# Mobility and the energiewende: an environmental and economic life cycle assessment of the Swiss transport sector including developments until 2050

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# Introduction

The transport sector consumes 35% of total final energy and accounts for 37% of greenhouse gas (GHG) emissions in Switzerland. Furthermore, transport related emissions contribute significantly to fine particle, nitrogen oxide, and many other emissions that are harmful to human and ecosystem health (FSO 2014). The transport sector is reliant on energy dense, easily storable energy carriers which are currently nearly exclusively petroleum products, totaling roughly 64% of Switzerland's total petroleum consumption (FSO 2014). Due to reasons of energy security, resource scarcity, rising costs and environmental concerns, the reliance of the transportation sector on fossil fuels is expected to be reduced in the coming decades, likely with electricity or hydrogen replacing fossil fuels in many applications.

In 2011 the Swiss Federal Council and Parliament decided to move away from nuclear based electricity production and restructure the energy system to meet ambitious energy and climate goals. Resulting from this decision, the Federal Council has developed the Energy Strategy 2050, which is a long-term national energy policy based on projections of energy supply and demand as well as climate goals under three different scenarios as reported in the document "Energy Perspectives 2050" (Prognos 2012). These three scenarios define three potential futures for the Swiss energy system. The Business As Usual (BAU) scenario considers only energy policy instruments that are currently in place and that energy demand and efficiency improvements will continue to develop as they have in recent history. The Political Measures (POM) scenario considers the implementation of all political measures currently being considered by the Federal Council and that energy demand and efficiency improvements will continue to develop as they have in recent history. The New Energy Policy (NEP) scenario is the goal scenario for the Federal Council and considers a possible development until 2050 that includes a reduction of yearly $CO_2$ emissions down to 1-1.5 t per capita. By 2050, Switzerland is projected to have 9 million people, 14% more than in 2010. Final energy consumed per person in 2050 is projected to reduce by 32-53% and $CO_2$ emissions per person by 54-83%, depending on the scenario. In the same time frame, the demand for personal and goods transport is expected to increase by 23-32% and 48-57% respectively (ARE 2012, Prognos 2012). Despite this large growth in transport demand, depending on scenario, final energy consumption by transport in Switzerland is projected to reduce by 29-54% and $CO_2$ emissions by 37.7- 85.7% by 2050 compared to 2010 (Prognos 2012).

The main reason for this projected decrease in final energy consumption is that transport efficiency is expected to improve more quickly than demand will increase for all transport modes. These efficiency improvements include reducing vehicle weight, improving aerodynamics, improving engine efficiency, fuel switching, and engine hybridization. Furthermore, in the longer term, the prevalence of electric vehicles is expected to greatly increase starting around 2030 which will greatly reduce the final energy consumption of personal transport as electric vehicles are inherently more energy efficient than internal combustion vehicles (Hofer 2014, THELMA Project 2014). Furthermore, a modal shift is expected which will see increased utilization of public transport as well as the shifting from roads to rails for goods transport. The reduction of transport $CO_2$ emissions until 2050 is mainly expected due to the decrease in final energy consumption by the transport sector, but also due to the reduced $CO_2$ intensity resulting from the shift from fossil fuels to electricity, which is expected to be produced by a base of hydro power and other renewables combined with natural gas fired power plants and/or electricity imports (Prognos 2012, PSI 2012).

Large changes are expected in the Swiss transport sector in the coming decades; decisions will have to be made regarding which technologies or transport modes to support and which infrastructure should be developed. In order to fully understand the implications of the decisions made related to these changes the costs, environmental performance, and improvement potential of all current and prospective technologies should be understood to the best degree possible. The objective of this dissertation is a comprehensive analysis of the costs and environmental performance of the Swiss transport sector from 2014 to 2050 that may be used to support such decisions.

This dissertation is embedded in the Swiss Competence Center for Energy Research (SCCER) Mobility project, which aims to develop and assess technologies that will help to reduce the energy consumption and environmental impacts of transportation technologies (SCCER Mobility 2014). In particular, I will contribute to work packages B2.1 "Drivetrain Technology and Fleet Scenario Analysis" and B2.2 "Transportation Impact Analysis". These two work packages are extensions of the work done in the PhD thesis of Johannes Hofer and in project THELMA in the Technology Assessment group at PSI; while project THELMA focused only on private passenger vehicles, this work will consider all major transport modes to develop a model of the entire Swiss transport sector (THELMA Project 2014). Furthermore, this dissertation work will attempt to implement advances to the Life Cycle Assessment (LCA) methodology such as parameterized Life Cycle Inventories (LCI), dynamic LCA and consequential LCA.

