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Key issues of lithium-ion batteries – from resource depletion to environmental performance indicators

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ABSTRACT

Lithium batteries increasingly popular, but what is the associated environmental impact to their use? This paper focusses on the environmental impacts of two lithium battery chemistries used in electric vehicles and on the problematic around resource availability. A full life cycle perspective is important in order to avoid burden shifts from one life cycle stage to another. Using a life cycle assessment methodology, a cradle to grave analysis is performed where the 3 different product life stages are assessed, production, use stage and end-of-life. Alongside, an extensive literature review is performed on lithium availability. It is concluded that this issue will not pose an obstacle. However, certain conditions have to be met in order to guaranty this situation. The chemistries used in this assessment are Lithium Manganese Oxide (LMO) and a Lithium Iron Phosphate (LFP). We conclude that the overall environmental performance of the battery is strongly dependent on its efficiency and directly tied to the energy mixes associated to its use stage. Lifetime energy, durability and efficiency are the key environmental performance indicators and are taken into account. The dominant differences between the two batteries are during the manufacturing and recycling stage. Depending on the impact category, the scores shift from both technologies. A production hotspot analysis is also performed in order to identify opportunities for eventual environmental damage reductions. During the manufacturing stage, key areas were found with issues related to manufacturing energy, manufacturing facilities, and raw material processing/assembly.
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1. Introduction

1.1. Lithium based energy storage overview

Energy storage systems based on lithium ion batteries have a wide range of sizes and usages. From small applications like portable batteries (cell phones, laptops, etc.) to bigger ones like batteries for electric mobility (bikes, electric vehicles (EVs), trains, etc.) to large battery groups for grid applications. Lithium rechargeable batteries provide energy devices as described above with capacities ranging from just a few Watt hours to megawatt hour. Typical laptop batteries have a capacity rating from 45 Wh to roughly 100 Wh. Cell phone batteries are significantly smaller and typical electrical vehicle applications have capacities in the range of dozens of kWh (while the Nissan Leaf has a 24 kWh, Tesla model S with its variants range from 40 kWh to 85 kWh) (Vazquez et al., 2010). Electrical grid applications using large scale lithium ion battery systems have capacities on the megawatt scale (Chen et al., 2009).

The fact that lithium batteries have so many kinds of applications makes the technology development to grow fast. Especially in emerging applications as it is electric mobility, where the demand of more efficient battery packs increases continuously in order to provide a competitive technology in terms of driving range and durability versus internal combustion engine vehicles. The continuous grow of batteries for EVs is also associated to the enormous effort that governments have put in electric mobility, in order to reduce emissions from road transport. Electricity as an energy vector for vehicle propulsion offers the possibility to substitute oil with a wide diversity of primary energy sources. This could ensure security of energy supply and a broad use of renewable and carbon-free energy sources in the transport sector, which

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consequentially, could help the achievement of targets on CO_2 emissions reduction (e.g. Kyoto agreements on emissions targets in 2020) (Messagie et al., 2014; Rangaraju et al., 2015).

This growing development of lithium batteries raises the question on whether future lithium metal availability can pose a threat to electric vehicle industry. Reliable analyses are therefore needed to make clear, to the extent of possible, if the availability of lithium will meet future requirements. Several assessments on the presence of lithium on earth, and its expected future demand, have been performed over the past years. They are used in this study to shed some light on whether lithium mineral could possibly become an obstacle, and if EV industry would be replacing the depletion of fossil fuels by the depletion of another non-renewable insufficient resource (Kushnir and Sandén, 2012).

1.2. Lithium resource availability

Addressing the issue of lithium availability requires first to clarify the difference between "resources" and "reserves". This classification is explained in broad terms as follows: resources are geologically assured quantities that are available for exploitation and; reserves are the quantity that is exploitable with current technical and socioeconomic conditions. There has been made extensive research on the definitions and classifications used for this two terms in literature (Evans, 2014; Gruber et al., 2011).

Several published studies of Li availability show significant discrepancies in the amounts of global resources and reserves. In order to give an accurate range considered to Li availability, nine of the most recent and relevant of these publications were reviewed for this study. In the studies the estimations are obtained by synthesizing all the available data of Li found in brine, pegmatite and sedimentary rock deposits, including recently discovered deposits, mostly in China and Russia.

The findings of these studies are summarized in Table 1.

