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CONFERENCE REPORT: 43RD DISCUSSION FORUM ON LCA

Life cycle assessment of electric mobility: answers and challenges—Zurich, April 6, 2011

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Abstract
Introduction Alternative ways and means of transportation are necessary in order to reduce the environmental impacts of mobility. In the recent years, biofuels were first seen as a main option and then LCA showed also possible hazards of this development. Recently, public interest is rapidly shifting towards electromobility. Therefore it is necessary to also gain better knowledge about the environmental impacts of this technology. This includes a modelling of the pathways of the necessary increase in electricity supply and an appropriate modelling of battery manufacture.
Summary of data presented At this forum most recent results of life cycle assessment studies of electric car driving compared to driving fossil- and agro-fuelled cars were presented. The environmental performance of individual and public electric mobility was discussed in view of promising win–win strategies. Policy implications and research needs derived from current LCA work were highlighted.
Conclusion The 43rd LCA forum profited from the input of several topical experts, covering aspects such as electricity demand of electric vehicles in everyday life, marginal electricity supply mixes, design, performance and manufacture of batteries as well as resource and raw materials availability. The following main conclusions were drawn: The main areas of improvement identified during the day are: weight of the car, battery manufacture, electricity mix used to load the batteries, technological dynamics (efficiency gains) and societal dynamics (changes in mobility habits, changing status symbols). All presentations shown during the day are available for download (www.lcaforum.ch).

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1 Introduction

Alternative ways and means of transportation are necessary in order to reduce the environmental impacts of mobility. In the recent years, biofuels were first seen as a main option and then LCA showed also possible hazards of this development. Recently, public interest is rapidly shifting towards electromobility. Therefore it is necessary to also gain better knowledge about the environmental impacts of this technology. This includes a modelling of the pathways of the necessary increase in electricity supply and an appropriate modelling of battery manufacture.

2 Policy and research context

The 43rd LCA forum was opened by Rolf Frischknecht (ESU-services Ltd.) who highlighted the zero emission claims of electric car manufacturers and the perfect fit of life cycle assessment to quantify the eventual environmental benefit of electric car driving.

The first session was dedicated to presentations related to the policy and research context related to life cycle assessment studies of electric car driving. Michael Held (LBP) presented results of a research project within the Fraunhofer System Research for Electromobility. The LCA covered mini class and compact class cars and modelled the situation today and in 10 years from now. The LCA covered car manufacture, battery manufacture and operation and excluded road infrastructure construction and maintenance. The relevant parameters identified in the study are power generation mix, battery system, driving cycle and mileage. The climate change impact of battery electric vehicles fueled with German power mix is similar to the climate change impact of fossil fueled cars. Choosing wind power instead may reduce the impact significantly. Udo Lambrecht (IFEU) presented results of life cycle assessments of electric cars carried out accompanying various fleet tests. The LCA describes a situation in Germany in 2030 with 12 million electric cars (classified as being ambitious) and using three different scenarios: (1) plug and play, immediate charging after use; (2) demand side management (DSM), homogenised charging and (3) DSM+RES, DSM combined with additional renewable power capacity. The LCA makes use of a detailed electricity supply model covering short-term and long-term reactions. Additionally, the model takes availability of renewable energy, market penetration of electric cars and potential electricity grid restrictions into account. DSM may considerably lower the peak load demand. The greenhouse gas intensity of the marginal electricity mix in the different scenarios varies considerably, being very low in the DSM+RES scenario and highest in the DSM scenario. He concluded that a significant reduction in climate change impact compared to fossil-fuelled cars is only achieved by scenario DSM+RES, i.e. if new renewable power production capacity is built up.

Rolf Frischknecht (ESU-services) presented the results of a life cycle assessment study of driving compact class and lightweight cars in Switzerland, fuelled by diesel and electricity. The results revealed that the differences between compact class electric and diesel cars in life cycle energy efficiency, environmental impacts and climate change impacts are minor. This is mainly due to the high environmental impacts of battery manufacture and the unclear situation related to its lifetime and performance. Lightweight diesel cars cause about 50% lower impacts, lightweight electric cars even 75% lower impacts as compared to the impacts of best in class diesel cars available today. Sensitivity analyses showed the important influence of the choice of the electricity product chosen (for instance the Swiss grid mix, certified renewable electricity, nuclear power or gas combined cycle-based electricity) and of the life time and the production effort of the lithium-ion battery. Using the Swiss supply mix increases the specific production of nuclear waste per kilometre driven by a factor of three to four compared to fossil-fuelled cars and electric cars using certified electricity. It was recommended to accentuate the requirements of the energy label of passenger cars, to provide incentives for lower specific fuel consumption by creating a minergy label similar to the one successfully applied on buildings and to improve the general conditions favouring intelligent combined mobility concepts.

