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Evaluation of the Environmental Benefits of The Global EV-Fleet in 40 Countries – A LCA Based Estimation in IEA HEV

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Executive Summary

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 2014 in the Technical Collaboration Program on "Hybrid&Electric Vehicles" (HEV) of the International Energy Agency (IEA) an expert group developed and applied the LCA to estimate the environmental effects of the increasing EV fleet globally. In 2018 about 5 million EVs were on the road in 40 countries by substituting fossil fuels ICEs. The environmental effects assessed are greenhouse gas emissions, acidification, ozone formation, particle matter emissions and primary energy consumption. Depending on the country specific electricity mix the environmental benefits are different but in total there is a significant growing improvement (2014 – 2017) on the environmental effects due to the strong increasing number of EVs globally.

Keywords: LCA (Life Cycle Assessment), environment, sustainability

1 Goal and Scope

Electric vehicles (EVs) have the potential to substitute for conventional internal combustion engine (ICE) vehicles and contribute to the sustainable development of the transportation sector worldwide, e.g. reduction of greenhouse gas (GHG) and particle matter (PM) emissions. There is international consensus that the environmental impacts of electric vehicles can be analysed on the basis of life cycle assessment (LCA), which includes the production, operation and the end of life treatment of the vehicles. Since 2011, a group of international experts have cooperated on the LCA of Electric Vehicles in the Technology Collaboration Program (TCP) on “Hybrid&Electric Vehicles within the International Energy Agency (IEA) and estimated the environmental effects of the current worldwide electric vehicle fleet of about 5 million Battery Electric Vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV) in 40 countries. The LCA of these vehicles, using the various national framework conditions, assessed the environmental effects of these vehicles by estimating the possible ranges of

- greenhouse gas emissions (CO_2, CH_4, N_2O) in CO_2-eq,
- acidification (NO_x, SO_2) in SO_2-eq,
- ozone formation (NO_x, CO, NMVOC, CH_4) in C_2H_4-eq,
- particle matter emissions in PM>10 and
- primary energy consumption (total, fossil, nuclear, renewable)

and compared them to those of conventional ICE vehicles. The system boundary chosen for the LCA is shown in Figure 1.

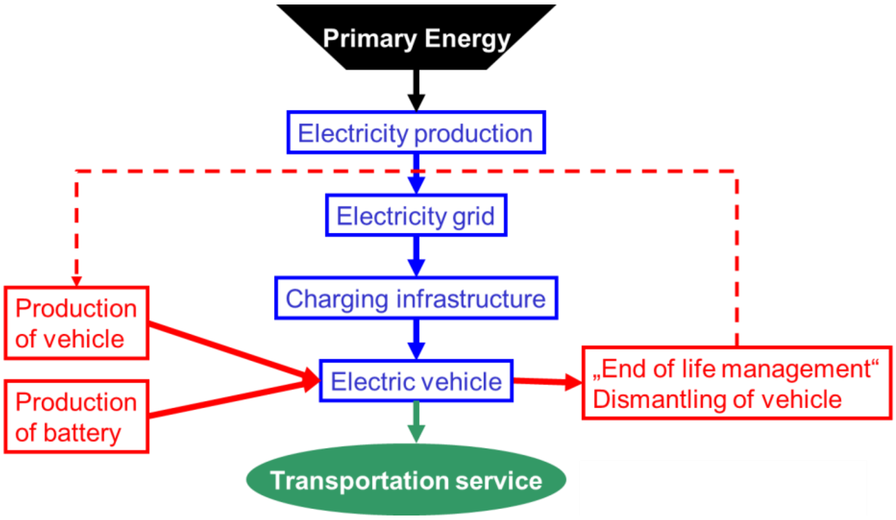

Figure1: LCA System boundary

The analysis is done for each of the 40 countries from 2014 to 2018 and each country’s results are summarized in a “Country Factsheets on Estimated Environmental Impacts of Current EV-Fleet” documenting

- “BASIC DATA” on electricity generation and size of electric vehicle fleet
  - share of generation technologies supplying the national electricity grid
  - estimated environmental effects of electricity at charging point
  - current situation and future development of national electricity market (import & export)
  - size of electric vehicle fleet: number of BEV and PHEV
- “Estimation of LCA based ENVIRONMENTAL EFFECTS” by substituting conventional ICE
  - absolute annual change
  - relative annual change.

The methodology for LCA of EV fleets was developed in IEA HEV Task 30 “Environmental Effects of EVs” (since 2011) and documented in [1-4]. An analysis of the possible future environmental effects of a large fleet of EV based on scenario analysis is not considered in this work.

2 Basic data and assumptions

There were approximately 5 million electric vehicles in 40 countries worldwide in 2018, of which

- 3.2 million are BEVs and 1.8 million are PHEVs
- 45% in China, 22% in the USA, 5% in Japan and 5% in Norway in 2018 (Figure 2).

