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研究課題名（和文）Assessing the contribution of transport electrification to climate change mitigation: An integrated modeling methodology

研究課題名（英文）Assessing the contribution of transport electrification to climate change mitigation: An integrated modeling methodology

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研究成果の概要（和文）：本研究は、経済モデルと気候モデルを組み合わせたグローバルな運輸モデルを用いて、交通部門の電化が気候変動対策に果たす役割を明らかにした。交通機関の電化は、運輸部門の直接的なCO2排出量削減に大きな効果があるが、電力部門における気候変動緩和のための野心的な取組みがなければ、電気自動車の導入はエネルギー生産からの排出量を増加させる結果となった。さらに、交通機関の電化政策の実施により、2℃目標を達成するための炭素価格が低下していることがわかる。低い炭素価格はGDPと社会厚生の損失率を大幅に軽減することができる。EV政策は、総じてマクロ経済に与えるマイナスの影響を緩和するのに役立つと考えられる。

研究成果の学術的意義や社会的意義
本研究は、運輸部門の電化が将来の世界全体の温室効果ガス排出量や気候変動にどのような影響を与えるか、また、排出削減や気候変動緩和のためにはどのような政策や戦略が必要かを明らかにした。今回の研究は気候変動緩和に対する運輸部門の電化の貢献や、低炭素移行に向けた潜在的な解決策としてのEVの役割を過小評価するものではない。むしろ、より調和のとれた包括的な政策を策定するためには、運輸部門の電化と電力部門の相互作用が必要であることを強調している。運輸部門の電化をカーボンプライシングなどのエネルギー政策と組み合わせることで、運輸部門からの排出削減と社会全体の低炭素化の同時達成をできる可能性がある。

研究成果の概要（英文）：A global transport model coupled with an economic model and climate model was employed to investigate the role of transport electrification in global climate change mitigation. Although the direct CO2 emissions from transport sector can be reduced significantly by transport electrification, the market diffusion of electric vehicles without implementing ambitious penetration of renewable energy in the power sector leads to the result of increasing emissions from energy supply. In addition, the carbon price for achieving the target of a 2°C global temperature rise decreased due to the undertaking of an ambitious transport electrification policy. The GDP and welfare loss rate associated with pricing carbon can be thereby mitigated significantly. EV policy can help to relieve the negative impacts of climate change mitigation efforts on the macroeconomy.

研究分野：環境学、土木計画学

キーワード：transport　electrification　electric vehicles　climate change　mitigation　integrated model

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１．研究開始当初の背景

The transport sector accounts for approximately a quarter of global greenhouse gas (GHG) emissions and is one of the major sectors where emissions are still rising. Within the transport sector, road transport is by far the biggest emitter, accounting for more than half of all transport-related GHG emissions. Rapidly growing mobility needs and private vehicle ownership counteract the global efforts to reduce global GHG emissions from transport. Due to society's persistent reliance on fossil fuels, the reduction of global GHG emissions from transport to limit the magnitude or rate of long-term climate change will be more challenging than in other sectors. Low-carbon vehicles, powered by electricity, offer an alternative to conventional fossil-fuel technologies, and switching to electricity for road transport has been proposed as a significant way to reduce direct CO_2 emissions and ease the imbalance between the supply and demand of oil. Because electric vehicles (EVs) are often considered a promising technology and an attractive solution for low-carbon transport, several governments have set goals and timelines for the phase-out of diesel and then gasoline engines by 2050.

