LCA of Energy-Efficient Passenger Transport in a Swiss Peri-Urban Region

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Abstract

The aim of this study is to assess the environmental impacts of future passenger traffic for the Toggenburg, a peri-urban region in the Eastern part of Switzerland. The inhabitants of Toggenburg generate 429 million passenger kilometers per year, 79% thereof are covered by private car another 15% by public transport. Today, this requires 213 GWh of final energy plus an additional 286 GWh of energy to supply the fuel thereby generating 70,260 tons of CO_2 equivalents. In the business-as-usual scenario for 2035 the primary energy consumption is reduced due to more efficient drive trains to 365 GWh (51,725 tons CO_2 eq.). The energy intensity in the scenarios can be further reduced by increasing electrification of the power train. In the case of light and highly efficient electric and partially electric cars and fuel efficient public transport only 161 GWh of primary energy are needed, emitting 16,360 tons CO_2 eq.

Keywords: "Life cycle assessment", "Mobility", "Scenario", "Plug-in hybrid vehicle", "Electric vehicle".

1. Introduction

Many Swiss municipalities and regions aim for a rational use of energy, an amplified utilization of renewable energy carriers and a higher degree of self-sufficiency. One motivation is the decarbonization of their urban energy system, another are ambitions to become energetically more independent. Besides housing, mobility is the major energy consumer in Switzerland and relied in 2003 by 96% on imported, fossil fuels [1]. Mobility in areas at the peripherals of Swiss cities (e.g. peri-urban) is characterized by high shares of motorized individual transport. The authorities of Toggenburg, a peri-urban region in the Eastern part of Switzerland, are aiming to achieve energy self-sufficiency in the domain by 2035, and to reach a 2,000 watt as well as 1 ton CO_2 eq. per capita society [2] by 2060. One key issue is to transform current individual mobility into a less energy intensive passenger transport system. This study shall illustrate status quo primary energy demand and greenhouse gas (GHG) emissions for the passenger transport in the region and demonstrate possible future alternatives. For the assessment a LCA model and different passenger transport scenarios for the year 2035 are developed including technological advances such as fuel efficiency gains, alternative fuels and step-wise electrification of the power train as well as the influence of changing behavioral patterns like increased participation in car sharing. Additionally the scenarios were compared to today's situation and a business-as-usual scenario for 2035. The model, developed for this study, allows for any arbitrary combination of technology scenarios. It can easily be extended with additional scenarios and adapted to other regions and circumstances. This work was carried out within the THELMA project (www.thelma-emobility.net) and funded by a range of stakeholders led by the Competence Center for Energy & Mobility and SwissElectric Research.

2. Methods

A model was developed that combines three parts: (i) traffic demand, (ii) scenario compilation, and (iii) life cycle emissions and resource use. For the assessment of sustainable mobility an accurate modeling of the traffic demand is important. In this study a top-down and a bottom-up modeling approach were applied. Mobility census data from the Swiss Federal Statistical Office [3] about average traffic demand and modes for rural areas was compared with data from the agent-based traffic simulation MATSim [4] that is able to model traffic demand and modes for each inhabitant of Toggenburg individually. Traffic demand data for public passenger transport was supplied by the regional transportation service providers.

Direct emissions of daily mobility were analyzed with data from HBEFA [5], a digital handbook of emission factors for road transport, which provides emission factors (CO_2, NH_3, N_2O, CO, HC, NO_X, and PM) and fuel demands for current and future vehicle categories (e.g. gasoline, diesel, and natural gas vehicles). Prospective fuel consumptions of hybrid, plug-in hybrid, and electric vehicles were derived from various studies from car companies. Upstream and end-of-life emissions and resource uses were modeled with data from the Ecoinvent database [6].

Assuming that total traffic demand and modes will not change significantly in the future, in a first step, technology scenarios for each vehicle category solely were developed, meaning that motorized individual transportation is provided only by one transportation technology (i.e. plug-in hybrid vehicles). This was performed for private as well as for public transport. In a second step, combined scenarios for different prospective vehicle fleet mixes were compiled in a life cycle inventory and assessed with IPCC 2007 GWP 100a [7] and CExD [8].

3. Results and Discussion

After analyzing traffic demand by means of the mobility census and MATSim it was modeled that only on weekdays, the 45,000 inhabitants of Toggenburg generate 429 million passenger kilometers per year, 79% thereof are covered by private car use another 15% by public transport (i.e. train and bus) and about 6% by non motorized transport like walking and bicycle (see Table 1). The focus was laid on weekdays, because MATSim is currently not able to model weekend traffic demand.

Table 1. Yearly weekday transport demand of Toggenburg's population.

	Mio pkm	Share
Non motorized transport	26.87	6.3%
Motorized individual transport	337.53	78.7%
Public transport (Train)	50.31	11.7%
Public transport (Bus)	14.19	3.3%
Total	428.90	100%

The demand of cumulative fossil exergy was analyzed for the technology scenarios. In these scenarios we assumed public transportation modes and technologies to the same for all and that motorized individual transport is covered only by one technology (i.e. PHEV with a electrical range of 20 km). Results in Fig. 1 show that today's weekday mobility in Toggenburg (reference scenario 2010) needs 286 GWh. In the reference scenario for the year 2035 204 GWh are needed. This reduction of 29% is achieved only by introducing more efficient internal combustion engines. Changing to only car shared private transportation would have almost the same affect, because car sharing increases the share of public transportation in the total transport demand on average by 12% [9]. A totally natural gas based car fleet would be slightly more efficient than the reference scenario (2035). The use of biogas would reduce cumulative fossil exergy demand by 87% compared to the reference scenario (2010). Partly and fully electricity based car technologies would reduce cumulative fossil exergy demand by 96% to 99% depending on the degree of electrification and efficiency of drive trains and assuming the use of the current Swiss electricity supply mix, which is almost free of fossil energy.

