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The need for lithium – an upcoming problem for electrochemical energy storages?

锂之需要 – 电化学能量储存即将带来的问题？

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Abstract - **In the context of the transition of energy systems, storage technologies currently attract high attention. As one of the most promising technologies, lithium-ion battery systems could be used not only for zero-emission mobility but also for several purposes surrounding the integration of renewable energy sources into the grid. But if these applications experience a large-scale penetration, manifold natural resources will be required for construction. This work has the aim to identify future demand paths for the essential resource lithium and to clarify whether temporary or even permanent critical situations on the lithium world market are to expect. For this, a simulation model was built, mapping the future market penetration of relevant applications of lithium batteries. By combining with particular material requirements, partly exclusive real data, and adding other demand, the annual total lithium demand can be modelled. Results show that especially when the electric mobility kicks in, an enormous rise in demand for lithium has to be expected, accompanied by considerably additional demand generated by stationary energy storage purposes.**

With the pending demand rise in mind, the supply side was analyzed. Due to ongoing technical progress, broadening the quantity of recoverable resources, a situation of permanent scarcity turns out to be unlikely. This will be even truer if lithium recycling becomes profitable and common.

Adopting the flow perspective, a different situation emerges: Presently, Chilean and Australian extraction dominates, but expansion prospects are limited. The installation of extraction capacities at a huge, nearly untouched Bolivian deposit requires much capital and know-how from outside, but the current nationalistic economic policy has the potential to discourage foreign investments. As a result, a temporary physical scarcity on the lithium market is supposable, causing a deficit in supply and an increase in market prices. Furthermore, a Bolivian market entry raises the market power of South American exporters, possibly leading to some kind of collaboration and again causing a risk for the broad penetration of battery technologies.

Keywords - **Energy storage, Battery storages, Resource criticality, Lithium, Electric Vehicles.**

I. INTRODUCTION

The structural change of energy systems with the main goal of replacing climate-damaging coal, oil and other non-renewable energy sources by renewable energy capacities like wind energy plants or solar collectors represents a complex economic and technical challenge. In the power sector, increasing fluctuating and noncontrollable generation can result in more unstable power supply with higher risks of blackout situations and therefore induced discussions about the necessity of conventional power plants as ‘backup capacities’ [1] and about an extension of the grid [2]. In the mobility sector, oil fueled transport dominates, while clean alternative traction technologies using hydrogen or electricity still face several technical or economic challenges [3].

Several electrochemical energy storage applications are already in use to overcome handicaps of clean energy. Worldwide a small number of stationary energy storages are operating, providing network stabilization services as well as taking advantage of temporal price differences by storing energy for arbitrage, which helps to balance differing generation and load patterns. Furthermore, batteries are an important power source option for any electric mobility which is independent from an expensive permanent power supply on track. If worldwide mobility is converted to electric traction, a tremendous increase of demand for batteries can arise.

Due to favorable electrochemical characteristics, already reached marketability for several purposes and ongoing research, it is strongly expected that for the energy transition lithium ion batteries will play a major role [4]. For their construction, numerous natural resources will be required, beginning with the essential alkali metal lithium. As lithium is finite, like any natural resource, the question arises whether the lithium supply will be able to meet the demand generated by power, mobility and other markets. A supply bottleneck can be of permanent or temporary nature, depending on the constitution of the market and reserve base. This paper's aim is to identify possible shortfall situations by connecting future demand scenarios with feasible resource and market conditions.

In Section II, the diffusion of the potential high scale applications stationary energy storages and electric mobility is modelled. In Section III, the resulting demand for lithium is calculated, which provides the basis for a critical examination of the supply side in Section IV. Section V concludes.

II. APPLICATIONS AND DIFFUSION MODELLING

2.1. STATIONARY ENERGY STORAGES

The benefits from stationary energy storages are manifold: If power supply exceeds load, for example due to massive renewable energy generation, batteries can absorb power and avoid uneconomical forced shutting downs. And if load exceeds generation, batteries can offer their stored power and therefore substitute backup generation capacity. Furthermore, placing storages at critical spots of the electricity network could help to cope with bottleneck situations in the short run and also avoid network extension in the long run.

