
*Key Messages and results*

*Expert Workshop*

# "LCA of Electric Vehicles – Current Status and Future Perspectives"

Edited by Gerfried Jungmeier, Martin Beermann

**Time:** November 11, 2015 09:00-17:30

**Place:** TechGate, 3rd floor, Room 3.2
Donau City Straße 1, 1220 Vienna

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# Content



# 1. Summary

The aim of the expert workshop „Life Cycle Assessment (LCA) of Electric Vehicles – Current Status and Future Perspectives" of the International Energy Agency (IEA) in Vienna, led by JOANNEUM RESEARCH, was to present and discuss recent experiences and results, closing 4 years of cooperation of DLR (Germany), EMPA (Switzerland), ARGONNE (US) and JOANNEUM RESEARCH (Austria).

With high-level representatives from industry and research the environmental effects of today's and future electric vehicles were discussed, focussing on the following topics:

1. Environmental effects of battery production and disposal
2. Impacts of light vehicle materials on the environment
3. Recycling of critical materials from end-of-life vehicles
4. Estimation of environmental benefits of almost 1 Mio electric vehicles worldwide

Task-leader Dr. Gerfried Jungmeier from JOANNEUM RESEARCH summarized the results: „Already today LCA of electric vehicles shows significant environmental benefits as long renewable energy is used and conventional vehicles are substituted. Future developments of battery production, use of innovative lightweight materials and focused recycling of critical materials from end-of-life vehicles will further improve these benefits."

The experts agreed that the method of LCA is increasingly acknowledged both in industry and policy, and that the data basis has been significantly improved internationally. As a consequence, the cooperation of Task 19 will be continued in the new IEA Task 30 „Environmental Effects of Electric Vehicles" (2016 – 2019). This task focusses on Water Footprint, Land Footprint and Material Footprint.

# 2. Program

**Wednesday November 11, 2015**

9:00 – 9:15: **Welcome address** from IEA

**Key Notes of IEA Task 19**

9:15 – 10:00: **Results of IEA HEV Task 19 Activities 2012 – 2015,** Gerfried Jungmeier (Operating Agent IEA HEV Task 19), JOANNEUM RESEARCH, Austria

10:00 – 10:45: **LCA of Automotive Battery Production & Recycling**, Jennifer Dunn (Vice Operating Agent IEA HEV Task 19), ARGONNE, USA

10:45 – 11:00: Round Robin **Introductions of participants** (all)

*11:00 – 11:30 Refreshment break*

11:30 – 12:00: **Scenarios for Lightweight Materials for EVs**, Simone Ehrenberger, DLR, Germany

12:00 – 12:30: **Critical Metals in the Automotive Industry**, Rolf Widmer, EMPA, Switzerland

**International Highlights on LCA of EVs**

12:30 – 12:45: **LCA of Current & Future Electricity Generation for EVs – Methodologies and Examples of an Attributional and Consequential Approach**, Alexander Stoffregen, thinkstep, Germany

12:45 – 13:00: **Discussion**

*13:00 – 14:00 Lunch Break*

14:00 – 14:15: **Results of Reviewing of 100 International LCA Studies on BEV and PHEV**, Georg Knaus, FH-JOANNEUM, Austria

14:15 – 14:30: **Project InitiativE-BW: Real Life Usage and Energy Consumption of EV-Fleets**, Holger Dittus, DLR, Germany

14:30 – 14:45: **"Electric car LCA - New Findings by Real-world data**, Eckard Helmers, Johannes Dietz, Susanne Hartard, University of Applied Sciences Trier, Germany

14:40 – 15:00: **Life Cycle Assessment of Battery Electric Vehicles Addressing Variability in the Portuguese Electricity Mix**, Fausto Freire, University of Coimbra, Portugal

15:00 – 15:15: **Second Life EV Batteries for Sustainable Batteries Waste Management**, Helena Gibert, IREC - Catalonia Institute for Energy Research, ES