Martin Jakob (TEP Energy) focused on methodological approaches to determining marginal electricity mixes. He first introduced the three different models used in life cycle assessment, namely the attributional, decisional and consequential approaches. He then asked questions related to the potential role of electric mobility in climate policy: what is the impact of electric mobility by itself, as compared to other policy options and in a portfolio of policy options? Are electric cars a substitute for fossil-fuelled cars or for bike trips, pedestrians or public transportation? He highlighted the fact that traditional technologies develop faster if challenged by new concepts referring to the sailing ship effect. He then described a dynamic energy model, which distinguishes between short-term dispatching and long-term investment decisions. The bottom-up model is process and technology based, includes technical and economic characteristics, establishes short-term and long-term load (demand) profiles and allows for externally defined constraints and boundary conditions. The model revealed, using a case study of an increase in heat pump applications, that the additional electricity demand is likely to be covered by fossil power plants (natural gas fuelled), except in case the price of natural gas increases by 50%, when renewables get competitive. These results are not directly transferable to electric car situation due to a significantly different temporal demand pattern. He also emphasised not to forget about improvements of competing technologies and changes in behaviour.

3 Mobility context

The second part of the discussion forum covered the mobility context by including other means of transportation. Markus Halder (Swiss Federal Railways SBB) pointed to the pioneering role of the Swiss railway company with regard to electric mobility: almost 100 years ago, the famous Swiss crocodile locomotive was developed, which was able to recuperate electric energy with regenerative brakes. He also introduced the environmental online calculator on the SBB website linked to the interactive timetable which allows for the quantification of the environmental impacts and greenhouse gas emissions of any railway trip. One main focus of SBB is on door-to-door mobility which includes e-mobility concepts for the first and last mile of a trip. Later this year they will launch Bikesharing (conventional and e-bike) and E-Carsharing pilot projects to even better cover door-to-door mobility. According to SBB sustainable development in the field of transport can only be achieved with a holistic approach including measures for reducing traffic, modal shift to more efficient transport modes and technical optimisation of all modes.

Hans-Jörg Althaus (EMPA) presented the results of a peer-reviewed comparative life cycle assessment of battery electric cars and cars fuelled with fossil fuels and agrofuels (all compact class cars) commissioned by AXPO, a large electric utility based in Switzerland. Like the work presented by Frischknecht, the LCA model includes car manufacture and its end-of-life treatment, road construction and maintenance, car operation and fuel supply. Althaus focused on the modelling aspect of car recycling, where the end-of-life recycling approach was chosen instead of the recycled content approach. Its effect on the results is however minor. The car manufacture is modelled in detail and fuel (and electricity) consumption during operation considers real-life conditions. He explained the differences in approaches used to quantify the environmental impacts of battery manufacture. He concluded that electric cars with smaller-sized batteries and fossil range extender show lower greenhouse gas emissions as compared to electric cars with large batteries. The ranking of electric, fossil fuel and agrofuel car driving depends largely on the environmental indicator chosen.

Andrew Simons (PSI) presented an LCA of different electric power trains including battery and fuel cells and compared to petrol-fuelled cars (compact class). There is only little difference between the greenhouse gas emissions of fuel cell or battery cars. Both require electricity with low greenhouse gas emissions to reach lower greenhouse gas emissions per kilometre driven compared to fossil-fuelled cars. With regard to the other environmental impacts considered (abiotic depletion, acidification and respiratory effects), electric cars performed worse than the fossil reference.

4 Technical aspects and future development

The afternoon session was opened by Marc-André Beck (Kamoo) talking about real-life electricity consumption of electric cars. He exemplarily showed the results of two test drives (actual commuting distance from his home to the office and back). The electricity consumption per trip differed by about 30% due to driving pattern (share of efficiency area of the motor used during the trip, downhill/uphill). The charging efficiency of the Zebra battery is above 85% (excluding standby losses).

Clémence Siret (Saft) presented the activities of the battery manufacturer with regard to electric mobility and the environment. Saft supplies various electric and hybrid cars and two-wheel vehicles with their batteries. Saft considers the environmental impact of each type of battery during design and manufacture and strives for an increased use of renewable energies and secondary raw materials making use of the Umicor process. Siret emphasised the complexity of a lithium-ion battery which must cope with requirements related to electrochemistry, software, thermal management, electrical system, electronics and the mechanical system. She warned from using black-box LCI data of lithium-ion batteries and pled for a PCR-like guidance for LCAs of e-mobility. Their communication policy allows for providing Saft-specific LCI data on batteries to their clients.

