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Climate Neutrality of Growing Electric Vehicles Fleets (2010 - 2050) in a Dynamic LCA Considering Additional Renewable Electricity: Example Austria

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Summary

The environmental effect of electric vehicles can only be assessed based on life cycle assessment (LCA) covering production, operation and end of life. Since 2011 in the Technical Collaboration Program (TCP) on “Hybrid & Electric Vehicles” (HEV) of the International Energy Agency (IEA) with 20 participating countries an expert group develops and applies LCA methodology to estimate the environmental effects of the increasing electric vehicle (EV) fleet globally. This approach was further developed to a dynamic LCA by taking the time depending effects of the BEV fleet introduction and the parallel increasing supply of renewable electricity into consideration aiming for a long-term climate neutrality. The BEV introduction in Austria started in 2010 and the BEV fleet is now 50,000 BEVs and consumes 140 GWh electricity, which is about 1% of the additional renewable electricity generated since 2010. Assuming each BEV substitutes for an ICE in 2020 the BEV fleet in Austria emitted 170 kt CO_2-eq and avoided 190 kt CO_2-eq. In a next step this methodology was applied in scenarios up to 2050 to reach a climate neutral Austrian transport sector and to identify its necessary framework conditions.

Keywords: LCA (Life Cycle Assessment), sustainability, primary energy, modelling, environment, deployment

1 Introduction

The environmental effect of electric vehicles can only be assessed based on life cycle assessment (LCA) covering production, operation and end of life treatment. Since 2011 in the Technical Collaboration Program (TCP) on “Hybrid & Electric Vehicles” (HEV) of the International Energy Agency (IEA) with 20 participating countries an expert group develops and applies LCA methodology to estimate the environmental effects of the increasing electric vehicle (EV) fleet globally [1, 2, 5].

Since 2014, IEA HEV Task 30 estimates the LCA based environmental effects of the worldwide EV fleet in 40 countries. In the LCA of these vehicles using the different national framework conditions, the environmental effects are estimated by assessing the possible ranges of GHG emissions, acidification, ozone formation, PM emissions and primary energy consumption in comparison to conventional ICE vehicles [3, 4, 6, 7].

Now this approach was further developed to a dynamic LCA by taking the time depending effects of the BEV fleet introduction and the parallel increasing supply of renewable electricity into consideration.

2. Issues on dynamic LCA of vehicle fleet

Issues on dynamic LCA, e.g. annual environmental effects, become relevant for the rapidly increasing of EV-fleets combined with an additional generation of renewable electricity. For this, the Task identified the following relevant methodological aspects:

1. timing of environmental effects in the three lifecycle phases,
2. timing of environmental effects of increasing supply of renewable electricity,
3. timing of environmental effects of EVs using increasing supply of renewable electricity, and
4. substitution effects and timing of environmental effects of EVs substituting for ICE vehicles.

The possible environmental effects of a system occur at different times during their lifetime. In LCA, the environmental effects are analysed for the three phases separately – production (for vehicles) or construction (for power plants), operation and end of life – over the whole lifetime of a system. Then the cumulated environmental effects over the lifetime are allocated to the service provided by the system during the operation phase, which is the functional unit in LCA, e.g. per kilometre driven for vehicles and kWh generated for power plants. Therefore, the functional unit gives the average environmental effects over lifetime by allocating the environmental effects for production and end of life over the lifetime to the service provided independent of the time when they occur.

Another approach considered in the Task is to reflect and keep the time depending course of the environmental effects in the life cycle and compare the absolute cumulated environmental effects in a dynamic LCA.

In Figure 1, the possible courses of the cumulated environmental effects of three systems in their lifetime are shown for the three phases – production, operation and end of life. All the three systems – A, B and C - have the same lifetime and provide the same service but the courses of the environmental effects are quite different. The system A has low environmental effects in the production/construction phase but high effects during the operation/use phase and again low effects in the end of life phase. While system B has very high effects in the production phase, very low further effects in the operation phase and declining environmental effects in the end of life phase due to the recycling of materials and a credit given for the supply of secondary materials for substituting primary material. The system C has lower effects in production/construction phase than system B and no further effects during the operation phase, but significantly declining environmental effects in the end of life phase, which is due to the reuse of certain parts, facilities or materials for other further purposes.

