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Life-cycle Based Environmental Effects of 1.3 Mio. Electric Vehicles on the Road in 35 Countries – Facts & Figures from the IEA Technology Collaboration Program on Hybrid & Electric Vehicles

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Abstract

There is an international consensus that the environmental effect of electric vehicles can only be assessed with life cycle assessment (LCA) including production, operation and end of life treatment. A group of international experts working since 2011 on the LCA of Electric Vehicles in the Technical Collaboration Program on "Hybrid&Electric Vehicles of the International Energy Agency (IEA), estimated the environmental effects of the current worldwide electric vehicle fleet of about 1.3 million in 35 countries. The environmental effects assessed for electric vehicles are greenhouse gas emissions, acidification, ozone formation, particle matter emissions and primary energy consumption, which were compared to conventional internal combustion engine vehicles.

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 1.3 million Battery Electric Vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV) in 35 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),
- acidification (NO_x, SO_2),
- ozone formation (NO_x, CO, NMVOC, CH_4),
- particle matter emissions 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.

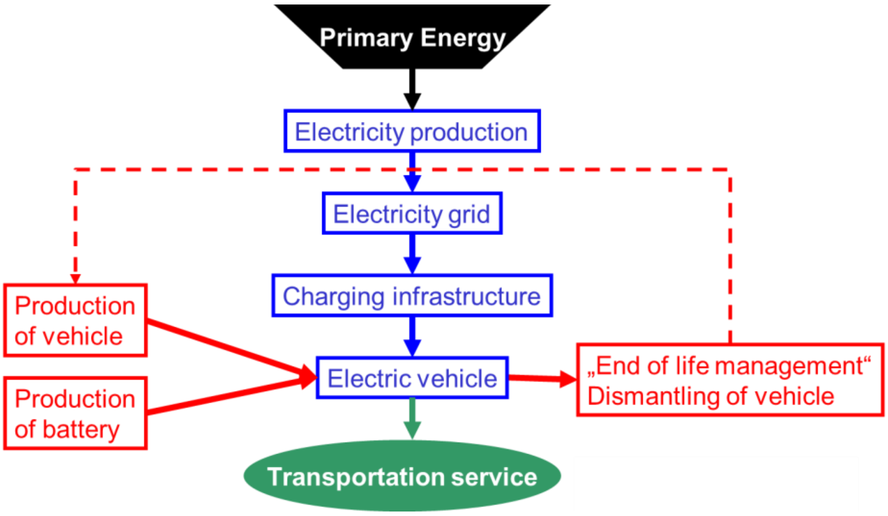


Figure1: LCA System boundary

The analysis is done for each of the 35 countries and each country's results are summarized in a "Country Factsheets on Estimated Environmental Impacts of Current EV-Fleet" documenting

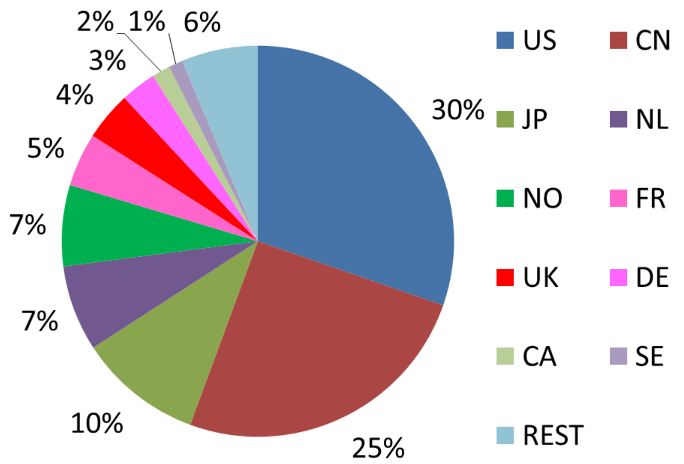
- "BASIC DATA" on electricity generation and size of electric vehicle fleet
  - share of generation technologies supplying the national electricity grid
  - estimated environmental effects of electricity at charging point
  - current situation and future development of national electricity market (incl. 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 19 "LCA of EVS" (20111 – 2015) and the subsequent Task 30 "Environmental Effects of EVs" (since 2016) and documented in [1-4].

