Preface

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Electric vehicles (EV) have made marvelous achievements in many countries all over the world. Notably, EVs have now entered a new period of rapid development and propagation. Thus, the issue of the whole life cycle of electric vehicles is manufacturing, use and end-of-life is more prominent and is creating great interest from governments and scientists alike.

A 2014 joint workshop at the Hanse-Wissenschaftskolleg (HWK) in Germany addressed the topic of electro mobility, leading to this special issue on “Electric Vehicles”. Various international experts gathered in Germany and discussed challenges and drivers in electro mobility. As an outcome, the International Journal of Life Cycle Assessment offered the possibility to publish selected manuscripts in the context of LCA-related approaches towards electro mobility.

HWK, located in the northern part of Germany, has the primary goal to support and inspire excellent and innovative research in Germany and the world. It offers junior and senior scholars (fellows) the opportunity to concentrate on research projects without the distraction of routine commitments and to gain insights from other disciplines and other scientific traditions.

Taking the opportunity to use the fruitful working atmosphere at the HWK Alexandra Pehlken from Germany, Chen Ming from China, and Steven Young from Canada, as organizers of the workshop “Electro Mobility: Assessing the Shift from Energy Efficiency to Material Efficiency in the

Automotive Life Cycle”, gathered a community of researchers in the field related to LCA in automotive to discuss topics related to materials in the automotive life cycle.

Why are materials of such high interest on future needs? It is commonly known that automobiles have become lightweight, smarter, safer, and more electric. Each of these trends has demanded new types and new combinations of materials—and these materials have become more complex.

Results of the workshop suggest that the dominant challenge for developers and manufacturers of cars in the future may no longer be focused on issues of energy efficiency and fuels. Instead, new questions are growing on the use of complex, sometimes scarce and environmentally problematic materials, which challenge the life cycle management of automobiles and materials.

Critical metals, for example, have already gained attention as important to the automotive sector, due to increased use of electrical devices like motors, sensors, and batteries. Cobalt and gallium, rare earth elements (e.g., neodymium, dysprosium, praseodymium, and terbium), and other rare metals are critical in automobiles—and all are classified as strategic raw materials by Europe, the USA, and others. It is therefore important to consider the management of critical materials at the end of service life, with an aim to recover them for further use. However, there is a lack of data concerning the amount of critical metals in vehicles and on recycling technologies that will need to keep up with rapid changes in material content of future vehicles.

After the intensive workshop, we identified the following needs for further work:

- a) Life cycle assessment (LCA) of electric vehicles—with the explicit observation that materials issues will dominate as we increase use of cleaner power for electro mobility.

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- b) End-of-life vehicles (ELV) is an area of great activity, including insightful presentations on existing activities and future needs in Germany, Switzerland and Sweden. Participants discussed end-of-life management and recycling technologies.
- c) Critical materials—particularly the “technology metals” which are growing in use in vehicles; yet their recovery and recycling rates are poor and the flows are poorly understood.

With these work tasks, we started a call for papers with the International Journal of Life Cycle Assessment to encourage the whole community to submit suitable papers related to these tasks. We wanted to approach other researchers who also examine the fundamental shift that is occurring in e-mobility and electric vehicles: the shift from energy intensity to material intensity. We received papers of high quality for this special issue. One theme in all these papers is not on the sources and use of electricity used in EVs, as this momentum towards clean electricity is assumed. Rather, the issue focuses is on the life cycle considerations associated with aspects of raw materials production and manufacturing—and especially their end-of-life.

Quantities of electrical and electronic components in cars have grown significantly in the last decades. Compounding this trend, there are now additional changes in drive trains—the shift to electric powered systems (hybrid electric, plug-in electric, fuel cell electric, etc.). What are the resource and environmental consequences and management implications?

Therefore, the focus of this special issue is on life cycle assessment (LCA) and life cycle management (LCM) of electric vehicles, with particular attention on issues of materials, critical resources, reuse, and recycling. The new material intensity of automobiles needs to be examined and managed using a life-cycle lens. The articles can be generally clustered into four topics:

- Assessing the use phase of EVs (Moro and Helmers 2016; Helmers et al. 2016),
- Resource driven assessments (Gemechu et al. 2016; Pehlken et al. 2016; Hernandez et al. 2016),
- The potential of EVs for energy storage systems in the smart grid as a cascading use option (Gemechu et al. 2016; Richa et al. 2016; Casals et al. 2016), and
- The assessment of fuel cell electric vehicles (Miotti et al. 2016).

