ENVIRONMENTAL IMPACTS OF ELECTRIC VEHICLES WITH RANGE EXTENDER ON THE BASIS OF EUROPEAN VEHICLE USE PROFILES

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Overview

The range autonomy is one of the main barriers to the commercial success of battery electric vehicles (BEVs). However, statistics show that a large proportion of the daily trips are far below the maximum range of current BEVs. Therefore, BEVs with a reasonable sized battery and a range extender could satisfy a majority of needs achieving zero emissions in a limited area and may enable an occasional over range trip. The main idea of the European project EVREST (project duration: 01/07/2012 - 30/06/2015) [1] is to study how extended range electric vehicles (EREVs) could match the different usage patterns and what would be the acceptance and impacts of such a solution. For this purpose, in EVREST analyses of users' profiles and expectations based on databases from different European countries are conducted. The results of these analyses are used to develop EREV specifications which show an optimized design from a technical, economic and environmental perspective. The considered range extender technologies are gasoline engines, diesel engines and fuel cells. The tasks of LBP-GaBi concentrate on the comparison of the environmental impacts (GHG emissions) of the developed EREVs with BEVs and conventional vehicles with internal combustion engines (gasoline and diesel) on the basis of Life Cycle Assessment (LCA). The specifications of all assessed vehicles are defined by IFSTTAR-LTE in cooperation with LBP-GaBi.

Within EVREST, LCA models of small and compact vehicles are developed. The LCA models consider the production (incl. all vehicle components) and the use phase (incl. mileage, electricity and fuel consumption on the basis of European usage patterns and boundary conditions). The assessments of small vehicles focus on an environmental comparison of the developed small EREV with an equivalent BEV. The assessments of compact vehicles concentrate on an environmental comparison of the compact EREV with equivalent conventional gasoline and diesel vehicles.

Results will show the environmental footprint of EREVs during production and use phase and an environmental comparison of all assessed vehicles. The environmental comparison will be realized in the form of LCA functions which allow the identification of break-even points. These break-even points define the mileage on which EREVs show environmental advantages (lower GHG emissions) compared to the equivalent BEVs and conventional vehicles.

Within the paper the environmental impacts of the developed EREVs are shown the first time in public. The results can contribute to a target-oriented design of electric vehicles from a technical, economic and environmental perspective in future.

Methods

For the environmental comparison of EREVs with gasoline engine range extender with battery electric vehicles (BEVs), gasoline- and diesel-powered vehicles, the analysed vehicle classifications were defined in a first step. In coordination with IFSTTAR-LTE the vehicle classifications “small vehicles” and “compact vehicles” were determined. As a reference vehicle of the small vehicle class a typical small BEV was used. In the compact vehicle class a typical conventional compact vehicle was selected as reference vehicle in two different versions, with gasoline and diesel engines. In the ongoing EVREST project there will be also two further range extender versions with diesel engine and fuel cell assessed.

Within the project, specifications for EREVs with optimized sizes of both the battery and the range extender were defined by IFSTTAR-LTE based on clusters (e. g. European cluster 2 for small vehicles) which were determined on the basis of statistics and analyses about user profiles in the European countries Austria, France and Germany [2]. To evaluate the electricity and fuel consumption of the vehicles as well as the pollutant emissions and the battery aging for each EREV sizing, the yearly energy consumption needed for the selected cluster was determined. To ensure the scalability of the Life Cycle Assessment models, the system optimization as well as the specifications of the EREV concepts were implemented in cooperation of IFSTTAR-LTE and LBP-GaBi within the shared work package WP2 of the EVREST project.

The definition of technical specifications of the assessed vehicles was conducted in cooperation with IFSTTAR-LTE and is shown in the following tables.

