energy system model　scenario

## １．研究開始当初の背景

As the transport sector represents a significant part of global emissions, accounting for approximately a quarter of global energy-related greenhouse gas (GHG) emissions, developing strategies to work toward the deep decarbonization of the transport sector will be utmost critical to meet the goal of Paris Agreement. However, rapid urbanization, economic development, and growing private vehicle ownership are driving the dramatic increase in passenger and freight transport activities, which will outweigh all mitigation measures and counteract the global efforts to decarbonize the transport sector. Moreover, transport sector is currently still a major consumer of fossil fuels, although clean energy transition particularly the improvement of vehicle battery technology seemingly permits an optimistic outlook for low-carbon transport. Due to the continuing growth in transport demand and persistent reliance on fossil fuels, the reduction of global GHG emissions from transport for climate change mitigation will be more challenging than in other sectors.

The emergence and widespread prevalence of the novel coronavirus disease 2019 (COVID-19) precipitated notable transformations in global lifestyles, thereby obligating human societies to undertake substantial modifications to adapt to a post-pandemic world and embrace the concept of a “new normal”. The worldwide pandemic has had substantial far-reaching effects on travel behavior and mobility patterns. The diverse changes induced by the pandemic have expedited the adoption of sustainable planning practices in the transport sector, propelling the progression and refinement of sustainable transport systems. When heading toward the goal of carbon neutrality, the transport sector is facing a complex set of risks, threats, and challenges, but also extraordinary opportunities associated with adjustment to the post-pandemic new normal. The prevalence of COVID-19 has substantially reduced transport demand due to the increase in remote working, telecommuting, online shopping, and telehealth, which has been accompanied by a lower consumption of fossil fuel. The immediate side effects of this change in human behavior include reductions in the use of public transport and carsharing services, which have been replaced by the growing use of private travel modes. This will have an adverse effect on attempts to decarbonize transport. Therefore, understanding the opportunities and challenges for low-carbon transport development and the transition to carbon neutrality presented by post-pandemic’s new normal is an important task.

## ２．研究の目的

To explore the role of the transport sector in achieving the carbon neutral target in the context of a post-pandemic world, the main purpose of this study was to provide an overall picture of the transport dynamics and emission profiles, and to show the long-term implications for decarbonizing the transport sector in the context of a post COVID world. As this study addresses a novel and emerging trend due to the COVID-19 pandemic, its scientific significance lies in an integrated methodology for analyzing transport dynamics with an energy focus while considering the unprecedented challenges and opportunities stemming from the post-COVID new normal. To identify the pathways toward deep decarbonization of the transport sector, using China as a research example, our goal was to generate new insights into the following three research questions: (1) How will the post-COVID new normal influence travel demand, energy consumption, and carbon dioxide ($CO_2$) emissions in the long-term? (2) What policies will yield the best results for decarbonizing the transport sector in the post-COVID era? and (3) How to depict a deep decarbonization pathway for the transport sector in the post-pandemic era?

## ３．研究の方法

(1) Given the lack of real-time $CO_2$ emission data from the road transport sector, an alternative approach was developed to estimate provincial-level time-series emissions based on monthly transport demand data that included both passenger and freight transport demand in China’s 31 provinces, as well as mode share, technology mix, energy intensity, and emission factor data obtained from an energy system model. The estimation of $CO_2$ emissions from the road transport sector can be represented as a function of passenger or freight transport demand, modal structure, technology share,

energy intensity, and emission factors. To investigate how the COVID-19 crisis affects transport emissions and what are the spatiotemporal characteristics of the changes in transport emissions, a spatial autocorrelation approach and hot spot analysis were used to detect the spatial structure and spatial dependence of changes in $CO_2$ emissions from road transport.

(2) A regional transport energy model was developed to project the future energy consumption and emissions of China's ground transport sector in 31 provinces by integrating a transport model and a bottom-up, technology-rich, energy system model. The transport model was established to offer spatially flexible and temporally dynamic simulations of transport demand and modal choices. The transport demand model was coupled with an energy system model to determine the optimal technology and energy mix, and the corresponding emissions in the transport sector. A bottom-up optimization model with a detailed technology selection framework associated with a technology database was used to describe the energy system. The study considered a time span of 45 years from 2015 to 2060 at one-year intervals. Several scenarios were created to analyze transport dynamics with an energy focus when considering the challenges and opportunities arising from the post-pandemic new normal. These scenarios were defined under varying model assumptions of lifestyle changes and mobility transformations to depict transport demand, modal choices, energy use, and emissions, to determine the long-term implications of deep transport decarbonization.