Considering the total cumulated environmental effects system C has the lowest and system A the highest effects in their lifetime. However, additionally it can be analysed at which time in the lifecycle the system C has lower cumulated environmental effects compared to the other systems. At t_1 system C has lower cumulated environmental effects than system A; at the time t_2 system B has lower cumulated effects than system A.

This timing of the environmental effects becomes more relevant in future, when new innovative systems substitute for conventional systems to reduce the overall environmental effects. However, it might take some time until the real reduction of environmental effects takes place by the new innovative system. This aspect becomes more and more relevant in the context e.g. of the global necessary reduction of GHG emissions with increasing energy efficiency and renewable energy. Therefore, in dynamic LCA the course of the cumulated environmental effects have to be considered and addressed more adequately.

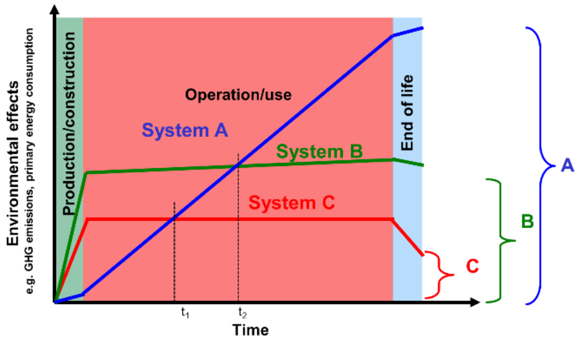

Figure 1: Timing of cumulated environmental effects of three systems with the same lifetime

2 Aim

The TCP HEV Task 30 developed the methodology of dynamic LCA to analyse and assess the environmental effects of electric vehicle and the necessary additional generation of renewable electricity. A dynamic approach is necessary to address also the future possibility of a "climate neutral mobility service" provided by electric vehicles using additional renewable electricity. The aim of this analysis is to apply this methodology to calculate the environmental effects over time for the Austrian situation. The analysis is split in three parts to show the stepwise application and results of this methodology. The application focuses on GHG emissions and the cumulated primary energy demand taking the development of the increasing BEV fleet into account. In the 1st step the GHG emissions of the supply of additional renewable electricity are calculated in the dynamic LCA. In the 2nd step the GHG emissions of introducing BEV in Austria since 2010 are calculated by substituting conventional ICE and in the 3rd step a scenario for a climate neutral mobility service by the Austrian passenger vehicle fleet in 2050 is shown.

In the dynamic LCA the greenhouse gas emissions (CO_2, CH_4, N_2O) in CO_2-eq, and the primary energy consumption (total, fossil, nuclear, renewable) are assessed.

3 Results

The results of applying dynamic LCA are given for the GHG emissions of increasing renewable electricity generation, the introduction of BEV since 2010 and scenarios for climate neutrality passenger vehicle fleet in 2050, all for the Austrian situation.

3.1 GHG emission of renewable electricity in Austria

The annual GHG emissions due to the installation of new renewable electricity generation plants in Austria were between 100,000 up to 800,000 t CO_2-eq per from 2005 to 2020, depending on the annual installed generation capacity and the type of renewable energy. E.g. the installation of a power plant to generate 1 GWh annually of PV with about 1,400 to 1,600 t CO_2-eq has significantly higher GHG emissions than hydro and wind with about 250 – 600 t CO_2-eq.

The combination of the annual GHG emissions and the additional electricity generation gives the specific GHG emissions of renewable electricity generation in Austria (Figure 2), on one hand the GHG emissions of the additional installed renewable electricity generation and on the other hand of the total renewable electricity mix in Austria. Due to the chosen dynamic LCA approach here, the GHG emissions of the construction of renewable electricity generation plants before 2005 are not considered in the years from 2005 onwards, only the relatively low GHG emissions of operating the plants for maintenance and the fuel supply for bioenergy are included. So the GHG emissions of renewable electricity generation in Austria in existing (before 2005) and newly installed power plants (since 2005) are in the range between 8 to 33 g CO_2-eq/kWh, whereas the GHG emissions of the additionally installed renewable electricity generation is between 31 and 250 CO_2-eq/kWh between 2005 and 2020.

