Regional Variability and Future Trends in Carbon Footprints of Electric Vehicles in China Based on THEMIS Model

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Abstract

This study analyses how carbon footprints of electric vehicles (EVs) in China vary across regions and how they may evolve with power decarbonisation. It is understood that carbon footprints of battery electric vehicles (BEVs) depend largely on electricity mixes, but few studies have quantified their interregional divergence and future changes in China. Using THEMIS model as an integrated LCA framework, together with future electricity mixes from MESEIC, a cost optimisation model for the power sector, we calculate current and future carbon footprints of passenger vehicles in China. Results show that, carbon footprints of BEVs across all the 6 regions will drop from 265-419 gCO_2e/km in 2017 to 116-383 gCO_2e/km in 2050, or 141-266 gCO_2e/km, with stringent carbon constraints applied to the power sector. The interregional divergence of BEV carbon footprints will shrink by 20% in the latter scenario. Under carbon constraints, BEV carbon footprints in East, Central, Northwest, and South will have their best-case reduction potentials, by 55%, 55%, 46%, and 5% respectively. Stringent carbon constraints lead to increased share of coal-based generation in North and Northeast, whose most favourable reduction potentials will be 42%, and 69%, respectively, when no carbon constraints exist.

Keywords: Integrated hybrid life cycle assessment, MESEIC energy scenarios, carbon footprint, electric vehicles, regional variations

1. Introduction

As one of the world's largest emitters of greenhouse gases (GHGs), China has committed in its Nationally Deter-mined Contributions (NDCs) to capping its GHG emission and reducing emission intensity. This target can only be achieved with strengthened efforts in key sectors such as energy and transport. The upstream-downstream relation between the two sectors has been augmented by the recent development of electric vehicles (EVs). An interesting question follows is how climate impacts of EVs will evolve in the long term based on mitigating efforts in the energy sector. In addition, for a country approximately the same size as Europe, it is necessary to consider the interregional difference of such trends. Both of these necessitate life-cycle assessments (LCAs) of EVs with explicit and careful accounts of the underlying energy system.

It is established that electricity mixes play a significant role in carbon footprints of EVs (Cox, Mutel, Bauer, Mendoza Beltran, & van Vuuren, 2018; Hawkins, Singh, Majeau-Bettez, & Strømman, 2013). Earlier studies reported results in China based on regional electricity generation mixes (Huo, Zhang, Wang, Streets, & He, 2010); others assessed future carbon footprints of EVs based on a national mix (Wu et al., 2018). In this study, we linked the spatial and temporal aspects together and derived region-specific carbon footprints of battery electric vehicles (BEVs) under future energy scenarios. We performed our analysis with THEMIS, an integrated LCA framework (Gibon et al., 2015), together with regional electricity consumption mixes and locally-sourced life-cycle inventories (LCIs), to improve understanding of regional variability and trends of carbon footprints of EVs in China.