2 Basic data and assumptions

There was approximately1.3 million electric vehicles in 35 countries worldwide in 2015, of which

- 0.75 million are BEVs and 0.55 million are PHEVs
- 30% in the USA, 25% in China and 10% in Japan (Figure 2), and
- 0.8 million vehicles in the 17 IEA countries and 0.5 million vehicles in the 18 non-IEA countries.



US: USA; JP: Japan, NO: Norway, UK: United Kingdom; CA: Canada; CN: China, NL: The Netherlands; FR: France, DR: Germany; SE: Sweden; REST: 25 other countries

Figure 2: Vehicle Fleet Worldwide in 2015

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 main vehicle data are shown in Table 1.

Table 1: Vehicle data

		BEV	PHEV	ICE	remark
consumption					
electricity	[kWh/km]	0.2 - 0.24	0.2 - 0.24	-	*1)*
fuel	[kWh/km]	-	0.42 - 0.51	0.47 - 0.57	*2), 3)*
annual kilometres					
electricity	[km/a]	14,000	8,960	-	*4), 5)*
fuel	[km/a]	-	5,040	14,000	

1) incl. 15% charging losses and aux. energy for heating/cooling
2) PHEV: in ICE-HEV mode 10% more efficient than ICE, in US and CA: 40%
3) ICE in USA and CA: 0.78 kWh/km (average)
4) annual kilometres USA and CA: 19,200 km/a
5) electric driven km of PHEV in USA&CA: 15,350 km/a; NL: 4,200 km/a

	emissions				primary energy				
	CO_2-eq.	SO_2-eq.	C_2H_4-eq	PM	fossil	renewable	nuclear	total	remark
	[g/km]	[g/km]	[g/km]	[g/km]	[kWh/km]	[kWh/km]	[kWh/km]	[kWh/km]	
EV (production&dismantling)	28 - 35	0.04 - 0.04	0.02 - 0.02	0.002 - 0.003	0.08 - 0.09	0.01 - 0.02	0.01 - 0.02	0.09 - 0.11	
ICE vehicle (production, operation&dismantling)	208 - 254	0.7 - 0.8	0.7 - 0.8	0.12 - 0.15	0.58 - 0.71	0.06 - 0.07	0.06 - 0.07	0.65 - 0.79	*1)*

1) ICE in USA and CA different, e.g. 290 g CO2-eq/km

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; for non-European countries, the imported electricity is assumed to be of minor impact.
- 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, PHEV) are assumed to be generic middle-sized class vehicles (e.g., "VW Golf class") for all considered countries (except. USA and CA).
- Life time for all vehicles (and battery for EVs) is 10 years.
- No distinction is made between gasoline and diesel vehicles, as the difference in fuel consumption and emissions are within the assumed ranges.
- Energy allocation is applied to calculate emissions and energy burdens for electricity generation from combined heat and power (CHP) plants
- The electricity used for EV is based on the country's specific annual average grid electricity generation mix (marginal approach, renewable electricity especially dedicated for EVs or differentiated charging during day/night time are not considered).
- The electricity generation mix for each country reflects actual generation in 2014 and 2015.
- The LCA based emissions are the sum of emission in the country and abroad for imported energy.
- The main CO_2 emissions of ICE vehicles is from the tail pipe, while EVs related emissions are from fossil-based electricity production, as EVs have no direct tail pipe emissions.
- 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.
- The particulate emission (< 10 µm) are only given in their total mass and not differentiated according to their size/toxicity.

The main data sources are:

- National electricity mix and market: IEA statistics, http://www.iea.org/statistics
- Number of EVs: IEA HEV annual reports, EVI – Electric Vehicle Initiative, ExCo members
- The data and the LCA based estimations of the environmental effects of the EV fleet in the USA were mainly provided by the GREET® model of ARGONNE - Argonne National Laboratory.
- LCA data for non-USA countries: ecoinvent, GEMIS
- Input from participants of the IEA HEV Task 30 expert workshop "Environmental Effects of Electric Vehicles – Water issues and benefits of EV fleets on energy consumption and air emissions" of "Environmental Effects of Electric Vehicles" in Graz/Austria (January 12 – 13, 2017).

3 Results

An example of the estimated environmental effects of the EV-Fleet in one country is shown for Austria, followed by results for the global EV fleet in 2014 and 2015.

