System-based feedback analysis of E-mobility diffusion in China

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Abstract

In the passenger car sector, purchasing decisions are driven by economic factors and acceptance. Based on cost analysis, the factors which can be attributed to different technologies are fuel costs and purchase price. The decision to buy a new car is always accompanied by comparing the costs of different alternatives. This leads to a compilation of costs and acceptance for each technology in terms of negative utility. In this study the development of the global automotive market, with a focus on China as the most important emerging market is analyzed considering both the diffusion of alternative drives and the development of car segments. The decision process on a micro level is solved by a Logit-Model. The execution within a system dynamics model allows the simulation of feedback loops. In contrast to earlier studies on future automotive markets in which the availability of key raw materials for alternative drives was not taken into account, the model presented in this paper gives an example of how to simulate feedback effects from raw material markets on the diffusion of emerging technologies. For this purpose, taking cobalt as an example, the effect of increasing battery production on the demand for raw materials and raw material pricing, including the feedback of higher battery prices on the development of electro mobility. This is accomplished by simulating two scenarios with and without the raw material feedback loop and a subsequent comparison of the results.

Introduction

Both resource efficiency and the reduction of greenhouse gases, particularly carbon dioxide emissions, are one of the major targets of future transport. In this context alternative drives will gain growing importance - not only from an economic point of view due to continuously increasing prices for fossil fuels. In this study a global mobility model (GloMo) was developed to analyze the future automotive market and the diffusion of alternative drives with regard to the economic development, population growth and prosperity, and energy and raw material pricing. The following technologies are taken into account (see Figure 1 on the left side):

- **Injection combustion engine (ICE):** Combustion engine for gasoline, diesel, compressed natural gas (CNG), liquefied petroleum gas (LPG) and bio fuels
- **Hybrid drive:** Hybrid technology recovers energy from every breaking process, which is stored in a battery and used for the electric drive.
- **Plug-in-hybrid drive (PHEV):** Also combines a combustion engine with an electric drive. In addition, it is possible to charge the battery.
- **Battery electric vehicles (BEV):** Electric drive that sources its energy from a large battery.
- **Fuel Cell:** The fuel cell transfers energy from hydrogen to electricity through a chemical reaction. Fuel cells are usually combined with electric drives.

