Pathways to decarbonize passenger car fleets – Insights from a simulation-based analysis of Germany, Poland, and Norway

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Abstract (150-200 words)

This study investigates pathways to decarbonize the passenger car fleets of Germany, Poland, and Norway, addressing the urgent need to reduce greenhouse gas (GHG) emissions in line with European Union (EU) climate targets. The research question focuses on identifying strategies that consider both tailpipe and life cycle emissions while accounting for uncertainties in vehicle adoption and energy systems. Using a dynamic stock and flow model, we simulate fleet evolution and energy system interactions from 2023 to 2050, incorporating Monte Carlo simulations to capture uncertainties in parameters such as market penetration and energy demand. Our results indicate that Norway is well-positioned to meet its emissions targets, while Germany and Poland face significant challenges due to slow vehicle turnover and low battery electric vehicle (BEV) penetration. Additionally, strategies effective in reducing tailpipe emissions do not always lead to lower life cycle emissions. This study highlights the need for tailored mitigation strategies that integrate vehicle decarbonization with renewable energy expansion, providing vital insights for policymakers and automotive manufacturers.

Introduction and Motivation

The EU's Climate Law aims for a reduction in GHG emissions targeting net-zero emissions by 2050. In this context, the transport sector is crucial, contributing nearly a quarter of GHG emissions in the EU, with passenger cars accounting for almost 60% of transport emissions. While strategies like multimodal transport and car sharing have been discussed, private car ownership continues to grow, complicating efforts to reduce emissions. Existing studies on decarbonization pathways often focus on new vehicle sales and overlook the current vehicle stock. Therefore, our research focuses on identifying effective national strategies for achieving these targets by assessing life cycle GHG emissions of the whole vehicle fleet while accounting for uncertainties.

Applied Method

We analyze decarbonization pathways for passenger car fleets in Germany, Poland, and Norway, focusing on tailpipe and life cycle GHG emissions. A dynamic stock and flow model simulates fleet evolution in connection with the energy sector from 2023 to 2050, categorizing vehicles by powertrain type and by segment. The model uses country-specific data regarding vehicle fleet composition, market dynamics, and energy mix, while a Monte Carlo simulation captures uncertainties, varying parameters like market penetration rates and changes in mobility demand. The simulation outcomes identify effective transformation pathways, assessing the impact on GHG emissions and broader energy system implications.

Results

Our results indicate that Norway is well-positioned to meet tailpipe GHG targets, achieving compliance in over 99% of simulations, due to its high renewable energy share and BEV adoption. Germany, however, faces significant challenges, meeting its target in only 2.7% of scenarios, requiring a high BEV market share and an internal combustion engine vehicle (ICEV) ban by 2035. Poland struggles the most, failing to meet its targets in any scenario due to slow vehicle turnover and low BEV penetration. Moreover, strategies effective at reducing tailpipe emissions do not always equate to lower life cycle emissions, illustrating potential burden shifting. Norway achieves better life cycle outcomes, while Poland faces high residual emissions due to older vehicles and limited renewables. Significant renewable energy expansion is necessary, particularly for Germany (peak demand renewable energy: 356 TWh in 2037) and Poland (peak demand renewable energy: 172 TWh in 2043).

Conclusions

Our findings suggest that effective GHG reduction strategies vary significantly among European countries, influenced by progress in transitioning to BEVs and renewable energy. Even advanced nations like Norway and Germany face ambitious linear tailpipe emission targets. Country-specific emission budgets can improve flexibility in achieving these targets, although it is unlikely that tailpipe emissions will reach zero by 2050, necessitating compensation for residual emissions. However, solely focusing on tailpipe emissions can lead to misleading incentives and potential burden shifting. Effective measures include increasing BEV sales, implementing ICEV sales bans, and promoting rapid fleet renewal. Additionally, ramping up renewable energy is essential for minimizing life cycle emissions, while e-fuels may support decarbonization of the existing vehicle fleet, despite production limitations. Our study highlights significant differences in mitigation drivers across countries, offering insights for automotive manufacturers and policymakers toward climate-neutral pathways.