The range of lithium resources varies greatly from the lowest 19.2 Mt, to the highest 71.3 Mt, according to Tahil (2007) and Mohr et al. (2012) respectively.

These estimations vary mainly due to: number of deposits considered, how conservative the study is, the availability of information and its interpretation, and the discrepancies between authors on the definition of reserves and resources. At present, the global demand of lithium is distributed across end-use markets, the battery market accounts for 22% (USGS, 2014). Fig. 1 shows how the current resources and reserves of lithium are distributed around the world.

Based on the material density of a lithium battery, Kushnir and Sandén (2012) estimate that 200 g of lithium per kWh of battery capacity is a reasonable approximation of lithium required in current designs for BEV batteries. With progress, 160 g of lithium per kWh may be a reasonable medium term estimate (Kushnir and Sandén, 2012). Currently, around 1.8 kg of lithium are required for the battery of a PHEV (9 kWh capacity), while 7.2 kg are required for a full EV (36 kWh capacity).

Table 1
Recently published assessments on lithium reserves and resources.

Reference	Deposits included	Reserves (Mt)	Resources (Mt)
Mohr et al. (2012)	45	23	71
Evans (2014)	24	n.a	30
Grosjean et al. (2012)	77	n.a	37–43
Kesler et al. (2012)	35	n.a	38
Vikström et al. (2013)	112	15	65
Kushnir and Sandén (2012)	n.a	30	n.a
Yaksic and Tilton (2009)	40	29	64
Tahil (2007)	15	5	19
USGS (2014)	8	13	40
Gruber et al. (2011)	61	n.a	31

Several studies calculated the demand of lithium at different future time dimensions. The different strategies and assumptions used for demand prediction, deliver results that vary substantially among each other (Evans, 2014; Grosjean et al., 2012; Vikström et al., 2013). However, the majority of the studies on this issue consider as a fact that large scale recycling will take place, to relive pressure from the extraction and production of primary lithium. Moreover, the studies suggest that the biggest source of lithium in the second part of the century will come from recycling (Kesler et al., 2012). Nevertheless, at present, the development of technology and strategies for recycling is far from reaching this situation. In addition, the studies suggest that the penetration of EVs will be significant (and predominant over other end-uses) by the year 2050, reaching levels from 60% to up to 100% of either hybrid or fully electric vehicles, which is a rather optimistic perspective. At the same time, there seems to be little agreement on which type of technology will be more widely use in the future, the evolution of the battery capacity in these technologies, and the required amount of lithium that will be needed for each battery.

Given the inherent uncertainties surrounding the future course of technological change and other determinants of mineral commodity prices, it is difficult to estimate with great accuracy how the demand will behave in future years. The development of technology may decrease the need of lithium for each battery, or it could make it less energy intensive to extract lithium from low quality reservoirs, among others. On the other hand, population growth, changes in the future consumer preferences, and the other determinants governing how rapidly society will move towards EV, are factors with a behavior difficult to predict. In addition, some critical information on mineral commodities is currently not available. For these reasons, it can be debated whether these kind of forecasting should be used for such long term periods (Grosjean et al., 2012). The actual demand of lithium in coming years can significantly differ from the predicted values, but at least the studies give a general impression on the situation of lithium depletion.

Nevertheless, when comparing the estimations on supply and demand it seems, at a first glance, that lithium shortage will not pose an obstacle for the EV industry. Certainly, the majority of the studies considered agree that lithium availability will not become a stringent factor for the electric vehicle industry.

While some authors (Evans, 2014; Gruber et al., 2011) assure that depletion of lithium is not a serious threat, some emphasize on the importance of the fast inclusion of recycling measures (Grosjean et al., 2012; Mohr et al., 2012). Others (Tahil, 2007; Vikström et al., 2013) state that availability is not assured, and that production rates may pose serious problems of competitiveness among the markets in need of lithium.

From an LCA point of view, the issue of resources depletion for batteries in electric vehicles and its specific components has been studied. Only three impact assessments methods in LCA actually provide a characterization factor enabling the estimation of environmental impact generated by the extraction and consumption of lithium. Among them are the CML 2002, EPS 2000 and the Ecoscarcity methods. When considering these methods it is clear that lithium is not categorized as a particularly high depletion risk metal. Other materials used in either Li-ion cells, the battery management system (BMS) or the battery casing, particularly precious metals, namely gold, silver and tin, are awarded higher depletion risks. This seems logical given that the availability of precious metals is smaller than that of most industrial metals;

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