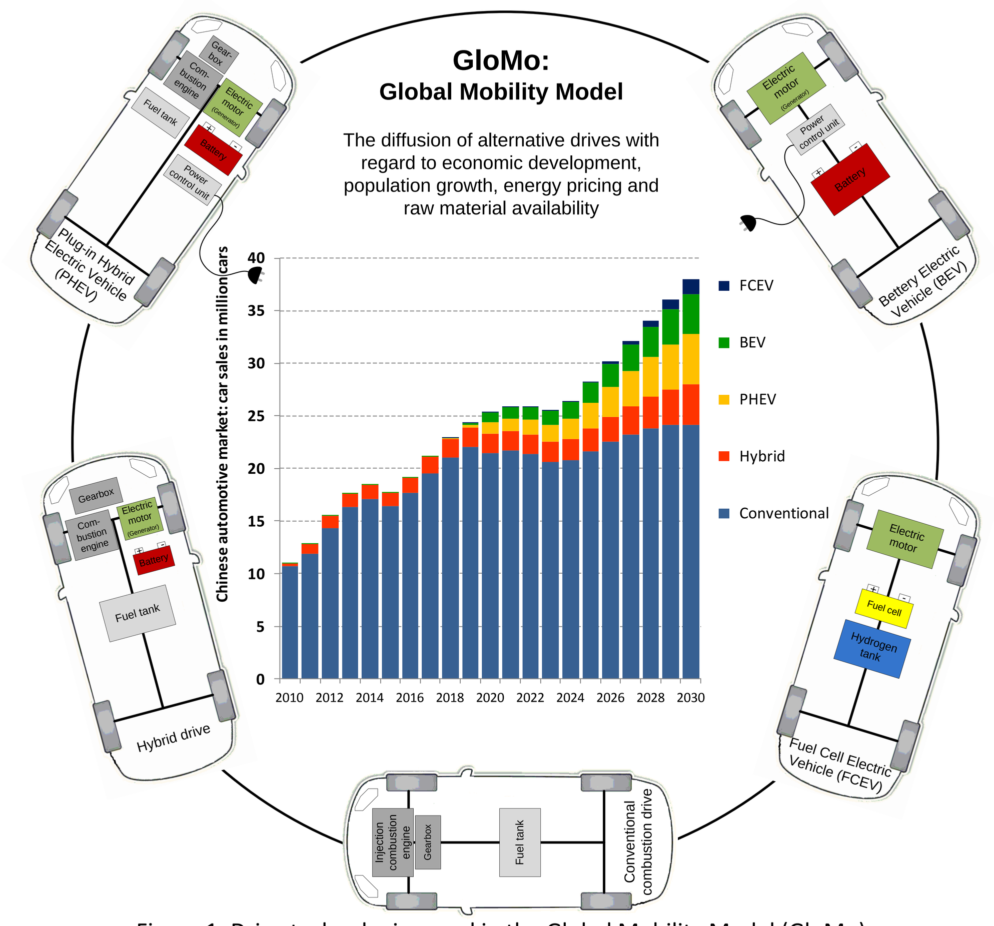

Figure 1: Drive technologies used in the Global Mobility Model (GloMo)

Methodology and model description

Model Overview:

The system dynamics model is divided into different modules, whose relations are displayed in Figure 2:

- **Economy:** Forecast of GDP growth and the key dependent income factors
- **Population:** Forecast of population and wealth (share of people living above the poverty line)
- **Purchased new cars:** Simulation of car fleet growth based on population and economy module
- **Segment & technology choice:** Total cost of ownership (TCO) and acceptance based decision within different segments
- **Fleet:** Realized as a stock model based on purchased cars, scrapped cars and fleet growth (see Figure 3)

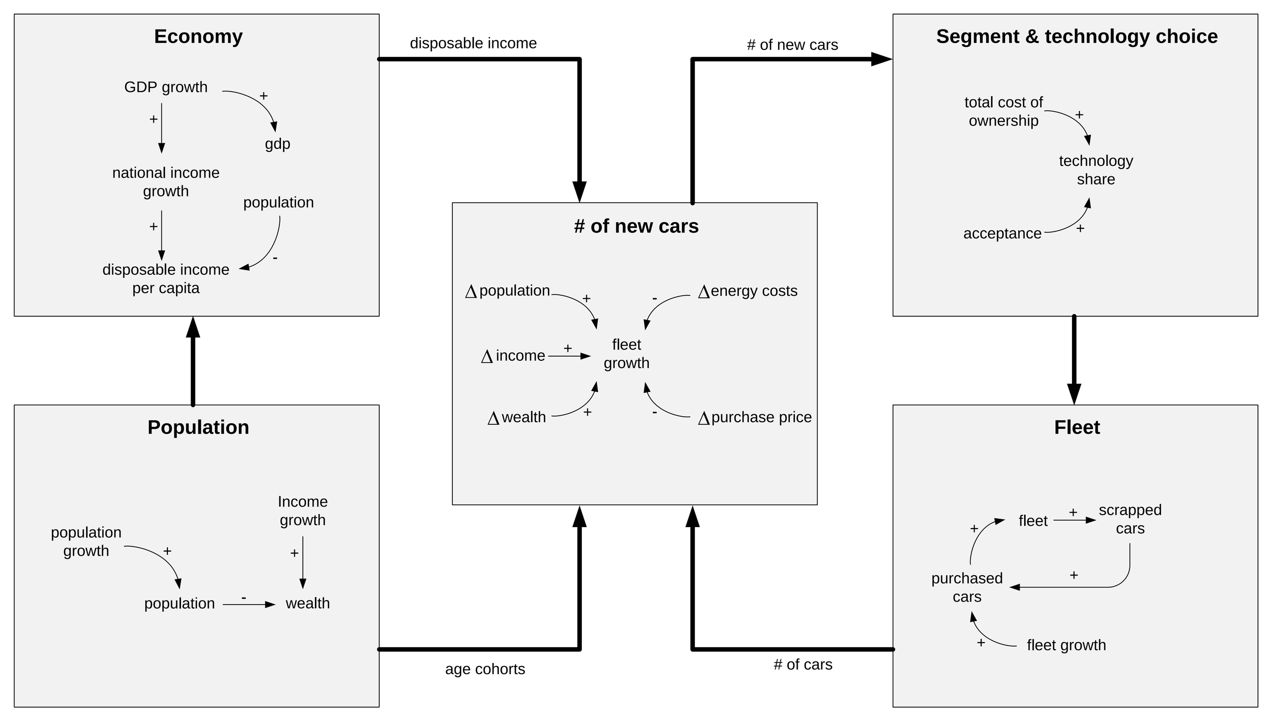

Figure 2: Overview of the Global Mobility Model (GloMo)

Discrete choice of technology and segment:

The segment and technology choice module integrates the LOGIT approach within a system dynamics environment. The LOGIT is a utility based discrete choice approach which takes TCO as well as acceptance factors into account. Different alternatives are compared with its utility (costs). The calculation is based on uncertainty due to the consumer's lack of information. The major output is the likelihood of each alternative drive to be chosen by a new car buyer.