Table 1: Small vehicles (European cluster 2: yearly mileage 4877 km)

Vehicle	**BEV**	**Small EREV**
Motor power [kW]	47	47
Battery capacity [kWh]	16	9
RE power [kW]	-	19
Total weight [kg]	1200	1258
Vehicle lifetime [a]	12	12

Table 2: Compact vehicles (European cluster 3: yearly mileage 12001 km)

Vehicle	**Gasoline**	**Diesel**	**Compact EREV**
Motor/Engine power [kW]	87	87	87
Battery capacity [kWh]	-	-	19
RE power [kW]	-	-	20
Total weight [kg]	1470	1490	1751
Vehicle lifetime [a]	12	12	12

Since IFSTTAR-LTE used an Euro 3 scooter engine for the emission measurements, the Euro 3 exhaust emission standard is also used in the EREV LCA model. This affects the comparison of EREVs with conventional cars since the LCA models of the compact gasoline vehicle as well as the compact diesel are based on the exhaust emission standard Euro 5. In the ongoing EVREST project also future scenarios will be developed and assessed in which the same exhaust emission standard, presumable Euro 6, will be used for all reference vehicles as well as for the EREV engine to ensure the comparability of the various vehicle types.

The environmental impact assessment is performed for the production and use phase according to the method of Life Cycle Assessment. The LCA models are created within the GaBi database. The models were set up flexible for each vehicle type and class to simply adapt single specification parameters without changing the whole model.

In the scope of the data collection for LCA, already existing background models (e.g. for fuel supply and electricity grid mixes) were used as a basis while to assess the environmental impacts of conventional vehicle components environmental, certificates and environmental commendations of different automobile manufacturers were evaluated. More intensive literature research was done for the drivetrain components like battery and fuel cell.

Since the objective of the EVREST project also includes the comparison of environmental impacts of EREVs in different European countries, the use phases of the EREVs are modelled with different electricity grid mixes. Next to the German grid mix of the year 2010, also the French and Austrian grid mix, each also of 2010, are used. The different grid mixes influence the share of the environmental impact of the electricity consumption during the use phase due to different shares of energy sources as for example renewable energy or nuclear power.

Both the small and the compact EREV are modelled with a gasoline powered range extender engine.

One assumption taken from literature research is a lifetime of 8 years of the batteries for BEVs and EREVs [3] [4] [5].

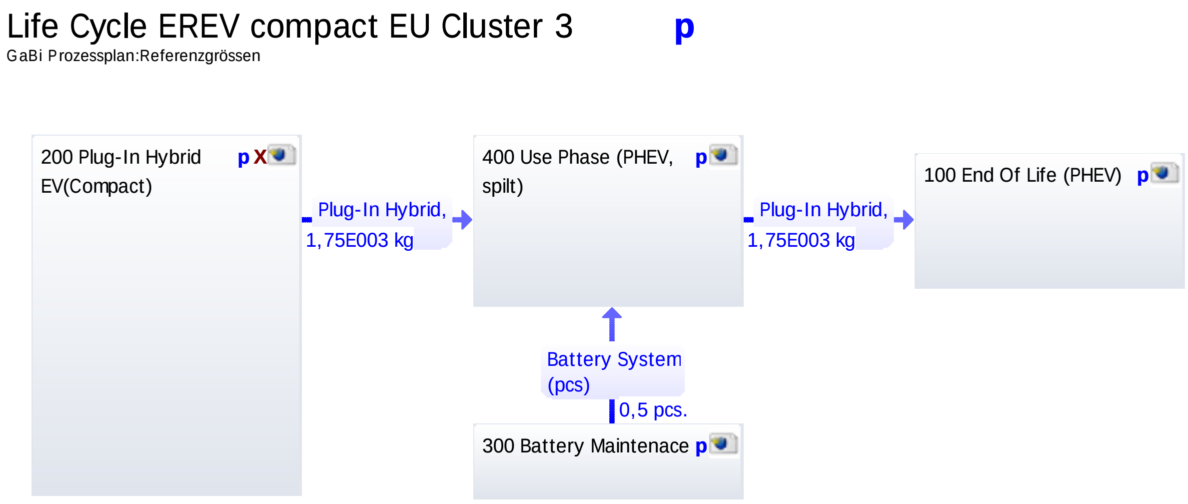

Figure 1: GaBi LCA model of the compact EREV (European cluster 3)

The Figure 1 shows the highest level of the LCA model of the compact EREV created with the GaBi software with the main LCA modules production phase, use phase, maintenance and end of life. The end of life will not be modelled within the EVREST project and will therefore not appear in the results. The LCA model considers all relevant resource and energy inputs taken from the environment as well as the emissions to the environment during the life cycle of the EREV.

