Strategies to Maximize Environmental Benefits of Electric Vehicles Using Life Cycle Assessment in a Cooperation of 18 Countries in the International Energy Agency (IEA) on Hybrid and Electric Vehicles (HEV)

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Introduction

Based on the LCA activities in its 18 member countries (A, B, CA, DK, F, FR, G, IR, I, NL, P, SK, ES, CH, S, T, UK, US), the IEA Implementing Agreement on Hybrid and Electric Vehicles (IA-HEV) operates 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 on EV related issues
- Improve “END OF LIFE MANAGEMENT” by promoting 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“.

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. The main topics addressed are:

1) LCA methodology, e.g. system boundaries, and co-products handling methods
2) Addressing frequently asked questions
3) Overview of international LCA studies
4) Parameters influencing the energy demand of electric vehicles
5) LCA aspects of battery and electric 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.

In November 2011, the IA-HEV Task established the research platform for life cycle assessment for electric vehicles to further augment the benefits and competitiveness of electric vehicles, which is operated by four countries: Austria, Germany, Switzerland and USA.

The Task considered the following propulsion systems and road vehicles:

- Propulsion systems:
    - battery electric vehicle (BEV) (focus interest of most countries)
    - hybrid electric vehicle (HEV) (focus interest of most countries)
    - plug-in hybrid electric vehicle (PHEV)
    - range extended electric vehicle (REV)
    - hydrogen fuel cell electric vehicle (FCEV) (incl. hydrogen production)
    - baseline ICE vehicle with gasoline, diesel and natural gas using current and future technologies

- Road vehicles:
  - passenger cars (focus interest of most countries)
  - (light) utility vehicles
  - busses
  - 2-wheelers and
  - fork-lift trucks

1.2. Motivation

Electric vehicles have the potential to substitute conventional vehicles and contribute to the sustainable development of the transportation sector worldwide, e.g. reduction of greenhouse gas and particulate emissions. There is international consensus that the sustainability of electric vehicles should 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 hypothetical vehicle cases shown (A, B and C):

Compared to vehicle B, vehicle A has lower environmental effects in the production phase, but higher environmental effects in the operation phase. However, the cumulative environmental effects of vehicle B are lower, as the higher initial effects of the production phase are compensated for by the 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 components are recycled to secondary materials, a substitution credit is given for the avoided primary material production, e.g. material from renewable resources.

In addition, all environmental impacts must also include the whole value chain and - if relevant – interactions from recycling from the dismantling phase to the production phase if recycled material is used to produce new vehicles or its components (**Figure 2**).