Feedback effects:

1 **Cobalt – battery price feedback:**

The more BEV are sold the higher the demand for cobalt, the higher the price. High prices will change the decisions of the buyers towards other technologies.

2 **Car stock energy consumption feedback:**

The more cars are in the stock, the more fuel will be consumed. Higher fuel consumption leads to higher prices and hence to fewer new cars.

3 **Car price feedback:**

The more cars are sold, the higher the price for new cars due to higher raw material demand and production capacity restraints.

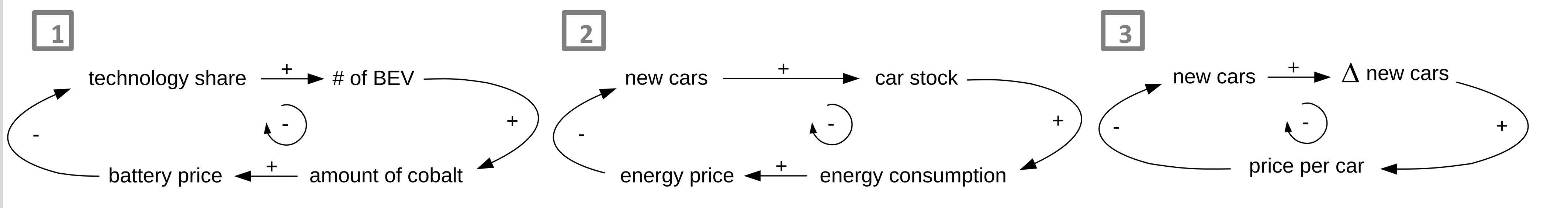

Figure 3: Feedback loops within the model

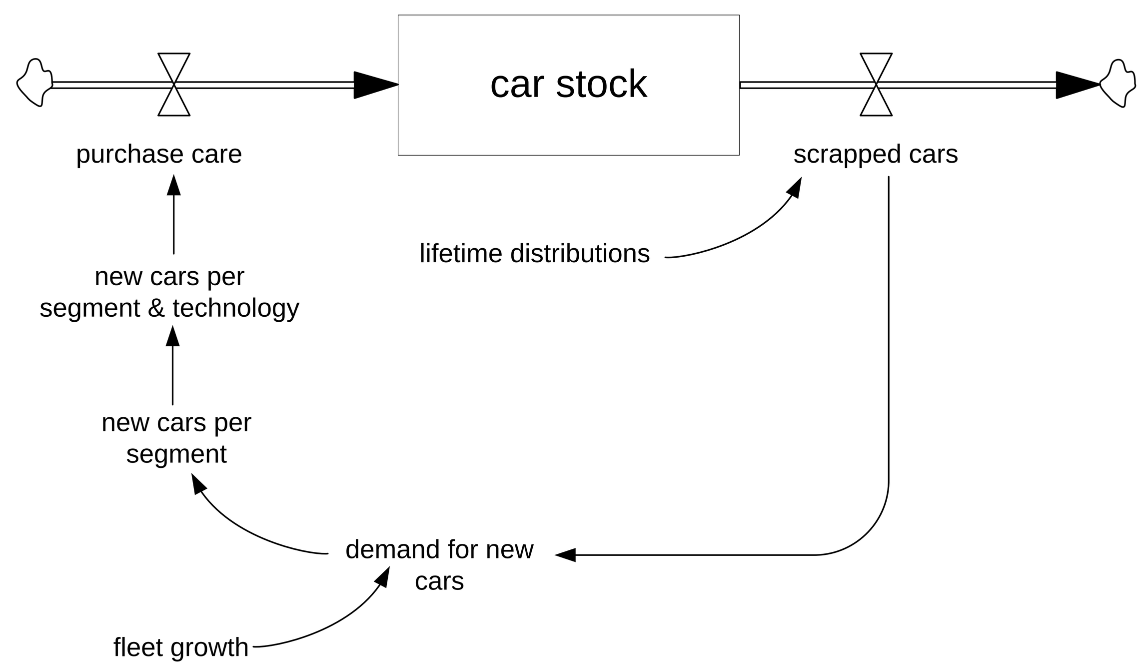

Figure 3: Detailed description of the car fleet module

