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Dynamic Modeling of Road Freight Battery-Electrification in Switzerland

System Dynamics Modeling as a Decision Support Tool

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Introduction

Road freight transportation is the most energy intensive mode of freight transportation per ton-kilometer, which depends on fossil fuels (Cabukoglu et al., 2017). In the recent years, there are developments to decarbonize this sector through road freight electrification. There are a variety of technologies and solution pathways such as batteries, fuel cell technology, inductive charging and overhead catenary systems, but battery-electric trucks seem to be a feasible solution for Switzerland in the next decade (Dehdarian et al., 2020).

However, there are lots of uncertainties about the technology, economic costs, policies and behavioural aspects of this technological solution. This research tries to develop a model, which can simulate the interaction between the technological and economic aspects of road battery electrification, in order to analyse the impact of different decision scenarios and business strategies on the future electrification of road freight transportation.

Methodology

System Dynamics modeling is a class of differential equation models (Rahmandad et al., 2015) that highlights dynamic problems arising in complex systems (Rahmandad and Sterman, 2008), nonlinear relationships, interdependencies, circular causality, information feedback and mutual interactions (Dehdarian, 2017). The model tries to simulate the main relevant dynamics of the system as several components, each one responsible for addressing one important aspect of these dynamics, often as a feedback loop.

Here the model has several components, and figure 1 shows a simple representation of the main dynamics of these components, known as Causal Loop Diagram. These components are the technology potentials based on the state of the art, the market potential that models the extent the technology potential could be realized in the market, combined transport electrification, as a business case to provide the initial momentum for electrification through the electrification of last mile operations, total cost of ownership of e-trucks, and purchasing price of e-trucks as an important decision factor.