It is expected that the EV fleet will further grow strongly, but the scenario development of the global EV fleet under different conditions is not part of the activities of the IEA HEV Task 30.

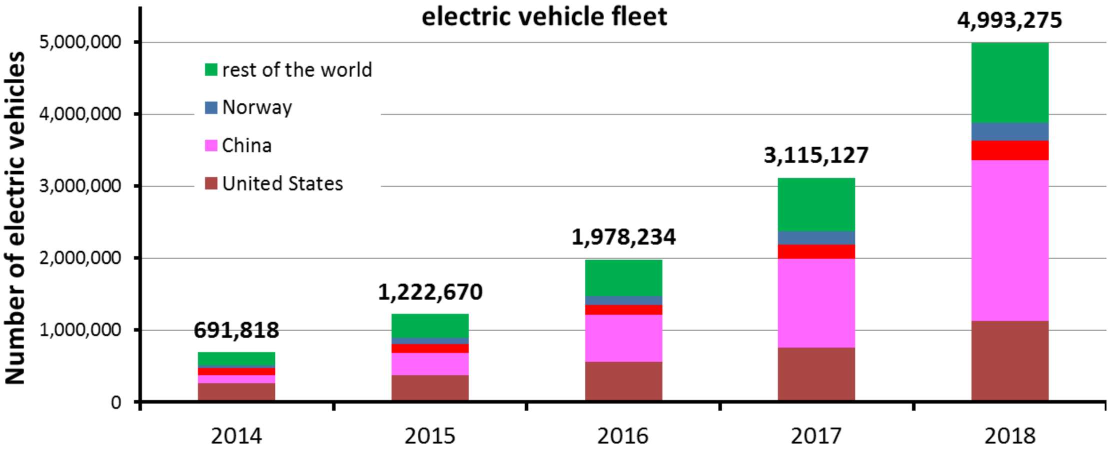

Figure 2: Vehicle Fleet Worldwide 2014 - 2018

The variation in the estimated impacts of electric vehicles between countries is due to variation in:

- Emissions from national electricity production
- Average electricity consumption (kWh/km) by EV fleet in real world driving cycles
- Average fuel consumption of substituted conventional ICEs
- Emissions standards for vehicles and stationary power generation
- Travel behavior (annual distance travelled by each vehicle technology)

The application of LCA to whole EV fleets also must consider possible rebound effects to avoid an overestimation of the environmental benefits. Ongoing research on possible rebound effects of the broad introduction of EVs show that not each driven kilometre by an EV also substitutes an ICE driven kilometre. The most relevant rebound effects identified are increasing global car fleet, EV become 2nd or 3rd vehicle in households, EVs substitute public transport, walking and cycling. The IEA task 30 analyses these possible rebound effects and estimated that in average an EV substitutes about 85% of ICE driven kilometres [6].

The main assumptions in the LCA of EVs and ICE vehicles are:

- Grid losses: 5% - 7% from power plants to charging point.
- The average European electricity mix with 7% grid distribution losses is assumed for imported electricity in European countries.
- The charging energy losses are assumed to be 15%.
- Substitution rate: 85% of the ICE vehicle driven kilometres is substituted by electric driven kilometres (BEV&PHEV).
- The vehicles (ICE, BEV, and PHEV) are assumed to be generic middle-sized class vehicles (e.g., “VW Golf class”) for all considered countries (except. USA and CA).
- The environmental effects of vehicle production and dismantling are generic for all countries as differentiation based on the region where they are produced cannot be made.

- Life time for all vehicles (and battery for EVs) is 10 years.
- The GHG emissions of the battery production (incl. recycling of materials) are estimated between 35 – 50 g CO_2-eq/km, but further reductions are expected in future due to the increase of the global production volumes of automotive batteries realising economy of scale effects on energy efficiency and a higher share of renewable electricity use in the battery production in Europe and the USA.
- The electricity used for EV is based on the country's specific annual average grid electricity generation mix, including imports and exports.
- The electricity generation mix for each country reflects generation in 2014 to 2018.
- The particulate emission (< 10 µm) are only given in their total mass and not differentiated according to their size/toxicity.

3 Results

The range of environmental effects of the current national electricity supply (at the charging point) for each of the IEA HEV countries is shown in Figure 3 (example GHG-Emissions in g CO_2-eq in kWh at the charging point). It is expected that the share of renewable electricity will further increase globally while reducing the amount of fossil based electricity. But the scenario development of the global future electricity mix EV fleet under different conditions is not part of the activities of the IEA HEV Task 30.

