What is the effect of charging infrastructure availability on electric truck adoption? An egg-chicken dynamics problem

Road freight transportation is a major contributor to global CO2 emissions, accounting for more than 7% of total emissions, and is expected to increase to 16% by 2050 (McKinnon, 2018). To combat this, a transition to fossil-free road freight transport is essential (McKinnon, 2018), and electric trucks are seen as a promising solution. However, one of the main challenges facing the widespread adoption of electric trucks is the lack of adequate charging infrastructure (ACEA, 2021; Swedish transport administration, 2021).

The charging problem of electric trucks is more challenging compared to light-duty passenger vehicles. This is because electric trucks have significantly larger battery sizes, higher power, and energy demands, longer charging times, and require significant changes in travel behavior (ACEA, 2021; Bassam Al-Hanahi et al., 2022).

The relationship between charging infrastructure expansion and market adoption of electric trucks is a classic example of a "chicken-and-egg" dynamics problem. Simply put, without a sufficiently dense network of charging stations, the adoption of heavy electric trucks becomes impossible, but the incentives for building charging infrastructure are low if there are no trucks that can use them. This raises the question of whether to first produce electric trucks or build charging infrastructures. Finding a solution requires a careful balance between the needs of truck manufacturers, infrastructure providers, and policymakers. Furthermore, significant time delays exist in the construction of infrastructure, including the time to perceive the level of infrastructure demand, the time for making investment decisions, and the time to construct new infrastructure. Thus, policymakers need to decide sooner to avoid a bottleneck in the system due to these time delays.

The study presents a system dynamics model that addresses the challenge of infrastructure expansion and electric truck adoption, which involves multiple stakeholders such as truck manufacturers, freight companies, charging infrastructure providers, and public authorities. The research questions include: i) how the availability of charging infrastructure will affect e-truck market adoption? ii) How could investment by public and private sectors lead to the construction of an adequate amount of chargers and prevent creating a bottleneck in the system? iii) How different policy interventions could affect the dynamic relationship within the system? The simplified version of the CLD model is presented in Figure 1, which highlights the key dynamics and feedback loops involved in the problem.

