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Scrutinising the electric vehicle material backpack

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ABSTRACT

Conventionally the use phase of a road vehicle contributes to more than 70% of the total environmental impact in terms of energy use or emissions of greenhouse gases. This figure is no longer valid concerning electric vehicles and a shift to other life cycle stages and impacts is expected and should be re-evaluated. The goal of this study is to assess the environmental performance of two prototype vehicle drivetrains; an internal combustion engine and an electric motor, from a life cycle perspective. The assessment is performed in a qualitative manner using the Environmentally Responsible Product Assessment (ERPA) matrix. The two vehicles in this study have similar car body construction, providing an excellent opportunity to highlight the significance of material differences in their drivetrains. The internal combustion vehicle demonstrated a better environmental performance in three out of five lifecycle stages (pre-manufacture, product manufacture, and disposal). In all of these stages, the impact of the electric vehicle is determined by the burden of the materials needed for this technology such as rare earth elements (REE) and by the lack of recycling possibilities. The study demonstrated a need to close the material cycle when it comes to Critical Raw Materials (CRM) such as REE which can only be achieved when the technology but also the incentives for material recovery are provided, i.e. by promoting the development of cost-efficient recycling technologies. Moreover, the need for relevant metrics and assessment indicators is demonstrated to be able to compare the two technologies fairly.

1. Introduction

The use phase of a road vehicle typically contributes to more than 70% of the total environmental impact regarding energy use or emissions of greenhouse gases (GHG). This figure is no longer valid concerning electric vehicles (EVs). EVs may bring about drastic reductions of carbon dioxide (CO_2) emissions during their use phase (Faria et al., 2012; Hawkins et al., 2013; Ma et al., 2012). However, the reductions depend on advanced technology based on specialised materials such as Rare Earth Elements (REE), lithium, or cobalt (Cullbrand and Magnusson, 2011; Steen et al., 2013) which could potentially offset the emission savings.

REE such as neodymium, dysprosium, and others can be found in the magnets and traction batteries of most EVs. Although these materials are not scarce in the Earth's crust, their geographical distribution to only a few regions creates a considerable supply and economic risk (Campbell, 2014; Golev et al., 2014; Walters and Lusty, 2011). Further, due to environmental constraints associated with their extraction, the European Commission has listed REE as Critical Raw Materials (CRM) (European Commission, 2017, 2014a). Despite their limitations, REEs have become essential components of many modern technologies within the transport but also the renewable energy sector (Alonso et al., 2012; Campbell, 2014; Smith Stegen, 2015). Although many highlighted the importance for their responsible use and recovery (Binnemans et al., 2013; Smith Stegen, 2015) recycling rates for REE remain negligible (Andersson et al., 2017; Binnemans et al., 2013).

To this end, an important question is raised: Can the benefits of reducing CO_2 emissions balance the negative impact of the usage of these materials, and under which circumstances? While current environmental vehicle policy focuses mainly on how much CO_2 a vehicle emits on its way from A to B (direct use phase emissions) (European Commission, 2016), the introduction of electric vehicles may also demand a stronger focus on preservation of (environmentally) valuable material.

The environmental performance of EVs has been assessed and compared to conventional internal combustion engine vehicle

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(ICEV) or other propulsion technologies in numerous studies (Hawkins et al., 2013; Ma et al., 2012; Samaras and Meisterling, 2008). A few examples are listed and analysed in Appendix A, Table A.1. From a life cycle perspective, EVs have the potential to reduce the CO_2 emissions during the use phase as most studies conclude. Different lifecycle emission reduction rates that favour EVs are reported in literature varying from 10% to 24% (Hawkins et al., 2013) to almost 50% (Ma et al., 2012). These savings occur mainly as a result of fuel change (from fossil fuels to less carbon intense electricity), reduced tailpipe emissions and improved engine efficiency (Hawkins et al., 2013; Ma et al., 2012) but depend also on the underlying assumptions with regard to electricity mix, driving range and more (Faria et al., 2013; Hawkins et al., 2013; Ma et al., 2012; Messagie et al., 2014).

As the environmental impact of the use phase decreases, the production stage of the EV becomes more critical from a life cycle perspective (Hawkins et al., 2013; Ma et al., 2012). However, as Hawkins et al. and Ma et al. observed the emissions during production increased not only in relative values (as expected) but also in absolute terms. In the assessment performed by Ma et al. the impact from vehicle production increased from 38 g CO_2 eq. per km (for the ICEV) to 54 g CO_2 eq. per km (for the EV). Batteries and other advanced electronic components are responsible for this shift due to advanced materials and intensive production processes (Hawkins et al., 2013; Ma et al., 2012). Moreover, a shift among environmental impacts is observed, i.e. from energy and climate to metal depletion, human toxicity and more (Hawkins et al., 2013; Notter et al., 2010).

It becomes apparent that a lifecycle perspective is essential for a fair comparison between EVs and ICEVs to avoid problem shifting situations. Moreover, need to address impacts of materials in such comparisons emerges.