Lorenz Erdmann (IZT Berlin) focused on the availability of raw materials and resources used in electric cars. In the past the value chains of raw materials and resources used in electronics and electric applications were under the control of governments. About 10 years ago liberalisation and globalisation weakened the role of governments. Erdmann introduced the criticality concept which considers the vulnerability and the supply risk of resources. He explained that four components used in electric cars contain potentially critical elements: traction motors (neodymium and copper), supercaps (aluminium), high-performance batteries (cobalt, lithium) and fuel cells (platinum). There are considerable short- to mid-term concerns related to rare earth metals and mid- to long-term concerns related to copper. While the former is mainly due to country risk and company concentration, the latter is mainly due to the decreasing reserve to production ratio.

Fausto Freire (University of Coimbra) presented a comparison of the environmental impacts of electric and conventional vehicles in Portugal. The analysis covered an urban and a suburban car (electric, plug-in hybrid, gasoline and diesel). One focus was on the electricity mix development in Portugal since 2004 and its projection until 2020. He concluded that the vehicle operation is the most dominating factor (except when using 100% wind power) and that the relative difference between fossil and electric urban cars is similar to the comparison of fossil and electric suburban cars. The electricity mix is highly influencing the LCA result and thus the future development of the Portuguese electricity mix is the key with regard to the potential climate change impact reduction potential.

Inbal Fried (Better Place) presented the recently launched research project “easybat” under the seventh framework programme of the EU. The project’s goals are to develop models for an easy and safe integration of battery packs in electric vehicles, develop generic interface concepts between the battery and the vehicle on-board systems and to develop new standards to build a consistent requirements framework for the battery pack generic interfaces. The project includes an assessment of the environmental impacts based on life cycle assessment of electric car driving with fixed batteries compared to cars which swap their batteries at dedicated battery stations.

Table 1 Characteristics of electric cars (compact class) operated today and climate change impacts of driving 1 km

	Held	Lambrecht	Frischknecht	Althaus	Simons	Freire
Car weight (kg)	1,670	n.a.	1,632	1,880	1,650	1,531
Lifetime performance car (km)	171,600	150,000	150,000	150,000	n.a.	200,000
Battery weight (kg)	400	250	312	400	250	329
Lifetime performance battery (km)	114,400	100,000	75,000	150,000	n.a.	100,000
Electricity consumption (kWh/100 km)	22.9	22	20	20	20	18.8
Electricity mix	DE	DE	CH	CH	CH	PT
Climate change impact (g CO_2-eq/km)	240	225	150	95	110	165

5 A summary of the LCA data presented

Several LCA results were shown during the 43rd LCA forum. This section provides an overview of the electric cars analysed and the results shown. The LCA studies were performed on different cars, different time horizons and in different countries. One common type of car is a compact class car as operated today. The LCA studies used various impact assessment methods. However, climate change impacts were shown in all studies presented. That is why the comparison of the results is limited to this indicator. It shows a large variation of climate change impacts of between less than 100 g CO_2-eq per km and 240 g CO_2-eq per km (Table 1). While some of the differences can be explained by the difference in electricity mix applied, this does not hold true for the studies using the Swiss grid mix. In that case the main difference stems from different LCI data used to represent the lithium-ion battery (Table 2).

6 Discussion

The plenary discussion was moderated by Arthur Braunschweig (E2 Management Consulting). He asked the attendees about their lessons learned and the questions that arose or were not answered during the day. The audience named topics such as the role of electric mobility in emerging economies, the role of noise and human health impacts in the discussion of electric cars as a substitute of fossil-fuelled cars or the potential role of vehicle to grid concepts. The question was raised which of the following two options would lead to larger reduction in greenhouse gas emissions: either to use additional renewable power plant capacity to replace current coal power plants or to use additionally produced renewable electricity in electric cars to replace fossil-fuelled cars.

Finally the participants of the 43rd LCA forum agreed on a short list of the main drivers of the environmental impacts of electric car driving:

- Weight of the car
- Battery production and performance
- Electricity mix used to load the battery
- Technological dynamics (mainly regarding improvements in battery production and performance but also regarding improvements in the efficiency of traditional internal combustion engines)
- Societal dynamics (reduction of the demand for mobility; shift to alternative and combined mobility concepts; shift of status symbols from large to (c)lean cars)

There was a felt consensus that the role of electric cars to reduce the manyfold environmental impacts of mobility is substantially overrated and that one key to lower environmental impacts of individual mobility is a substantial downsizing in terms of vehicle weight and power.

Table 2 Life cycle-based climate change impacts of manufacture of 1 kg of lithium-ion batteries according to different sources

	Climate change impact (kg CO_2-eq/kg)
ecoinvent data v2.2 (ecoinvent Centre 2010)	5.8
ESU-services (Leuenberger and Frischknecht 2009)	17.1
Input–output (USA)	17.8
Ishihara et al. (2002)	10
Zackrisson et al. (2010)	15.5–25.5

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