15:15 – 15:30: Discussion

*15:30 – 16:00 Refreshment break*

**Stakeholder dialogue**

16:00 – 17:00: **"Is LCA killing the electric car?" or "How to communicate LCA"** with EV stakeholders (automotive industry, research, LCA experts, government)

Panellists:

- Jennifer Dunn, ARGONNE, USA
- Dietmar Hofer, MAGNA STEYR Engineering, AUSTRIA
- Reinhard Pfliegl, A3PS, AUSTRIA

Moderator: Martin Beermann, JOANNEUM RESEARCH

17:00 – 17:30: **Summary and Outlook**, Gerfried Jungmeier, JOANNEUM RESEARCH, Austria

# 3. Key messages from presentations

| Results of IEA HEV Task 19 Activities 2012 – 2015 |
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| Gerfried Jungmeier (Operating Agent IEA HEV Task 19), JOANNEUM RESEARCH, Austria |

**Key messages**:

- The main activities influencing the environmental impacts of electric vehicles on a life cycle basis are:
  - Production and life time of the battery,
  - Electricity consumption of the vehicle in the operation phase, incl. e.g. energy demand for heating,
  - Source of the electricity, only additional renewable electricity maximizes the environmental benefits and
  - End of life treatment of the vehicle and its battery.
- The IEA Task 19 has established an international expert platform on LCA of electric vehicles.
- Environmental Assessment of EVs has been conducted based on Life Cycle Assessment compared to conventional vehicles
- About 700,000 EVs worldwide are on the road (end of 2014): Main countries US, JP, CN, F, DE, NO
- Estimation of average environmental effects substituting diesel/gasoline shows
  - GHG-reduction: - 20%
  - PM < 10 reduction: - 60%
  - Acidification increase: + 40%
  - Ozone reduction: - 30%
- Broad estimated ranges are mainly due to variation in:
  - Emissions of national electricity production
  - Electricity consumption of EVs at charging point
  - Fuel consumption of substituted conventional ICEs
  - Data availability, uncertainty and consistency, e.g., PM
- Additional renewable electricity with adequate charging maximizes environmental benefits
- Loading strategies are essential for further significant reductions
- The results show that the environmental effects depend on the national framework condition, e.g., national electricity generation.
- In most of the countries, a significant reduction of these LCA based emissions of up to 90% is reached.
- So there is scientific evidence that under appropriate framework conditions, electric vehicle can substantially contribute to a sustainable transportation sector in the future.

**Discussion**:

- Black Carbon emissions of diesel vehicles (US has some data)
- Real world energy consumption of ICE and EVs

- Ecoinvent starts to build local data centres e.g. Brazil India, South Africa

**LCA of Automotive Battery Production & Recycling**
Jennifer Dunn (Vice Operating Agent IEA HEV Task 19), ARGONNE, USA

**Key messages**:

- For the most part, electric vehicles powered by lithium-ion batteries exhibit lower energy consumption and GHG emissions over the course of their life cycle than conventional vehicles
- Lithium-ion battery recycling has a great potential to cut energy and environmental burdens of lithium ion battery production
- Technical and economic challenges remain before widespread battery recycling will be a reality
- The air, water, and land impacts of producing metals for batteries are under-explored
- Air impacts of use phase are under investigation at a regionally explicit level but ongoing investigation needed taking into account standards and real-world emissions data

**Discussion**:

- Energy consumption in LCA must always be cumulated primary energy consumption with the shares of renewable, fossil and other energy
- Functional unit: per kg battery as same functionality for various batteries is assumed
- GREET gives good information on total energy balance
- Comparison of various battery models, esp. GREET and ecoinvent
- Life time of battery: same as vehicles 150,000 miles
- Battery testing currently based on 200,000 km lifetime, but driving behaviours influences battery lifetime significantly
- Producers give you battery guarantee for 150,000 miles, also used in LCA
- New "grid services" will change battery performance/lifetime in future
- 2nd use of batteries: liability is the most relevant issues to be guaranteed

