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Key Issues in Life Cycle Assessment of Electric Vehicles - Findings in the International Energy Agency (IEA) on Hybrid and Electric Vehicles (HEV)

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Abstract

Electric vehicles have the potential to substitute for conventional vehicles and to contribute to the sustainable development of the transportation sector worldwide, e.g. reduction of greenhouse gas and particle emissions. There is an international consensus that the improvement of the sustainability of electric vehicles can only be analysed on the basis of life cycle assessment (LCA) including the production, operation and the end of life of the vehicles. Based on LCA activities in the 17 member countries, the International Energy Agency (IEA) Implementing Agreement on Hybrid and Electric Vehicles (IA-HEV) works in a Task on the LCA of electric vehicles. In this Task 19 "Life Cycle Assessment of Electric Vehicles - From raw material resources to waste management of vehicles with an electric drivetrain" the key issues of applying LCA to EVs&HEVs are identified and applied in various case studies. The following seven categories of key issues were identified, analysed and applied in "best practice" applications: 1) General issues, 2) Life cycle modelling, 3) Vehicle cycle (production – use – end of life), 4) Fuel cycle (electricity production), 5) Inventory analyses, 6) Impact assessment and 7) Reference system. For these seven key issues the main relevant factors were identified, reviewed and verified in international "best practice" applications.

Keywords: BEV (battery electric vehicle, energy consumption, environment, LCA (life cycle assessment), PHEV (plug in hybrid electric vehicle)

1 Introduction

1.1 The IEA HEV Task 19 “LCA of Electric Vehicles”

Based on the LCA activities in its 17 member countries, the IEA Implementing Agreement on Hybrid and Electric Vehicles (IA-HEV) operates the Task 19 “Life Cycle Assessment of Electric Vehicles - From raw material resources to waste management of vehicles with an electric drivetrain”. The main goals of this Task are

- provide policy and decision makers with FACTS for decisions on EV related issues
- improve “END OF LIFE MANAGEMENT” by promotion of best available technologies and practices
- identify DESIGN for recyclability and minimal resource consumption
- establish a "RESEARCH PLATFORM for life cycle assessment including end of life management for electric vehicles“ to augment the benefits and competitiveness of vehicles with an electric drivetrain.

The Task is a networking activity, which means that the experiences from the national projects are fed into the IA-HEV LCA Platform and discussed on an international level. Each participant contributes to the different topics in the Task based on a work sharing principle. The main topics addressed in the three year working period are:

1) LCA methodology, e.g. system boundaries, allocation
2) frequently asked questions, e.g. to develop explanations about points that typically confuse the public and policy makers
3) overview of international LCA studies
4) parameters influencing the energy demand of vehicles
5) LCA aspects of battery and vehicle production
6) end of vehicle life management
7) LCA aspects of electricity production, distribution and vehicle battery charging
8) summarizing further R&D demand.

A research platform for life cycle assessment including end of life management for electric vehicles is established in IA-HEV, to further augment the benefits and competitiveness of electric vehicles. The Task started in November 2011.

The Task considers the following vehicles and propulsion systems:

- Propulsion systems:
  - battery electric vehicle (BEV)
  - hybrid electric vehicle (HEV)
  - plug-in hybrid electric vehicle (PHEV)
  - range extended electric vehicle (REV)
  - hydrogen fuel cell electric vehicle (FCV) (incl. hydrogen production)
  - in comparison to ICE vehicle with gasoline, diesel and natural gas using current and future technology.
- Road vehicles:
  - passenger cars
  - (light) utility vehicles
  - busses
  - 2-wheelers and
  - fork-lift trucks.

1.2 Motivation

Electric vehicles have the potential to substitute for conventional vehicles and to contribute to the sustainable development of the transportation sector worldwide, e.g. reduction of greenhouse gas and particle emissions. There is international consensus that the improvement of the sustainability of electric vehicles can only be analysed on the basis of life cycle assessment (LCA) including the production, operation and the end of life treatment of the vehicles (Figure 1). There are three different vehicles shown (A, B, C). Vehicle A has compared to vehicle B lower environmental effects in the production, but higher environmental effects in the operation phase. But the cumulated environmental effects of vehicle B are lower, as the higher initial effects of the production phase are then compensated by lower effects in the operating and “end of life” phase. Vehicle C has the highest environmental effects in the production phase, but as most of the material is recycled to secondary material a substitution credit is given for the avoided primary material production.