Existing studies have identified the potential market for EVs and the key factors affecting EV utilization and benefits, such as vehicle usage behavior, cost, battery weight, charging patterns, battery range limitations, and the lack of public awareness about the availability and practicality of these vehicles, the associated infrastructure, and safety regulations. Different types of EV (battery EVs, hybrid EVs, and plug-in hybrid EVs) have been compared to determine the vehicle technology that is likely to dominate in the coming decades. Because integrated assessment models (IAMs) have been extensively used to explore decarbonizing pathways in the transport sector, representations of technological advancement, consumer preferences, and increased market shares of EVs have been input to global IAMs. Current research clearly indicates the overwhelming importance of the role of transport electrification in a low-carbon transition. However, despite EVs reducing transport-related emissions and these benefits not being substantially affected by changes in travel distances, battery ranges, or charging frequencies, it is still very difficult to detect the cross-sectoral effects of transport electrification (e.g., the impact of the deployment of EVs on the CO_2 emitted by the power sector and the impact of EV penetration on mitigation costs). It remains uncertain if EVs will deliver the transition toward a green future.

Unlike internal combustion engine (ICE) vehicles, EVs do not emit carbon dioxide, but the power in their batteries must be sourced from somewhere. A transport electrification policy could produce an additional demand for electricity, which could result in an increase in emissions if the electricity is generated from fossil fuels. It would be problematic to overlook the interaction between the transport sector and other sectors (e.g., the power sector) when the deployment of EVs is implemented. The electrification of the transport sector requires the integration of vehicles into a reliable and efficient clean energy network. The associated infrastructure, i.e., suitable recharging points, is another determining condition for a fully electrified transport system. Although EVs will probably make up a significant portion of our future transport needs due to technological development and decreasing battery costs, it is necessary to investigate whether EVs are as green as they are claimed to be and what overall results transport electrification policies may have.

２．研究の目的

To investigate how transport electrification would impact emission trajectories and climate change, as well as what policies and strategies are needed for emission reduction and climate change mitigation, this study developed a global transport model to project the global transport demand of passengers and freight in terms of the choice of transport mode and its technological details to predict world transport energy use and emissions. The transport model was coupled with a global economic model and a simplified climate model to reveal the interactive mechanisms between transport electrification, economics, energy, and climate change. Such model coupling will enable electrified transport to be represented in an IAM by providing technological or behavioral factors. To explore the combined effects of transport electrification and climate change mitigation efforts, we developed a set of scenarios according to socioeconomic pathways, transport electrification strategies, and energy policies, such as carbon pricing and a high reliance on renewable energy.

３．研究の方法

A global transport model was developed to provide spatially flexible and temporally dynamic simulations of transport demand, energy use, and emissions with consideration given to various technological factors such as device cost, speed, travel time, load factor, and preferences. The model considered different distances, modes, sizes, and technologies for the global projection of passenger and freight transport demand in 17 regions around the world. Global passenger and freight transport demand was distinguished between short- and long-distance travel, and different modes, vehicle sizes, and technologies. Energy use and CO_2 emissions from transport can be estimated according to technology-wise transport demand.

The transport model was coupled with a global economic model and climate model to capture the interactions and tradeoffs between the transport sector, energy, emissions, macroeconomy, and climate change. The frameworks of the Computable General Equilibrium (CGE) model and the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) were employed for global economic and climate modeling. The CGE model was developed for 17 regions, which was consistent with the transport model. The CGE model is classified as a multi-regional, multi-sectoral, computable general equilibrium model that covers all economic goods, while considering production factor interactions. An iterative procedure was used to obtain the convergence of the coupled model. The economic model passed the macroeconomic variables to the transport model to project the transport demand, with consideration given to the modal structure and technology shares. Then, the transport demand, energy consumption from transport, and transport device cost from the transport model were fed back to the economic model to re-estimate the parameters. This loop continued until the energy consumption from transport calculated in the economic model and the transport model were equal. Next, global GHGs and other air pollutant emissions were passed to the climate model to generate climate outcomes, such as radiative forcing and global mean temperature changes.

A set of scenarios was created to investigate the long-term (to year 2100) impacts under various EV technology assumptions and energy policy schemes. These scenarios were defined according to two dimensions covering the model assumptions of transport electrification and energy policies, respectively. Transport electrification is designed based on the technological preferences for EVs, including cars, buses, two-wheelers, and small trucks, which reflect the key behavioral factors influencing consumers' willingness to purchase or select EVs. It was assumed in the HiEV scenarios that 100% EV market share will be achieved around the world by 2050 due to the EV policy incentives, while no stringent EV policy would be considered in the LoEV scenarios. In the HiEV scenarios, the parameters of the technological preferences for ICE vehicles were exogenously set to zero by 2050, while higher preference parameters were given in relation to consumer's purchasing decisions regarding EVs to achieve the target of 100% market share.