**Scenarios for Lightweight Materials for EVs**
Simone Ehrenberger, DLR, Germany

**Key messages**:

- Different components, requirements and designs enable a variety of lightweight concepts and dedicated lightweight design
- the LCA approach evaluates the potential shift of environmental burdens from operation to production stage
- Energy saving potential through lightweight reduction is higher for conventional ICE than for advanced electric vehicles (particularly in urban drive cycles), but it enables an increase of the electric range

- Recycling is still a challenge for some lightweight materials

**Discussion**:

- GHG reduction cost in €/(g CO2e*km)
- Processing of secondary fibres is an interesting area for further developments, but benefits/quality of secondary fibres are still unknown
- Energy balance of recycling of composite materials

**Critical Metals in End-of Life Vehicles**
Rolf Widmer, EMPA, Switzerland

**Key messages:**

- Critical Metals (CM) in Passenger Vehicles (PV) are found in a wide range of (small) mass fractions;
- Results of studies are difficult to compare (due to inconsistent assembly of PV) and if tried show large differences in CM content
- Even larger uncertainties appear in extrapolating CM content of entire fleet (due to limited information regarding the types and cohort of the investigated vehicles)
- currently substantial effort is required to better define the taxonomy of vehicle and fleet assemblies in order to make research results compatible.
- in order to quickly advance the 'mapping the urban mine', it might be beneficial to focus on 'hot spots' of CM in PV and other relevant reservoirs.
- Even though we were able to make a «mass balance», the interpretation of the results should be done carefully!
- Magnets and populated PWBs contained the highest quantities of scarce SM among the 17 components considered
- Most of the investigated scarce metals leave the ELV shredder mainly through the shredder light fraction or the sieve fraction (fine fractions)
- Fe and Al surfaces do not carry much of the CM

**Discussion**:

- Economics of recycling of critical metals
- What happens with shredder light fraction (60%organics, 35% glass & sand and a couple of % metals→ municipal incinerator
- Translate critical metals to LCA: e.g. recovery of Indium from surfaces possible, economically feasible, manual labour can be beneficial, "real de-manufacturing"

**LCA of Current & Future Electricity Generation for EVs – Methodologies and Examples of an Attributional and Consequential Approach**
Alexander Stoffregen, thinkstep, Germany

**Key messages**:

- The electricity supply is a key factor of the environmental performance of electric vehicles.

- Consequential LCA can help to better understand the environmental benefit of electric vehicles, but is complex.

**Discussion:**

- Data of EV production based on various literature -> generic model
- Public subsidies are not properly reflected, esp. until 2030 -> free market approach, only Carbon cabs
- SCelecTRA report is available

**Results of Reviewing of 100 International LCA Studies on BEV and PHEV**
Georg Knaus, FH-JOANNEUM, Austria

**Key messages**:

- Most studies published 2009-2012,
- Greet most used Software
- EV higher impact at Production - lower at operation, Infrastructure rarely considered
- BEV/PHEV powered by Coal Power = Worst Case, Expand Renewables, Smart Grid
- Difficult to compare Emission Values (Electricity Mix, Type of Vehicle, Vehicle use)
- Installation of Flue Gas Cleaning Systems
- Comparison sometimes not fair

**Discussion:**

- Influence of infrastructure is small concerning additional environmental effects
- "Fair" comparison: smaller EVs with bigger conventional vehicles
- 2nd use of battery: 2 papers have analysed this, e.g. use in family house for load shift

**Project InitiativE-BW: Real Life Usage and Energy Consumption of EV-Fleets**
Holger Dittus, DLR, Germany

**Key messages:**

- Status quo: 204 vehicles ordered and 44 equipped with data loggers; ~133,000 km and ~310 days with measured data
- Next steps:
  - Equipping of more electric vehicles with data loggers
  - Additional vehicle types
  - Correlation with questionnaire
  - Advanced analyses of measured data
  - Publication of project results
  - Use concept
  - Charging cycles
  - Real life uses driving cycles of electric vehicles