The material intensity of EVs as associated impacts, however, has so far been assessed in only a limited number of studies as Nealer and Hendrickson, and Nordelöf et al (Nealer and Hendrickson, 2015; Nordelöf et al., 2014). observed in their extensive literature reviews. According to the latter, only 28 LCA studies out of 79, i.e. about 35%, considered impacts other than energy use and Global Warming Potential (GWP). As these cannot be viewed as representative impact categories, despite their extensive use (Moberg et al., 2014), the increased impacts of raw materials may be overlooked, concerning both the impact of consumption and at the end of life. This, in turn, may entail a risk for overestimating the potential benefits of the EV technology.

Given this background, this paper aims to shed light on the importance of CRM, especially REE, in a life cycle perspective as EVs are being introduced on a larger scale to replace ICEV and to discuss policy implications of our findings.

To investigate the environmental significance of materials vs other aspects throughout the lifecycle, we have compared two existing prototype vehicles; one vehicle with a traditional combustion engine and one with an electric driveline. The vehicles were identical in every aspect except for the drivetrain. To rid the comparison of differences that are not inherent to the choice of the drivetrain, the vehicles were elemental and lack features such as air conditioning, infotainment, electric mirrors, and radio. Hence, the LCA comparison between these vehicles differs from earlier studies in that it concerns only the drivetrain, which is where the significant differences regarding CRM arise, and the actual transport function of the vehicles. For regular fleet cars, it is difficult to distinguish the transport function from the total energy consumption and carbon emissions. The paper explicitly sets out to answer the following questions:

What major differences in terms of environmental impact can be identified between an electric vehicle and a fossil fuel vehicle if the drivetrain is studied phase by phase: extraction of raw materials, product manufacture, delivery, product use and refurbish/recycle/disposal?

What implications for environmental vehicle policy may be identified based on the answer to the first question?

The comparison in this paper was made as a Streamlined Life Cycle Assessment (SLCA) of the two prototype vehicles. SLCAs are suitable tools to be used for screening purposes, i.e. for identifying the environmental "hotspots" of a product (Graedel and Saxton, 2002). In SLCAs the demand for quantitative life cycle inventory (LCI) data is lower compared to full quantitative LCA which simplifies the implementation process. Detailed data on the material composition of EVs are somewhat scattered in the literature. It is often the case that information on advanced materials used for electronics and other components of the EV drivetrain, is omitted or poorly reported even in full-scale quantitative LCAs (Hawkins et al., 2012; Nordelöf et al., 2014). Such data gaps affect not only the quality of the assessment but also the conditions based on which conclusions are established (Nordelöf, 2017). Further, it has been noted in the literature that uncertainties about ways that materials and other abiotic resources are handled and considered in existing impact assessment methods used in LCAs remain high (Finnveden et al., 2009; Nordelöf, 2017), also leading to less comprehensive and comparable results. It can be therefore argued that by using SLCA for this work, assessment complexities and inconsistencies are avoided while results are more straightforward to interpret and communicate.

1.1. *Specialised materials in vehicles*

The material composition of vehicles has changed considerably over the last years. The increased number of electronics in the vehicle in combination with the electrification of the drivetrain and increased equipment level has given rise to the use of materials such as copper, lithium, neodymium, dysprosium and other REE and critical minerals (Cullbrand and Magnusson, 2011; Steen et al., 2013). EVs depend heavily on REE primarily for the magnets and batteries needed for their operation (Habib and Wenzel, 2014; Widmer et al., 2015)

When comparing the materials of EVs and ICEVs, the most significant difference between these two technologies concerns the drivetrain (Elwert et al., 2015; Hawkins et al., 2013). If the car body is mostly the same (consisting mainly of steel and aluminium), the difference is in the amount of CRM needed in the EV drivetrain, for example, REE with significant upstream impacts.

The primary challenge associated with REE supply concerns the limited regions where REE extraction can be economically feasible leading to an almost monopolistic situation with Chinese dominance of REE production (Campbell, 2014; European Commission, 2017; Smith Stegen, 2015). It is important to know that REEs are not scarce but the issue lays in the market monopoly that is a very limited supply chain (Tukker, 2014). In addition to economic constraints, mining of REE results in environmental as well as societal pressures for example releases of toxic and radioactive materials (Nordelöf, 2017; Rowlatt, 2014). REE are therefore labelled as CRM (European Commission, 2014b; National Research Council, 2007; Speirs et al., 2013; U.S. Geological Survey, 2013).

At present only a very limited fraction (less than 1%) of REE are recycled at the end of life (EOL), resulting in a considerable loss of resources (Binnemans et al., 2013). Concurrently, the transition towards sustainable energy supply and mobility, and the introduction of advanced technologies such as photovoltaics, electric propulsion systems, fuel cells etc. has increased the global demand of REE which is expected to continue rising (Alonso et al., 2012; Habib and Wenzel, 2014; Tukker, 2014). As a consequence, the