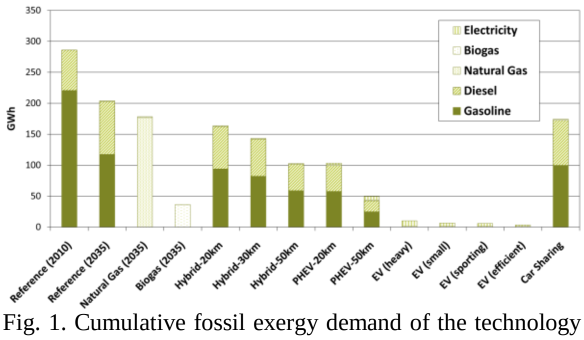

Fig. 1. Cumulative fossil exergy demand of the technology scenarios covering the yearly weekday transport demand of Toggenburg.

The one-sided technology scenarios were then compiled to reasonable but only hypothetical scenarios called: (i) Natural Gas/Biogas, (ii) Car Sharing Option, and (iii) Electric Future. Opposing to the technology scenarios in the combined scenarios the private car fleet mix consists of different technologies. Natural Gas/Biogas represents a scenario were people are driving in either gas driven or gasoline and diesel driven cars. This reduces GHG by 38% compared to the reference state (2010). The Car Sharing Option scenario with a share 25% of collectively used cars in car fleet has almost the same potential to reduce GHG as a more efficient car fleet in the reference scenario for 2035. A big leap forward would be the gradual electrification of the private car fleet. This could reduce GHG by 77% for the notional Electric Future scenario.

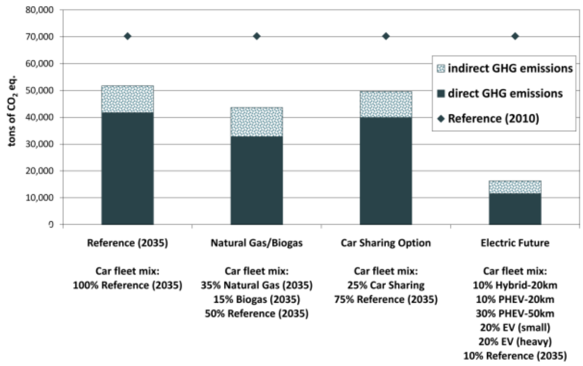

Fig. 2. Total greenhouse gas emissions of combined scenarios covering the yearly weekday transport demand of Toggenburg. Fleet mix of public transport technology is the same for all scenarios.

4. Conclusions

The goal of energy self-sufficiency is analyzed by comparing the local availability of alternative fuels and electricity, which was not presented here, with the primary energy consumption of different scenarios. The results show that fossil fuel only based combined scenarios cannot help to achieve the energy goals Toggenburg. The availability of biogas from local production in Toggenburg is limited and only of minor interest in Toggenburg's passenger transport. This is also because of the low efficiency of internal biogas combustion engines. The direct use of biomass for producing electricity is a more efficient pathway in most cases. Locally produced electricity for instance by river run-off hydro power or photovoltaics would be enough to cover the electricity demand in the Electric Future scenario.

However, technology alone will not suffice. Additional changes in people's mobility behavior are needed. The results also show that with higher sufficiency in terms of increased car sharing has almost the same effect as efficiency gains in drive train technology. Reducing the absolute amount of traffic is the most effective way of reducing energy consumption and GHG emissions. Furthermore, the shift from individual car mobility towards efficient public transport system brings large improvements.

Only a combination of technological development and behavioral changes will put the ambitious goals within practical reach. The modeling system developed for this study allows for any arbitrary combination of technology scenarios. It can easily be extended with additional data and adapted to other regions and circumstances providing a versatile and useful modeling tool.

5. References

[1] Keller, M., *Der Energieverbrauch des Verkehrs 1990 - 2035*, in *Update*. 2007: Berne (CH). p. 1-199.

[2] Stulz, R., et al., *Leichter leben*. 2005: Zürich (CH).

[3] BFS/ARE, *Mobilität in der Schweiz, Ergebnisse des Mikrozensus 2005 zum Verkehrsverhalten*. 2007, Bundesamt für Statistik (BFS)/Bundesamt für Raumentwicklung (ARE): Neuchâtel (CH).

[4] Balmer, M., K.W. Axhausen, and K. Nagel, Agent-Based Demand-Modeling Framework for Large-Scale Microsimulations, *Transportation Research Record*, Vol. 1985, 2006, pp. 125-134.

[5] <http://www.hbefa.net/>, (Accessed 6 February).

[6] Ecoinvent, *ecoinvent data v2.1- Life Cycle Inventory database*. 2008.

[7] Frischknecht, R., et al., *Implementation of Life Cycle Impact Assessment Methods, ecoinvent report No. 3, v2.0*. 2007, Swiss Centre for Life Cycle Inventories: Dübendorf (CH).

[8] Boesch, M.E., et al., Applying cumulative exergy demand (CExD) indicators to the ecoinvent database, *International Journal of Life Cycle Assessment*, Vol. 12, No. 3, 2007, pp. 181-190.

[9] Muheim, P., *CarSharing - der Schlüssel zur kombinierten Mobilität*. 1998, Bundesamt für Energie BFE: Ittigen (CH).