Simulation results: GloMo's main output

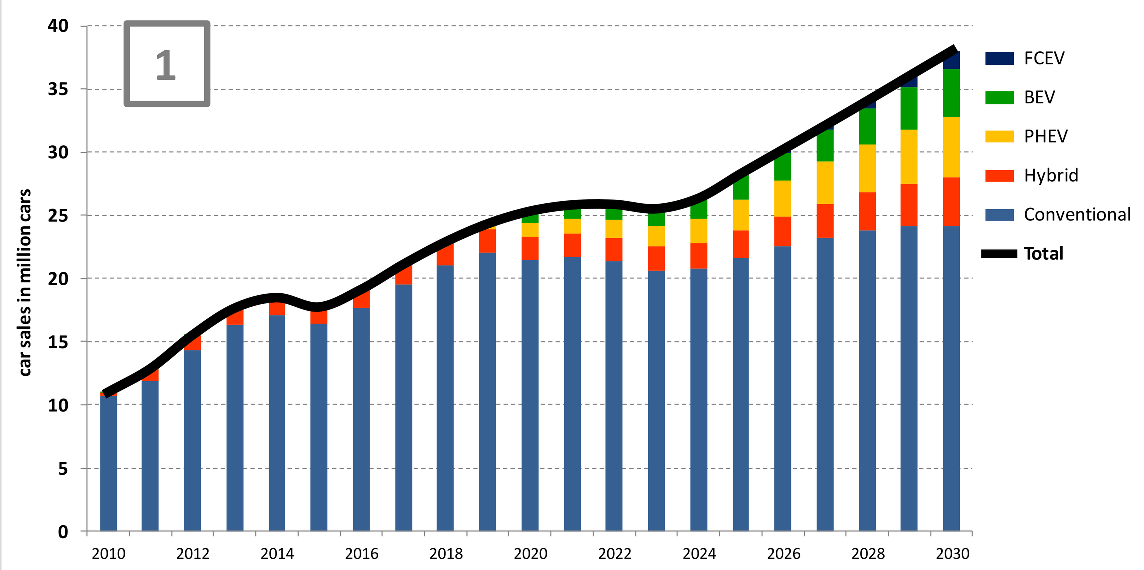

Figure 4: Forecast of the sales by technology in China

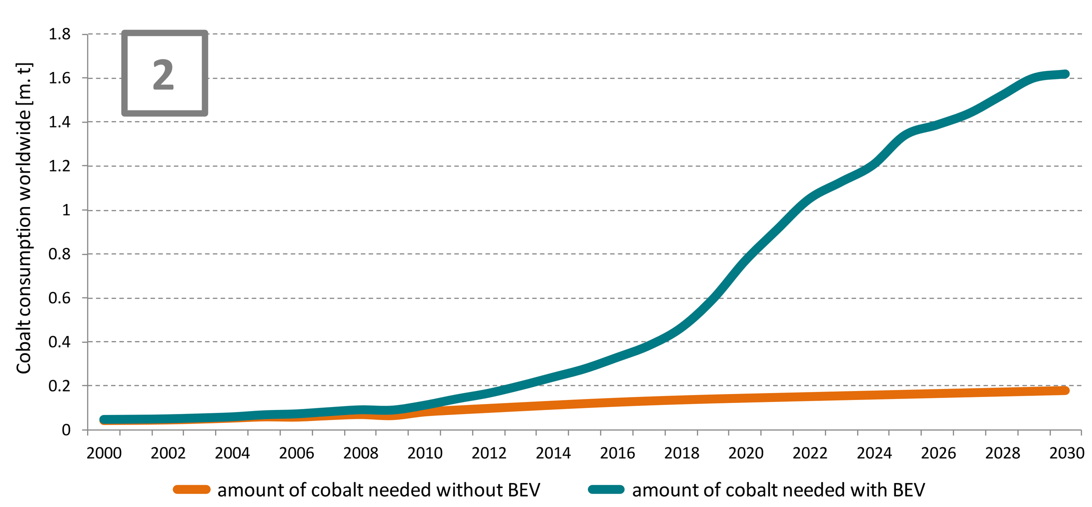

Figure 5: Worldwide cobalt consumption with and without BEV sales

1 **Simulation results baseline scenario:**

According to the baseline scenario the traditional combustion engine (ICE), with up to 60% of the total sales in 2030, will still be the dominant drive technology. As BEVs will appear in basic and small segments, the success of PHEV will be limited to bigger segments. Due to an early market stage, FCEV will remain on a low level. The total car sales in China will increase up to 37 million cars per year in 2030. Thus car sales will quadruple compared to 2010.

