

Development of a methodical approach for the description of the use phase of electric vehicle concepts in life cycle assessment

Michael Baumann^{1,*}, Michael Held¹

¹Fraunhofer Institute for Building Physics, Department Life Cycle Engineering (GaBi),
70771 Leinfelden-Echterdingen, Germany

*Michael.Baumann@ibp.fraunhofer.de

Abstract Due to limited potential for improvement of conventional vehicle power trains regarding fuel consumption and emissions, electric vehicle concepts will gain increasingly in importance in future. Within the research project “Fraunhofer System Research for Electromobility” in this study was developed a methodical approach, which enables the environmental assessment of use phases of different electric vehicle concepts. The structure of the method is characterized by calculation modules, which allocate state of the art data to the categories “energy demand”, “energy supply” and “maintenance and use characteristics”. As a result of the application of the method the crucial parameters on environmental impacts of chosen electric vehicle concepts could be determined (underlying driving cycle, electricity grid mix and life span and dimensioning of the battery system). The method can be used as a basis for further LCA electric mobility research projects.

1 Introduction

Since future improvement of conventional vehicle power trains regarding fuel consumption and emissions is limited, electric vehicle concepts will gain in importance in future. The German federal government has within the national roadmap for electric mobility set the goal that there are one million electric vehicles going to be used in Germany in 2020 [1]. In the research project “Fraunhofer System Research for Electromobility” which is promoted by the German Federal Ministry of Education and Research it is aimed at generating knowledge and technology along the entire value-added chain. Within this project in this study at the Department Life Cycle Engineering (GaBi) was developed a methodical approach, which enables the environmental assessment of use phases of different electric vehicle concepts. The study focuses on three main issues:

- Development of a methodical approach for the description of the use phase of electric vehicle concepts in a life cycle assessment considering the identification of relevant information, components and parameters
- Validation and application of the methodical approach on basis of state of the art electric vehicle concepts (BEVs and PHEVs)
- Identification of significant influencing factors on environmental impacts of use phase and comparison to conventional vehicles

2 Method development

In the scope of this study a systematical approach was developed, which enables the environmental assessment of use phases of electric vehicle concepts in LCA. Based on this method battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs) can be assessed. The degree of electrification of these concepts is shown in Fig.1.

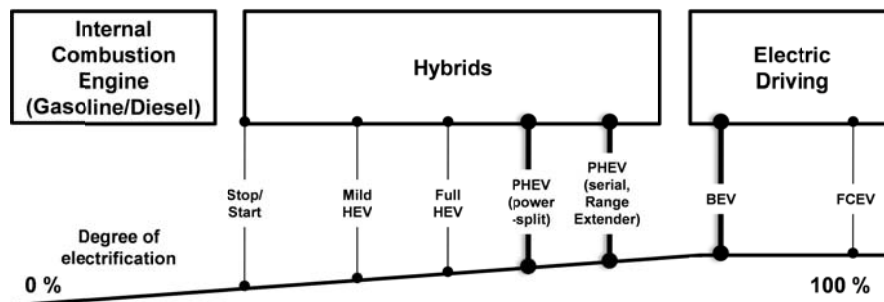


Fig.1: Degree of electrification of vehicle powertrains [2]

The method is focused on electric mobility concepts with a high degree of electrification and a connection plug to a static electricity grid. The structure of the use phase method includes a division in three modules.