3.1 Country Fact Sheet – Example of Austria: In Figure 3, the Country Fact Sheet for the EV fleet of Austria in 2014 and 2015 is shown summarizing the most relevant results. The environmental effects of BEVs and PHEVs substituting diesel and gasoline in Austria as shown in Figure 3 are as follow:

- GHG-reduction: 43% to 58%
- PM reduction: 66% to 89%
- Acidification reduction: 56% to 76%
- Ozone reduction: 63% to 85%
- Fossil primary energy reduction 33% to 44%

- Renewable primary energy increase 10% to 15%
- Nuclear primary energy increase 4% to 6%
- Total primary energy reduction 12% to 16%

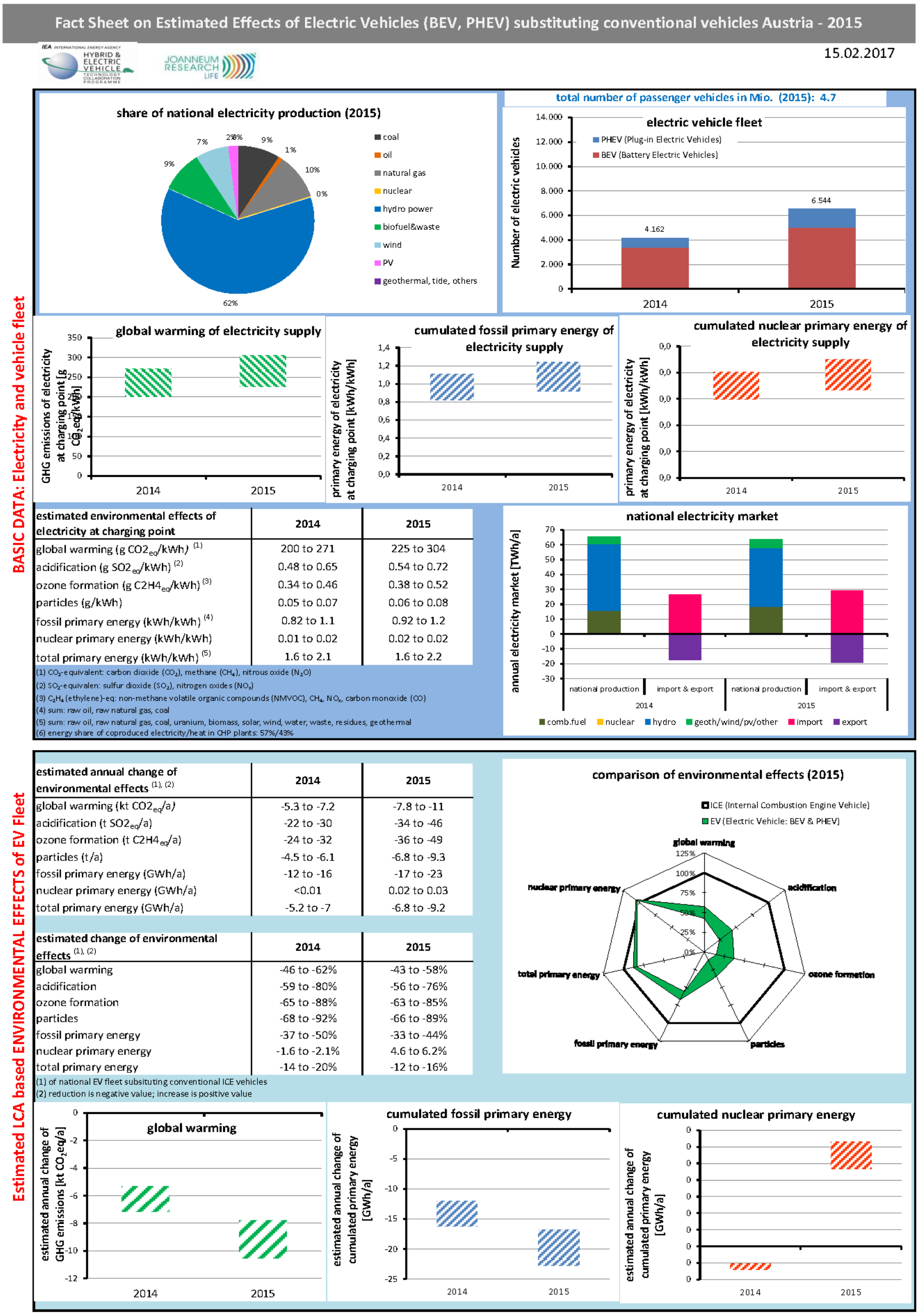


Figure 3: Country Fact Sheet – Example of Austria

3.2 Results of global EV-Fleet: The range of environmental effects of the current national electricity supply (at the charging point) for each of the IEA HEV countries are shown in Figure 4 (GHG-Emissions) and Figure 5 (cumulated fossil and nuclear primary energy).