The assessment of the use of EVs and its performance is highly dependent on the battery performance and a better understanding of battery degradation, as addressed in Casals et al. (2016). However, authors observe that the use of batteries is only advisable if charged by renewable energy. In addition, the environmental trade-offs across cascading lithium-

ion battery life cycles is intensively compared by Richa et al. (2016) to lead-acid batteries. Here, two systems were jointly analyzed to address the consideration of stakeholder groups corresponding to both first (EV) and second life (stationary energy storage) battery applications. From the perspective of EV applications, cascading reuse of a lithium-ion battery in stationary energy storage can reduce net cumulative energy demand and global warming potential compared to lead-acid batteries. As result, this analysis of battery reuse alternatives allows stakeholders in both the EV and utility sectors to plan more effectively for the design, technology requirements, and business models needed to enable economically and environmentally feasible reuse strategies. This is exactly the plan for design for environment: when “upcycled” applications are considered as second life option. Resources could be saved in the so-called cascading approach as second use. Ahmadi et al. (2016) present a cascaded life cycle of reuse of electric vehicle lithium-ion battery packs in stationary energy storage systems and demonstrate a case study. Their study characterizes the extended lifetime of lithium-ion battery packs using a complex functional unit to cover both use and reuse phases over an 18-year lifetime. They conclude for most impact categories that the cascaded use system appears significantly beneficial compared to the conventional system. However, the energy efficiency fade (a degradation in battery state-of-health) is a considerable determinant of potential performance for second use. In addition, as the other authors Ahmadi et al. (2016) conclude that only by consuming clean energy sources for both use and reuse, the overall environmental pollution is reduced.

Since manufacturing and resources were identified as another key driver in EVs, Gemechu et al. (2016) address the geopolitical-related supply risk assessment as a complement to environmental impact assessment within the case of electric vehicles. In this paper, the criticality aspect is added to life cycle sustainability assessment (LCSA) framework since the weakness of resource indicators in LCA is heavily discussed in the LCA community for some time. The authors introduce the GeoPolRisk indicator to complement the environmental and extend the established environmental LCA impact categories. The GeoPolRisk indicator can play a indicative role in managing the supply chain of critical resources used in future products as it highlights their potential supply constraints. On the other hand, it suggests in this case study that there are important elements present in very small quantities in the EV that may be crucial to the overall LCSA. In conclusion, the authors agree that resource challenges in a short-term time perspective can be better addressed by including social and geopolitical factors in addition to the conventional “depletion” indicators that are based on their geological availability. However, this is an active research area that needs to be explored, including more

case studies. In addition to the overall resource discussion, Pehlken et al. (2016) assess some material flows calculations and pose the question: Is there a resource constraint related to lithium-ion batteries in EV? The obtained results and particularly the conclusions derived from the results remain debatable as long as uncertainties in the overall assessment cannot be eliminated. Their study is aimed at giving a more comprehensive understanding of challenges—including the issue of uncertainties—that the broad implementation of e-mobility could place on resource availability and especially on a sustainable management of special metals for high-voltage traction batteries. As main conclusion the authors imply a shift from managing primary resources, resource uses, and waste separately, towards managing materials, i.e., resource flows and their implications over the entire life cycle. These insights contribute directly to emerging ideas of the “circular economy”.

Furthermore, Hernandez et al. (2016) focus on the impact of traction electric motors for EV applications and combine the resource demand and the efficiency. The focus of their LCA study is the traction electric motor based on permanent magnets for EV applications only. The amount of energy consumed is highly dependent on the efficiencies of the powertrain, which is why improving use efficiency is recommended as crucial for decreasing the environmental footprint produced by the motor.

Besides the resource driven aspects also the assessment of the use phase of EVs is gaining high interest in the scientific community. As we excluded the effect of the usage of renewable energies, we could also identify other aspects to the use phase of EVs. For example, Helmers et al. (2016) performed an LCA on the electric car based on real-world mileage and the electric conversion scenario. Their assessment aims at quantifying the LCA based on a real-world vehicle composition and energy consumption data measured before and after the electric conversion of a mini class car. Surprisingly, their electric conversion of a used combustion engine vehicle can save an additional 16% (CO₂-eq) and 19% (single score endpoints) of the environmental impact over a lifetime, respectively, when compared with the new EV.

Focusing in more detail on the fuel consumption and energy savings, Moro and Helmers (2016) present a novel hybrid method for reducing the gap between well-to-wheel (WTW) and LCA in the carbon footprint assessment of electric vehicles. Their proposed method (hybrid WTW + LCA) keeps the main hypotheses of the WTW methodology, but integrates them with LCA data restricted to the global warming potential (GWP) occurring during the manufacturing of the battery pack. This bridging action might be useful in the future, when a larger share of renewable energy sources feeding the electric grid will make the impact of the GHG emissions due to the production of EVs not

negligible, compared to the GHG emissions of the electric energy mix, as it is now.

As the only paper on non-battery electric vehicles, Miotti et al. (2016) performed an integrated environmental and economic assessment of current and future fuel cell vehicles. In this study, they assess the environmental impacts and costs of a polymer electrolyte membrane fuel cell system for use in light-duty fuel cell vehicles and integrate these results into a comparative evaluation between fuel cell vehicles (FCV), battery driven EVs, and internal combustion engine vehicles (ICEVs). FCVs are an attractive alternative to ICEVs in terms of vehicle performance criteria such as range and refueling time. However, the technological challenges associated with reducing other environmental impacts and costs of FCVs seem to be as large, if not larger, than those associated with the capacity and costs of batteries for BEVs. Since fuel cells are just entering the market, we need more case studies related to fuel cells assessment. In addition, the discussion on the hydrogen infrastructure is a story of its own and involves also political discussions.

As result, we hope to have gathered very interesting papers and can only conclude: please derive as much value and much fun with this special issue as we had reviewing it.

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