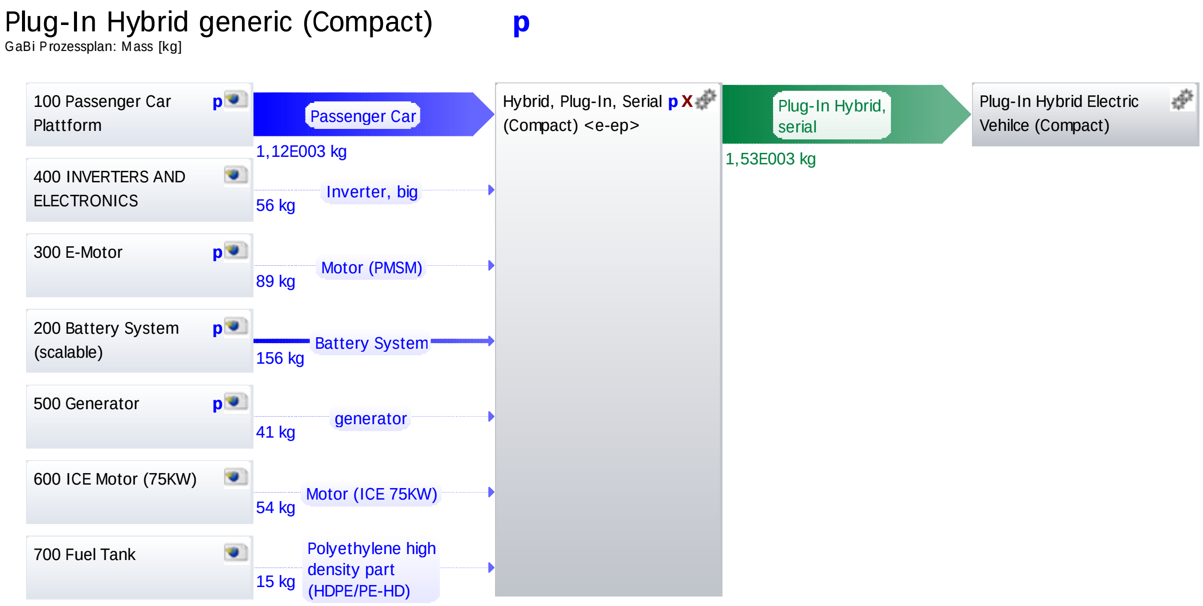

Figure 2: GaBi LCA model of the EREV production phase level

In the production phase level of the GaBi LCA model the single vehicle modules like the car platform or the e-motor can be found. In the levels below, single components and their production including material production and processing to the final components can be found.

Based on the data collected and the vehicles modelled as described above, first results of the production and use phase of the proposed EREVs and the reference vehicles were assessed and are shown in the next chapter. Detailed LCA models of the production phase, including the whole production chain and the use phase were developed in the LCA software GaBi and adapted to the boundary conditions.

Results

In this chapter first results of the environmental footprint of EREVs during their production as well as use phase are shown and compared to conventional combustion engine and battery electric vehicles. The LCA results of the two EREV sizes are presented for the use in the countries Austria, France and Germany. The comparison of the EREVs with reference BEVs and conventional vehicles is also illustrated with LCA functions to locate break-even points.

In this paper the focus of the assessment of environmental impacts lies on the LCA impact category Global Warming Potential (GWP). The GWP is influenced by emissions from combustion which have an impact on the global warming as for example CO_2 and CH_4. Other impact categories will be assessed within the ongoing EVREST project but are not addressed in this paper.

Small vehicles

The small vehicles (European cluster 2) are modelled with 12 years of operation while having a mileage of 4877 km/year.