Actual LCA results show that about 90% of the greenhouse gas emissions of an battery electric vehicle running on renewable electricity from hydro power derive from the production and end of life treatment of the vehicle, and only 10% stems from vehicle operation. In addition, all environmental impacts must also include the whole value chain and - if relevant – interactions from recycling in the dismantling phase to the production phase, if recycled material is used to produce new vehicles (Figure 2).

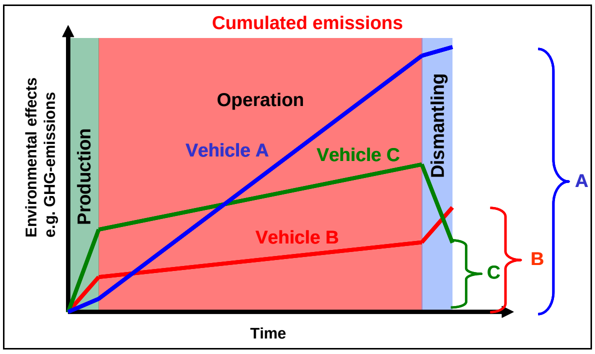

Figure 1: Life cycle assessment of the three phases in the life cycle of a vehicle – production, operation and dismantling for 3 hypothetical vehicle types [1]

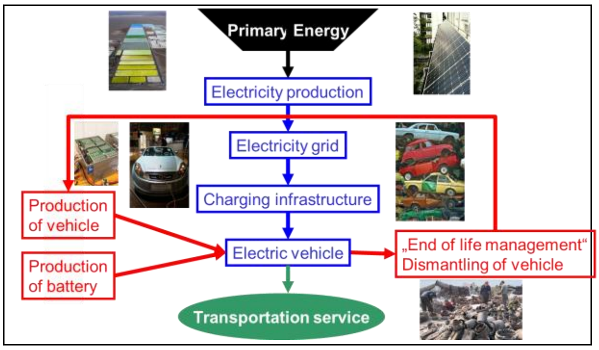

Figure 2: Assessment of LCA-aspects over full value chain [1]

2 Scope of the analyses

Based on LCA activities in the 17 member countries, the Task 19 identifies the key issues of applying LCA to EVs&HEVs in various case studies.

The Task 19 collected international LCA studies on vehicles with an electric drivetrain, which are documented in a data base for further analyses. Based on a critical analyses and expert judgements of about 70 international LCA studies of vehicles with an electric drivetrain the examples for "best practise" applications of these key issues are selected to demonstrate the importance of the proper handling of the key issues to gain reliable and realistic results of comparing the possible environmental effects of electric to conventional vehicles. These key issues are analysed and shown in the following with some selected examples demonstrating the practical handling.

3 Key issues in LCA of EVs

3.1 Overview of key issues

The following key issues for applying LCA methodology to vehicles with an electric drivetrain were identified by Task 19 in a Workshop on "LCA Methodology and Case Studies", which are described in the following chapters in more detail

1. General issues
2. Life cycle modelling
3. Vehicle Cycle (production – use – end of life
4. Fuel Cycle (electricity production)
5. Inventory analyses
6. Impact assessment
7. Reference system.

These issues are a compact summary of on-going LCA activities in the different countries and projects, e.g. eLCAr [2], Thelma [3], ELECTRA [4], in which the workshop participants are involved.

3.2 General issues

In the goal and scope definition of the LCA, it is very essential to describe the state of technology of vehicles and batteries considered including also the assumptions for possible future developments. Especially the future policy framework might influence possible future developments significantly like e.g. incorporate new efficiency standards, eco-labelling. In addition, possible rebound effects by substituting conventional vehicles by electric vehicles should be discussed or considered, e.g. using "green vehicle" more often or instead of other more environmental types of mobility like walking a short distance.

As the key influence on the environmental effects of vehicles with an electric drivetrain are the electricity demand per kilometre and the technology for electricity consumption a sensitivity analyses on these two aspects is recommended.

3.3 Life cycle modelling

The modelling of the life cycle is the base for the assessment of the environmental effects of electric vehicles compared to conventional vehicles. The main issues to be addressed are the choice of an average or marginal approach. Also, the dealing with multi-functionality throughout the analysis can influence the results. The preferred way of dealing with functionality is avoiding allocation, but in most of the cases it is not practicable. For example, electricity from CHP plants and the fate of components recovered at the end of life can be handled with different allocation methods, e.g. energy or exergy content, substitution of conventional heat source.

3.4 Vehicle cycle

The vehicle cycle includes the production, use and end of life of the vehicle including its battery. It is generally recognised that the production of electric vehicles has higher environmental impacts compared to conventional vehicles mainly due to the necessary production of the battery [1], [5]. So the details of the battery production and its key technical data (e.g. life time of battery, energy content) must be described. For the materials used to produce the vehicle, the main assumptions and data (e.g. light weight material, electricity production mix) must be described.