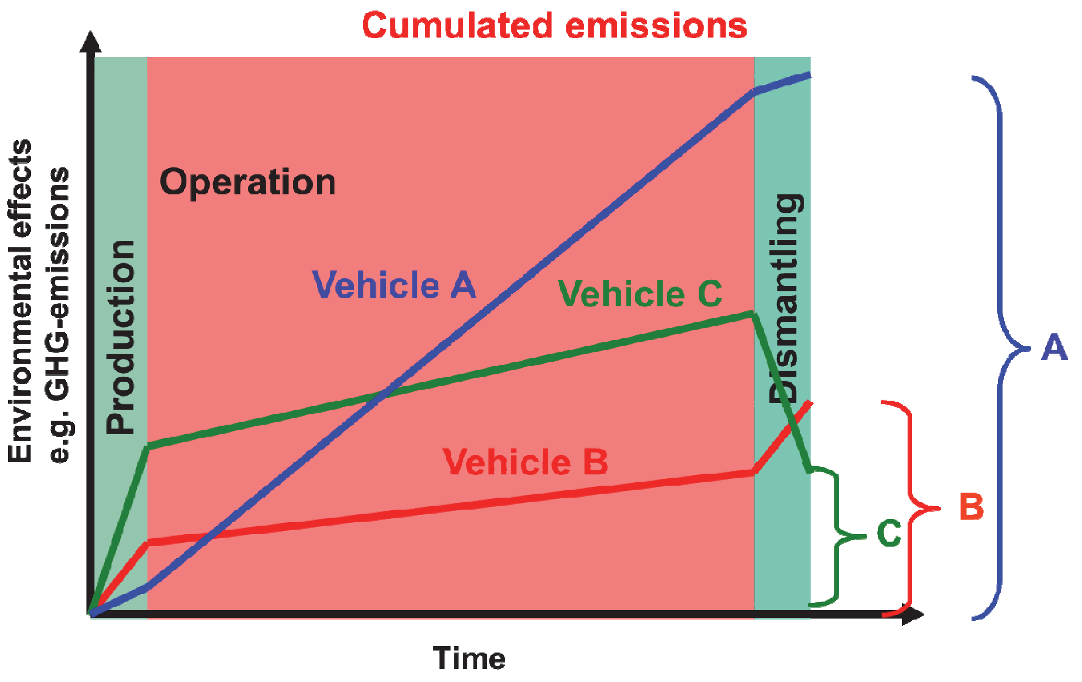

Figure 1: Life cycle assessment of the three phases in the life cycle of a vehicle – production, operation and dismantling for 3 hypothetical vehicle types A, B and C [Jungmeier 2013].

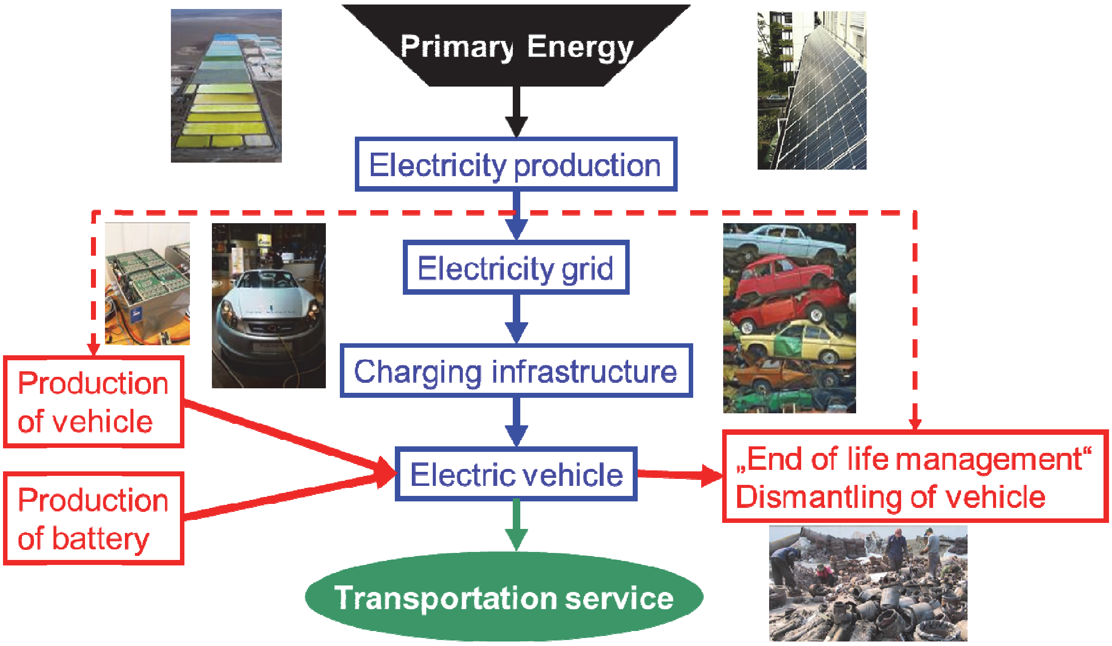

Figure 2: Assessment of LCA-aspects over full value chain [Jungmeier 2012].

In this Task 19 “Life Cycle Assessment of Electric Vehicles - From raw material resources to waste management of vehicles with an electric drivetrain” strategies are developed to maximize the environmental benefits of applying LCA to EVs&(P)HEVs and using results from international LCA studies. The following seven categories of key issues of this strategy were identified and analysed to quantify the maximum environmental benefits of vehicles with an electric drive train:

1. Vehicle operation and efficient electricity use from heating and cooling,
2. Source of electricity and future electricity mix in various countries,
3. Linking additional renewable electricity generation with loading strategies of electric vehicles,
4. Production of electric vehicles with focus on battery materials,
5. Vehicle dismantling and “end of life management” towards high recycling rates and
6. Replacing strategies for conventional vehicles with gasoline and diesel engines.

For these six key issues the main relevant factors were identified, reviewed and verified in international “best practice” applications [Jungmeier 2014]. Based on review analyses and expert judgements of about 100 international LCA studies of vehicles with an electric drive train [IEA HEV Task 19 2014] the examples for “best practise” applications are selected and documented to underline the importance of these issues in maximising the environmental benefits of electric vehicles in substituting for conventional vehicles.