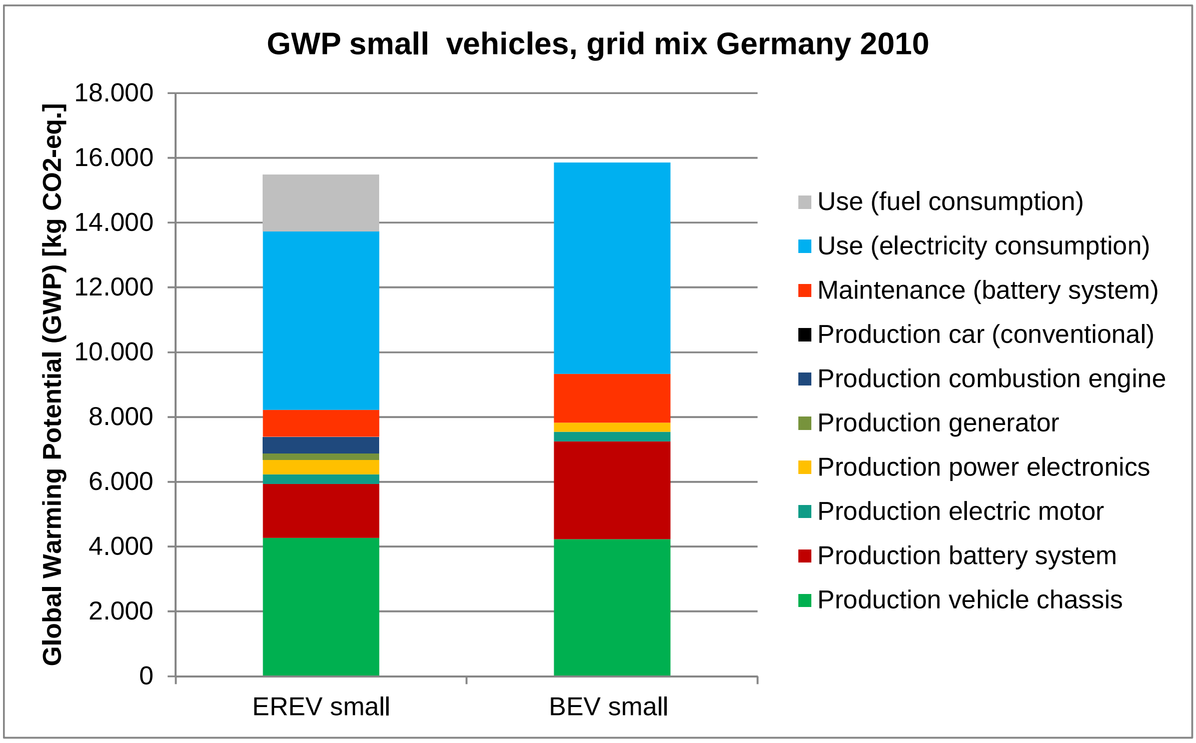

Figure 3: Global Warming Potential of the small vehicles (European cluster 2), both modelled with the German electricity grid mix of 2010 with shares of single component production and use phase

Figure 3 shows the comparison of the Global Warming Potential of the small EREV and reference BEV. They are both modelled with the German electricity grid mix of the year 2010. The diagram shows that the production of the bigger battery as well as its maintenance affect a higher Global Warming Potential for the BEV as for the

EREV with a smaller battery. The total GWP of the BEV is therefore still a little higher than the total GWP of the EREV, even with the EREV having a bigger impact during the use phase by also consuming fuel.

A further method to graphical illustrate an environmental comparison besides simple bar charts is by LCA functions. These functions show the increasing total environmental impact during the use phase and therefore allow the identification of break-even points, when the various alternatives change their ranking. The break-even points of the LCA functions shown below define the mileages on which EREVs show environmental advantages or disadvantages compared to the reference vehicle like the equivalent BEV for the small vehicle class.

