RESULTS ON RESOURCES, WASTE AND LAND USE

In June 2019, Task 30 held an expert workshop on the effects of EVs on land use, resources and waste in Washington D.C., USA. The aim of this expert workshop was to analyse and assess the environmental effects of EVs on land use, resources and waste based on LCA in a cooperation of the participating countries in the IEA. The current status and the future perspectives of an EV's LCA on these issues in comparison to that of a conventional vehicle, an ICE, were presented and discussed. The focus was on BEVs and PHEVs.

In a group of relevant stakeholders from government, industry, research and NGOs, the relevant issues of effects on land use, resources and waste were identified and discussed referring to the ongoing large-scale market introduction of EVs.

Resources and waste

Concerning the effects of resources and waste the following topics were discussed:

a) LCA of battery production,
b) LCA of battery recycling,
c) LCA of electric motor recycling (mainly magnets), and
d) LCA of power electronics recycling.

LCA of battery production

The following key battery materials were updated in GREET (LCA model):

- cobalt: shares of Co coproduced with Ni/Cu; shares of sulphide/laterite; ore grade,
- nickel: shares of sulphide/laterite; ore grades; SOx emissions control,
- lithium: shares of lithium produced form brine/minerals,
- graphite: shares of natural/synthetic graphite.

The most relevant categories on energy demand and emissions of an NMC111 LIB under baseline condition are:

- NMC111 Cathode: Cobalt (sulfate production); Nickel (refining); other cathode steps (NMC11 precursor & powder production),
- aluminium: alumina reduction & SF4/S2F6 abatement,
- battery management system (BMS): electricity source, and
- cell assembly: heat and electricity source.

As an example in Figure 2 the Cradle-to-Gate environmental impacts of a 1 kWh NMC111 battery are shown, where cathode, production energy and aluminum are notable contributors:

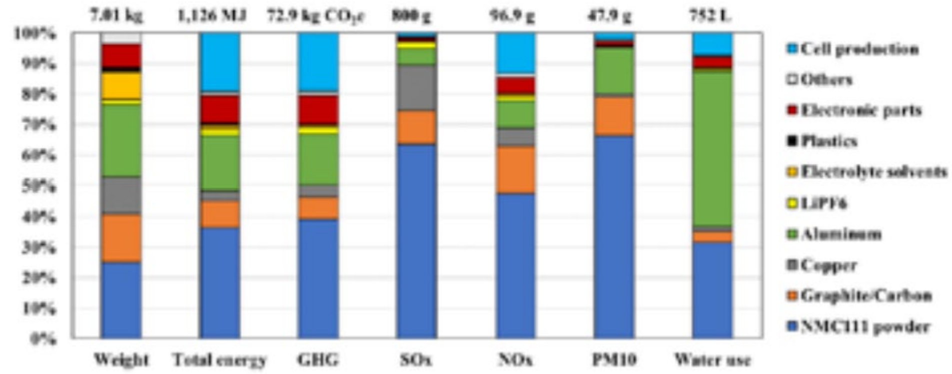

Figure 1 Cradle-to-Gate environmental impacts of 1 kWh NMC111 battery[1]

[1] L Gaines: LCA and Direct Recycling for Lithium Ion Batteries, Presentation at Task 30 workshop, June 2019

LCA of battery recycling

Actually, there are three main processes for the recycling of batteries:

1. pyro process for recycling of batteries,
2. hydro process for recycling of batteries, and
3. direct recycling of batteries (under development).

Based on current experiences in Germany initial conclusions on battery recycling are drawn:

- A careful dismantling offers significant environmental benefits.
- Major credits are possible from housing materials and other components (e.g. from recycling of steel, aluminium, copper, precious metals).
- Recycling of battery cells offers credits for Co, Ni, Cu; furthermore, lithium recycling would be possible, but a further process development is necessary.
- Huge importance for attenuating pressure on primary demand for key materials.

LCA of electric motor recycling (magnets)

An LCA was performed within the German project “MORE – Recycling of components and strategic metals from electric motors”. The following three different processing routes were analysed with the major interest to recover neodymium (Nd) and dysprosium (Dy):

1. direct reuse (cleaning): production of 1 kg magnet via reuse,
2. remelt (closed loop magnet remelting): production of 1 kg secondary magnet (70% primary and 30% secondary materials), and
3. feedstock recycling (recovery of “rare earth” oxides from EoL-magnets): production of 1 kg “rare earth” oxide (mixed or separated).