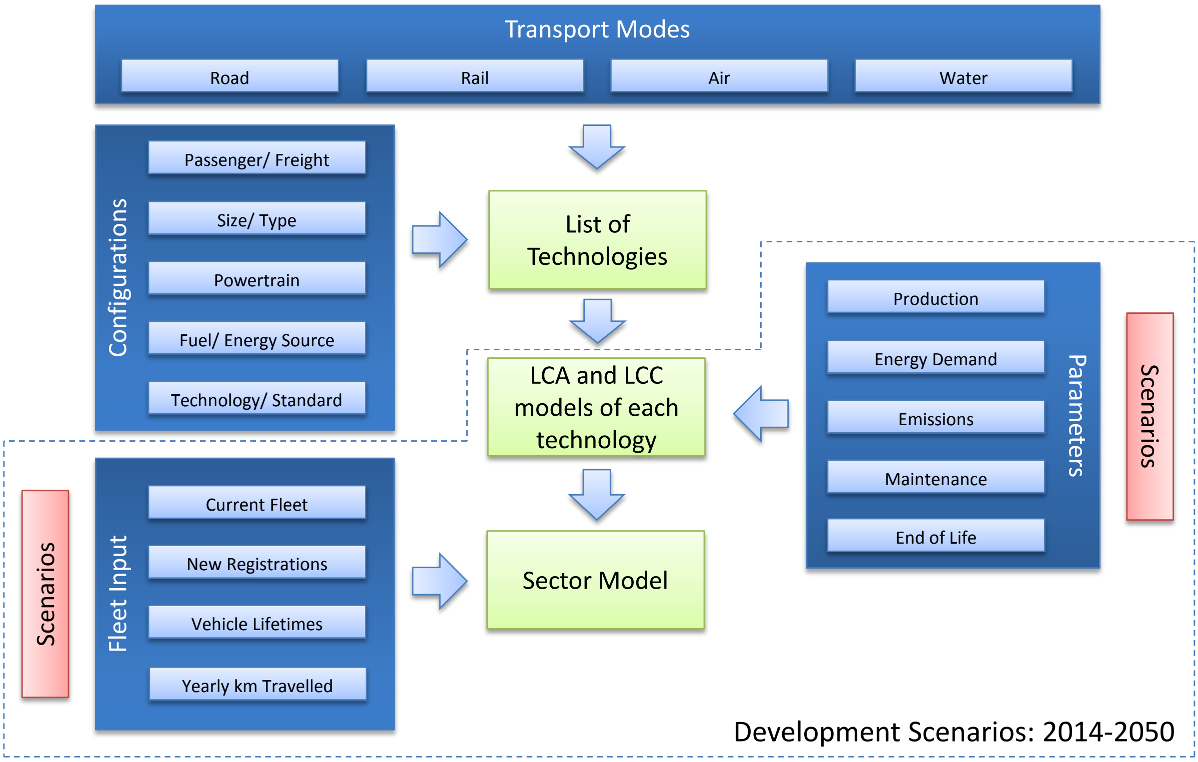
## Objectives

The main objective of this dissertation work is to develop a bottom-up economic and environmental life cycle assessment model of the entire Swiss transport sector. Figure 1 below shows a schematic of how this model will be constructed. In a first stage, this model will be developed for the current (2014) Swiss transport sector. In contrast to other sector scale models, which often consider only tailpipe emissions or tank-to-wheel energy consumption, this model will include the complete life cycle of all major freight and passenger transport technologies. The model will enable consistent economic and environmental impact comparison among all major Swiss transport alternatives while avoiding the problems of less detailed models, such as burden shifting.

In a second stage, the model will be adapted to include potential technology and fleet developments until 2050. By including base case as well as bounding scenarios, the relative potential of each transport technology to reduce costs and improve environmental performance will be explored. Furthermore, the model can be used to evaluate the feasibility of Swiss transport sector energy consumption and greenhouse gas emission goals defined by the Swiss government.

Additionally, the large amount of high quality life cycle inventory (LCI) data generated in this work will be complimented by the use of state-of-the-art LCA methodologies such as dynamic LCA (including temporal aspects into LCA) and consequential LCA (including the effects of decision making into LCA) to improve the usability of results for decision makers and to develop a more detailed understanding of the Swiss transport sector and the technologies used within it. Moreover, attempts will be made to further integrate economic indicators, such as life cycle costs, into the LCA framework.

Figure 1 Bottom-up model of Swiss transport sector




## Methodology

In order to develop a bottom-up economic and environmental model of the Swiss transport sector, life cycle assessment and cost models will first be developed for all major transport modes and technologies based on 2014 level technologies. Where possible, technologies will be disaggregated to include significant variations in parameters such as size, powertrain, energy source, and emission standard (see Figure 1 above). Furthermore, datasets will be constructed to take advantage of the new capability of ecoinvent version 3 to accept parameterized life cycle inventories that will improve the accuracy of results1. While large amounts of transport LCI data are already available in ecoinvent and internally at PSI, the level of detail and disaggregation required for this work is often not yet available. Thus, a major task at the beginning of this thesis will be to develop high quality LCI datasets for each transport technology. Among others, datasets for two-wheeled passenger transport, road public passenger transport and air freight and passenger transport have been selected for major overhauls. Sources of information for this work will include literature review, expert interviews and primary manufacturer data, where available.