In Figure 4 the estimated GHG change of EVs compared to ICE are shown for the considered countries. In countries with a GHG emission > 600 g CO_2-eq per kWh electricity an increase of GHG emission is detected.

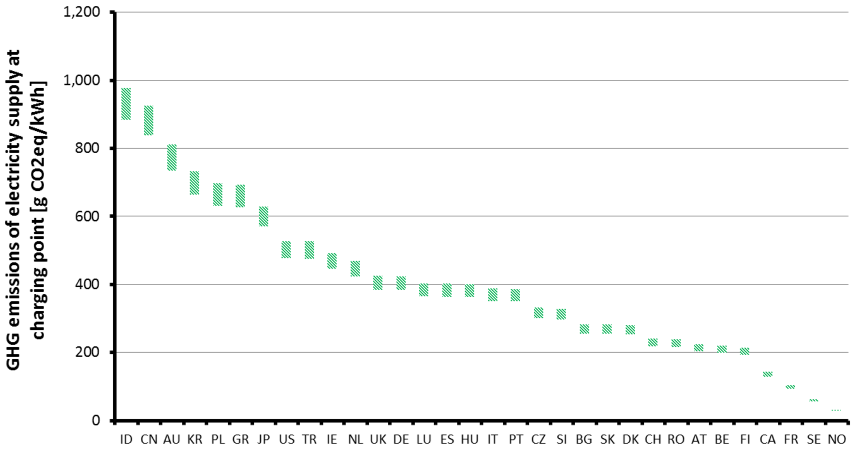

Figure 3: Estimated range of GHG emissions of electricity at charging point in considered countries in 2017

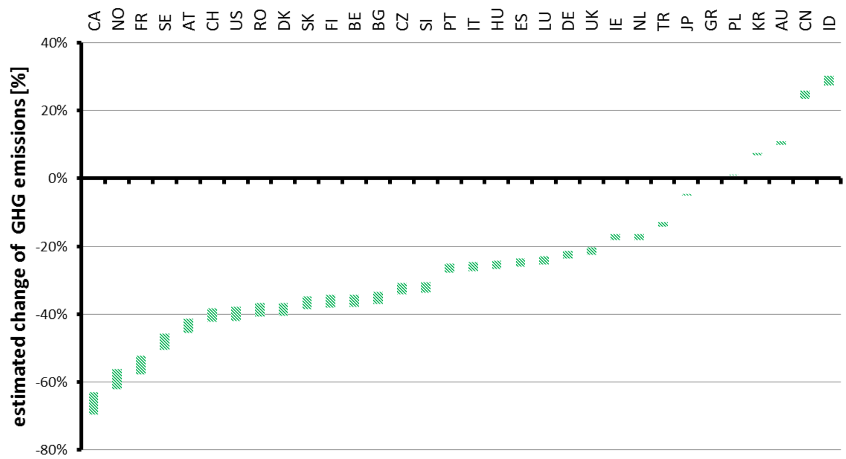

Figure 4: Estimated range of GHG emissions reduction of EVs substituting ICE vehicles in considered countries in 2017

Finally, the total global environmental effects in 2014 to 2017 of the globally increasing EV fleet are estimated. In Figure 5, the total reduction of GHG emissions is shown with a range between 1.7 – 1.9 mio. t CO_2-eq in 2017, mainly deriving from the EVs fleet in IEA HEV countries. In Figure 11, the estimated change in acidification shows a slight global increase due to electricity production in non IEA HEV countries. Figure 12 shows the cumulated primary energy change, with a reduction between 1,900 – 2,400 GWh/a.

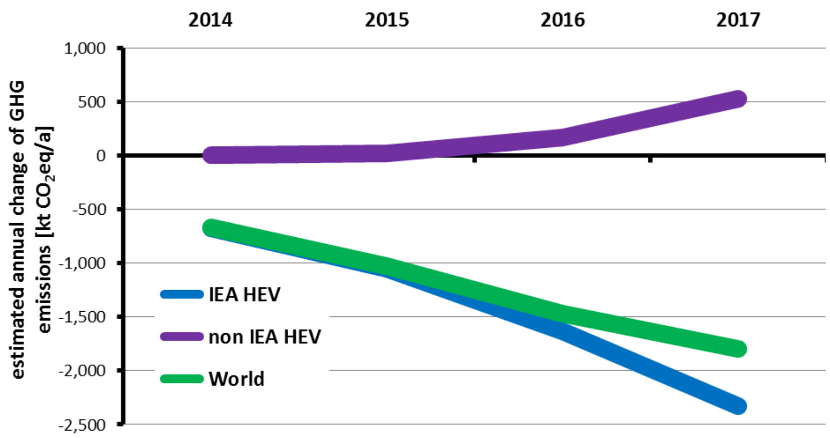

Figure 5: Estimated range of increasing GHG reduction of EVs substituting ICE vehicles globally (2014 – 2018)