The most influencing factor of the environmental effects of vehicles is the energy consumption in the operation phase. Especially for vehicles with an electric drivetrain all auxiliary energy uses for heating and cooling must be included properly. Also the user behaviour (e.g. urban driving, who buys an EV&PHEV) is quite relevant for the energy consumption. For plug in hybrid electric vehicles (PHEV) the share of driving pure electric must be specified and justified in detail, e.g. it must be distinguished between "electricity generated on board" versus "electricity generated off-board". For battery electric vehicles (BEV) the possible driving range must be described in real life applications (see above incl. heating and cooling demand). As the driving range of electric vehicles with one charging is significantly lower compared to a conventional diesel or gasoline car, all details for the assumption of the daily, monthly and yearly driving distances must be described.

The end of life management of an electric vehicle might also influence the overall environmental effects significantly. Therefore the details of the dismantling phase must be given including aspects of material and energy recovery, (e.g. recycling for production "close loop").

3.5 Fuel cycle

The fuel cycle includes the electricity production with the supply of the fuel, the electricity distribution network and the charging station. The main issue to be addressed is the choice of the electricity generation technology or mixes, e.g. analysing the time depending electricity generation mix of a country: choice of an annual average electricity production or mix, or additionally (marginal) produced electricity for charging electric vehicles. In cases where significant amounts of electricity are stored, e.g. in hydro power pumping plants, the electricity mix of consumption might be more relevant for LCA than the production mix. If fluctuating renewable electricity from wind or solar power is used the key question is, how it is guaranteed that the renewable electricity is "de facto" ending up in the battery of the electric vehicle or if other effects are initiated in the grid. So, the production of the renewable electricity must be harmonised with the charging of the electric vehicle. In most of the cases the use of only (fluctuating) renewable electricity must be combined with an adequate electricity storage system (incl. its storage losses) or in some specific cases electricity from variable hydro power from dams (not pumped storage). Otherwise a realistic share of (fluctuating) renewable electricity from wind and solar with thermal power from biomass or fossil fuels must be considered. Further, it must be ensured that the renewable electricity for the EVs is really produced additionally, as shifting the use of the currently generated renewable electricity from a stationary application to the mobile application in an EV brings no additional environmental benefits. Summarizing it has to be born in mind that the consideration of renewable electricity for the charging of vehicles with an electric drivetrain is only justified if this renewable energy is specifically and additionally generated for this purpose.

3.6 Inventory analyses

The basic data for the inventory analyses must be documented with special attention given to the battery production, the vehicle production, the energy consumption of the vehicle in the operation phase, the electricity production, the charging of the vehicles and the "end of life " treatment of the vehicle with its battery. The (assumed) state of technology or its possible future development must be described. The uncertainty range of all data must be indicated properly and discussed in sensitivity analyses.

3.7 Impact assessment

The impact assessment might include a wide range of possible environmental effects, but due to the available data most LCA activities concentrate mainly on the greenhouse gas emissions (GHG) and energy resource depletion e.g. the cumulated primary energy demand. As a minimum requirement the cumulated primary energy demand must be given in the contributing share of fossil, renewable and other energy carriers. In some LCA studies also the material resource depletion e.g. cumulated material demand with its main share of different materials are calculated, e.g. metallic raw materials, biogenic materials. Also some other impact categories caused by gaseous emissions (e.g. CO, NO_x, particles [6]) like acidification, ozone formation are calculated more and more often. Generally it is observed, that the mid-point impact assessment is often done for GHG emissions and primary energy consumption with an already high reliability and robustness. But the "end point damage assessment" and "single scoring methods" e.g. external costs are still under discussion and/or development due to their high methodological complexity and the lack and uncertainty of data for other impacts than GHG, energy and material consumption. But the trend in recent years show that end point methods are used more and more in the LCA community and the acceptance is increasing. It is recognised that the methodological choices (e.g. modelling, system boundaries, determination of relevant electricity generation,…) adds very much higher (relative) uncertainty to all impact assessment results (also to GWP) than the uncertainties in endpoint modelling. Characterization factors (CF) for e.g. toxicity midpoints are almost as uncertain as CF for human health damage (i.e. end point).