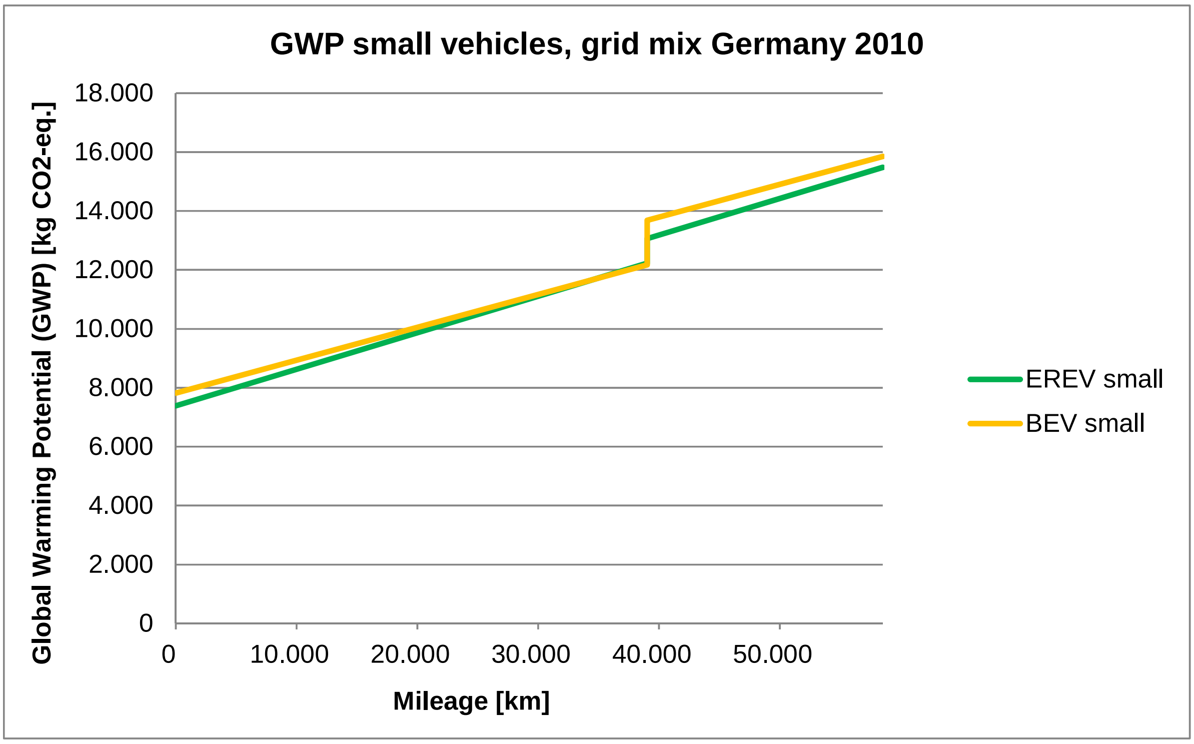

Figure 4: LCA function showing increasing Global Warming Potential of the small vehicles (European cluster 2) during the use phase, both modelled with the German electricity grid mix of 2010

The comparison of the small EREV with the small BEV using the German electricity grid mix of 2010 shows that their total environmental impact doesn't differ very much over the use phase, since they start with nearly the same impact after the production while the EREV has a slight advantage which disappears during the use phase due to its additional fuel consumption. Shortly before the battery maintenance after 8 years which causes the gap in both curves, the BEV GWP impacts even undercuts the impacts of the EREV. After the maintenance which causes a higher impact for the BEV due to its bigger battery, the EREV shows a small but clear advantage for the final 4 years of the 12 years operation time.

The selected electricity grid mix clearly influences the size of the share of the use phase electricity consumption. This effect is illustrated by the following diagram comparing the small EREV modelled with the German grid mix with the same vehicle modelled with the French grid mix as well as the Austrian grid mix. All grid mixes are of the year 2010.