In this paper two examples of this analyses are shown:

1) Environmental effects of the current electricity mix in various countries,
2) Energy demand of vehicle.

Environmental effects of the current electricity mix in various countries

The type of electricity production is a main factor for the LCA results of EVs, so the electricity production, distribution and storage strategies must be correlated to the charging strategies. To cover these fluctuating power demands of different loading strategies electricity storage systems might be integrated in the electricity system. So additional environmental effects must be considered due to the storage losses during operation, the construction and the dismantling of these storage facilities. In Figure 3 the GHG Emissions for different loading strategies with renewable electricity using two different electricity storages (battery and hydro pumping) are shown, where the amount of electricity that has to be storages varies between 0 and 100%. If the electricity from wind is used directly to charge an electric vehicle the wind electricity has a GHG emission of about 15 g CO_2-eq/kWh, if all the wind electricity must be stored first the GHG emissions increase up to 28 g CO_2-eq/kWh. Besides using an electricity storages system the fluctuating electricity demand can also be satisfied by using a combination of different types of electricity production plants, e.g. hydro power, natural gas, nuclear.

In Figure 4 the type of the current national electricity production is shown for various countries based on official statistics. Some of these countries have a very high share of renewable electricity (e.g. 95% in Norway) and some have a very low share (e.g. below 10% Australia). With these electricity generation mixes a LCA is made to calculated the possible range of GHG emissions incl. the electricity distribution, which are shown in Figure 5. Depending on the electricity generation mix in some countries these GHG emissions are below 50 g CO_2-eq/kWh and in some countries they are above 800 g CO_2-eq/kWh.

In Figure 6 the LCA based possible range of GHG Emissions of a battery electric vehicle (20 – 30 kWh/100 km) in the different countries with the current national electricity generation is shown. It can be concluded that in most of the countries the GHG emissions are lower than the GHG the emissions from conventional small to medium sized vehicles with gasoline and diesel (that range between 180 – 220 g CO_2-eq/km). If the additional marginal supply of oil stems from unconventional shale oil and gas (that range between 260 – 290 g CO_2-eq/km) the GHG saving is even higher.

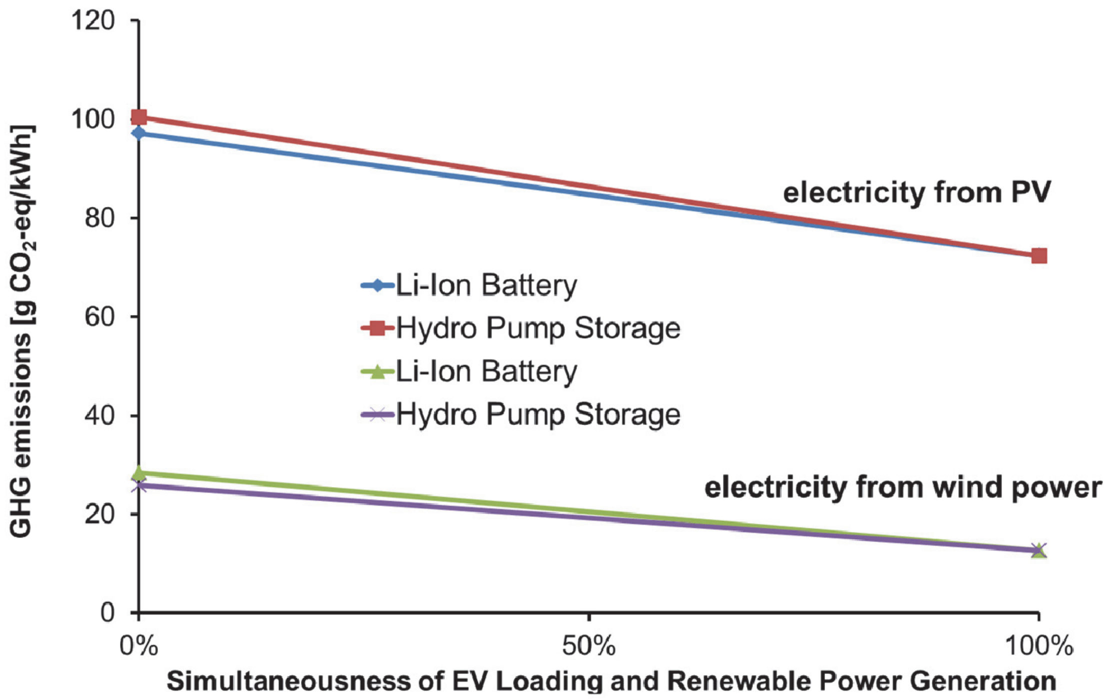

Figure 3: GHG Emissions for different loading strategies with renewable electricity [Jungmeier 2014].