3.8 Reference system

Generally the reference system is directly linked to and depending on the goal and scope of the LCA. In most cases the reference systems for electric vehicles are mainly gasoline and/or diesel ICE vehicles with their current and future technologies. As transportation biofuels become a reality on the fuel market in more and more countries, e.g. 7 vol-% blending of biodiesel to diesel in Austria [1]; the aspects of biofuels should be integrated in the reference system more often in the future. In some countries also natural gas vehicle (incl. its new infrastructure) might be part of the reference systems. As described already in chapter 3.5 the environmental benefits of electric vehicles might be maximised by using renewable electricity it must be made sure that additional renewable electricity is generated and not be taken away from other electricity uses. And so all environmental effects associated with this additional renewable electricity production e.g. building a dam for a hydro power plant, must then be allocated to the electric vehicle.

4 Examples

Based on the initial activities in IEA HEV Task 19 some examples from current international LCA experiences to the above identified issues are shown in the following. These examples are meant to illustrate the practical handling of these key issues and were part of the discussion in IEA HEV Task 19 on the workshop held in Brauschweig/Germany in December 2012.

- Sensitivity analyses of fuel consumption on GHG emissions of electric and conventional vehicles (Figure 3)
- Environmental effects of battery production (Figure 4)
- Power demand for different charging strategies (Figure 5)
- GHG Emissions for different loading strategies with renewable electricity (Figure 6)
- Fluctuation of GHG emissions for each 15 minutes (Figure 7)
- Comparison of noise for different vehicles (Figure 8)
- Relevance of different environmental impact categories (Figure 9)

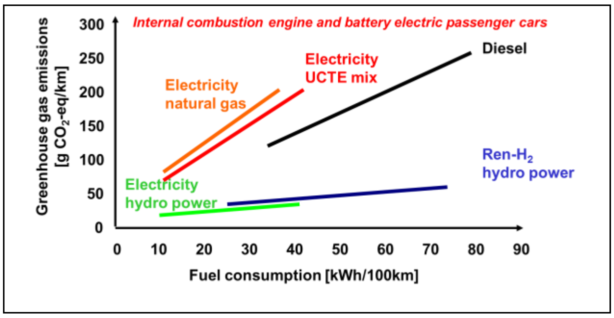

Figure 3: Sensitivity analyses of fuel consumption on GHG emissions of battery electric and vehicles with an internal combustion engine [1]

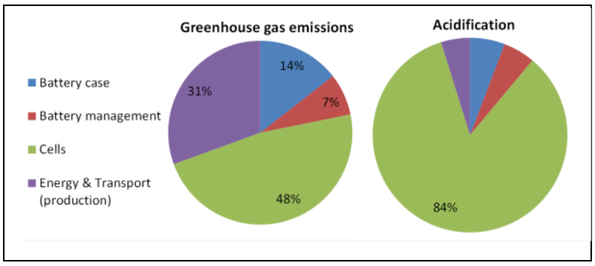

Figure 4: Environmental effects of battery production [7]

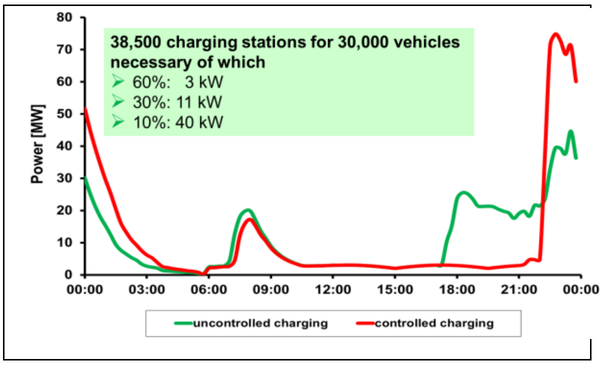

Figure 5: Power demand for different charging strategies [1]

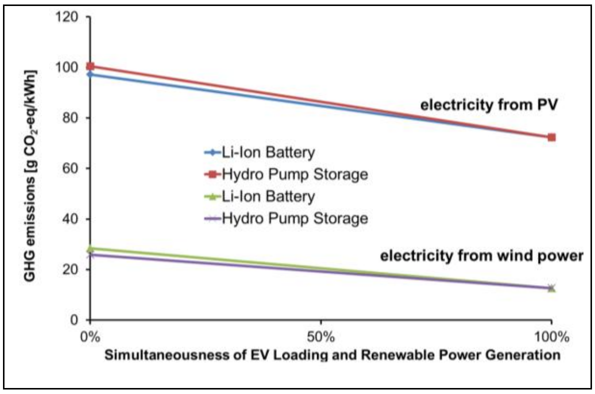

Figure 6: GHG Emissions for different loading strategies with renewable electricity [1]