The next phase of the dissertation will be to determine the number vehicles in each technology category currently operational in the Swiss fleet and the cumulative yearly distance travelled with each technology. Such information is available to a large degree from the Swiss Federal Statistical Office, and will be supplemented with data from the SBB and other transport providers. The combination of LCA and cost models for each individual transport technology and the cumulative

[1] For example, a parameterized model for the three phases of air travel: taxiing, take off/ landing, and cruising will be developed using flight length as an input variable, thereby improving accuracy of air transport inventories. Furthermore, the distinction between which emissions occur on the ground and which occur at altitude will allow improved life cycle inventory definitions. Where applicable, this method will be extended to other transport modes.

yearly distance travelled with each technology will allow an estimation of the costs and environmental impacts of the entire Swiss transport fleet in 2014.

Once the model is developed for the current conditions, it can be adapted to also consider future developments. The development potential of each individual transport technology and energy source will be included into the LCA and cost models using concepts such as technology learning curves and economies of scale with inputs based on literature review and interviews with technology development experts. With this information the relative improvements in each technology category may be examined to better understand the potential of each technology and energy source to improve environmental and cost performance. Additionally, the potential changes to the size and composition of the Swiss transport fleet will be considered by developing scenarios with parameters including transport demand, penetration rates of new technologies, vehicle lifetimes and government policies. Base case and bounding scenarios will be created for both individual technology and fleet level developments that will lead to a better understanding of the potential for and feasibility of large scale improvements to Swiss transport sector environmental and economic performance until 2050. The model can also be used to examine the feasibility of top-down mobility sector visions developed within the SCCER Mobility.

The development of such a large database of detailed and consistent transport sector LCI data will enable work to the further the development of LCA methodology, which will result in better understanding of the system being studied. For example, dynamic LCA may be used to better understand the temporal aspects of the emissions and environmental impacts due to mobility. Consequential LCA may be used to better understand the implications of potential political decisions such as the electrification of personal mobility in Switzerland, or the increased use of biomass sourced fuels for mobility. Time slots have been included in the project timeline, shown in Figure 2 below, for “advanced fleet analysis” which will be used for such methodological developments.

## Expected Results

It is expected that the following results will lead to conference presentations, journal publications, and/ or project reports during the course of the dissertation work:

- Generation of high quality disaggregated life cycle inventory and cost data for different transport technologies including different vehicle sizes, fuel types, and powertrain configurations.

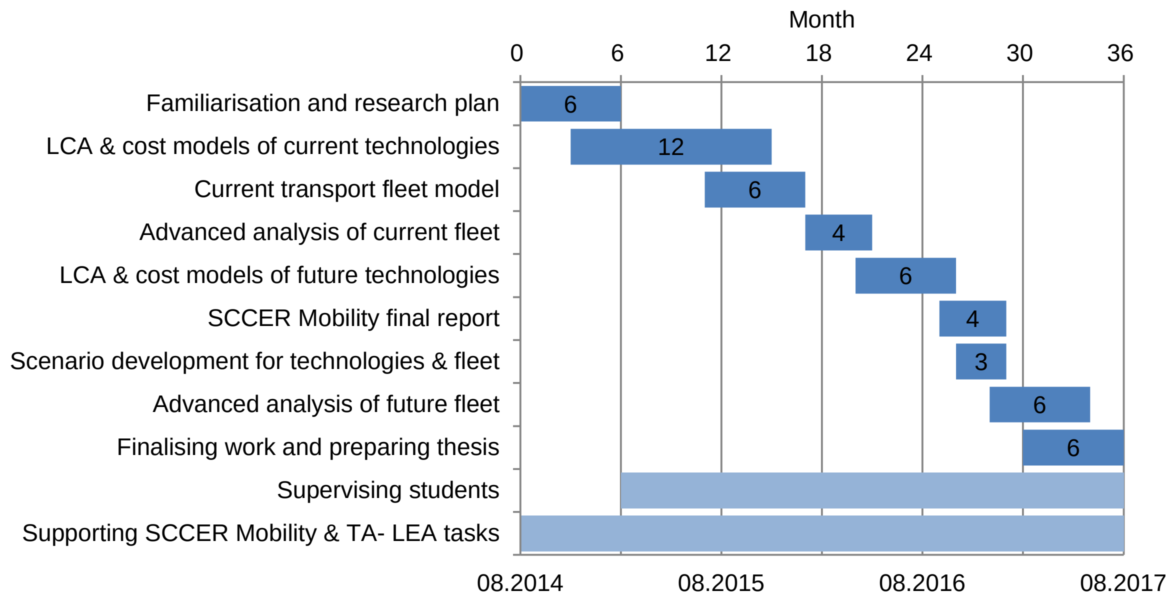
- Quantification of the costs, energy consumption and environmental impacts of the entire Swiss transport sector using life cycle assessment methodology, with a focus on the novel inclusion of embodied energy consumption and emissions.

- An analysis of the feasibility of top-down energy consumption and climate goals for the Swiss transport sector based on life cycle methodology.

- Detailed interpretation of the research findings, explicit conclusions, and their implications for policy.

# Timeline

Figure 2 Research timeline

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# Signatures

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