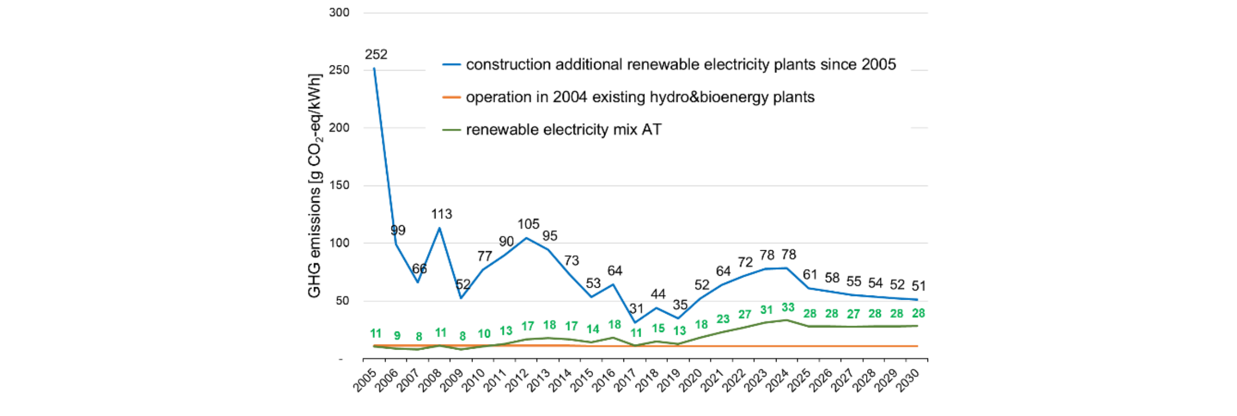

Figure 2: GHG emissions of renewable electricity generation in Austria

3.2 GHG emissions of BEV introduction in Austria

The introduction of BEV in Austria started in 2010. The annually registered BEV increased significantly and reached nearly 16,000 new BEVs in 2020. The BEV fleet increased up to about 46,000 BEVs in 2020. Assuming an electricity demand of about 0.22 kWh/km (incl. heating, cooling and auxiliaries) and 10% grid and charging losses the additional renewable electricity demand for the operation of the BEV fleet increased from 0.3 GWh in 2010 up to 142 GWh in 2020. Considering the increased renewable electricity generation since 2010 in Austria the demand to operate the BEV fleet is in a range of 0.1 to 1.1% of the additional renewable electricity generated since 2010. Concluding, also in this system perspective it is evident that the Austrian BEV fleet is operated on renewable electricity, while the increasing demand for electricity is met with increasing supply of renewable electricity.

Considering the course of the annual GHG emissions of the renewable electricity generation in Austria the GHG emissions of the operations of the BEV fleet in Austria are calculated using the GHG emission (2010 – 2020) between 10 to 18 g CO_2-eq/kWh. The GHG emissions of BEV fleet operation using the renewable electricity mix in Austria are in average between 2.5 to 4.5 g CO_2-eq/km. Therefore, in average between 2010 and 2020 the GHG emissions of a BEV operating in Austria are about 3.6 g CO_2-eq/km.

In addition, the GHG emissions from the production of the new registered BEV are calculated in a dynamic LCA perspective. The average GHG emissions of the global battery production has decreased from about 100 kg CO_2-eq per kWh battery capacity in 2010 to about 70 kg CO_2-eq/kWh. At the same time the battery capacity of a new BEV in Austria increase from about 30 kWh in 2010 to about 65 kWh in 2020 in average, due to the lower battery costs and the demand for higher driving ranges. Therefore, the production of a new BEV between 2010 and 2020 causes GHG emissions between 8.5 up to 10.5 t CO_2-eq. In comparison, the production of a conventional new ICE vehicle causes about 6 t CO_2-eq. However, the operation of a conventional substituted ICE vehicle has GHG emissions of about 145 g CO_2-eq/km with an average fuel consumption of about 0.52 kWh/km.

The GHG emissions of the BEV introduction since 2010 in Austria are calculated by considering the GHG emissions of the production from the annually new registered BEV and the operation of the BEV fleet by taking the substituted conventional ICE vehicles into account.

In Figure 3, the change of GHG emissions of the BEV fleet substituting an ICE fleet in Austria are shown. In 2020, the GHG emissions of the production of the newly registered 16,000 BEV are about 167 kt CO_2-eq and the GHG emissions of the BEV fleet operation of about 45,000 vehicles with renewable electricity are about 3 k t CO_2-eq.