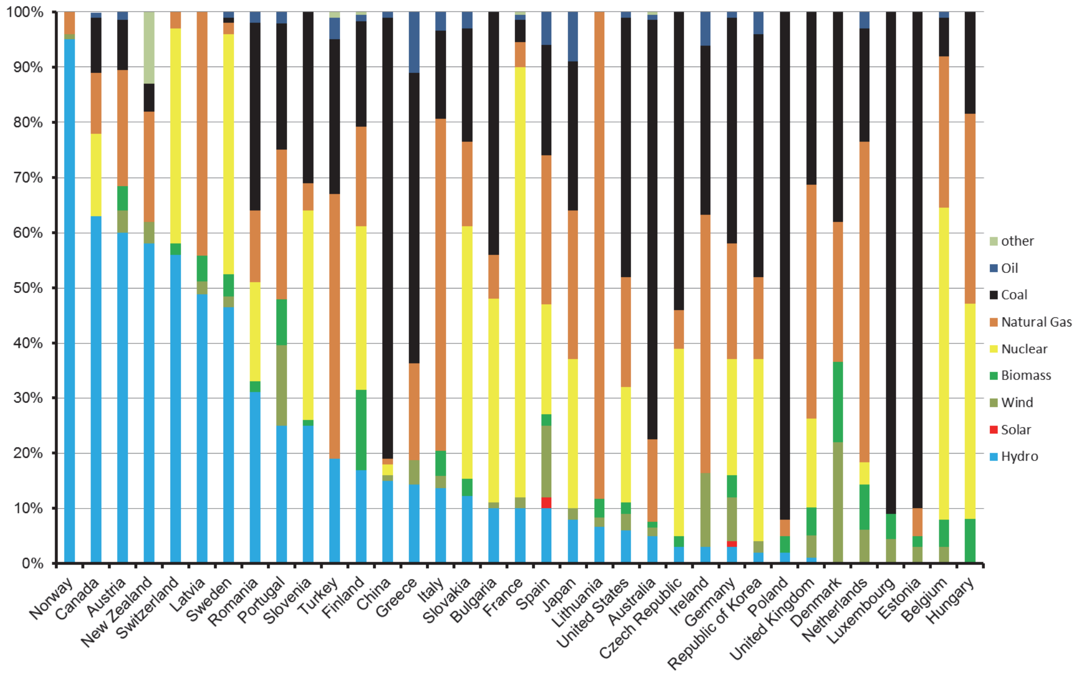

Figure 4: Type of national electricity generation in various countries.