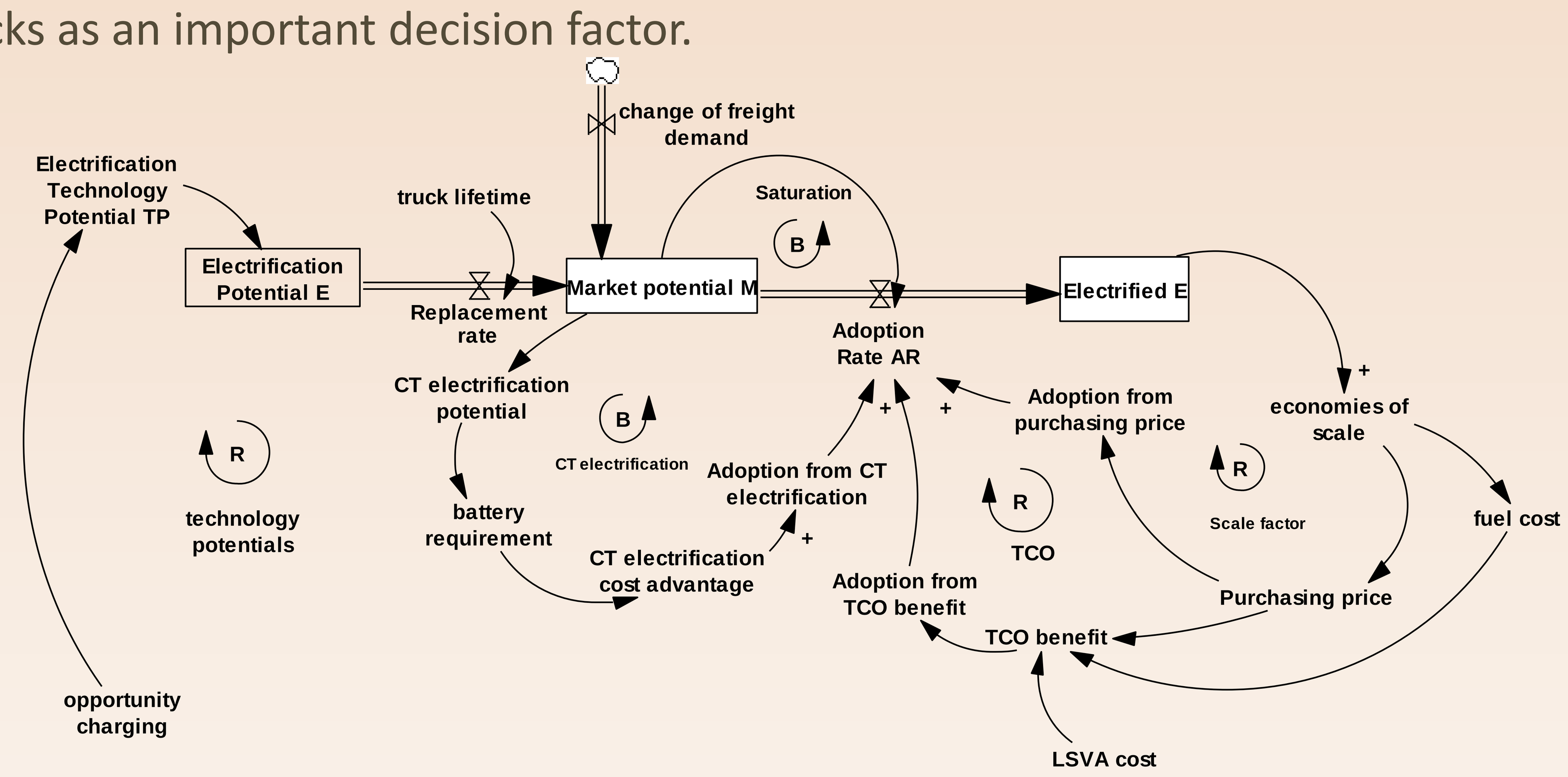

Figure 1. The Causal Loop Diagram (CLD) of road battery electrification

System Behavior

As a result of interaction between these feedback loops, the system behavior can be analyzed. The main variables in a System Dynamics model are the stock variables (boxes), that accumulate the flow variables, and behave as system memories. Figure 2 shows the behavior of these three variables under the assumption that purchasing price of e-trucks is the main decision factor to buy a truck, rather than its total cost of ownership.