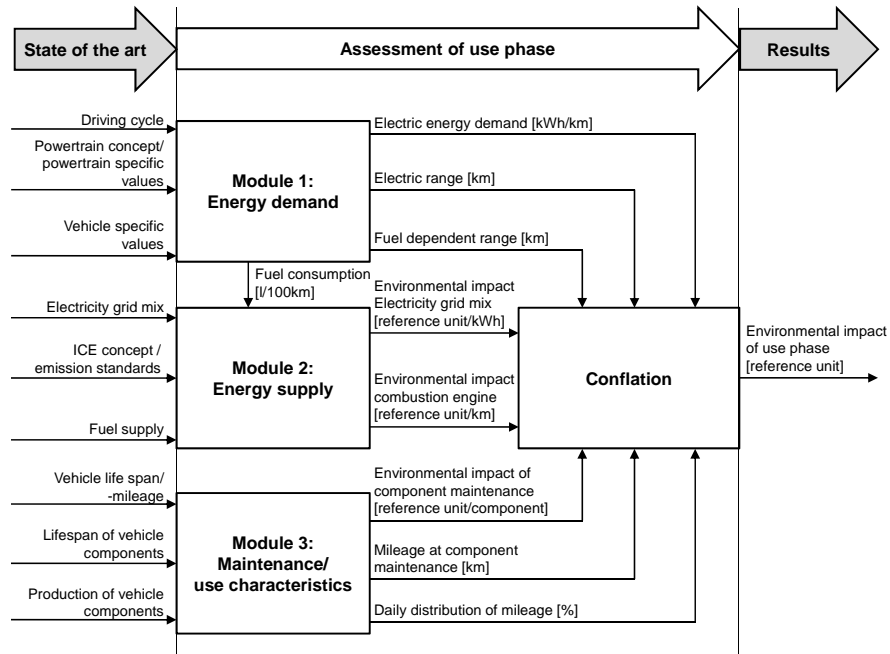


Fig.2: Structure of the method for the environmental assessment of use phase of electric vehicle concepts

In the first module the energy consumption values of electrified vehicles are assessed. The energy consumption data for module 1 is based on the chosen driving cycle, powertrain concept (powertrain specific values, e.g. component efficiencies) and vehicle specific values (e.g. vehicle weight, air resistance). To calculate the results of module 1 a calculation tool has to be developed which considers all relevant input data and processes them to a meaningful output. The second module contains the energy supply for the vehicle concepts. This energy supply module includes the electric energy supply for electric powertrain (chosen electricity generation mix) and the energy supply for fuel dependent powertrain (fuel supply). The input data is processed and categorized within the LCA-software GaBi [3] to environmental impacts. The third module addresses the maintenance and use characteristics of the chosen vehicle concepts. This module considers all maintenance components which have a shorter life span than vehicle life span and have to be replaced with a new component. For electric vehicle concepts the battery system is the maintenance component with the biggest importance. The environmental impact is assessed and categorized within GaBi. The two further outputs of module 3 are calculated in the scope of a developed calculation tool. The results of all three modules are joined in a conflation

calculation tool, where the environmental impact of the use phases of electric vehicles is assessed.

3 Method application and validation

To guarantee the applicability of the developed method, the method was validated with available data. The validation was introduced with a state of the art research of electric mobility. The method was applied by using the investigated data. Afterwards the method was validated by a comparison of results with available measured values of electric vehicles.

3.1 State of the art of electric vehicle concepts

The chosen electric vehicle concepts are aligned with electrified models of automotive manufacturers which are in development phase and soon will enter the market. The development activities of automotive manufacturers are mainly focused on BEVs (Battery electric vehicles) and PHEVs (Plug-in hybrid electric vehicles). The data used within the study is based on the following car models (including market introduction year).

- **BEVs (mini-class)**
Mitsubishi i-MiEV (2010), Smart ED (2012), VW Up Blue-E-Motion (2013)
- **BEVs (compact-class)**
Nissan LEAF (2010), VW Golf Blue-E-Motion (2013)
- **PHEV serial (Range Extender) (compact-class)**
Opel Ampera (2011), Mercedes-Benz BlueZERO E-CELL PLUS (study)
- **PHEV power-split (compact-class)**
Toyota Prius Plug-In Hybrid (2012)

The specifications of the chosen car models were averaged and summarized. Based on further research of weight and efficiency data of powertrain components specific values for the method application were assumed. In all regarded BEVs and PHEVs Li-Ion battery-systems are used for energy storage. For current battery systems LiNi_{1/3}Co_{1/3}Mn_{1/3}O₂-cells and a life span of 8 years are assumed. The electric powertrain is currently located in the center of the car and permanent magnet synchronous motors (PMSM) are used for power supply. The life span of

all vehicles and all other powertrain components is assumed to be 12 years. The daily mileage of 39 km is based on information of the German DAT-report [4].