Assuming each BEV substitutes for an ICE, about 16,000 newly registered conventional ICE vehicle were substituted in 2020 avoiding GHG emissions from their production of about 96 kt CO_2-eq and avoiding GHG emissions of about 94 k t CO_2-eq in the ICE fleet operation of about 45,000 conventional ICE vehicles. Therefore, in 2020 the BEV fleet in Austria emitted about 170 k t CO_2-eq and avoided about 190 kt CO_2-eq from substituting conventional ICE vehicles, which results in an overall GHG saving in 2020 of about 20 k t CO_2-eq.

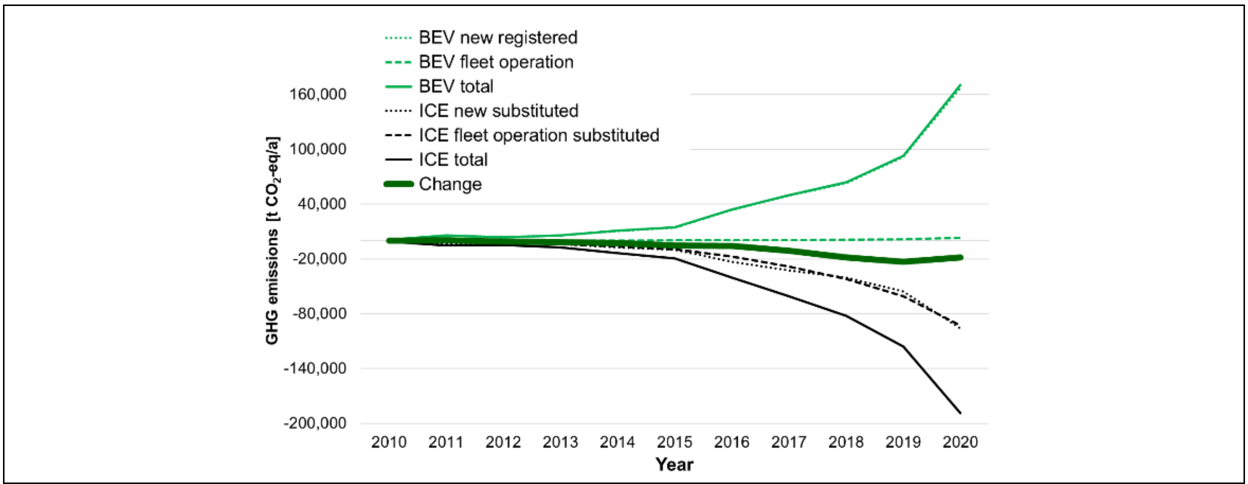

Figure 3: Change of GHG emissions of BEV fleet substituting ICE fleets in Austria

3.3 BEV for Climate neutrality until 2050 in Austria

The dynamic LCA is used for the future development of the Austrian passenger vehicle fleet for reaching climate neutrality in 2050. Based on the historic development and the current stock of passenger vehicles scenarios are developed to reach the following goals:

- 2030: 55% GHG reduction compared to 1990
- 2040: climate neutrality for the transport sector
- 2050: climate neutrality for all global GHG emissions in dynamic LCA

In Figure 4 (left) the development of the passenger vehicle fleet in Austria is shown, with a strong increasing share of new registered BEV and a limitation of the total passenger stock (5.2 Mio vehicles) based on 2020. On the right hand side, the final energy demand is shown with a strong increase in electricity and a constant amount of biofuels based on 2020. To reach the 2030 target of 55% GHG reduction in transportation sector the amount of fossil fuels is limited to about 16 TWh and climate neutrality in 2050 to 0 TWh.

In Figure 5 the GHG emissions (left) and primary energy demand (right) of Austrian Passenger Vehicle Fleet are shown based on dynamic LCA. The GHG emissions of vehicle fleet operation in 2030 is 55% less than in 1990 and 0 in 2040. The remaining GHG emissions e.g. electricity supply, in the dynamic LCA are reduced until 2050. The GHG emission from “end of life” and “vehicle export” are negative as GHG credits for secondary material and 2nd use of vehicles are given. The GHG emission from the production of the “newly registered vehicles” increases between 2020 and 2030 as the production of BEV have significant higher GHG emissions than conventional ICEs. The total GHG emission decrease significantly after 2025 due to the strong increasing amount of BEV in the vehicle fleet. The cumulated primary energy demand also significantly decreases due to the higher energy efficiency of BEV using renewable electricity.