The initial conclusions regarding LCA of electric motor recycling (magnets) are:

- Major GHG emission credits for recovery of “rare earth” oxides, also remelting with secondary share of 30% offers benefits.
- GHG emissions of recovery effort generally well outweighed by credits for Nd and Dy oxides, magnitude strongly depends on allocation method (economic or mass based).
- In addition, other categories show strong credits for recovery of “rare earth” oxides.
- Data availability for assessment of primary production of RE, especially Dy, is very limited and uncertain.

LCA of power electronics recycling

An LCA was performed within the German project “ElmoRel 2020 – Electric vehicle recycling 2020 – key component power electronics”. The following three different processing routes were analysed

1. conventional car shredder (reference route),
2. dismantling & Waste of Electrical and Electronic Equipment (WEEE) recycling of power electronics, and
3. dismantling & WEEE recycling of power electronics incl. chemical dissection of polychlorinated biphenyls (PCB).

The initial conclusions in relation to LCA of power electronics systems are:

- In comparison to the conventional car shredder, route extraction of power electronics unit enables high recovery rates for gold, silver and palladium; recovery rates of tin and copper can also be increased.
- LCA shows good results for both routes, with dedicated WEEE recycling providing additional benefits from some higher recovery rates and corresponding credits.
- Main benefit of dedicated WEEE recycling from a resource conservation perspective.
- The effort for the additional recovery of tantalum (Ta) from PCB seems to be too high as to be environmentally attractive.
- The WEEE recycling route is economically viable, but offers a lower profit margin than the car shredder route.

Land use

The possible environmental effects of land use are relevant because:

more than half of the earth's terrestrial land is actively being used by humans,

the resulting loss of biodiversity and soil functions expressed by ecosystem services is of scientific, political, societal and economic concern,

there are many methods that can be developed to address land use impacts in LCA, and

therefore, country and region specific characterisation factors should be a mandatory requirement.

Land use is correlated to occupation of land and transformation of land. In relation to LCA, the inventory data are relevant for land occupation [m^2*a] and land transformation [m^2]. However, especially for mining processes these input data are often not known exactly and are therefore estimated. So far, there is no consistent comparison of possible land use effects of EVs and ICEs available. For EVs, the mining activities for battery materials resources and the generation of renewable electricity, mainly, might be relevant for land use, whereas for conventional ICEs the extraction of oil might be relevant.

Finally, the main issues of resources, waste, and land use that should be addressed in an LCA of EVs were identified in the workshop discussions. These are:

- Resources:
    - minerals, o fossil fuels,
    - resource criticality,
    - resource depletion not a primary environmental concern,
    - virgin,
    - recycled,
    - no consensus on impact assessment methodology in LCA,
- Waste:
    - reuse,
    - recycling,
- Land use:
    - land transformation [m^2],
    - land occupation [m2*a],
    - ecosystem services.

In Figure 3 a mind map on “Land Use – Resources – Waste in LCA of EVs”, with further details on the key issues, is shown.

Figure 2 Mind map on “Land Use – Resources – Waste in LCA of EVs”

<u>RESULTS ON AUTONOMOUS VEHICLES</u>

A special topic at the above mentioned workshop was on LCA of autonomous vehicles. The aim of this special topic was to present and discuss the evaluation of autonomous vehicles on LCA. Key issues on the LCA of autonomous vehicles were discussed and summarised within an interactive group looking at the rapid development of autonomous vehicles.

The vehicle automation is defined at multiple levels; the Society of Automotive Engineers (SAE) gives 5 levels, with level 0 for no automation:

- Level 1 – 2 require significant human interaction/monitoring of the environment all times, and the human driver will serve as the fall-back plan; this only applies to some driving modes, e.g. cruise control, lane keeping, parking.
- Level 3 – 5 have increasing degrees of “full automation” where the vehicle system is responsible for sensing, actuation, and environment monitoring:
  - Level 3: certain driving conditions automated, but driver must be able to intervene,
  - Level 4: certain driving conditions automated, no driver intervention,
  - Level 5: all conditions automated, no intervention.

