The competition of zero-emission vehicle technologies in road freight

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Overview

Commercial road-freight vehicles play an important role in decarbonizing the transport sector (Noll et al., 2022). In the passenger vehicle sector, a transition to zero-carbon drive-technologies is not only imminent, but the transitional technology itself is largely determined—battery electric vehicles (EVs) are poised to corner the market (IEA, 2020). Though we expect a similar transitional timeline to follow in the commercial vehicle sector, it remains uncertain which specific low-carbon technologies (e.g., battery electric or hydrogen fuel cell) will become prevalent, at what time, and in which specific applications. To address this uncertainty we develop a system-dynamics model to project the competition of technologies for road-freight vehicles. We represent different market segments and global regions, which are linked through technological and geographical spillovers. The outputs of this model offer both the market share forecasts themselves as well as a comprehensive analysis tool, with which policy makers may use for evaluation of appropriate intervention points to assess the energy transition in the road freight sector.

While there exist a handful of models that project market shares of road-freight vehicle drive-technologies, they are largely nationally or sub-nationally focused, consider only select vehicle drive-technologies, and do not include the effects of cost reductions from endogenous capacity deployment or technology advancements in outside markets (Fulton et al., 2009; ICCT, 2012; Seitz and Terzidis, 2014). We address these gaps by modeling a number of drive-technology options in specific application segments and global regions to capture positive feedback from experiential learning and exogenous market spillovers as well as to consider key global markets, namely the US, the EU, China, India and Brazil, which offer further insights into the future development and prevalence of alternative drive-technologies.

Methods

At the core of the model are the following key insights: competition between drive-technologies is modeled by way of investor simulation and the resulting endogenized system feedback. First, we assess the initial degree of competition between drive-technologies (i.e. diesel, battery-electric, fuel cell electric, etc.) in different application segments (i.e. light-duty urban, heavy-duty long-haul) by comparing the total cost of ownership (TCO) of a vehicle (Noll et al., 2022). A probabilistic discrete choice simulation of independent investors then determines the selection of specific drive-technologies. It is assumed that the drive-technology with the lowest TCO would be the most attractive to a rational commercial investor.

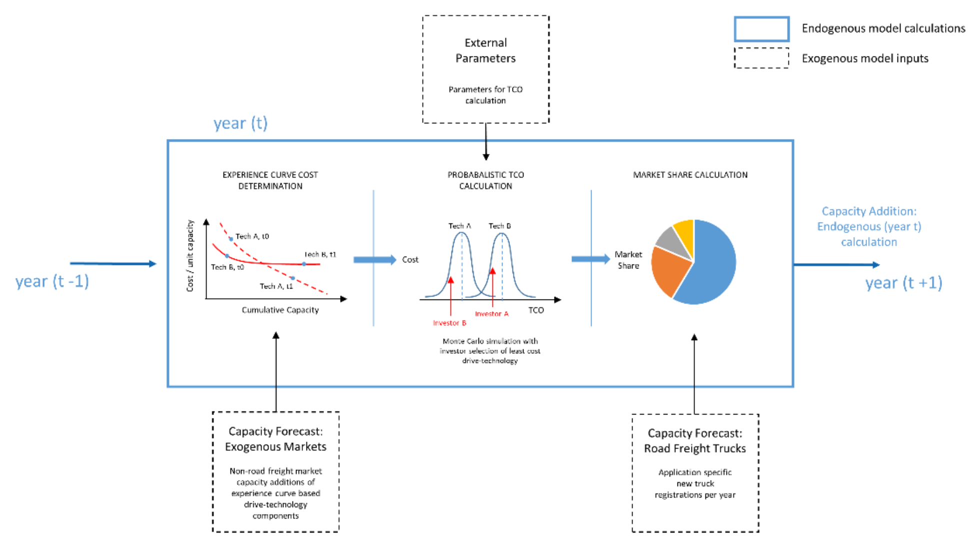

Figure 1. Schematic of the system-dynamics model that uses experience curves and investor simulation to project market shares of alternative drive-technologies in different road-freight application segments and global regions.

Next, investor simulation and selection enables endogenized system feedback. Market share diffusion of low-carbon drive-technologies is dependent upon experience curve-based cost projections (Figure 1) (Nykvist and Nilsson, 2015; Schmidt et al., 2017). Technology costs move down along their respective experience curves when total deployment capacity is increased due to larger market shares (Arthur, 1989; Mowery and Rosenberg, 1979; Schmidt et al., 2016). Similarly, exogenous feedback from external market spillovers also drives down costs along their experience curves (Beuse et al., 2020). Deployment of lithium-ion batteries, for example, in other prominent sectors, such as passenger EVs or stationary storage, extends the maturity of the technology and thus "spills over" to the road-freight sector by way of reduced battery costs.

Results and Conclusion

Our preliminary results show high market share projections of battery electric drive-technologies. For application segments with higher operating expenditure, such as low- or medium-duty application segments with lower energy storage capacities, competitiveness of battery electric vehicles is apparent already within the next five years. For application segments with higher capital expenditure, such as heavy-duty long haul segments with large energy storage requirements, high market shares of battery electric vehicles are realized later. Spillovers between modeled segments and regions as well as from exogenous markets seem highly relevant. We discuss these results' implications for policy makers and sustainability transitions modelers. To enable the low-carbon transport transition in the road-freight sector, assistance from policy-makers is paramount—market forces alone will not suffice, especially in global regions where existing high-emission vehicles are cheap and low-emission charging infrastructure sparse. Strategic policy intervention is therefore required.

References

Arthur, W.B., 1989. Competing Technologies, Increasing Returns, and Lock-In by Historical Events. Econ. J. 99, 116–131.

Beuse, M., Steffen, B., Schmidt, T.S., 2020. Projecting the Competition between Energy-Storage Technologies in the Electricity Sector. Joule 4, 2162–2184. https://doi.org/10.1016/j.joule.2020.07.017

Fulton, L., Cazzola, P., Cuenot, F., 2009. IEA Mobility Model (MoMo) and its use in the ETP 2008. Energy Policy 37, 3758–3768. https://doi.org/10.1016/J.ENPOL.2009.07.065

ICCT, 2012. Global Transportation Roadmap Model. Icct 48.

IEA, 2020. Global EV Outlook 2020. Paris.

Mowery, D., Rosenberg, N., 1979. The influence of market demand upon innovation: a critical review of some recent empirical studies. Res. Policy 8, 102–153.

Noll, B., del Val, S., Schmidt, T.S., Steffen, B., 2022. Analyzing the competitiveness of low-carbon drive-technologies in road-freight: A total cost of ownership analysis in Europe. Appl. Energy 306, 118079. https://doi.org/10.1016/J.APENERGY.2021.118079

Nykvist, B., Nilsson, M., 2015. Rapidly falling costs of battery packs for electric vehicles. Nat. Clim. Chang. 5, 329–332. https://doi.org/10.1038/nclimate2564

Schmidt, O., Hawkes, A., Gambhir, A., Staffell, I., 2017. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110. https://doi.org/10.1038/nenergy.2017.110

Schmidt, T.S., Battke, B., Grosspietsch, D., Hoffmann, V.H., 2016. Do deployment policies pick technologies by (not) picking applications? A simulation of investment decisions in technologies with multiple applications. Res. Policy 45, 1965–1983. https://doi.org/10.1016/j.respol.2016.07.001

Seitz, C., Terzidis, O., 2014. Market Penetration of Alternative Powertrain Concepts in Heavy Commercial Vehicles: A System Dynamics Approach.