Tab.2: Boundary conditions

	BEV (mini-class)	BEV (compact- class)	PHEV serial (compact- class)	PHEV power-split (compact- class)
Battery technology	Li-Ion (LiNi1/3Co1/3Mn1/3O2)			
Gravimetric energy density of cells [Wh/kg]	135			
Energy content of battery [kWh]	17	25	17	5,2
E-motor PMSM [kW]	39	83	106	60
Combustion engine [kW]	-	-	52	73
Generator [kW]	-	-	52	73
Total mass of EVs [kg]	999	1.510	1.600	1.596
Life span battery [years]	8			
Life span other components [years]	12			
Mileage (daily/annual/life span) [km]	39/14.300/171.600			

The calculation of energy and fuel consumption of the vehicles is based on the ADAC Eco-Test [5] and NEDC [6] driving cycles. Further emission data of combustion engine operation refers to the Handbook emission factors for road transport (HBEFA 3.1) [7]. The electricity supply and fuel supply data is assessed according to LCA-database GaBi [3].

3.2 Application and validation

According to the method shown in Fig.2 the state of the art data is used as input for environmental assessment. Within module 1 the electricity demand, the electric range and the fuel dependent range (PHEVs) of the electric vehicle concepts are calculated. These resulting energy demand values consider the different powertrain structure of the electric vehicle concepts. Furthermore the energy demand of auxiliary consumers is integrated in the energy modeling. The energy chain of a BEV is shown in Fig.3.

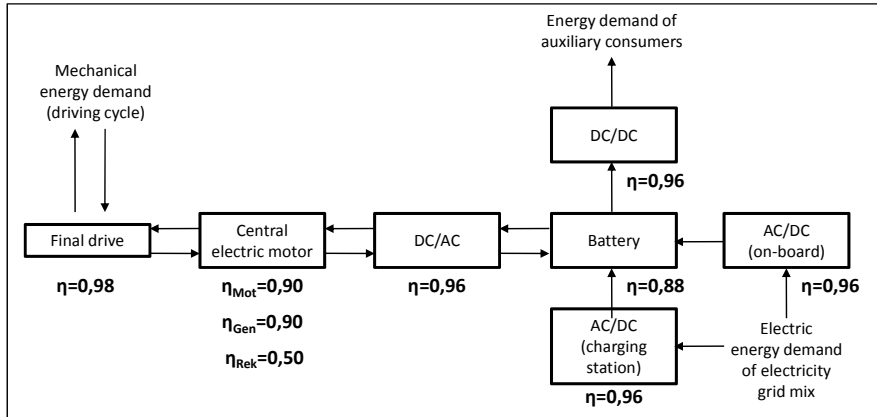


Fig.3: Internal energy chain of BEVs with efficiencies

In module 2 the electricity supply and fuel supply is used as input to assess the environmental impact of electricity grid mix and internal combustion engine. To guarantee the later assumption of main influence parameters, two electricity grid mix scenarios are assessed: A scenario of current German electricity grid mix and a pure wind power scenario. On basis of the state of the art data concerning module 3 (maintenance / use characteristics) the environmental impact of component maintenance is calculated and connected with the mileage at maintenance. The third output of module 3 is the daily distribution of mileage which is a result of the average daily mileage of vehicles. This third output is primarily important for the assessment of PHEVs, because the share of electric mode driving operation and hybrid (fuel dependent) mode driving operation is determined. Significant results of all modules are summed up in Tab.3.

Tab.3: Significant results of calculation modules

	BEV (mini-class)	BEV (compact- class)	PHEV serial (compact- class)	PHEV power-split (compact- class)
Energy consumption (electric mode) [kWh/100 km]*	18,4	21,9	21,1	7,8**
Fuel consumption (hybrid mode) [l/100 km]*	-	-	7,1	6,0
Electric range [km]*	115	137	72	51
Fuel dependent range [km]*	-	-	565	745
Distribution of daily mileage (electric mode / hybrid mode)*	-	-	88% / 12%	74% / 26%

*Calculation according to ADAC EcoTest; **No pure electric mode, additional fuel consumption in the case of higher driving speeds

The method for the calculation of energy consumption has been validated with available published test data [8], [9], [10], [11]. The energy consumption values assessed following the method show a good accuracy in comparison with these measurements. The energy consumption of BEVs shows a difference between 1,4 and 3,7 % compared to measured values. The serial PHEVs had a deviation of 5,9 % in comparison to the measurements. The difference of calculated values compared with measured values in the case of power-split PHEVs varied between 6,8 and 8,3 %.