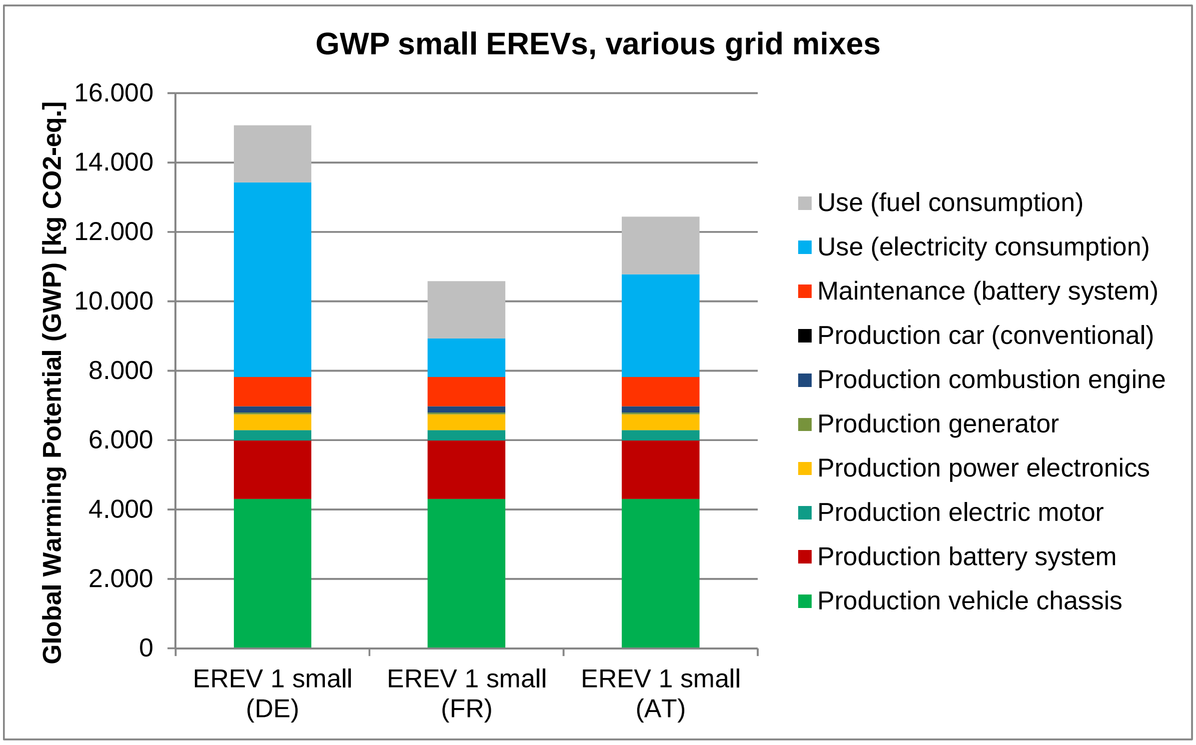

Figure 5: Global Warming Potential of the European cluster 2 small EREVs modelled with different grid mixes of the year 2010 with shares of single component production and use phase

Figure 5 shows how the different grid mixes influence the share of the environmental impact of the electricity consumption during the use phase. The impact of the grid mix is due to different shares of renewable energy as well as nuclear power. While the French grid mix has especially low impacts caused by a very high share of nuclear power with having a very low impact on the Global Warming Potential, the Austrian grid mix has a significant lower impact compared to Germany due to a high share of hydropower.

Compact vehicles

The compact vehicles are also modelled with 12 years of operation while having a mileage of 12001 km/year.

As already mentioned before, the comparability between the compact vehicles is restricted due to the EREV being modelled with the exhaust emission standard Euro 3 while the reference vehicles are based on the exhaust emission standard Euro 5. This means the EREV is assessed adversely in comparison with the gasoline and diesel compact vehicles. Furthermore, since the environmental impact of EREVs is supposed to be assessed with operation in different European countries, the use phase is modelled with various electricity grid mixes. The use phase is therefore modelled as before for the countries Germany, Austria and France, each using the grid mix of 2010.