**Discussion:**

- Energy demand for heating
- Energy demand for cooling/air conditioning

**Electric car LCA - New Findings by Real-world data**,
Eckard Helmers, University of Applied Sciences Trier, Germany

**Key messages:**

- LCA of electric vehicles modeled so far are widely based on standardized inventory data (energy consumption, materials cake). However, recently reported strong real-world deviations of combustion engine vehicles from type approval (+ 60 % in energy consumption, + 600 % in toxic emission) suggest to consider real-world data for modeling.
- BEV drive most efficient in urban use, ICEV least efficient. This implies to model urban usage specifically for small BEV. In our results, this changed the overall impact: Even under the German electricity mix of 2013, a small BEV drives environmentally beneficially.
- By converting a used Smart from combustion engine to electric in our lab, and by quantifying the energy consumption before disassembling and after re-assembling, three base vehicles (new ICEV, new BEV, converted BEV) were modeled, together with sensitivities resulting in 36 sub-models. The electric conversion of a used combustion engine vehicle can save an additional 16 % (CO 2-eq) and 19 % (single score endpoints) of the environmental impact over lifetime, respectively, when compared with the new BEV.
- The analysis of the process modules of the individual impact categories surprisingly exhibited that electricity consumption during battery cell production in China as well as impacts due to microelectronic components, although only a minimal share in the BEV ' s material, are quite dominant within the whole life cycle.

**Discussion:**

- Converting conventional vehicles to EVs does not give full energy efficiency
- PHEV might be an optimum combinations of advantages of BEV in urban driving and of ICE in mixed driving

**Life Cycle Assessment of Battery Electric Vehicles Addressing Variability in the Portuguese Electricity Mix**
Fausto Freire, University of Coimbra, Portugal

**Key messages:**

- Including a finer temporal resolution in LCA of electricity provides a more accurate picture of BEV impacts and opportunities for improvement.
- Life-cycle (LC) GHG emissions of a BEV operating in Portugal may vary significantly within the year, due to temporal variability in electricity generation (e.g., hourly variation between months up to 52%, in 2013).

- Reduction of electricity GHG emissions in the summer may significantly reduce GHG emissions of BEVs in Portugal.
- Night-time charging driven by lower electricity pricing may not lead to lower BEV LC GHG emissions. Currently, night-time charging of BEVs results in higher GHG emissions than day-time charging due to a higher share of coal-based generation.

**Discussion**

- Coal power for hydro-pumping, adequate counting for LCA effects necessary
- Very flexible coal power plants in winter time, might lead to very inefficient electricity

| **Second Life EV Batteries for Sustainable Batteries Waste Management**<br>Helena Gibert, IREC - Catalonia Institute for Energy Research, ES |
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**Discussion**

- Re-use of second life batteries might represent today's solution for batteries end-of-life management so the battery recycling industry can mature meanwhile.
- Economic viability in the future will partially depend on the cost of re-purposing of those batteries, whether they are directly re-used (maintaining BMS and refrigeration systems) or dismantle into module/cell level as well as the forecast for new Li ion battery costs.
- The design for re-use is also to be further investigated

| **Panel discussion:**<br>**How to communicate LCA results** |
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- LCA can bring facts and figures on EVs
- "Cherry picking" of positive/negative LCA must be avoided
- More aspects are relevant for decision makers
- LCA is one communication tool but combine it with other tools, e.g. time related cost models
- LCA just reflects only dimension of sustainability
- Implement "life cycle thinking"
- LCA is reaching relevance in governmental and industrial institutions

- LCA results should be clear but still complex issues
- LCA is important instrument to judge on real environmental effects
- Current design of automotive components is relatively qualitative mainly for eco-design, design für recycling, cheque lists,
- More than carbon footprint necessary
- LCA labelling of produced vehicles could be an advantage on the car market, already energy efficiency targets, environmental management systems, some LCA based data are already part for the public reporting
- Economic aspects are more a criteria than environmental aspects on the competitive automotive market
- Educate LCA receivers on LCA aspects and the use of results, e.g. results,
- "Culture of recycling" was developed in the last 20 years and LCA can do similar in future