4 Identification of significant influencing factors on environmental impacts of use phase

The significant influencing factors were identified on basis of the application of the developed method. All mobility relevant environmental impacts were assessed and categorized into environmental potentials. Fig.1 shows the example of the use phase chart of greenhouse warming potential. Since in this chart only use phase is considered, all use phase curves start with zero impacts at the beginning of use phase.

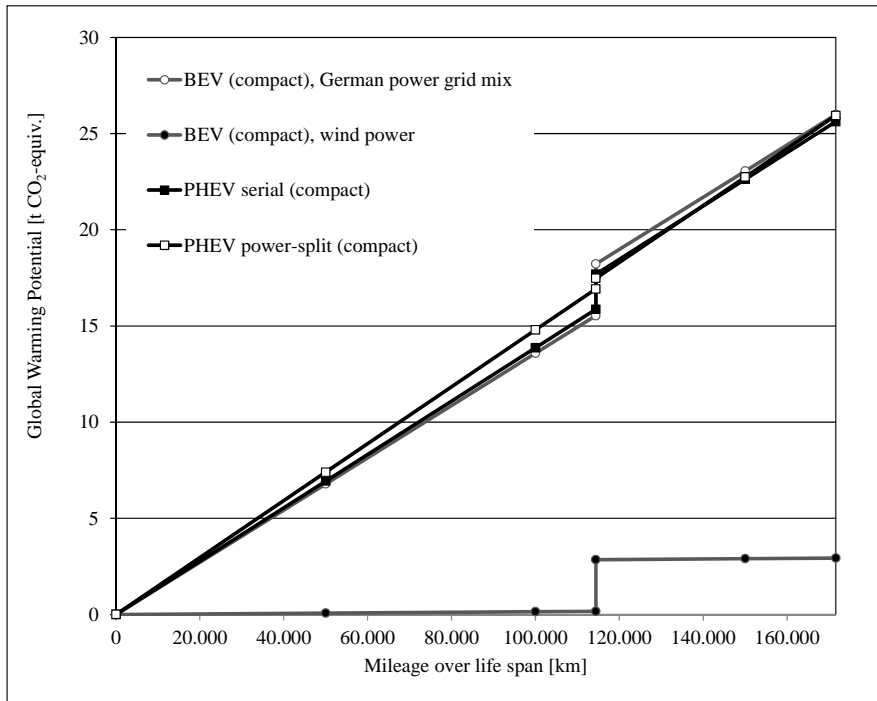


Fig.4: Use phase chart of greenhouse warming potential (GWP) for electric vehicles (compact-class)

Based on the assessed environmental impacts, the main influence parameters on use phase of electric vehicle concepts were determined. According to Fig.4 the following parameters have a significant influence on use phase curve:

- Driving cycle**
 The gradient of the use phase curve is direct proportional to the mechanical energy demand of the chosen driving cycle.
- Electricity grid mix**
 The gradient of the use phase curve depends on the chosen electricity grid mix of energy supply.
- Life span and dimensioning of battery system**
 The vertical step of the use phase curve shows the battery life span and dimensioning of the battery system. The length of the step depends on the energy content and the life span of the battery system. The use phase curve of PHEVs shows a shorter step because of lower battery energy content.

- **Increase of vehicle efficiency**
Vehicle efficiency can be increased by a reduction of vehicle weight and the increase of efficiency of powertrain components.
- **Vehicle concept specific user profiles**
For all vehicle concepts the same life span and mileage is assumed. The mileage at battery replacement depends on the assumed total mileage of vehicle and the battery life span (year-dependent).

5 Summary and conclusion

The development of the methodical approach for the description of the use phase of electric vehicle concepts was carried out based on the current state of the art. Considering the technology of current electric vehicles the method was applied and validated. Following the resulting environmental profiles of electric vehicles the significant influencing factors on environmental impacts of use phase were identified. All environmental impacts of electric mobility were compared with environmental impacts of conventional vehicles (gasoline/diesel).

Since there is only little information for the environmental profiles of electric vehicle concepts available, the presented method allows a profound assumption of the use phase of electric vehicle concepts in LCA. The developed method provides a basis for future research for LCA of electric mobility.

In future a selective advancement of details especially in the field of use characteristics will be introduced. This includes a development of vehicle concept dependent use models (e.g. vehicle use in urban areas). A further improvement of results can be expected when announced electric vehicles are available and further official measured values (e.g. energy consumption) can be considered.

6 References

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