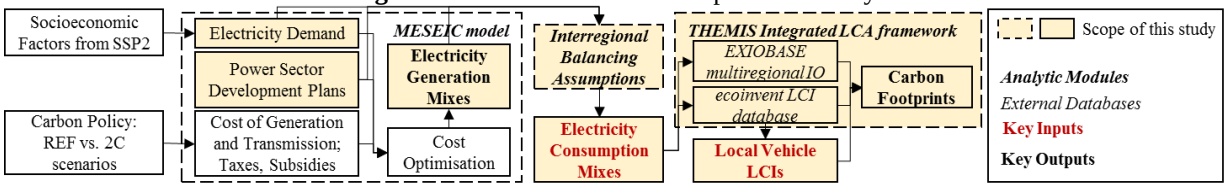
2. Methods and Data

A schematic map of this study is displayed in **Fig. 1**. For LCI inputs to THEMIS, we selected BEVs of A-size segment (wheelbase 2,600-2,750mm) as the product system assessed, with the function of providing mobility service. The functional unit is set as 1km of mobility service averaged across BEV lifespan. Manufacturing, operation, maintenance, disposal, and lithium battery are included in the assessment. All LCIs originate in China-based factories (ANL, 2018; CATARC, 2018), except for disposal processes from ecoinvent (2018). Generation mixes of 6 regions in China (largely following the region-level grid systems) were obtained from MESIEC, an optimisation model that minimises power generation and transmission costs. We chose SSP2 as the long-term socioeconomic setting, together with two scenarios, REF and 2C; the latter includes stringent constraints to carbon emission in the power sector (Cai et al., 2018). By assuming unidirectional interregional trans-mission where transmission channel exists, we obtained consumption mixes of 6 regions as inputs to THEMIS.

3. Results and Discussion

From **Fig. 2**, carbon footprints of BEVs across all 6 regions will drop from 265-419 gCO_2e/km in 2017 to 116-383 gCO_2e/km in REF, and 141-266 gCO_2e/km in 2C, respectively, as of 2050, except for South, with increased share of coal in power generation (76%) in 2050 REF. According to MESEIC, in 2050, coal-based gene-ration in North and Northeast will be higher in 2C than REF (N: 46% vs. 42%; NE: 8% vs. 0%), which results in 10-24% higher of BEV carbon footprints in 2C compared with REF and only 5% lower than the current value. The greatest reduction (369 to 116 gCO_2e/km, or by 69%) take places in Northeast 2050 REF with no coal in its generation mix and surplus in generation amounts. Despite zero local power generation from coal in 2050 2C, East and Central have 12% and 7% of coal-based power in their consumption mixes, respectively, due to interregional transmission. Our study shows that carbon footprints of EVs across regions will decrease by -45%-69% in 2050 (REF), and by 5%-61% with stringent carbon constraints introduced in the power sector (2C). The great interregional divergence in EV carbon footprints continues existing with power construction (REF), yet shrinks by around 19% under carbon constraints. Emission-reducing schemes in the power sector may lead to interregional re-allocations of power generation and transmission amounts and alter the local electricity generation and consumption mixes, which ultimately impacts the region-specific climate implications of EVs. In this regard, the climate benefits of EVs in Northwest, Central and East are enhanced by both power sector expansion and stringent carbon constraints.

Figure 1. The context and the scope of this study



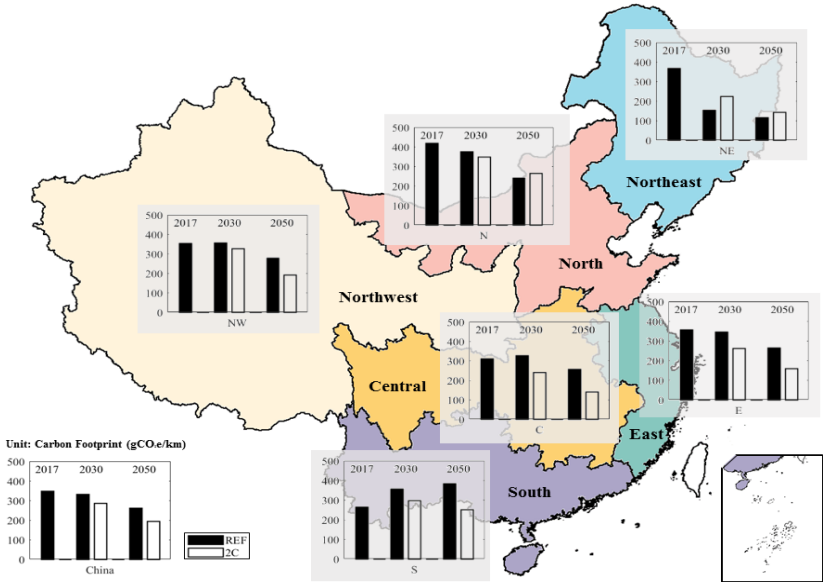


Figure 2. The interregional variations and trends of carbon footprints of electric vehicles in China

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