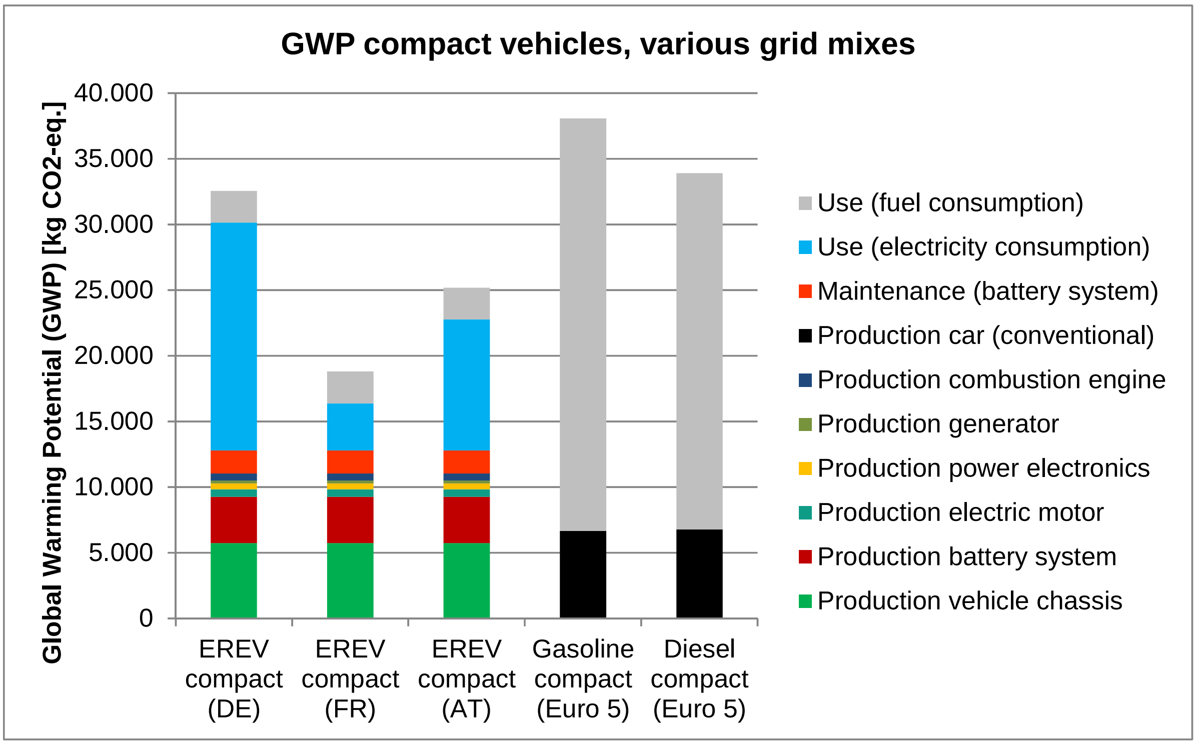

Figure 6: Global Warming Potential of the compact vehicles (European cluster 3), modelled with different electricity grid mixes of the year 2010 with shares of single component production and use phase

In Figure 6 all compact EREVs show a distinct advantage compared to the two reference compact vehicles even with the EREVs being assessed adversely due to the use of the older Euro 3 exhaust emission standard.

While the production of the conventional cars causes nearly only the half of the GWP of the production of the EREVs including the battery maintenance, the use phase of both reference cars dominates their total impact. The use phase of the EREVs is again strongly influenced by the used electricity grid mix.