# 4. Information on Task 30 "Assessment of Environmental Effects of Electric Vehicles"

***Analysis and assessment of environmental effects of electric vehicles (EVs) on water, land use, resources and air based on life cycle assessment in a cooperation of 18 countries in the International Energy Agency (IEA) (2016 – 2019).***

Electric vehicles have the potential to substitute for conventional vehicles to contribute to the sustainable development of the transportation sector worldwide, for example, in the reduction of greenhouse gas (GHG) and particle emissions. There is international consensus that the improvement of the sustainability of electric vehicles can only be analysed on the basis of life cycle assessment (LCA), which includes the production, operation, and the end-of-life treatment of the vehicles and the fuel cycle. All environmental impacts must include the whole value chain and - if relevant - interactions from recycling in the dismantling phase to the production phase, if recycled material is used to produce new vehicles.

**Programme of Work**

Task 30 is using the results of the completed Task 19 "Life Cycle Assessment of Electric Vehicles" (2011 – 2015, www.ieahev.org/tasks/task-19-life-cycle-assessment-of-evs/, led by JOANNEUM RESEARCH) as a foundation to subsequently examine the environmental effects – benefits and impacts - of vehicles with an electric drivetrain (EVs), based on life cycle assessment (LCA). With an eye on the three phases of LCA, such as production, operation and dismantling of EVs, various environmental effects of EVs on water, land use, resources and air, among others, will be analysed and assessed. Thereby a strong accent is put on the comparison of environmental effects between pure battery EVs (BEV) and Plug-in hybrids (PHEVs) on one hand and conventional ICE vehicles using gasoline, diesel and natural gas on the other side.

Task 30 will focus on following topics covering methodologies, data and case studies:

- Effects of EVs on water (emissions to water, waste water, "Water Footprint" of EVs)
- Effects on EVs on land use-resources-waste (land use, occupation and degradation, demand of renewable and fossil resources, recycling)
- Effects on EVs on air (local emissions and effects of NOx, PM and CxHy, human health effect and non-energy related emissions from tires and brakes)
- Overall environmental effects and their assessment (comparing and assessing different impact categories, single score methodologies, stakeholder involvement)

**Working Method**

Within the Task, methodologies for helping countries implement EVs by identifying possibilities to maximize the environmental benefits will be developed. Besides, various case studies will be analyzed and networking combined with information exchange will be supported within the Task's frames. For the purpose of research, the extension of the already in Task 19 established and international "Research Platform for Life Cycle Assessment (LCA) and End-of-Life Management for Electric Vehicles" will be included challenged.

The Task will proceed by holding a series of workshops addressing the following objectives:

- Methodologies on assessment of environmental effects
- Analyses of necessary and available data
- Overview of international studies/literature
- Analyses of current knowledge and future challenges
- Overview of key actors and stakeholders and their involvement
- Communication strategies to stakeholders
- Summarizing further R&D demand

**Duration**

The Task 30 will officially launch in January 2016 and run until the end of 2019. During the period a total of four international expert workshops addressing water, land use-resources-waste, air and the overall environmental effects, respectively, is planned.

**Benefits**

Members in this Task will compile a list of environmental benefits and impacts of EVs with the goal to increase their overall acceptance. Thus, numerous advantages of EVs compared to conventional vehicles will be shown. These results should help the industry and government to support further development and employment of EVs in all transport modes.

**Task Management**

Operating Agent: Gerfried Jungmeier, JOANNEUM RESEARCH, Austria

Vice operating Agent: Jennifer Dunn, ARGONNE, USA

The Implementing agreement "Hybrid and Electric Vehicle" of IEA (International Energy Agency has 18 member countries".

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|---|---|---|
| Austria | Germany | Spain |
| Belgium | Ireland | Sweden |
| Canada | Italy | Switzerland |
| Denmark | The Netherlands | Turkey |
| Finland | Portugal | United Kingdom |
| France | Republic of Korea | United States |

*http://www.ieahev.org/tasks/task-30-assessment-of-environmental-effects-of-electric-vehicles/www.ieahev.org/tasks/task-30-assessment-of-environmental-effects-of-electric-vehicles/*