The results of the estimated environmental effects of EVs compared to conventional ICEs are shown in relative and absolute terms for 2015 in Figures 6–12, whereas the main difference between the countries lies in the mix of the national electricity generation.

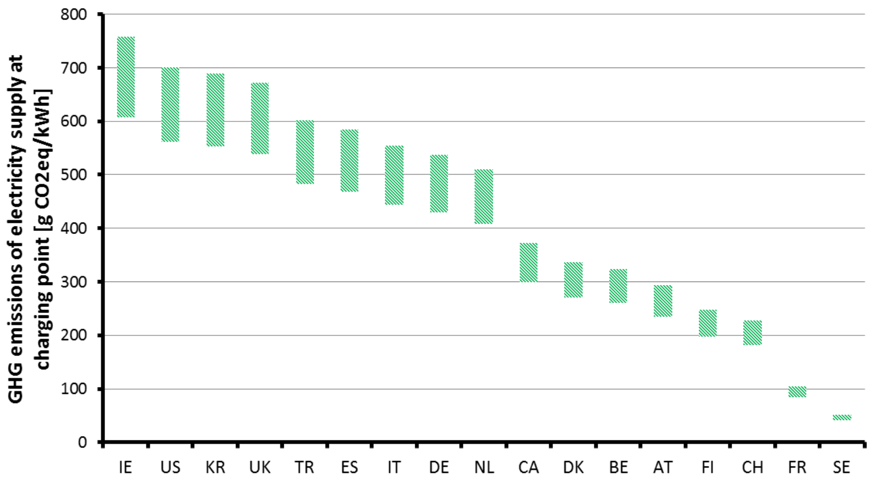


Figure 4: Estimated range of GHG emissions of electricity at charging point in IEA HEV countries in 2015

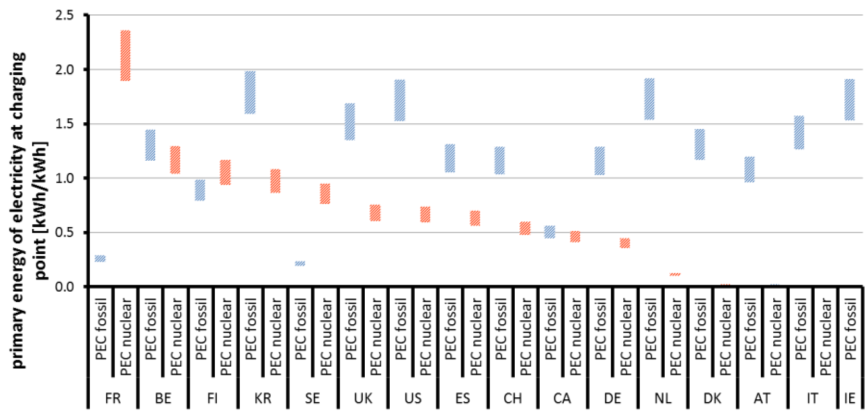


Figure 5: Estimated range of cumulated fossil and nuclear primary energy for electricity generation at charging point in IEA HEV countries in 2015

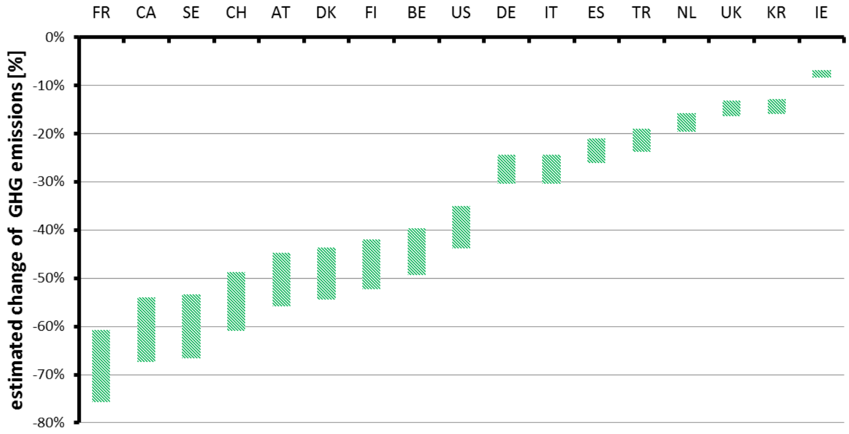


Figure 6: Estimated range of GHG emissions reduction of EVs substituting ICE vehicles in IEA HEV countries in 2015