2 **Cobalt consumption with and without diffusion of BEV:**

The cobalt consumption of BEVs is significantly high compared to the worldwide market volume. The introduction of BEVs and PHEVs into the market will lead ti eight times as much cobalt being needed worldwide. In 2030, 1.6 Million tons of cobalt are needed to satisfy both car manufactures and other industry sectors.

3 **Price changes of cobalt under consideration:**

Due to this development, prices will change according to demand changes. Higher battery prices lead to less demand and hence a less significant decrease of the amount of cobalt. This feedback loop creates oscillating prices and demand. At the early stage of BEV introduction, the price variation from the baseline scenario with up to +22% quite high.

4 **Feedback of cobalt's price changes on BEV demand:**

The influences of price changes on demand of BEVs is rather small. Even in case of price changes up to +22% the demand for BEV varies only by -1,2% (costumers will choose other drive technologies). Reasons therefore are comparable small changes of the total car price as price changes of batteries do not change the total price of a BEV significantly.

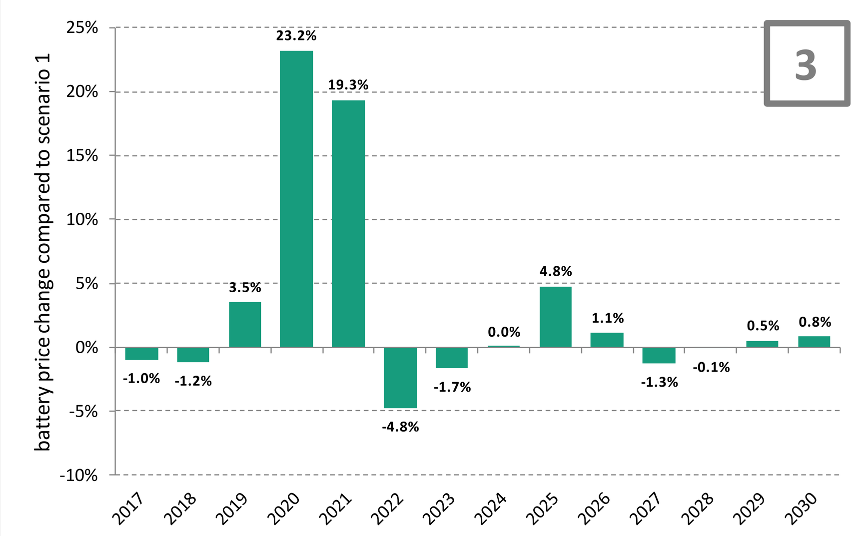

Figure 6: battery price change caused by demand changes

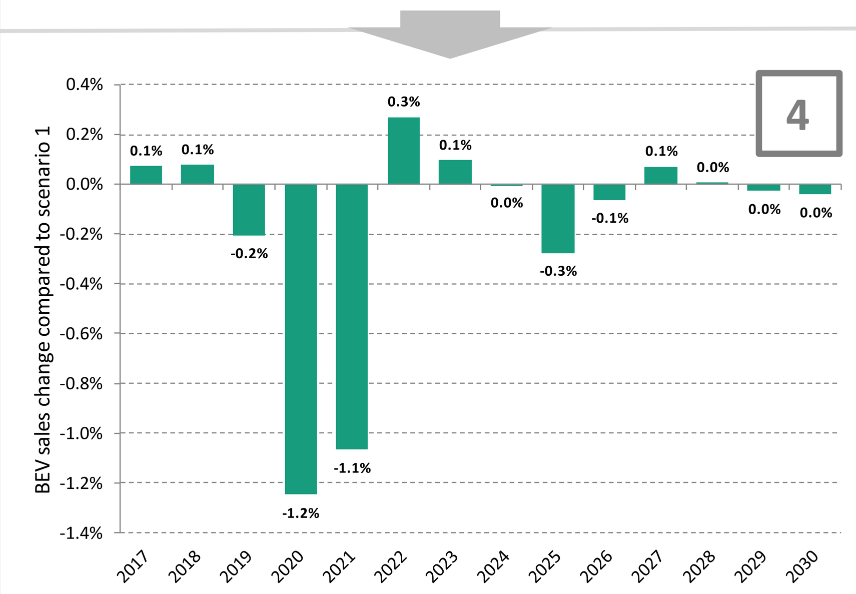

Figure 7: changes in BEV demand due to volatile battery prices

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