The promises of vehicle automation are:

- convenience for drivers and passengers,
- reduced congestion,

- increased safety,
- increased productivity,
- faster travel,
- vehicle platooning (improved efficiency),
- lower “taxi” costs (taxi here is inclusive of mobility as a service companies),
- drive smoothing (less abrupt start and stops), and
- right vehicle for the trip (mode matching).

The challenges of vehicle automation are:

- rebound effect for distance lived from work,
- increased number of trips, especially taxi trips,
- empty miles (dead-heading),
- automated hunting for parking,
- safety concerns, and
- equity and less jobs.

The key parameters possibly affected by autonomous vehicles in an LCA are:

- fuel consumption affecting the operating of vehicles,
- the vehicle size and composition affecting the vehicle manufacturing, and
- lifetime of the distance travelled affecting per kilometre/miles from manufacturing the vehicle.

Due to the additional necessary equipment of an autonomous vehicle, the vehicle mass and the additional load are increasing. Current estimations for the additional load are between 200 W and 2 kW. The additional mass can also be compensated by lightweight structures; a typical rule of thumb is that light weighting can offer about 7% energy decrease by 10% mass reduction. The smoother driving might reduce energy consumption by up to 15%.

The five main areas of LCA of autonomous vehicles were identified as:

- vehicle level (e.g. energy consumption, vehicle mass changes, level of automation, vehicle lifetime mileage),
- operating conditions (e.g. climate, fleet composition, driving cycles),
- behaviour (e.g. user acceptance, user misuse),
- infrastructure (e.g. V2I/V2V – vehicle to infrastructure/vehicle to vehicle, energy consumption, traffic lights, parking space), and
- system level (e.g. rebound effect, mode shift, ride sharing, ride smoothing).

ESTIMATED ENVIRONMENTAL EFFECTS OF WORLDWIDE EV-FLEET

Since 2014, the Task has estimated the LCA based environmental effects of the worldwide electric vehicle fleet in 38 countries. In the LCA of these vehicles using the different national framework conditions, the environmental effects are estimated by assessing 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 (PM) emissions and primary energy consumption (total, fossil, nuclear, renewable) in comparison to conventional ICE vehicles. The key parameters influencing the environmental effects of vehicles with electric drivetrains are the electricity demand per distance travelled, the mix of technology for electricity generation, and the substitution factor of ICE vehicles by EVs in a globally increasing vehicle stock.

The analysis is done for each of the 38 countries separately and the main country specific results are summarised in "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 (referring to substituted ICE vehicles).

There are approximately 5 million electric vehicles in 38 countries worldwide in 2018[2,3], of which:

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

Based on the country specific results the total global environmental effects in 2014 to 2018 of the globally increasing EV fleet are estimated finally. Figure 4 shows the total reduction of GHG emissions with approx. 5 Mt CO2-eq in 2018, mainly resulting from the EVs fleet in IEA HEV countries, whereas the sum of the non IEA HEV countries has nearly no effect in changing the GHG emissions. The estimated cumulative primary energy change of the global EV fleet gives a reduction of approx. 5,000 GWh/a, which is shown in Figure 5. The IEA HEV countries substantially contribute to this reduction, where the non IEA HEV countries even result in an increase of cumulated primary energy demand.