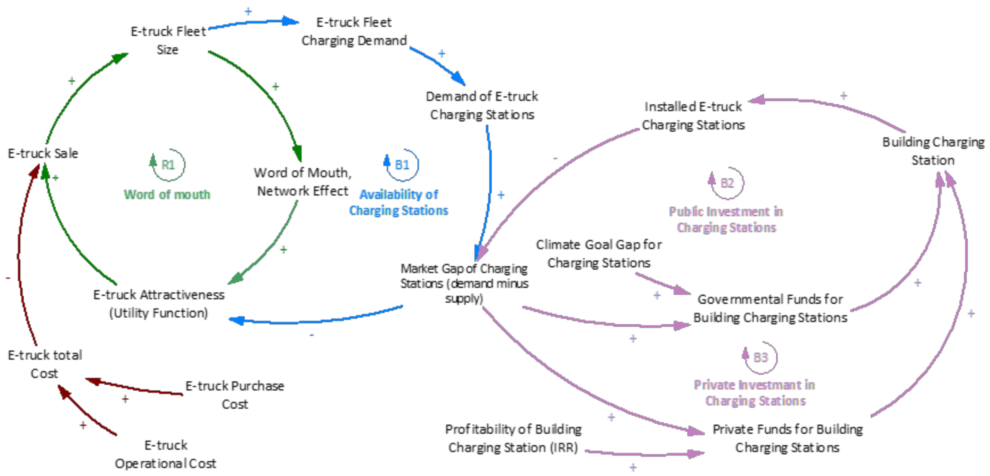

Figure 1 Simplified CLD Model Structure with Key Feedback Loops

First, the reinforcing loop of "*word of mouth*" is identified, which extends the Bass diffusion concept to include the impacts of word of mouth, marketing, and social exposure to the new vehicles (Bass et al., 1994). As e-truck sales increase, so does the e-truck fleet size. This leads to more network effects, or "*word of mouth*," which in turn increases the attractiveness of e-trucks and leads to further sales growth. This reinforcing loop will increase e-truck sales.
At the same time, the loop "*availability of charging stations*" balances this increase: As the sale and fleet size of the e-truck increase, there is more e-truck fleet charging demand. There is a market gap in the e-truck charging stations, with a lack of installed charging stations to meet the demand. This gap decreases the attractiveness of e-trucks, thereby slowing their sales growth.
To close this market gap, the balancing loops of "*public investment in charging stations*" and "*private investment in charging stations*" come into play: Both public and private sectors become willing to invest in new charging stations when the demand for charging stations outstrips the existing charging infrastructure. Filling the climate goal gap is also important for the government, while the private sector is motivated by the potential profitability of charging stations, as reflected in the Internal Rate of Return (IRR). These investments lead to the construction of more charging stations, increasing the installed charging stations and closing the market gap. As the cost of e-trucks plays a significant role in the model, we considered both the purchase and operational cost of e-trucks in our model. We calculated the ratio of "utility to price ratio" to understand how the utility rate and cost will affect e-truck sales.
The stock and flow diagram in this study comprises six interconnected modules: fleet size, utility function, charging station availability, investment, charging station cost and profitability, and vehicle cost. The model is demonstrated using Sweden's freight transport system data from 2017 to 2040, showcasing its applicability and potential impact.
Fig. 2 and Table 1 represent the model's preliminary result and demonstrate how it predicts the e-truck fleet size, charging station, and market shares, even though we are still in the phase of model validation and preparing some scenario analysis. The study's findings can help policymakers, infrastructure providers, and other stakeholders in planning for the development of heavy electric trucks and infrastructure.

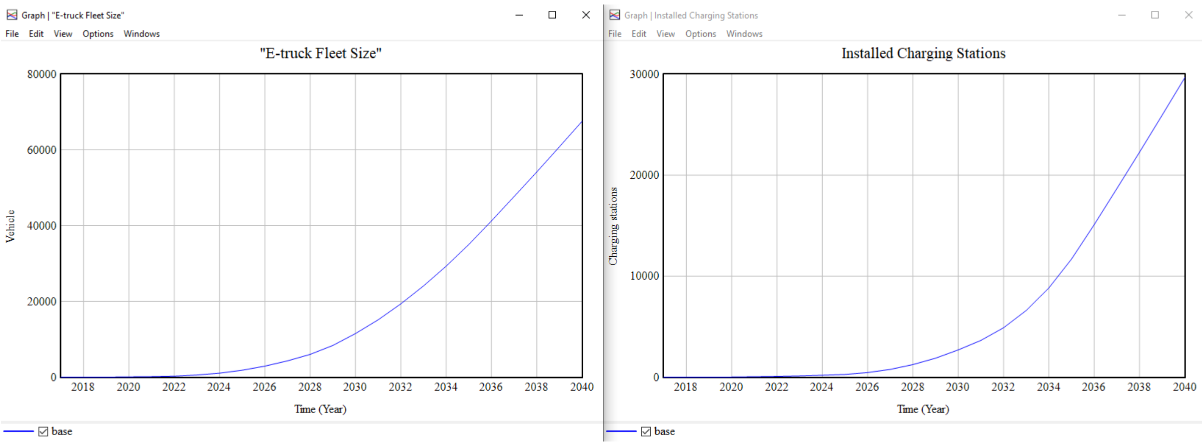

Figure 2 e-truck fleet size and installed charging station in Sweden in the base scenario.

Table 1 market share of e-truck in total fleet size and new sales in Sweden (2025-2040)

	2025	2030	2035	2040
Share of electric trucks in total fleet size	2.1%	11.9%	31.9%	53.9%
Share of electric trucks in new sales	10.5%	32.5%	57.4%	77.9%

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