Decarbonising freight transport systems: the assessment of the dynamic

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Abstract

Transport decarbonisation is one of the most urgent challenges for society nowadays. The freight transport sector is one of the most difficult economic activities to decarbonize due to its expected demand increase and its heavy dependence on fossil fuels. As decarbonisation strategies have quite specific and narrow time windows to take effect, the time dependence of these effects is an essential factor to take into account. The fact that multiple stakeholders take decisions based on each other's actions with different time lags turns this system into a dynamically complex one.

The System Dynamics (SD) modelling approach was created to represent such feedbacks, lagged responses, and time dependence of effects. Therefore, SD is an important tool for the design and test of decarbonisation strategies. These characteristics contributed to its use for assessing the impact of various policies and strategies over time (Ylén and Hölttä, 2007; Maalla and Kunsch, 2008) becoming a powerful tool for policymakers to analyse complex system changes and future scenarios in different contexts. The applicability of SD for modelling transportation systems was described by Abbas and Bell (1994) and Shepherd (2014). However, Shepherd (2014) indicated the lack of sufficient research in freight transport and decarbonisation using this systematic approach.

Considering the importance and possibilities of SD to decarbonisation of freight transport systems, we carried out a systematic literature review focusing on studies that evaluate decarbonisation strategies for inter-urban freight transportation using an SD approach. We classified the selected studies using the Green Logistics Framework (McKinnon, 2018) that identifies the following main categories of decarbonisation strategies: freight transport demand, mode choice, vehicle utilization, vehicle efficiency, and alternative fuels. The TIMBER Framework (ibid.) was used to identify the external forces that can affect logistics emissions: technology, infrastructure, market, behaviour, energy, and regulation. Another important factor is the dynamics, i.e. the time lag between strategy implementation and their effects.

One of the main results we found is that no integrated model is addressing the five decarbonisation strategies together. While new policies for vehicle efficiency improvement could influence mode choice, for instance, no models including such linkages were found. Most importantly perhaps, the reported SD studies do not clarify how time-dependent behaviour is imposed in the models. This suggests the existence of a significant research gap that can be critical for climate mitigation policies for freight transport.

In this sense, we propose a causal loop diagram that involves the five decarbonisation strategies addressed in the previous literature review, highlighting the delay marks between some key variables. This simplified model is presented in Figure 1.

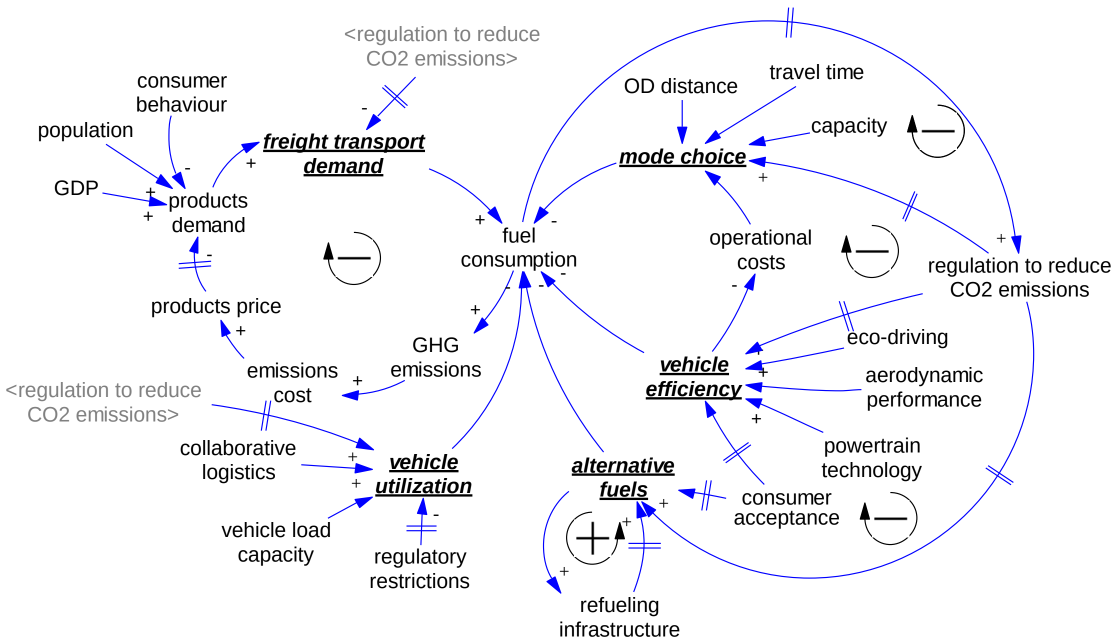

Figure 1 – Cause and effect relationships between decarbonisation strategies.

According to Figure 1, the fuel consumption is increased by the freight transport activity, but its volume also depends on mode choice, vehicle efficiency, type of fuels, and vehicle utilization. The relation between fuel consumption, greenhouse gas (GHG) emissions, emissions cost, and products price is directly proportional, considering the internalization of external costs. Such an impact could decrease products demand, and consequently, the freight transport activity. Therefore, this first loop described is negative, which means that it brings equilibrium to this subsystem.

The regulation to reduce CO_2 emissions plays an important role in all decarbonisation strategies since it enforces the change in fuel consumption patterns and no extra effort is required in regulation in this sense, reaching the equilibrium represented by the other negative feedback loops in the system.

Besides regulation, a set of other measures affects strategies for decarbonisation. The vehicle utilization can be affected by regulatory restrictions, vehicle load capacity, and new concepts of collaborative logistics. The mode choice can be influenced by distance, travel time, capacity, and operational costs. These operational costs are an example of how different decarbonisation strategies (mode choice and vehicle efficiency) are linked. Vehicle efficiency can be impelled by eco-driving, aerodynamic performance, and powertrain technology improvement, while consumer acceptance affects both vehicle efficiency and the use of alternative fuels.

A positive feedback loop is presented between refuelling infrastructure and the use of alternative fuels, indicating a reinforcing relationship and the need for investments and subsidies to impel such decarbonisation measure. As this is the only positive loop, it balances the proposed model, although the influence of each loop is not measured at this modelling stage.

Other factors that pervade the whole system are its dynamics and uncertainty, affecting all transport industry. An example is evidenced by crisis times, like due to coronavirus.

In this sense, the change in consumer patterns, for example, intervene in freight transport demand but can induce to an improvement in terms of logistics collaboration, while the decrease in oil prices bring barriers for alternative fuels and the economic crisis can postpone investments in fleet renovation, efficiency improvement, and mode shift. Such uncertainty is an important factor to be considered since the system dynamics, which is related to the time delays taken from decisions and their goals, will be very affected. Therefore, the system dynamics for the freight transport decarbonisation need to evolve incorporating the assessment of how and when the emissions mitigation policies can be achieved.

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