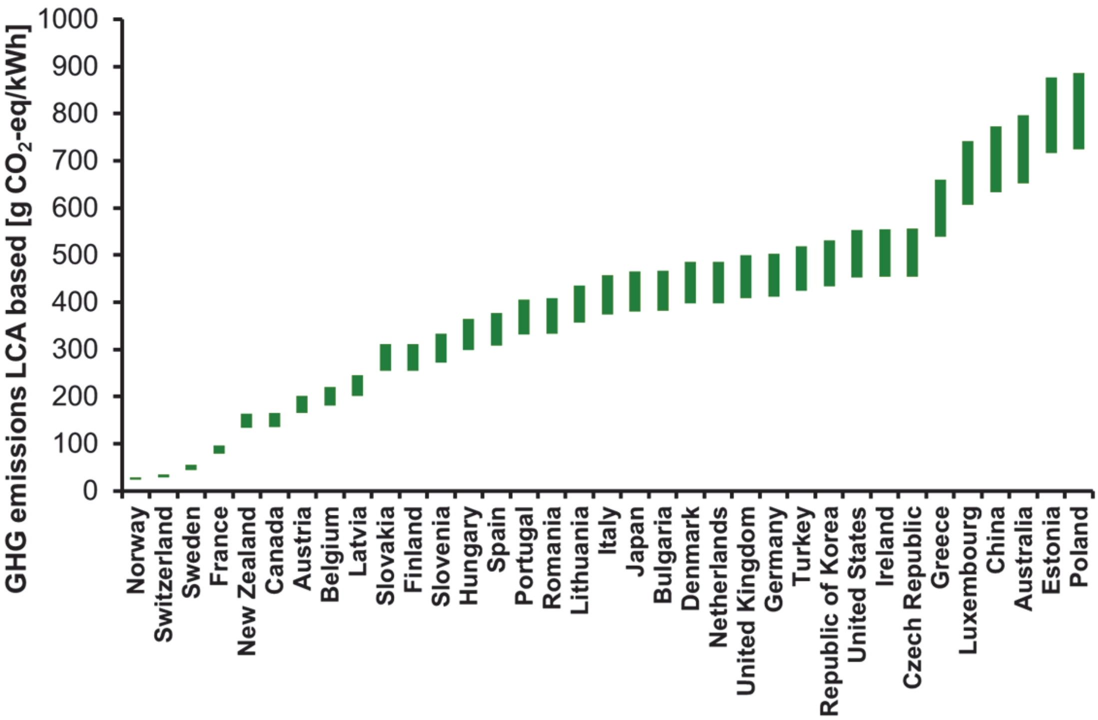

Figure 5: LCA based possible range of GHG emissions of national electricity generation incl. distribution in various countries.

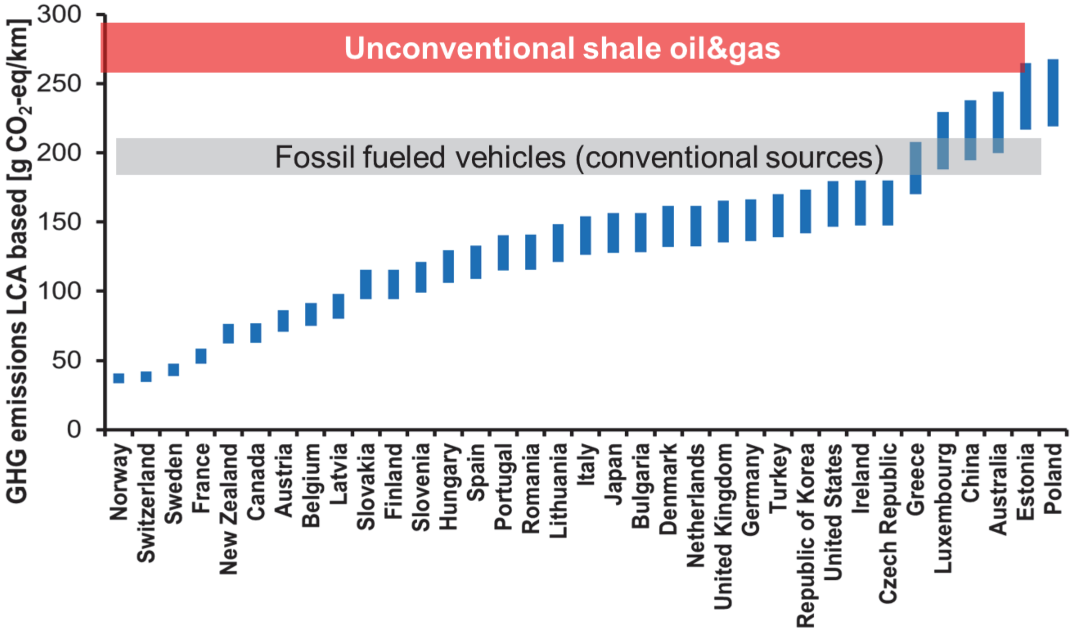

Figure 6: LCA based range of possible GHG Emissions of a battery electric vehicle in different countries with the current national electricity generation