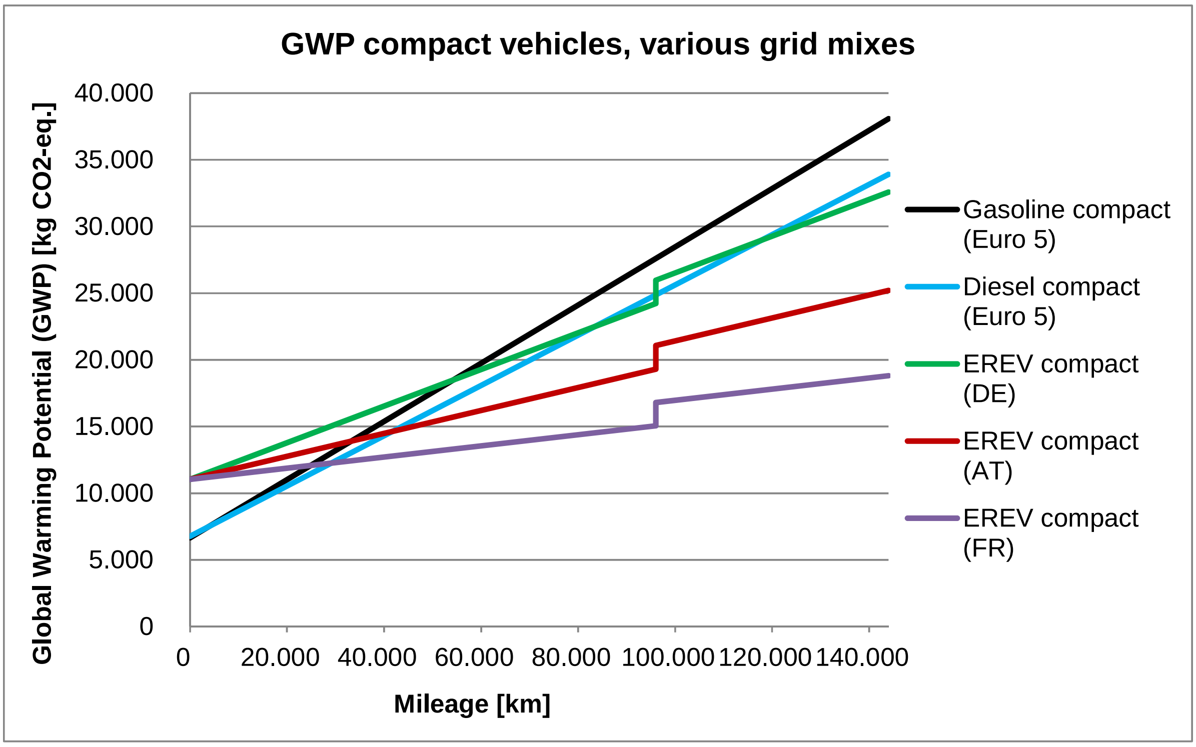

Figure 7: LCA function showing increasing Global Warming Potential of the compact vehicles (European cluster 3) during the use phase, modelled with different grid mixes of the year 2010

The EREVs all start with a higher GWP than the conventional vehicles right after the production phase due to the higher production effort of the electric system and mainly its battery.

The break-even points of the LCA functions shown above define the mileage on which the various EREVs show environmental advantages compared to the conventional reference vehicles. The exact break-even points of the Global Warming Potential are also shown in the table below.

Table 3: Break-even points of the compact EREV in comparison with the conventional reference vehicles

Break-even points (Global Warming Potential)

EREV compact (DE) ⇔ Gasoline compact	54.068 km
EREV compact (DE) ⇔ Diesel compact	83.220 km
EREV compact (DE) ⇔ Diesel compact	117.653 km
EREV compact (FR) ⇔ Gasoline compact	24.801 km
EREV compact (FR) ⇔ Diesel compact	29.038 km
EREV compact (AT) ⇔ Gasoline compact	33.118 km
EREV compact (AT) ⇔ Diesel compact	41.605 km

For the comparison of EREV compact (DE) and diesel compact, two mileages are registered in the table due to the EREV already coming below the total GWP of the diesel vehicle after a mileage of 83.220 km but then exceeding again with the battery maintenance after 8 years.

Conclusions

The results show that there is a potential for EREVs to provide large environmental advantages for the Global Warming Potential especially in comparison with conventional vehicles when using electricity with high shares of renewable energy.

Other impact categories which will be assessed within the ongoing EVREST project but were not addressed in this paper are the Acidification Potential AP (emissions from combustion which cause acid rain as SO_2 and NOx), the Photochemical Ozone Creation Potential POCP (formation of low level ozone by sunlight instigating the photochemical reaction of nitrogen oxides with hydrocarbons and volatile organic compounds) and Eutrophication Potential EP (nutrient input into water and land from substances from agriculture, combustion processes and effluents). Furthermore also the total primary energy from non-renewable resources will be assessed within the project.

First screenings of results showed that the EREVs don’t show advantages in all environmental impact categories compared to the other powertrain options. In environmental impact categories which are strongly influenced by pollutant emissions (e.g. Photochemical Ozone Creation Potential) the EREVs show higher impacts than the reference vehicles, mainly also resulting from the old Euro 3 exhaust emission standard of the range extender. This might change when using the same exhaust emission standard for all assessed vehicles when modelling the future scenarios. Further high environmental impacts that influence the comparison of the EREVs with conventional cars result from the battery change after 8 years of the vehicle lifetime.

In the ongoing EVREST project next to the future scenarios there will also be modelled and assessed future EREV versions with diesel and fuel cell range extenders which might also deliver interesting results.

It can be assumed that even in other impact categories the highest potential for advantages in comparison with conventional vehicles for EREVs can be found for use cases with electricity coming from non-polluting renewable energy sources.

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