System level impacts of electrification on road freight transport efficiency - *a System Dynamics approach*

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Summary

Efficiency in road freight transport is a complex concept, with different definitions depending on the stakeholders (e.g., logistics companies, recipients, or society) and the specific level of the transport system considered (e.g., infrastructure utilisation or broader social impacts like emissions). In the past, road freight transport efficiency mainly focused on cost and economic aspects: efficiency for business. However, as sustainability becomes more integral to the vision of the future transport system, a new aspect of efficiency emerges: efficiency for society. Yet, enhancing societal efficiency doesn't necessarily correspond to improving business efficiency. Therefore, being efficient in a sustainable way is a complex problem, as stakeholders in the system may have new and conflicting goals.

Within this complex system context, we explore how electrification, as a new technological trend, will impact road freight transport efficiency. Our modelling efforts aim to explore how to achieve a more sustainable system through an increase in road freight transport efficiency (both for society and business, considering the introduction of these new technologies and trends). The research questions are as follows:

1. What are the dynamics between different types of freight transport efficiency? Both at different levels (vehicle, society, etc.) and from different stakeholders' perspectives

2. How does electrification affect road freight transport efficiency?
    a. What additional parameters/stakeholders/dynamics should be considered?
    b. How do these additional parameters/stakeholders/dynamics impact road freight transport efficiency?
    c. Are there any trade-offs or rebound effects that should be considered?

3. How can we intervene in the system so that road freight transport efficiency increases and the system becomes more sustainable?
    a. What types of policies/incentives could be implemented by the public sector? (at national and/or European level)
    b. What types of decisions should different stakeholders make in the system?

We use System Dynamics (SD) as a modelling method to understand complex systems with many interacting variables and feedback loops. This methodology is particularly relevant for the road freight transport system, which involves various stakeholders. In system dynamics, Causal Loop Diagrams (CLDs) map cause-and-effect relationships and feedback loops, helping us grasp how changes in one variable affect others, either reinforcing or balancing those effects.

Our contribution is to model how different kinds of efficiencies influence each other dynamically, and to understand how electrification impacts (or adds new) dynamics to the system. Moreover, the model includes the estimation of the rebound effects between cost and transport demand (induced demand) and how electrification influences these rebound dynamics. Our model can help policy makers and transport planners to understand the dynamics of the system and make sustainable decisions. In addition, our key takeaways can be summarised as follows.

- There are several interconnections and dynamics between different kinds of efficiencies, which affect the system as a whole, as shown in Figure 1 (further elaborated in section 6.1). Our results distinguish between seven different kinds of efficiencies (explored in the model), with several

dynamics between them. The interplay between the efficiencies and the stakeholders is also shown in the picture.

- New technological trends, such as electrification, add more stakeholders and complexity to the game. In our system dynamics model, the impacts of electrification on the efficiencies mentioned above are explored. One example is that the introduction of electrification will increase the system fuel efficiency (see Figure 15), defined as the amount of energy used in the system compared with the minimum amount of energy needed. This increased efficiency showcases that the introduction of electric vehicles brings a higher system level efficiency.
- The planning strategy is a very important input to the model, that substantially changes the results. For example, the building of charging infrastructure can be based on two different planning strategies: one that relies solely on the demand from the current eclectic vehicle fleet size, without considering future sales forecasts, and another that factors in the anticipated future demand for electric vehicles. This distinction highlights the contrast between short-term and long-term investment planning in charging station infrastructure, and the results are shown in Figure 18.
- The results of the model reflect the trade-off between the availability and the utilisation of the charging infrastructure. A lower availability of charging stations results in higher utilisation, which benefits the charging infrastructure providers but impacts negatively the carriers. If more charging stations become available, the utilisation rate decreases, which instead benefits the carriers but impacts negatively the charging infrastructure providers. Due to these different impacts, there needs to be a trade-off between these two efficiency variables (Figure 16).

The main planned future work includes:

- Interviews, workshops and expert meetings to further explore the conceptual model, evaluate the performance and the accuracy of the results
- Developing the mathematical model by using validated data from the Swedish freight transport statistics
- Initial exploration of potential policies and insights on how policymakers can intervene to improve transport efficiency in a sustainable way.

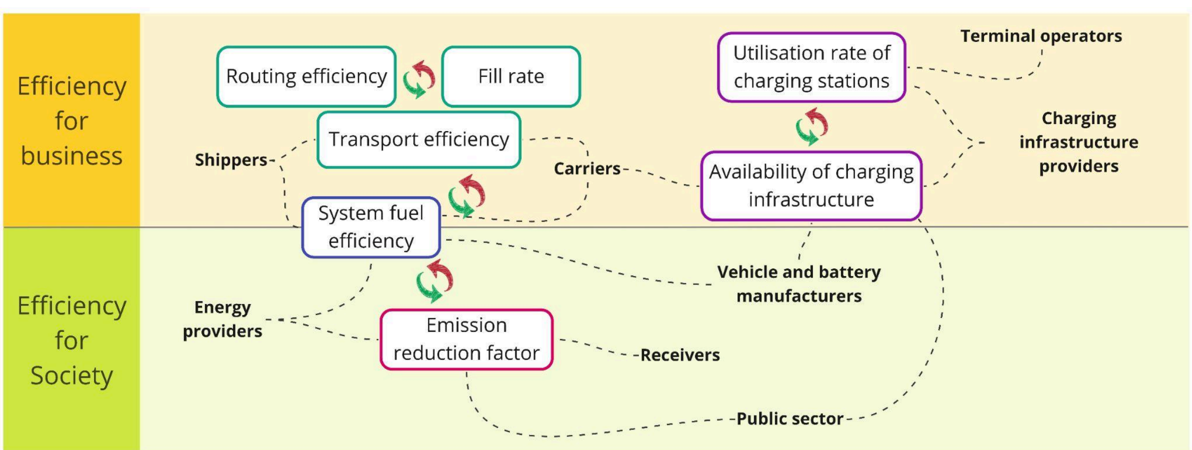

Figure 1 - In the figure, the different kinds of efficiencies are represented, divided into efficiencies for business and for society. Moreover, the connection between different stakeholders and the efficiencies is shown with dashed lines.