(3) At the urban scale, an urban economic model was developed in the tradition of an urban spatial computable general equilibrium (CGE) model that represents the interplay between land use and transport to project future transport demands. The urban economic model was extended to incorporate detailed energy technology representations, to capture transport dynamics with an energy focus and to project energy consumption and $CO_2$ emissions. The model handles the cross-sectoral tradeoffs and interactions between location choice and transport through a series of market equilibrium conditions under which the behaviors of households and firms are defined explicitly by utility or profit maximization. The Chinese city of Changzhou was used as an example to investigate how the arrival of the post-COVID new normal will contribute to the achievement of the carbon neutral goal. A set of scenarios was structured to project the long-term (to 2060) trends of transport demand, modal choices, energy use and emission profiles in consideration of the arrival of the post-COVID new normal. These scenarios were defined under varying technological and behavioral assumptions of lifestyle changes, mobility transformations, and policy interventions.

## ４．研究成果

(1) The impacts of COVID-19 on $CO_2$ emissions from the road transport sector

Using provincial monthly transport demand data and a bottom-up approach to represent the technology mix over the period from January 2019 to December 2020, an analysis of transport-related $CO_2$ emission changes associated with the COVID-19 outbreak was conducted. The main outcomes of this study were (1) the quantification of $CO_2$ emissions from passenger and freight transport based on provincial monthly data from 2019 to 2020 and (2) a deeper understanding of the spatiotemporal dynamics of transport emissions across Chinese provinces during the COVID-19 pandemic. The national decrease in $CO_2$ emissions was clearly due to the impact of COVID-19 on China's provincial $CO_2$ emissions, and an understanding of how the situation has arisen will be useful for policymakers when proposing low-carbon transport development strategies in the post-pandemic era. The overall decrease in transport emissions was estimated to be 183 Mton in 2020, representing a 25% decrease compared with 2019, and implying a significant effect of the COVID-19 pandemic on emission reductions in China. The largest monthly reduction in 2020 was observed in February, and the most significant emission reduction in February was observed in Hubei, which was consistent with the spatial pattern of COVID-19 infections. In terms of the sectoral emissions from passenger and freight activities, passenger transport emissions were much lower than the pre-COVID level, whereas emissions produced by freight transport increased significantly with the recovery from COVID-19. This indicates that passenger transport was more sensitive to the pandemic. A regional differentiation of emission reduction potential was verified by a hot spot analysis, which proved that the emission increases were concentrated in eastern China.

(2) Opportunities and challenges of decarbonizing transport in the post-pandemic

world

The lifestyle and mobility transformations in response to the COVID-19 pandemic with the arrival of the new normal will lead to substantial changes in energy consumption and $CO_2$ emissions. The simulation results suggested a pathway toward the decarbonization of the transport sector through the positive effects of lifestyle changes, such as spending more time working from home and shopping online (Figure 1). Because remote working and e-commerce may become more prevalent and may even become a permanent feature compared with pre-COVID times, they are likely to contribute substantially to a long-term energy transition and emission reductions. However, the model findings should not be considered to be firm evidence supporting a carbon neutral roadmap for the transport sector in the post-pandemic world because it is also expected that the inevitable modal shift from public transport to private travel and the reduction in the use of car-sharing services will increase energy consumption and $CO_2$ emissions. The positive outcomes of carbon-neutral transport resulting from the new normal will be unavoidably offset by the negative effects on emission reductions, generating uncertainty and instability in the contribution of the new normal to transport decarbonization. Therefore, the tradeoffs and interactions between different scenarios need to be taken into account when proposing policies for carbon neutral transport development.