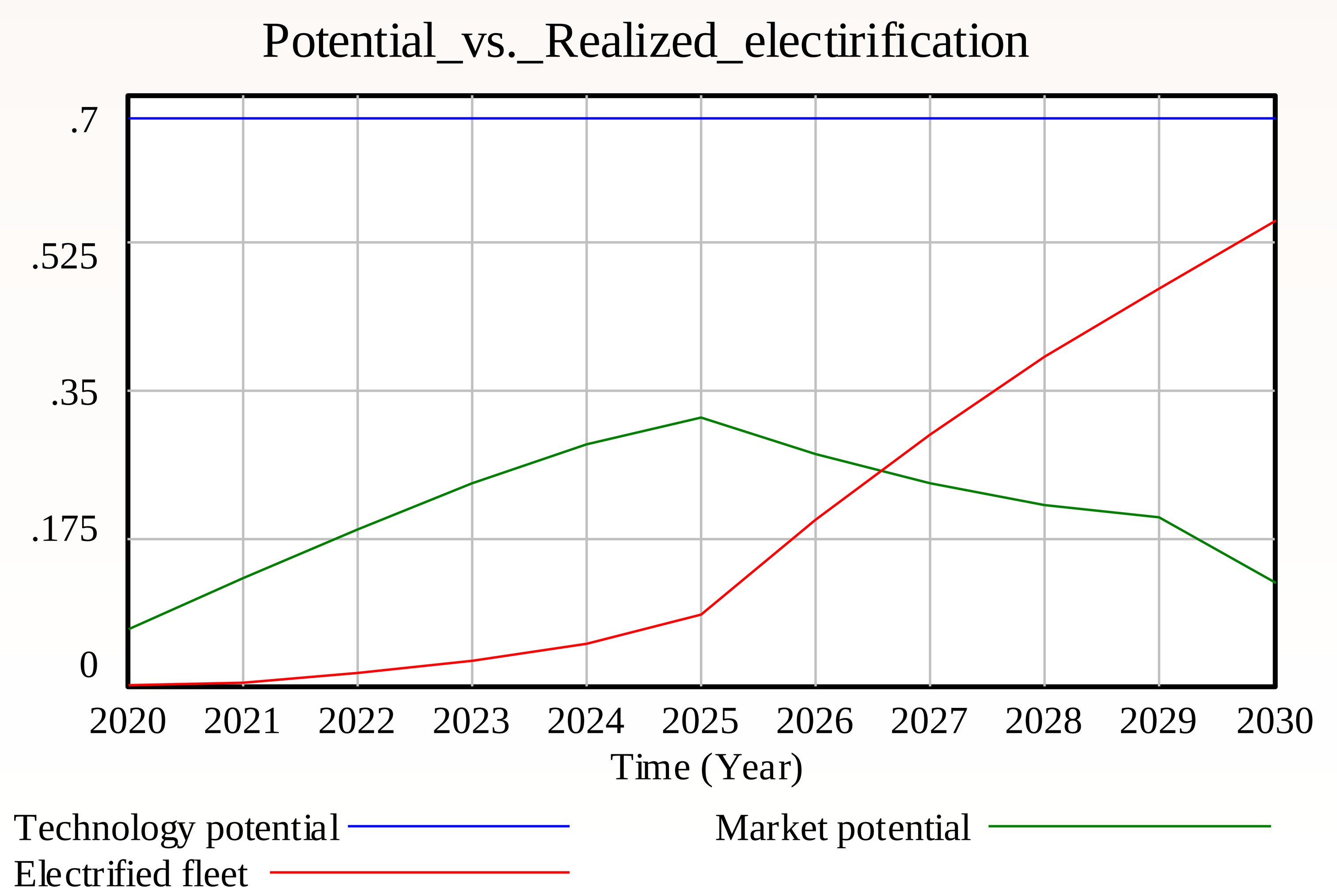

Figure 2. System behavior under the initial conditions

Modeling Scenarios

Figure 2 reveals that during the period of analysis, the electrification rate (red) is much lower than the electrification potentials (blue), although the market has unfulfilled potentials (green), simply meaning there is freight demand in the market that could be electrified based on the existing technology, but it is too expensive for truck owners to use it; especially in the early years when the economies of scale is relatively weak, up to the point some groups of trucks become economically feasible for freight operators to purchase.

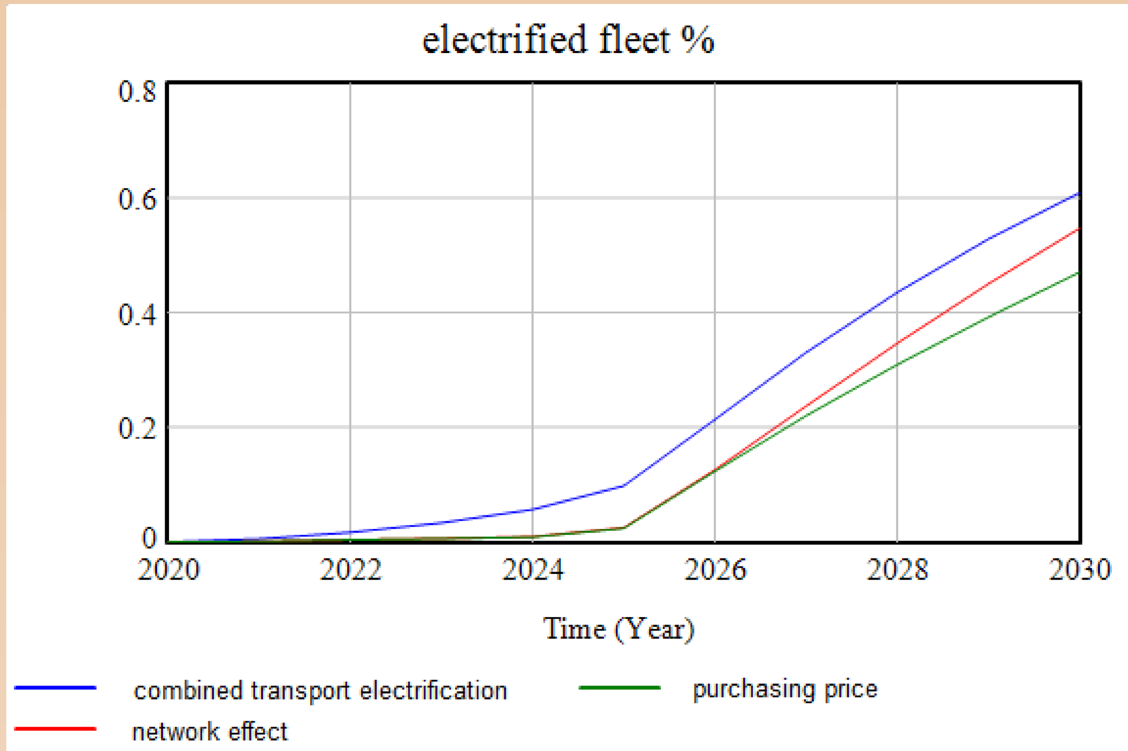

Figure 3. Modeling different decision scenarios

However, other scenarios could be modeled as well, based on other assumptions. For instance as figure 3 shows, when there is network effect, meaning that the decision to buy an electric truck depends somehow on the decision of the others to buy one, the electrification rate increases compared to our base case (red). But it cannot influence the early years that much. Another scenario to address the early years, is a business cases where some road freight operators are convinced to use a dedicated truck for the last mile of combined transport services, in order to buy a cheaper truck, which of course has limited capability. The impact is visible on the early years, as well as on the long term electrification rate (blue).

