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Lithium availability in the EU27 for battery-driven vehicles: The impact of recycling and substitution on the confrontation between supply and demand until 2050

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ABSTRACT

The adverse impacts of climate change are widely recognized as well as the importance of the mitigation of carbon dioxide (CO_2). Battery driven vehicles are expected to have a bright future, since GHG emissions can be reduced. Lithium-ion (Li-ion) batteries appear to be the most promising, due to their high energy density. Recently, the discussion concerning adequate lithium carbonate (Li_2CO_3) resources is resolved. The current challenge is the needed increase in flow rate of Li_2CO_3 into society to foresee in forecasted demand. This research determines ten factors which influence the availability of Li-ion batteries for the EU27 in the coming decades. They are used in a system dynamics analysis. The results of this research show that undersupply can be expected in the EU27 until 2045 somewhere between 0.5 Mt and 2.8 Mt. Substitution of Li_2CO_3 in other end-use markets and recycling can relieve the strain on Li_2CO_3 supply to some extent. In 2050, 20% of the vehicle fleet in the EU27 can be battery electric vehicles (BEVs). The lack of resources in the EU27 and the geographical distribution of lithium in politically sensitive areas suggest that the shares of lithium available for the EU27 will be less than assumed in this research. The increase in flow rate shows to be the bottle-neck for a transition to (partly) battery driven vehicles in the EU27, at least when Li-ion batteries are used. Focusing on large-scale application of BEVs with Li-ion batteries in order to substantially mitigate CO_2 emissions in transport is a futile campaign.

Introduction

The adverse impacts of climate change are widely recognized as well as the importance of the mitigation of carbon dioxide (CO_2). Besides the adverse environmental impact, the dependence on fossil fuels has resulted in increasing scarcity, which is accompanied with rising energy prices. The electrification of the vehicle fleet can contribute to the mitigation of CO_2, because the application of (partly) electric vehicles reduces greenhouse gas (GHG) emissions when renewable energy sources are used for the production of electricity, or when for example carbon capture and storage is applied. Since transport is responsible for half the global oil consumption (Fulton, 2004), large scale application of battery driven vehicles has potential to mitigate GHG emissions and decrease oil demand. Furthermore, a decreased oil demand and an increase in energy derived from a variety of renewable energy sources increases security of energy supply. Lithium-ion (Li-ion) batteries have a high energy or power density (Grosjean et al., 2012) compared to other common battery chemistries. Therefore Li-ion batteries appear to be the most promising for application in battery driven vehicles.

As emphasized by Gruber et al. (2011) there are significant variations in the estimates for lithium carbonate (Li_2CO_3) resources and reserves. Recently, they resolved the controversy in literature concerning the adequate resources of Li_2CO_3. Long term scenarios until 2100 show that lithium resources are sufficient to fulfil future demand for batteries (Gruber et al., 2011). A select group of countries has direct access to these lithium resources and Europe (i.e., Serbia and Portugal) possesses only 3% of them, whilst it is expected to become one of the largest end-users, which makes Europe import dependent (Gruber et al., 2011; Grosjean et al., 2012). Europe's influence on the supply side is therefore limited. Grosjean et al. (2012) expect Europe to be the greatest victim of the geostrategic bottleneck concerning the polarized distribution of lithium resources. Despite the sufficiency of resource availability, Gruber et al. (2011) emphasize the challenge to foresee in the establishment of lithium producing facilities at a rate demanded by the automotive industry. Kushnir and Sandén (2012) also emphasize the possible constraint on an increase of the flow rate of lithium into society.

The bottleneck for a successful transition to an electrified vehicle fleet with Li-ion batteries seems to be the possible limit on increasing the flow rate of Li_2CO_3 into society, together with

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the share of the Li_2CO_3 flow available for car batteries, which are both still subject to discussion. The main aim of this research is to analyse the confrontation between supply and demand for Li_2CO_3 in the 27 member states of the European Union (EU27) until 2050 for a penetration scenario of (partly) electric vehicles and draw conclusions about the feasibility of such a scenario.

A system dynamics analysis is commonly used to study the complexity of a systems' stocks, flows and feedback loops over time. Such studies are not done so far with regard to the lithium availability for large scale introduction scenarios of battery driven cars.

A system dynamics analysis starts with the identification of the drivers and factors that influence the system. Ten factors can be indicated for the case of lithium availability for large scale introduction scenarios of battery driven cars, namely trends in Li_2CO_3 production (1), the production trends of battery driven vehicles for the EU27 (2), the lithium requirements per kW h battery capacity (3), the range of a battery driven vehicle (4), trends in battery recycling and lithium recovery (5), the share of Li_2CO_3 available for the EU27 (6), the lifetime of a battery (7), the share of Li_2CO_3 available for vehicle batteries (8), trends in other end-use markets of lithium (9) and substitution of lithium in other end-uses (10). These factors are analysed in order to resolve whether the global lithium resources are enough to fulfil the ambitious targets set out by the EU. The technological factors in the system are chosen quite optimistic which should result in an estimate for the lower boundaries in lithium demand belonging to the chosen scenario.