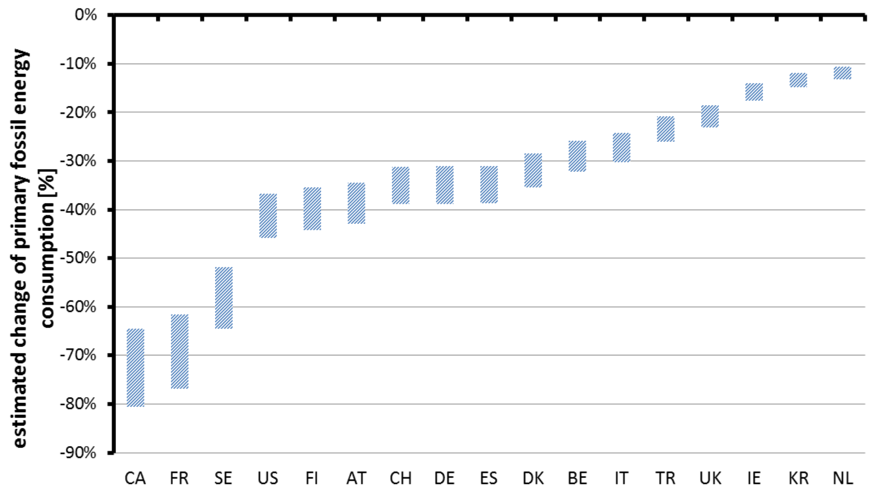


Figure 7: Estimated range of fossil primary energy reduction of EVs substituting ICE vehicles in IEA HEV countries in 2015

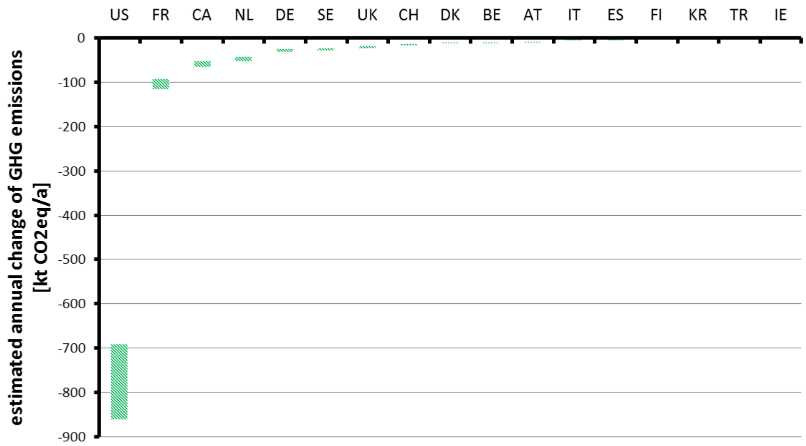


Figure 8: Estimated range of annual GHG emissions reduction of EVs substituting ICE vehicles in IEA HEV countries in 2015

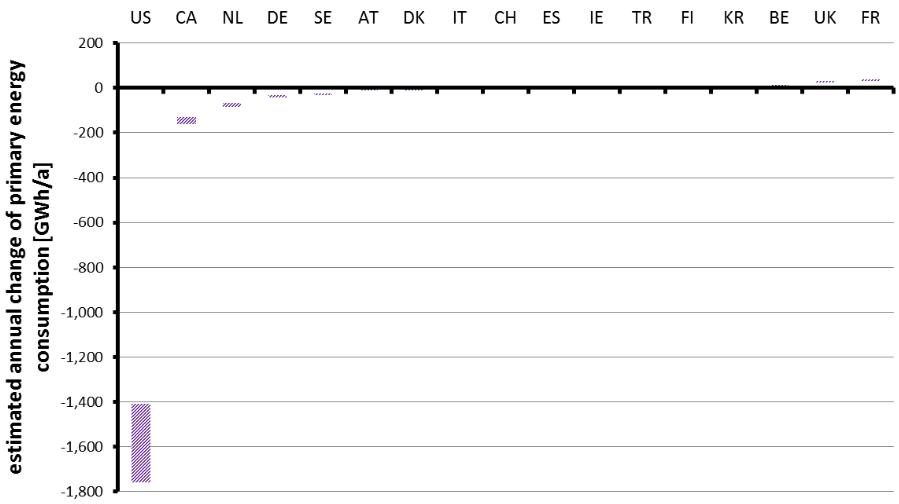


Figure 9: Estimated range of annual primary energy changing of EVs substituting ICE vehicles in IEA HEV countries in 2015