Scenarios for energy policies included carbon pricing and a preference for renewable energy. The carbon pricing scenarios considered corresponded to a 2°C climate stabilization target versus no climate action. The 'BaU' scenario assumed no climate mitigation efforts, whereas the '2D' scenario imposed a price on carbon, which was consistent with the 2°C target, with the global mean temperature increase peaking at 1.82°C in 2090 and settling at 1.8°C in 2100. The radiative forcing level associated with the 2°C target was around 2.8 Wm−2 in 2100. The renewable energy preference scenarios examined the sensitivity of high preferences on renewable energies. In the CGE model, a factor for representing renewable energy preference determined the share parameter as a logit function, which accelerated the usage of renewable energies, such as wind and solar, when a high value was used.

４．研究成果

The energy use in the transport sector indicated that the transport sector would consume more electricity if the targets for the implementation of electric road transport were achieved through scenarios HiEV_BaU, HiEV_2D, and HiEV_Renew, regardless of whether energy policies were established (Figure 1a). However, the global consumption of oil and biomass was lower with the deployment of EVs, implying that transport electrification could reduce oil dependency and the moderate demand for biofuels. Figure 1b shows the CO_2 emissions by transport mode. Without ambitious transport electrification goals, cars and trucks were major contributors to CO_2 emissions, whereas with the policy goal of 100% EVs, emissions from road transport, including cars, buses, two-wheelers, and small trucks, decreased to zero. In all the transport electrification scenarios, transport modes such as large trucks, aviation, and navigation, which are currently difficult to electrify without breakthrough efforts and technological changes, are expected to emit most emissions in the future. Moreover, the deployment of EVs (HiEV_BaU) was more effective at reducing emissions than carbon pricing without the introduction of EVs (LoEV_2D), because road transport cannot achieve zero emissions by the implementation of carbon pricing alone. A high preference for renewable energies did not have direct positive effects on emission reduction in the transport sector.

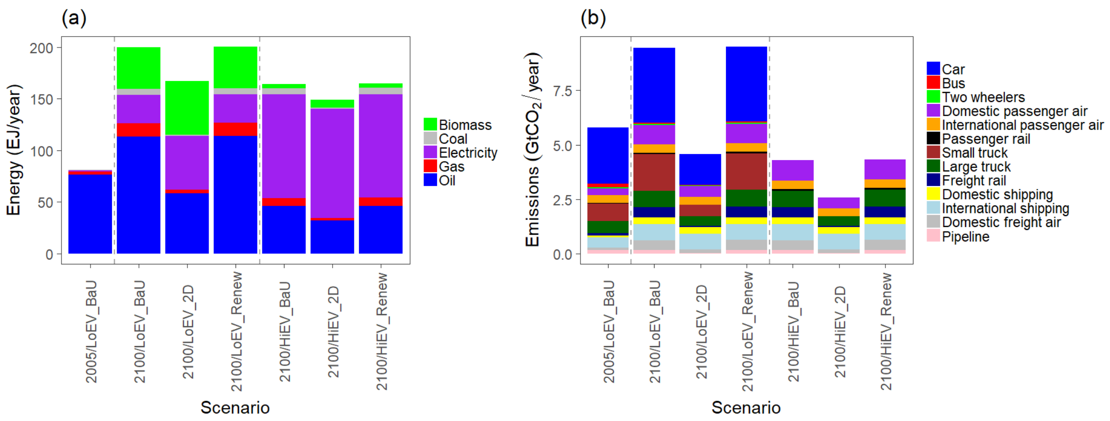

Figure 1. Effects of transport electrification on energy use and CO_2 emissions. Energy use from transport (a) and emissions from transport (b).

