EV Market Development Pathways –
An Application of System Dynamics for Policy Simulation

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ABSTRACT (TWO PAGES MAXIMUM)

(1) Overview

Introduction

The transport sector is a major user of energy and a major source of emissions. In 2006, transport accounted for 27.5% of the world total final energy consumption, 23% of global energy-related CO_2 emissions and 13% of greenhouse gas (GHG) emissions (IEA, 2008). In particular, road transport (mainly road passenger) accounted for 72.9% and 74% of total transport energy use and CO_2 emissions, respectively (IPCC, 2007). In 2010, the global vehicle stock reached 1 billion units (Wards, 2011), with most of the stock relying on oil-based fuels. Various projections indicate that this figure could double or even triple by 2050 (Gomez et al., 2013). From this foreseeable trend, important energy and environmental implications can be deduced, and a challenge to improve sustainability in the road transport sector arises. One proposed technological solution towards this goal is the deployment of electric vehicles (EVs), replacing conventional internal combustion engine vehicles (ICEVs). EVs are expected to significantly contribute to oil independency and CO_2 mitigation in the road transport sector.

Objectives and Structure

The main objectives of this paper are: (a) to explore various possible future vehicle market development pathways and (b) to estimate the impacts of these developments on oil demand and CO_2 emissions. The study focuses on passenger light-duty vehicles (PLDVs)[1], with an interest in electric vehicles (EVs). In particular, the paper examines the impacts of hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), extended range electric vehicles (EREVs) and battery electric vehicles (BEVs). The geographical scope of this paper is key OECD countries (USA, France, Germany and UK), which have high motorisation rates and are currently promoting EV technology, as well as China and India, where rapid motorisation is happening (the trend is expected to continue) and interest in the deployment of EVs has been shown. The time horizon of the study extends until 2050.

The proposed structure of the paper is as follows: in Section 1 the past and current relevant trends are analysed and the argumentation in favour of the need for vehicle electrification is presented; Section 2 briefly includes the justification of the modelling approach and introduces the System Dynamics (SD) method; Section 3 shows the simulation model and its key output; in Section 4 conclusions are drawn and future lines of research presented.

(2) Methods

For the purpose of exploring the long-term development of the passenger vehicle market under various scenarios and the corresponding key energy and environmental impacts, a simulation model is developed. The method selected for this purpose is System Dynamics (SD). SD enables to simulate the dynamic behaviour of the complex road transport system and its interconnections with energy and the environment in a flexible way, and it therefore represents a plausible modelling approach for this task. SD is an approach to better understand complex dynamic systems characterised by interdependence, mutual interaction, information feedback and circular causality. The SD approach, used for policy analysis and design, involves *inter alia* the identification of independent stocks and their inflows and outflows (SDS, 2013) (Meadows and Wright, 2008). The variables of the system under analysis are interconnected forming causal feedback loops which are then, by means of the software[2], translated into a stock-and-flow structure (Bossel, 2004). Figure 1 shows a simplified version of the passenger car stock, hinting the transformation of the causal loop diagram into the stock-and-flow diagram (Sterman, 2000).

Three basic scenarios have been constructed. In Scenario 1, an extension of current trends where the presence of conventional vehicles is almost total, gasoline and diesel vehicles are considered to be the only technologies. Scenario 2 is affected by a hybridisation of the vehicle market, though PHEV/EREVs and BEVs fail to penetrate the

[1] According to IEA, this category includes automobiles, light trucks, sports utility vehicles (SUVs) and mini-vans.

[2] The Vensim® software is used for our purpose.

market. In Scenario 3, EVs experience a successful market penetration and PHEV/EREVs and BEVs progressively become the dominant vehicle technologies.

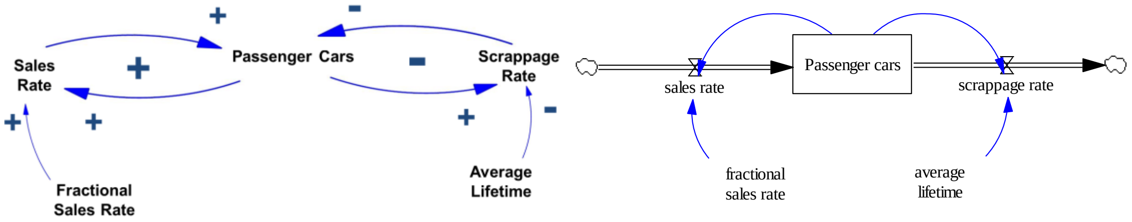

Fig. 1: Simplified causal loop (*left*) and stock-and-flow (*right*) diagrams for the car stock. Own work following Sterman (2000), using Vensim®

(3) Results

Based on those scenarios, the SD model is used to produce simulations until the year 2050. Figure 2 shows the key model output for the third scenario, indicating the impacts of its projected vehicle stock development on energy demand and CO_2 emissions. The results shown in Figure 2 include the aggregated output of the six countries analysed.

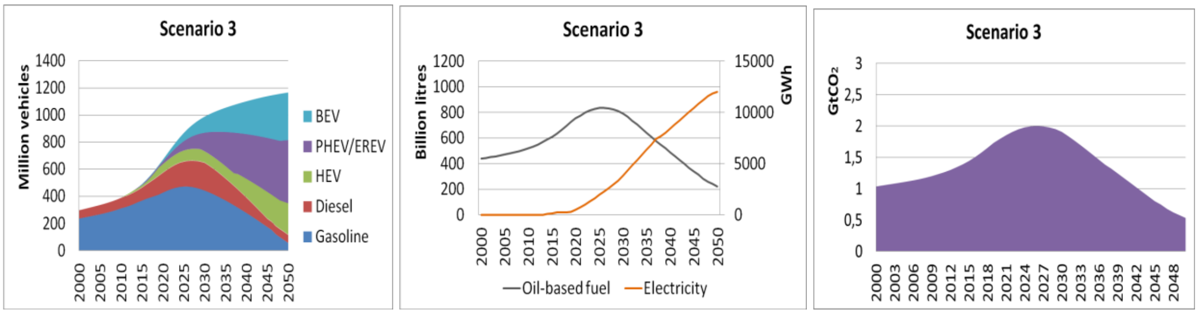

Fig. 2: Scenario 3: projected vehicle market development (*left*), energy demand (*middle*) and CO_2 emissions (*right*). Own work

(4) Conclusions

The results shown in Figure 2 indicate a remarkable increase in the vehicle stock held by the analysed countries as well as an initial steady rise in the corresponding oil demand and CO_2 emissions. These seem to peak at around the year 2030 and decline thereafter. In contrast, electricity demand grows significantly between 2020 and 2050.

Our results show that EVs can potentially achieve substantial reductions in oil consumption and CO_2 emissions beyond 2030, positively contributing to energy security and GHG mitigation. However, additional efforts in transport might be needed to contribute to the goal of limiting GHG concentration in the atmosphere to around 450 parts per million (ppm) of CO_2, limiting the global increase in temperature to 2°C and thus avoiding dangerous climate change (IPCC, 2007).

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