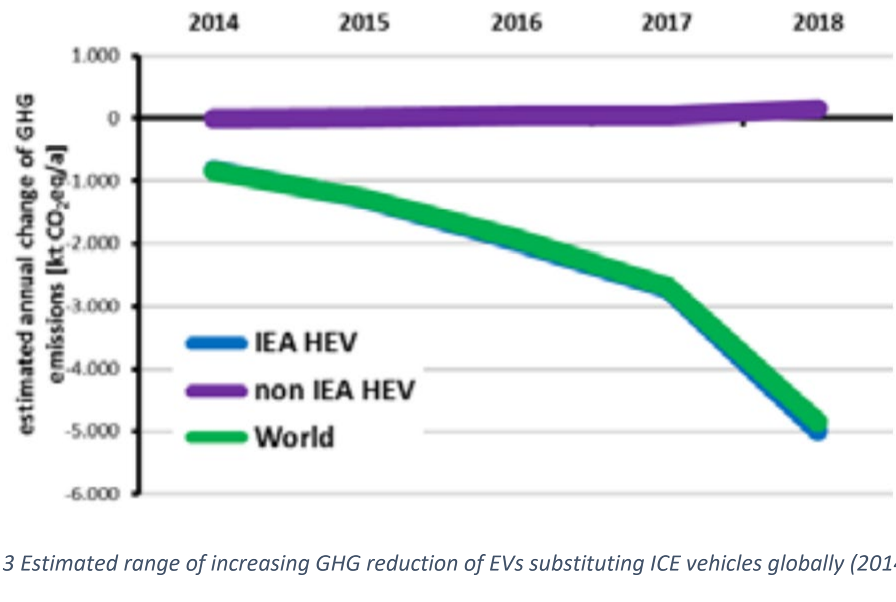

Figure 3 Estimated range of increasing GHG reduction of EVs substituting ICE vehicles globally (2014 – 2018)

[2] IEA 2019: Global EV Outlook - Scaling-up the transition to electric mobility, https:// webstore.iea.org/global-evoutlook-2019

[3] IEA-HEV 2019: Annual Reports 2014 – 2019, http://www. ieahev.org/news/annualreports/

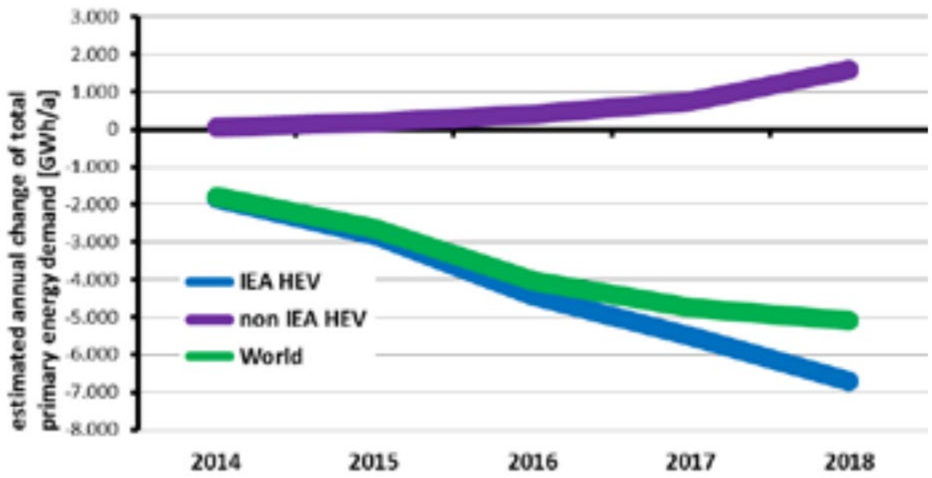

Figure 4 Estimated range of change in cumulative primary energy consumption of EVs substituting ICE vehicles globally (2014 – 2018)

The share of electricity produced from fossil fuel has a substantial influence on the EV related emissions. A relatively large share of renewable or/and nuclear electricity contributes to substantial environmental benefits in the affected countries (e.g., NO, FR, AT). On the other hand, a relatively large share of fossil electricity contributed to an increase of impacts in the relevant countries (e.g., PL, CN).

<u>NEXT STEPS</u>

The dissemination activities were:

- Paper & presentation: Time and Rebound Effects in the LCA of Electric Vehicles - Methodological Approach and Examples, IEWT 2019, Vienna University of Technology, Vienna, Austria, February 13 – 15, 2019,
- Presentation & paper "Evaluation of the Environmental Benefits of The Global EV-Fleet in 40 Countries – A LCA Based Estimation in IEA HEV", EVS32 – Electric Vehicle Symposium Lyon, France, May. 19 – 22, 2019,
- Keynote presentation in Plenary session "Life Cycle Assessment of Electric Vehicle - Experiences of in the IEA Collaboration Program on Hybrid and Electric Vehicles (HEV)", EV2019 - Electric Vehicles International Conference & Show, October 3-4, 2019 in Bucuresti, Romania
- Reviewed Publication "An international dialogue about electric vehicle deployment to bring energy and greenhouse gas benefits through 2030 on a well-to-wheels basis, Transportation Research Part D 74 (2019) 245–254"