In order to approach these factors a supply forecast curve has been developed. Subsequently, vehicle developments in the EU27 and recycling rates have been analysed. The size of other lithium end-use markets has been estimated and the share of substitutable lithium in these markets has been determined.

This article is organized as follows. First the further outlining of the research context, followed by a description of the developed model and scenarios, the associated results discussing the impact of substitution and recycling and the feasibility of a full electric scenario, a discussion including a sensitivity analysis and a thought experiment addressing the application of plugin hybrid electric vehicles (PHEVs) at the cost of battery electric vehicles (BEVs) and a concluding section which reflects on the constraints concerning lithium supply in the coming decades.

Research context

The data available from literature on which the model, to estimate Li_2CO_3 demand for the EU27 until 2050, is based is elaborated in this chapter. Vehicle development is discussed, combined with the applied forecast for PHEVs and BEVs in two scenarios. The theoretical minimum amount of Li_2CO_3 in a Li-ion battery and recycling rates of Li-ion batteries are subsequently addressed. When referring to the terms resource or reserves the definitions as formulated by the United States Geological Survey (Jaskula, 2009) are applied.

Lithium supply curve

Gruber et al. (2011) estimate the minimum reserve to be 102 Mt. This includes all in-situ Li_2CO_3 resources, such as brines, pegmatite and sedimentary rock. Brines contribute for 66% to the total lithium resource. Only 33% of the estimated lithium reserves are currently in production. When looking at the current Li_2CO_3 production sites, it becomes clear that the current producing pegmatite reserve is in the order of 15% of the total reserve, against 85% from brines. At this moment there is no Li_2CO_3 produced from sedimentary rock (Gruber et al., 2011; Jaskula, 2012).

Kushnir and Sandén (2012) argue that a possible increase in production in the Salar the Atacama could very well be a limiting factor for incentives to start production elsewhere; starting a new mine can take a decade before production starts, which meanwhile ensures the dependency on brine facilities. This is underlined by Ebensperger et al. (2005) whom argue that Chile possesses the overwhelming share of Li_2CO_3 in the Salar de Atacama. Their government tries to retain its world leadership in Li_2CO_3 production, which should be possible when taking their reserve position and mining culture into account. Therefore Ebensperger et al. (2005) conclude that even though it is not desirable, the most likely outcome is a continuing status quo in the Chilean world leadership. The geographical concentration of directly available resources and the possible unavailability of a major source of production (e.g., through external interference or unexpected dropping of production) can put a severe strain on the Li_2CO_3 production rate (Kushnir and Sandén, 2012).

Because of the uncertainties in future production two supply curves are developed in order to determine the bandwidth of supply. Rockwood Holdings, Inc. recently issued a press release in which they announced to increase production to 50 kt (Rockwoodspecialties.com, 2012). In 2009 the government of Bolivia has begun to build a new brine facility for the production of 30 kt per annum (Goonan, 2012). Sociedad Química y Minera de Chile S.A. states in a press release from March 2012 that they aim to maintain their market share of approximately 33% in coming years (Sqm.com, 2012). The open-pit pegmatite mining operation at Greenbushes in Australia has the target of doubling their production in 2012 to 110 kt of Li_2CO_3 (Talisonlithium.com, 2012). The best case (BC) scenario takes such developments into account and therefore assumes an average increase in supply in the order of 8% per annum. The business as usual (BAU) scenario assumes an average increase of 6% per annum (see Fig. 1).

Table 1 provides some absolute numbers as a reference. Growth rates are estimated based on the 2010 production of 125 kt Li_2CO_3 (Kushnir and Sandén, 2012). The first half decade of this century showed an annual growth rate of about 3% in production and consumption until 2005 (Ebensperger et al., 2005). The BC scenario assumes a 45 fold increase, which is theoretically feasible for the Salar de Atacama (Kushnir and Sandén, 2012). We assumed the Li_2CO_3 reserves to be between 75 Mt, which is half of the total

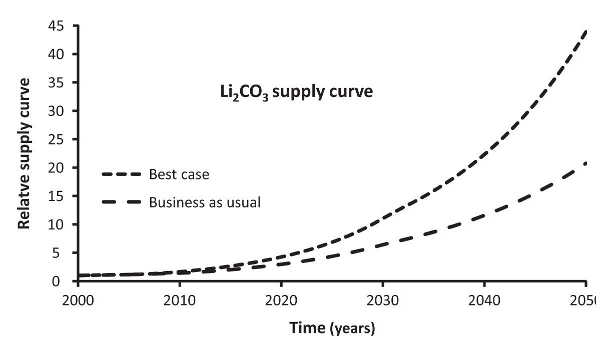

Fig. 1. The relative supply forecast for Li_2CO_3 until 2050 for the BC and BAU scenario.

Table 1
Absolute estimated global supply data for Li_2CO_3 for both scenarios.

Time	BC (kt)	BAU (kt)
2000	80	80
2020	340	237
2050	3511	1659