Despite the powerful and effective impact of transport electrification on reducing direct CO_2 emissions from the transport sector, it is unwise to reach an overly optimistic conclusion by ignoring the indirect CO_2 emissions from the electricity generation that energizes EVs. As displayed in Figure 2, the deployment of EVs increases emissions from electricity production. A comparison of HiEV_BaU with LoEV_BaU shows an increase in indirect emissions, although direct emissions decrease with the stringent penetration of EVs during 2005 to 2100. Thus, without decarbonization of the future power supply by means of energy policies, instead of a low-carbon transition, electrified transport would lead to an increase in total emissions. A high preference for renewable energy would reduce the indirect emissions to some extent, whereas a significant emission reduction could be achieved by carbon pricing.

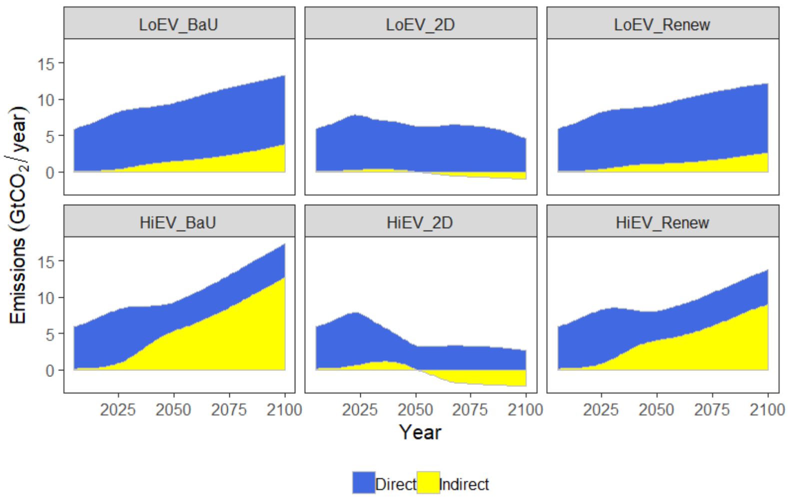

Figure 2. Direct CO_2 emissions from transport and indirect CO_2 emissions from electricity generation that energize electric vehicles (EVs).

Figure 3a presents a more detailed analysis of CO_2 emissions from the energy supply sector. Without the ambitious climate change mitigation efforts in the power sector, the deployment of EVs resulted in increased emissions from energy production. Such increases in energy supply–related emissions can be interpreted as a globally growing demand for the electricity required as a result of deploying more EVs. The emission trajectories of LoEV_2D and HiEV_2D showed that carbon pricing could significantly reduce the emissions in the energy-supply sector, because of the switch to renewable and less carbon intensive fuels. As shown in Figure 3b, deploying EVs alone could not effectively mitigate temperature increases, implying that an EV policy will not reduce CO_2 emissions from all sectors if the transport is not powered by decarbonized electricity generation.

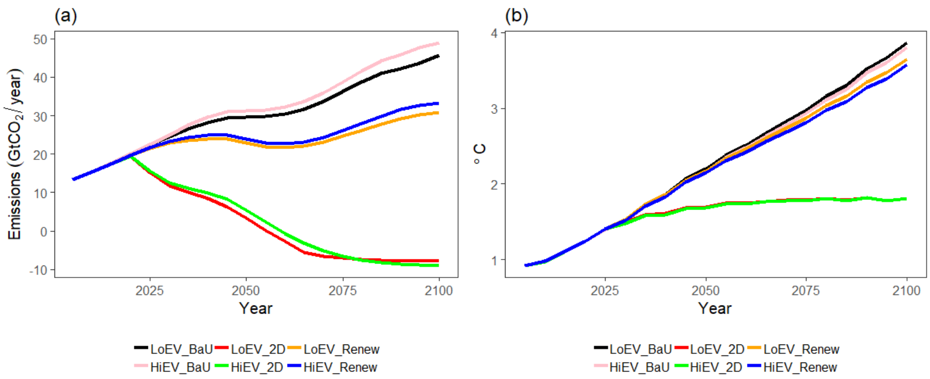

Figure 3. CO_2 emissions from the energy sector (a), and global mean temperature increase above pre-industrial levels (b).