Finally, the total global environmental effects in 2015 of the 1.3 million EVs are estimated. In Figure 10, the total reduction of GHG emissions is shown with a range between 1.0 – 1.3 million metric tons of CO_2-eq, 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.

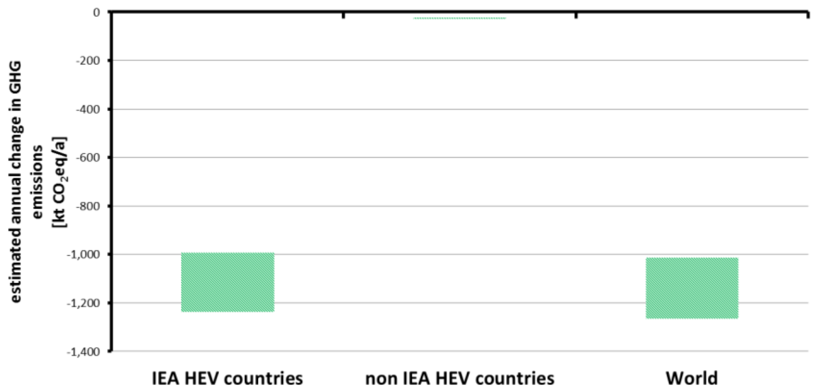


Figure 10: Estimated range of change in GHG emissions of EVs substituting ICE vehicles globally in 2015

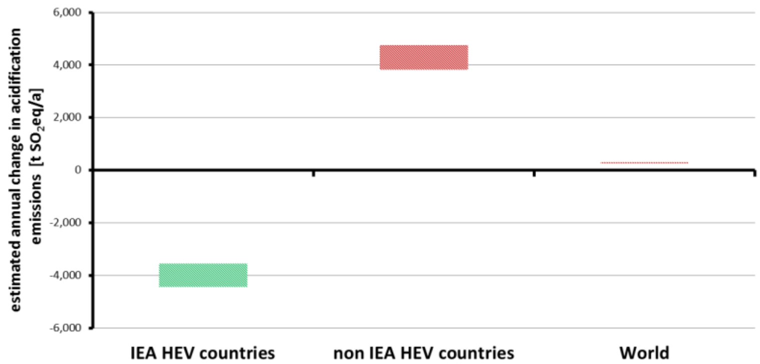


Figure 11: Estimated range of change in acidification of EVs substituting ICE vehicles globally in 2015

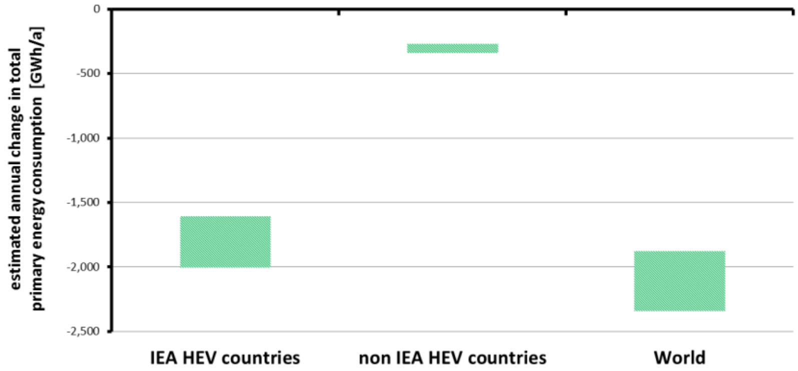


Figure 12: Estimated range of change in cumulated primary energy consumption of EVs substituting ICE vehicles globally in 2015

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:

- GHG-reduction: 25% to 30%
- PM reduction: 40% to 50%
- Acidification: 0% to 5%
- Ozone reduction: 50% to 60%
- Fossil primary energy reduction 25% to 30%
- Renewable primary energy increase 10% to 15%
- Nuclear primary energy increase 600% to 800%
- Total primary energy reduction 15% to 20%

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 sychronized 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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