Management Cockpit

There are a variety of variables and decision factors that could be modeled. Therefore, a management cockpit was developed to enable decision makers to analyze the impact of changing scenarios based on their mental models, and look at the behavior of important variables (figure 4).

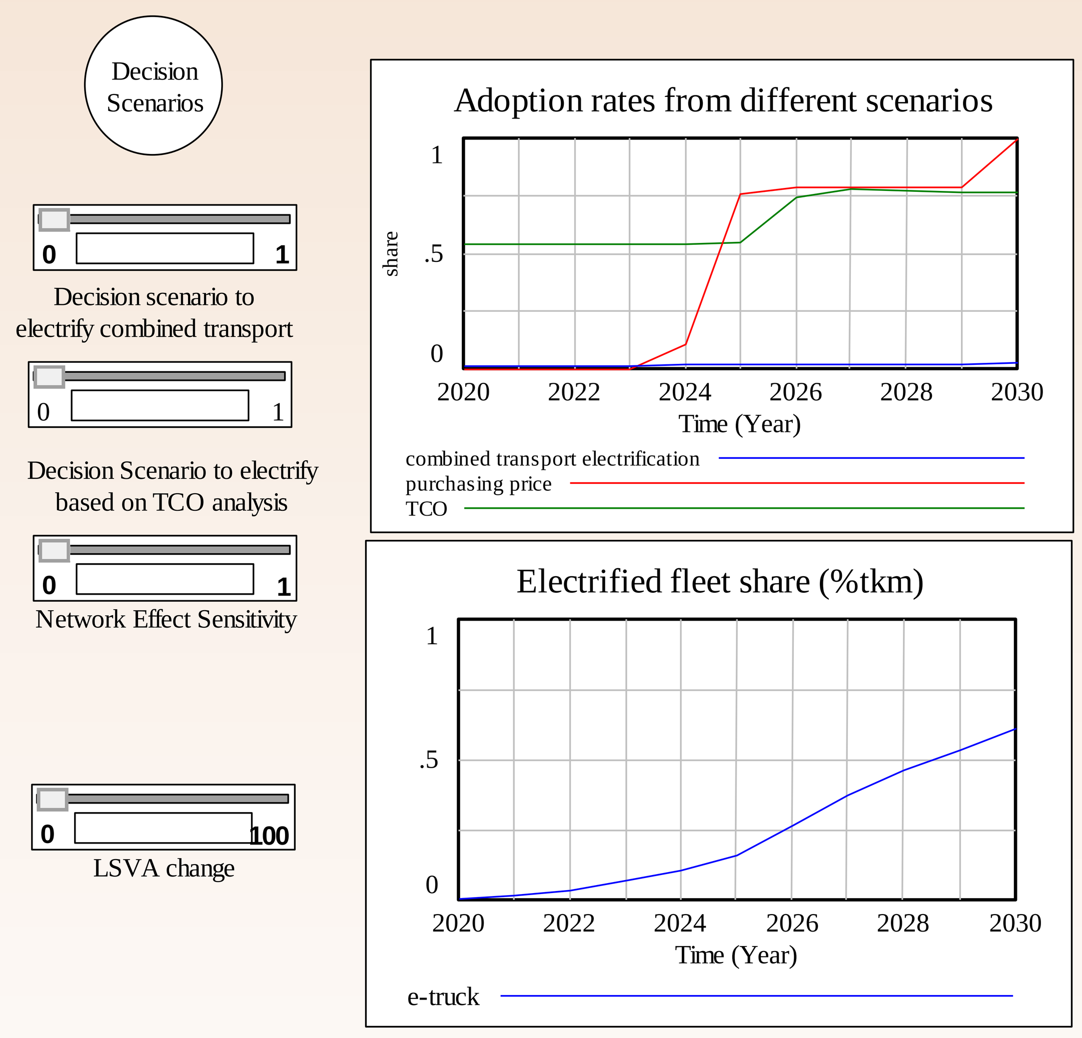

Figure 4. An example from the management cockpit

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