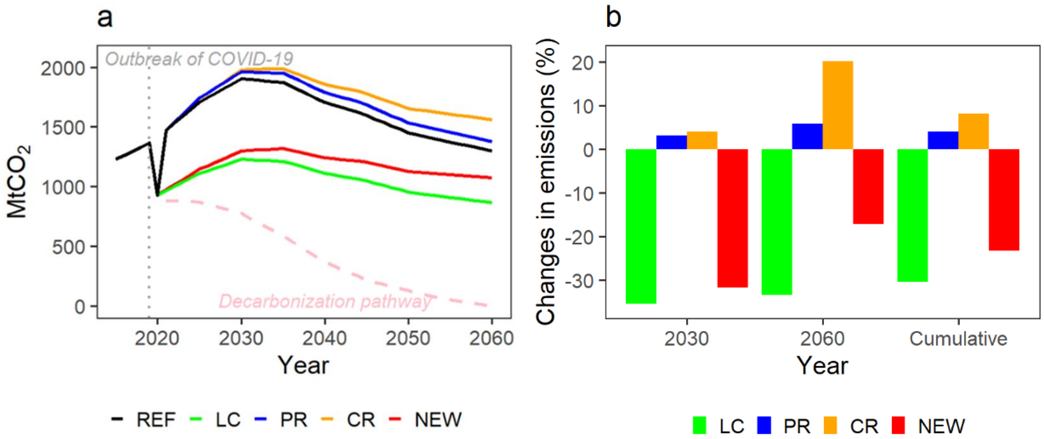


**Figure 1. $CO_2$ emissions from China's transport sector under different scenarios. (a) Emission trajectories from 2015 to 2060. (b) Emission reduction potential in 2030, 2060, and the whole period from 2015 to 2060 in four scenarios compared with the REF scenario. REF: reference scenario. LC: lifestyle change scenario. PR: public transport service reduction scenario. CR: car-sharing service reduction scenario. NEW: new normal scenario.**

The role of the transport sector in achieving the carbon neutral target in the post-pandemic era differed across China's 31 provinces (Figure 2). Rebound effects of the new normal on emission reductions were observed in developed regions and metropolitan areas, such as Beijing, Tianjin, Shanghai, and Jiangsu, implying that these regions faced great pressure to reduce emissions driven by economic development. Our findings should not be interpreted as overlooking the potential emission reductions with the oncoming new normal but, rather, should be used to highlight the regional disparities of the impacts on emission reduction and mitigation cost. The contribution of transport decarbonization to China's carbon neutrality will require a region-specific policy package for the realization of carbon-neutral transport development.

(3) Decarbonization pathways of urban transportation in the post-COVID's new normal

Our simulation results propose a low-carbon roadmap and decarbonization pathways for urban transportation (Figure 3). The results suggest a trend toward more time spent working from home and shopping online, both of which will contribute to reductions in energy consumption and $CO_2$ emissions, as remote working and online shopping are widely expected to become a more permanent feature compared to pre-COVID times. In the long-term, a bike-friendly infrastructure is also expected to positively affect the energy transition and emission reductions. The achievement of $CO_2$ emission reductions arises from decreases in travel demand, modal shifts from car to less energy-intensive modes such as public transport and active transport, and vehicle technology improvements toward less carbon-intensive fuels such as natural gas, electricity, hydrogen, and biomass. However, it is also expected that a significant shift from public transit to private cars and decreasing usage of car-sharing services will occur, which would adversely affect $CO_2$ emission reductions. Thus, the post-COVID new normal depicts an uncertain picture of transport decarbonization, ranging between worst-case and best-case scenarios. Due to the tradeoff between positive and negative effects on emission reduction, it is inappropriate to draw an overly optimistic conclusion regarding transport decarbonization in the post-COVID world.