The economic costs and benefits of transport electrification over the long term were evaluated using a global transport model coupled with an economic model, with the coupling model describing the interactions between the transport sector and macroeconomy. A measure of the economic effects of transport electrification is to detect how the cost of climate change mitigation would be modified with the stringent penetration of EVs, which can be indicated by carbon price, GDP loss rate, and welfare loss rate required to achieve an emission reduction consistent with the stabilization objective of the 2°C scenario. Figure 4 shows that the carbon price for achieving the target of a 2°C global temperature rise decreased from 1,072 to 511 USD in 2100 due to the undertaking of an ambitious transport electrification policy. The GDP and welfare loss rate associated with pricing carbon can be thereby mitigated significantly because the goal of emission reduction can be achieved more easily by electrification of the road transport sector through EVs rather than by putting a heavy price on carbon emissions. Carbon-neutral road transport can instantly contribute to the reduction of transport-related emissions by accelerating the market diffusion of EVs, which helps to relieve the negative impacts of climate change mitigation efforts on the macroeconomy. Therefore, economic development does not necessarily have to run counter to climate change policy goals when low-carbon transport technologies are taken into consideration.

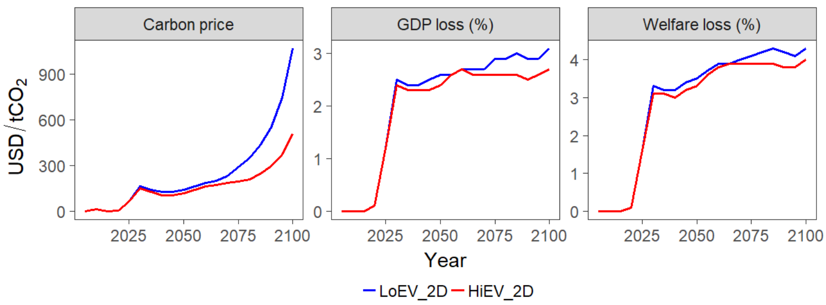

Figure 4. Mitigation cost metrics for the 2°C target.

Many governments have encouraged the adoption of EVs as an important step toward a clean energy future because of their contribution toward reducing direct emissions from transport. However, our research confirmed that an EV policy without decarbonizing power generation fails to contribute to emission reduction, although direct emissions from transport can be reduced significantly because an EV policy would shift emissions from the transport sector to the power sector. Despite the rapid technological progress made with EV technologies, an analysis of combined transport electrification and energy policies revealed an uncomfortable truth—transport electrification alone does not successfully reduce emissions and mitigate climate change. Instead, to meet stringent climate targets, the linkages between the transport sector and energy sector deserve attention. Renewable energy as a means to decarbonize power generation needs to play a key role when electrifying the transport sector. Our findings should not be interpreted to downplay the contribution of transport electrification to climate change mitigation or to deemphasize the role of EVs as a potential solution toward a low-carbon transition. Rather, we highlight the interaction required between transport electrification and the power sector to formulate more harmonized and inclusive policies. Combining transport electrification with energy policies, such as carbon pricing, could facilitate emission reductions from transport and a simultaneous transition to a low-carbon future.

５．主な発表論文等

〔雑誌論文〕　計12件（うち査読付論文　12件／うち国際共著　6件／うちオープンアクセス　5件）

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２．論文標題 The role of transport electrification in global climate change mitigation scenarios	５．発行年 2020年
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２．論文標題 Transport Electrification: A Global Simulation of the Penetration of Electric Vehicles	５．発行年 2020年
３．雑誌名 Energy Proceedings	６．最初と最後の頁 1～4
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6．研究組織

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

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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