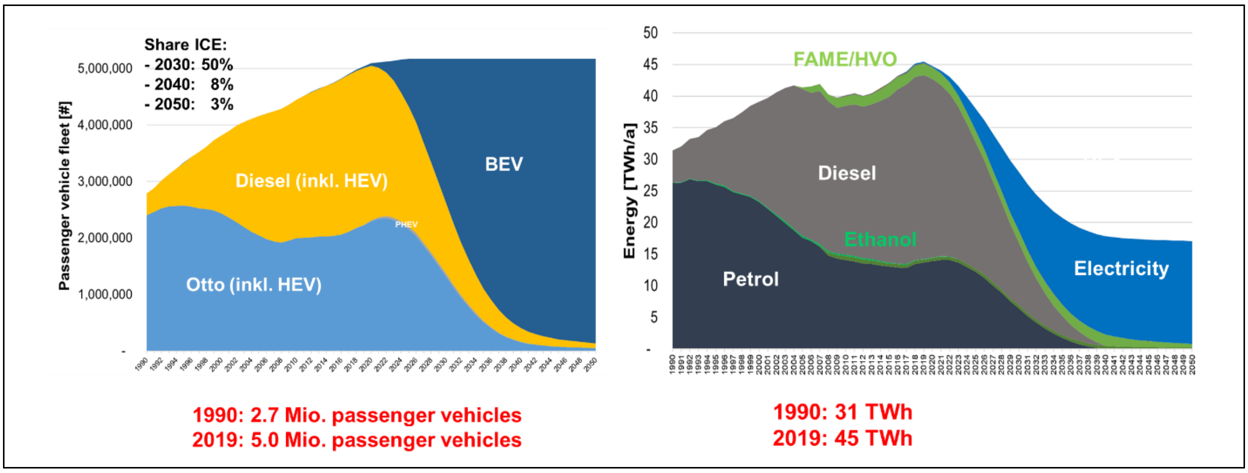

Figure 4: Characteristics and final energy demand of Austrian passenger vehicle fleet

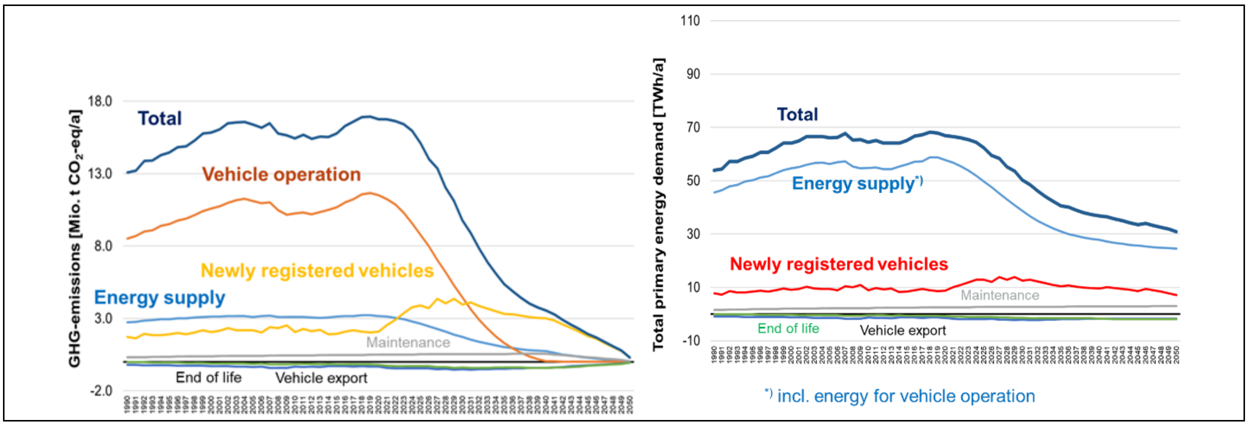

Figure 5: GHG emissions and primary energy demand of Austrian passenger vehicle fleet based on dynamic LCA

4 Conclusions

Timing of environmental effects in LCA of EVs covering production, operation and end-of-life phases becomes relevant in the transition time of strong BEV introduction in combination with a strong increase of additional renewable electricity generation and improvement of battery production technologies.