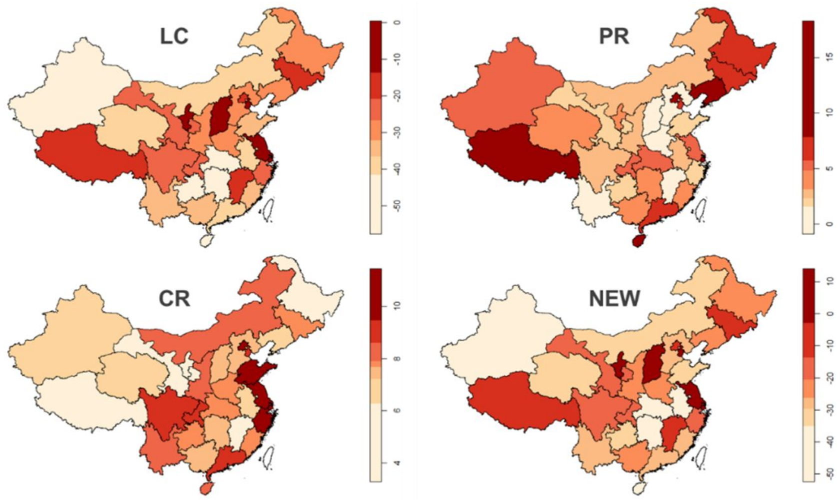


**Figure 2. Provincial differences in the changes in cumulative $CO_2$ emissions in the LC, PR, CR, and NEW scenarios compared to the REF scenario.**

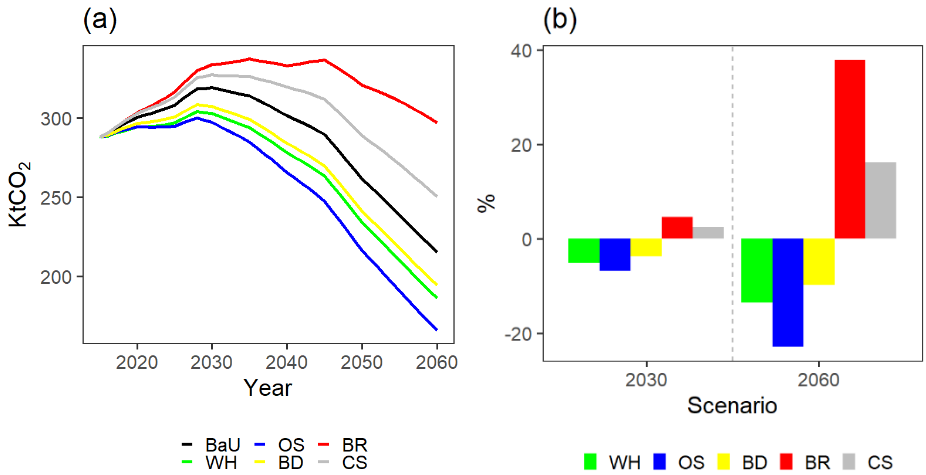


**Figure 3. Emission trajectories and emission reduction potential from 2015 to 2060 under six scenarios: business-as-usual (BaU) scenario, working-from-home (WH) scenario, online-shopping (OS) scenario, bike-friendly design (BD) scenario, bus service-reduction (BR) scenario, car-sharing service reduction (CS) scenario.**

Increasing populations in suburban and peripheral rural areas will be driven by the oncoming new normal, and such population redistribution may be accelerated when pursuing an objective of maximum emission reduction. The core-periphery relocation would facilitate urban expansion and economic development in suburban and rural areas, which may also help relieve traffic congestion and strong environmental pressure on overly high land prices and ease the imbalance between increasing land demand and the general lack of available land resources in the CBD. The new normal may overcome the disadvantages of agglomeration caused by the clustering of consumers, workers, companies, and services in urban centers, which may lead to diseconomies of scale. Meanwhile, the positive effects of agglomeration or clustering in urban central areas might be weakened by lifestyle changes such as teleworking and online shopping. Therefore, the impacts of a post-COVID new normal on urban structure and organization deserve more attention.

5．主な発表論文等

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| 1．著者名<br>Runsen Zhang, Junyi Zhang, Wenchao Wu, Tatsuya Hanaoka | 4．発行年<br>2022年 |
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〔産業財産権〕

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６．研究組織

| | 氏名<br>（ローマ字氏名）<br>（研究者番号） | 所属研究機関・部局・職<br>（機関番号） | 備考 |
|---|---|---|---|

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

| 共同研究相手国 | 相手方研究機関 | | | |
|---|---|---|---|---|
| 中国 | Shanghai Jiao Tong University | Dalian University of Technology | Sun Yat-sen University | |
| インドネシア | National Research and Innovation Agency | | | |
| 米国 | The National Bureau of Asian Research | | | |
| 中国 | Shanghai Jiao Tong University | Shanghai University | NUAA | |