Energy demand of vehicles

The energy demand on operating the vehicles has one of the highest influences on the LCA results. In Figure 7 a sensitivity analyses of the energy consumption on GHG emissions of electric and conventional vehicles is shown. The possible GHG emissions of all fuels might have a wide range depending on e.g. the size of the vehicle, the technology, the driving cycle, and the auxiliary energy for heating and cooling, driving behaviour. A "fast driving and heavy" diesel vehicle with a fuel consumption of 80 kWh/100 km has about 250 g CO_2-eq/km based on LCA, where a "small and slow driving" diesel vehicle with a fuel consumption of 35 kWh/100 km vehicle has 135 g CO_2-eq/km. The small and light battery electric vehicle using 12 kWh/100 km of renewable electricity from hydro power has 30 g CO_2-eq/km, and the heavy battery electric vehicle using 45 kWh/100 km of electricity from natural gas has 210 g CO_2-eq/km, which are higher GHG emissions compared to a small diesel vehicle. Additionally in the case of electricity generated by PV a battery energy storage is included to combine the fluctuating PV electricity generation with the electricity loading demand of the EV adequately. Based on these results the influence of the energy demand of the vehicles is evident and therefore in all LCA results the energy consumption per kilometre must be shown explicitly.

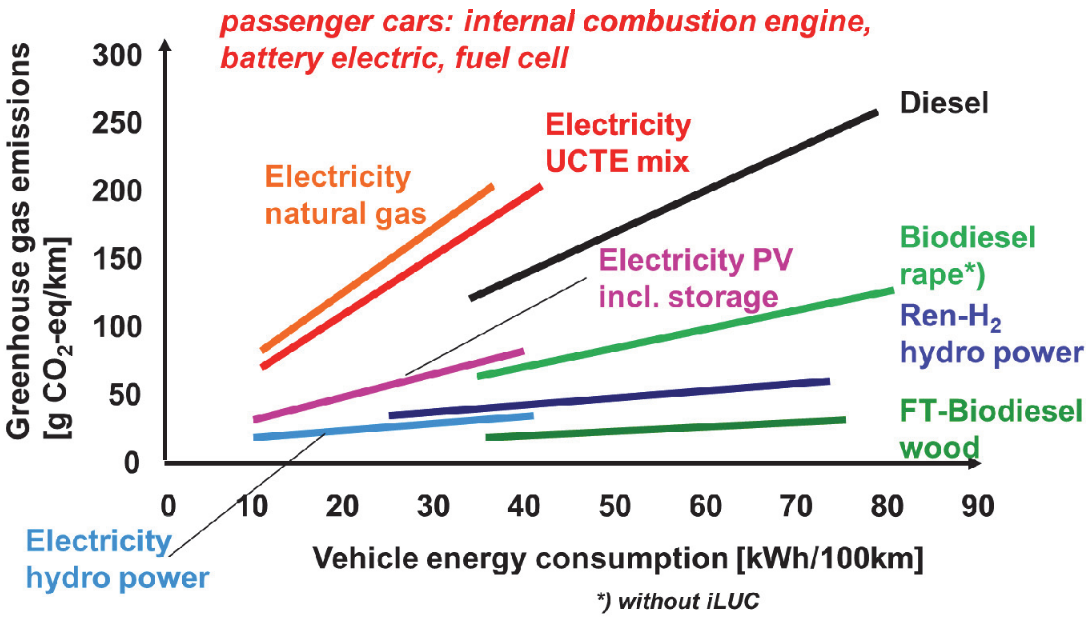

Figure 7: Sensitivity analyses of fuel/electricity consumption on GHG emissions of battery electric vehicles, vehicles with an internal combustion engine (diesel, biodiesel) vehicle with hydrogen fuel cell. [Jungmeier 2013, Jungmeier 2014]

Conclusions

The key issues for applying LCA methodology to vehicles with electric drivetrains are identified and described. The main activities influencing the environmental impacts of electric vehicles on a life cycle basis are: 1) Production and life time of the battery, 2) Electricity consumption of the vehicle in the operation phase, incl. e.g. energy demand for heating, 3) Source of the electricity, where only additional renewable electricity maximizes the environmental benefits and 4) End of life treatment of the vehicle and its battery.
The strategies to maximize the environmental benefits of vehicles with an electric drivetrain should include the following issues:

1) Environmental Assessment of EVs only possible on Life Cycle Assessment compared to conventional vehicles
2) Production and “end of life phase” relevant for EVs, e.g. mass production and recycling of batteries
3) Renewable electricity offers high environmental benefits for EVs with adequate loading strategies
4) Electricity consumption of EVs must be optimized incl. heating and cooling demand
5) Consumer behaviour is essential on environmental benefits/impact of EVs

The IEA Task 19 has established 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 organized and documents workshops. Further information: http://www.ieahev.org/tasks/task-19-life-cycle-assessment-of-evs/

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