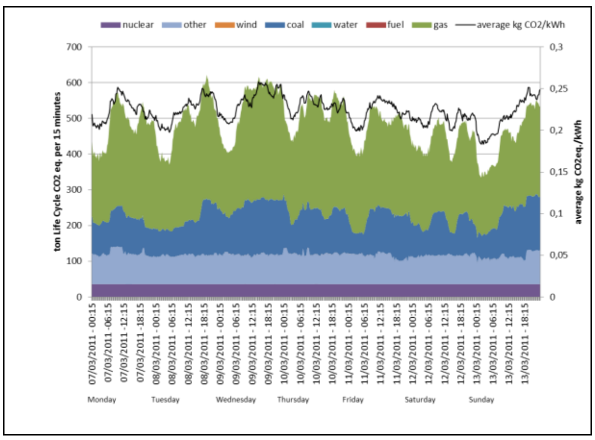

Figure 7: Fluctuation of GHG emissions for a typical year in Belgium with a temporal resolution of 15 min. [8]

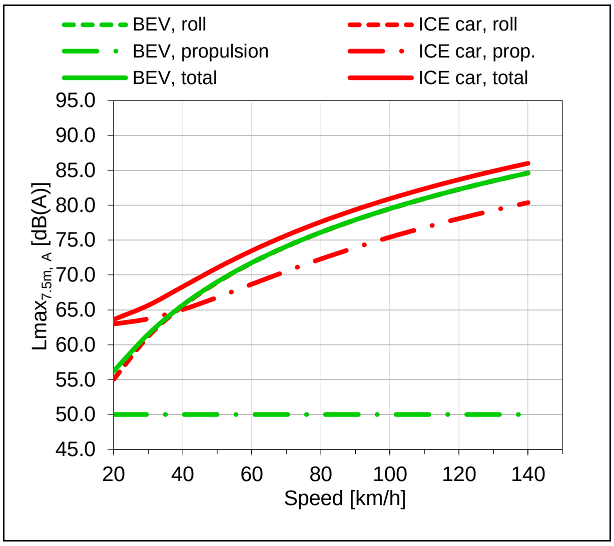

Figure 8: Comparison of noise for different vehicles [9]

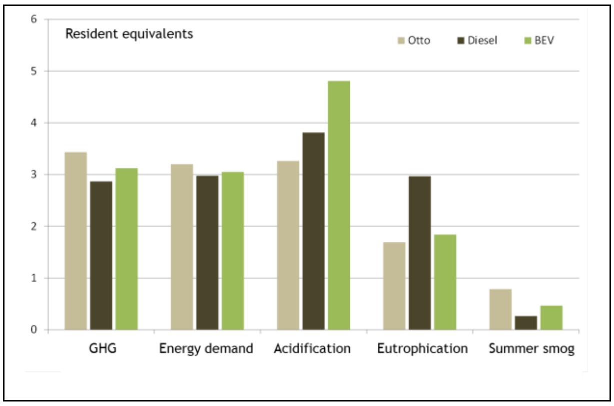

Figure 9: Relevance of different environmental impact categories of vehicles on human beings (in resident equivalent) [7]

5 Conclusions and outlook

In this analysis, the key issues for applying LCA methodology to vehicles with an electric drivetrain are identified and described.

Based on the proper description of the methodology, the modelling approach and the available data sources, the main influences of the environmental effects of vehicles with an electric drivetrain in the life cycle are

- Production and life time of the battery
- Electricity consumption of the vehicle in the operation phase incl. energy demand for heating and cooling
- Production and source of the electricity, where only additional generated

renewable electricity might maximise the environmental benefits
- End of life treatment of the vehicle and its battery

The IEA Task 19 will continue to establish an international expert platform on LCA of electric vehicles. Beside the scientific review and discussion on the practical application and further development of LCA to EVs, the task organises and documents further workshops e.g.

- "LCA aspects of battery and vehicle production"
- „End of life management of electric vehicles"
- „LCA aspects of electricity production and infrastructure"

Further information:
http://www.ieahev.org/tasks/task-19-life-cycle-assessment-of-evs/

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Highlights of professional experiences:

- life cycle assessment of bioenergy for transport, electricity, heat and biorefineries
- greenhouse gas assessment of products and services
- sustainability assessment and future scenarios for transportation fuels of the future – biofuels, e-mobility and hydrogen.

Present Positions:

- Operating Agent of IEA HEV Task 19 "LCA of Electric Vehicles"
- Key Researcher on "Energy Systems and Strategies" at JOANNEUM RESEARCH, Austria
- Lecturer: Vienna University of Technology; University of Graz; University of Applied Science, University of Applied Science Kapfenberg, Danube University Krems
- Austrian Team Leader in IEA Bioenergy Task 42 "Biorefinery"