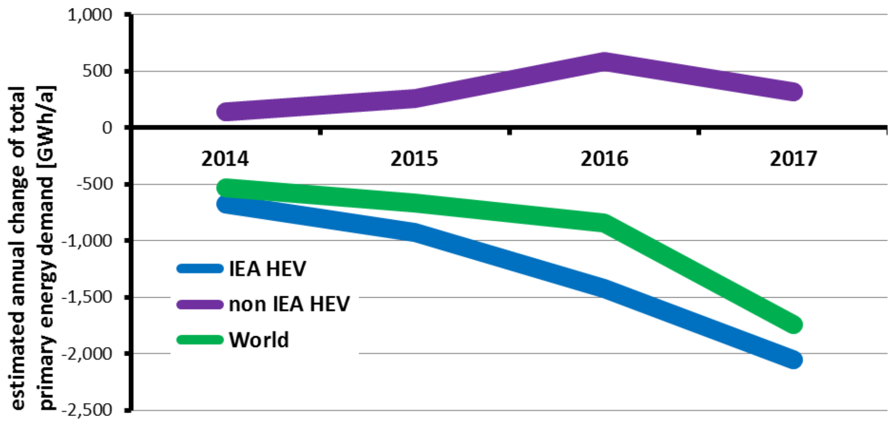

Figure 6: Estimated range of change in cumulated primary energy consumption of EVs substituting ICE vehicles globally (2014 – 2018)

Generally, it can be observed that the share of fossil produced electricity has a substantial influence on the EV related emissions. In countries with a relative high share of renewable or/and nuclear electricity, the estimated emission reduction is significant (e.g., NO, FR, AT), whereas in countries with a relative high share of fossil electricity, an increase of emissions is observed (e.g., PL, CN).

The estimation of the average environmental effects of BEVs and PHEVs substituting diesel and gasoline ICE vehicles globally shows for 2017 (Table 1):

- GHG-reduction: 16% to 18%
- PM reduction: 76% to 84%
- Acidification: 58% to 64%
- Ozone reduction: 60% to 66%
- Fossil primary energy reduction 19% to 21%
- Renewable primary energy increase 48% to 53%
- Nuclear primary energy increase 1,100% to 1,200%
- Total primary energy reduction 2.5% to 2.8%

Table 1: Estimated change of environmental effects of global EV fleet in 2017

Environmental effect		Unit	Change		
Emissions					
	GWP	[kt CO2eq/a]	-1700 to -1900	-16 to -18	%
	Acidification	[t SO2eq/a]	-18000 to -20000	-58 to -64	%
	Ozone formation	[t C2H4/a]	-18000 to -20000	-60 to -66	%
	Particles	[t PM>10/a]	-4200 to -4600	-76 to -84	%
Cumulated primary energy					
	fossil	[GWh/a]	-5700 to -6200	-19 to -21	%
	nuclear	[GWh/a]	3400 to 3700	1100 to 1200	%
	renewable	[GWh/a]	1400 to 1600	48 to 53	%
	total	[GWh/a]	-800 to -900	-2.5 to -2.8	%

The broad estimated range of environmental effects are mainly due to variation in the emissions of national electricity production, the electricity consumption of EVs at charging point, and the fuel consumption of substituted conventional ICEs. In particular, the results show that the environmental effects strongly depend on the national framework condition, i.e., national grid mix of electricity generation. In some countries, a significant reduction of emissions (up to 80%), compared to conventional ICE vehicles, is reached due to a high share of renewable and non-fossil based electricity generation. Additional renewable electricity with synchronized charging will maximize the environmental benefits of EVs and adequate loading strategies are essential for further reductions.

There is strong evidence from the current data of EV fleet deployed in various countries that under appropriate framework conditions, electric vehicles can play a substantial role in the future of sustainable transportation, especially with the expected increase in renewable electricity generation.

4 Conclusions

The main conclusions of the environmental assessment of EVs based on Life Cycle Assessment compared to conventional ICE vehicles are:

- The environmental effects depend on the national framework condition, e.g., national grid electricity generation mix. In most countries, a significant reduction of emissions of up to 90% is reached.
- A broad range of results is mainly due to variation in:
    - Emissions of national electricity production
    - Electricity consumption of EVs at charging point
    - Fuel consumption of substituted conventional ICE vehicles
- Additional renewable electricity with synchronized charging maximizes the environmental benefits
- Adequate loading strategies to optimize the use of renewable electricity are essential for further significant emissions reductions

There is strong evidence that under appropriate framework conditions, electric vehicle can contribute substantially to a sustainable future of the transportation sector in various countries.

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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 future 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 HEV Task 30 “Life Cycle Assessment of Electric Vehicles”.