Within the framework of LCA a methodology is developed and applied to the annual environmental effects of an increasing BEV fleet and substitution of ICE vehicles by considering the environmental effects of

- new vehicle production
- supply of renewable electricity from existing and new power plant
- substituted operation of ICE vehicles and
- end of life or export of vehicles.

The scenarios for Austria up to 2050 show that Climate Neutrality in Austria passenger vehicle fleet is possible with BEV. The main influences to reach climate goals in passenger vehicle fleet are:

- increasing high number of newly registered BEV
- development of total vehicle stock
- development of annual driven mileage of vehicle fleet
- generation of additional renewable electricity for BEV

References

[1] Jungmeier Gerfried, Dunn Jennifer B, Elgowainy Amgad, Gaines Linda, Ehrenberger Simone, Doruk Enver Özdemir, Widmer Rolf: *Key Issues in Life Cycle Assessment of Electric Vehicles - Findings in the International Energy Agency (IEA) on Hybrid and Electric Vehicles (HEV)* (EVS27, 2013)

[2] Jungmeier Gerfried, Dunn Jennifer B, Elgowainy Amgad, Gaines Linda, Ehrenberger Simone, Doruk Enver Özdemir, Widmer Rolf: *Life cycle assessment of electric vehicles – Key issues of Task 19 of the International Energy Agency (IEA) on Hybrid and Electric Vehicles (HEV)*, TRA 2014

[3] Gerfried Jungmeier, Jenifer Dunn, Amgad Elgowainy, Simone Ehrenberger, Rolf Widmer: *Estimated Environmental Effects of the Worldwide Electric Vehicle Fleet – A Life Cycle Assessment in Task 19 of the International Energy Agency (IEA) on Hybrid and Electric Vehicles (HEV)*, Conference Proceedings, EEVC 2015 - European Battery, Hybrid and Fuel Cell Electric Vehicle Congress, Brussels, Belgium, 2 – 4. December 2015

[4] Gerfried Jungmeier, Jennifer B. Dunn, Amgad Elgowainy, Linda Gaines, Martin Beermann, Simone Ehrenberger, Rolf Widmer: *Life-cycle Based Environmental Effects of 1.5 Mio. Electric Vehicles on the Road in 35 Countries – Facts & Figures from the IEA Technical Cooperation Program on Hybrid & Electric Vehicles* (EVS 30, 2017)

[5] Gerfried Jungmeier, Amgad A. Elgowainy, Simone Ehrenberger, Gabriela Benveniste Pérez, Pierre-Olivier Roye, Lim Ocktaeck: *Water Issues and Electric Vehicles - Key Aspects and Examples in Life Cycle Assessment* (EVS 31, 2018)

[6] Gerfried Jungmeier, Amgad A. Elgowainy, Simone Ehrenberger, Gabriela Benveniste Pérez, Pierre-Olivier Roye, Lim Ocktaeck: *LCA Based Estimation of Environmental Effects of the Global Electric Vehicles Fleet – Facts & Figures from the IEA Technology Collaboration Program on Hybrid & Electric Vehicles*, Transport Research Arena TRA 2018 in Wien, 16-19 April 2018

[7] Gerfried Jungmeier, Lorenza Canella, Jarod C. Kelly, Amgad A. Elgowainy, Simone Ehrenberger, Deidre Wolff: *Evaluation of the Environmental Bene-fits of the Global EV-Fleet in 38 Countries – A LCA Based Estimation in IEA HEV* (EVS 32, 2019)

[8] Annual Report 2021 *The electric drive continues* of TCP on Hybrid and Electric Vehicles, https://ieahev.org/publicationlist/2021_annual_report/

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Highlights of professional experiences: 1) life cycle assessment of energy systems, 2) greenhouse gas assessment of products and services. 3) sustainability assessment and scenarios for climate neutral transportation systems. Key researcher at JOANNEUM RESEARCH “Future Energy Systems and Lifestyles” and Lecturer at Vienna University of Technology, University of Applied Science in Kapfenberg and Danube University Krems". Operating Agent of IEA TCP HEV Task 30 “Environmental Effects of Electric Vehicles”, Task 46 “LCA of Electric Trucks, Buses, Two-wheelers and Other Vehicles” and of Task 33 “Battery Electric Buses”