In 2014, around 500 Megawatt (MW) installed capacity was in operation [5]. The individual size of storage systems differs from <1 MW to >30 MW – this modularity is one advantage over dominating pumped hydro storages with a total of around 140 Gigawatt (GW) installed capacity. The future diffusion of battery storages will be influenced by several factors, including the future extension of renewable energy generation, alternative energy storage technologies including power-to-heat and power-to-gas as well as by the legislative and economic framework on the market.

To obtain possible paths of diffusion, two scenarios have been modelled. Scenario 'Market Niche' assumes an increase of installed capacity to 300 GW in 2050, whereas scenario 'Boost' assumes an upsurge to 1,000 GW. Based on the diffusion research of Rogers [6], an S-curve model was adopted, mathematically expressed by the hyperbolic tangent concept. Fig. 1 shows the capacity numbers each year.

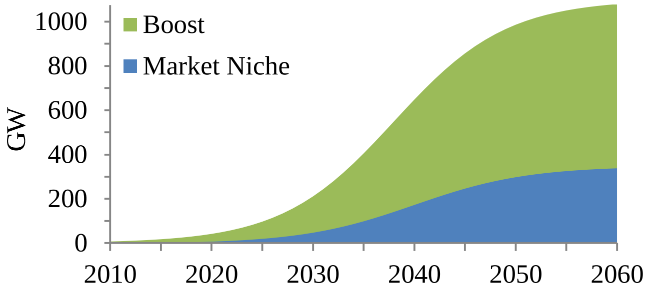

Fig. 1, Installed capacity of stationary energy storages.

By comparing every year with the previous one, the current net construction can easily be calculated. Adding end-of-life replacements, total production is obtained. To include randomness, it is assumed that the life-time of the batteries is normally distributed with a mean of 20 years in scenario 'Market Niche' and 14 years in scenario 'Boost' and a standard deviation of 2.5 for both scenarios. The resulting total production p.a. can be obtained from Fig. 2 by adding up net construction and replacements for the respective scenario.

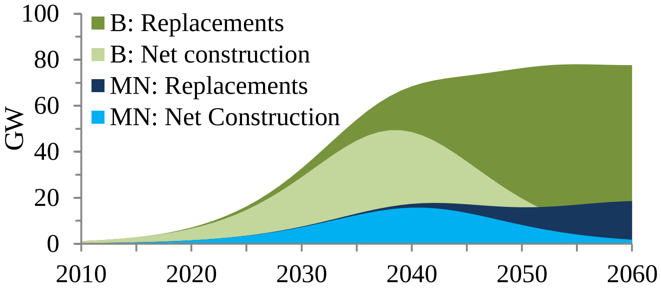

Fig. 2, Net construction and end-of-life replacements of stationary energy storages.

2.2. TRACTION BATTERIES OF ELECTRIC VEHICLES

Despite market potential for other types of vehicles like busses, trucks, trains and ships, the following analysis is focused on electric cars. Today, manifold models are offered, which can be categorized as in Table 1.

TABLE 1, DEFINITIONS OF ELECTRIC CAR TYPES

	Technology	Examples
ICE	Conventional combustion engine	VW Golf, Honda Civic, Ford Focus, etc.
HEV	Combustion and electric engine	Toyota Prius, Honda Insight
PHEV	As HEV, but with plug-in to recharge	Chevrolet Volt, BMW í8
BEV	Electric engine only, recharged by plug-in	Tesla Model S, Nissan Leaf

While cars of the category 'Internal Combustion Engine' (ICE) and 'Hybrid Electric Vehicles' (HEV) carry comparatively small batteries, provides the option to connect 'Plug-in Hybrid Electric Vehicles' (PHEV) and '(Full) Battery Electric Vehicles' (BEV) to the electricity network for battery sizes up to 85 kilowatt hours (kWh, Tesla Model S 85). In the following, the groups of PHEV and BEV are combined and denoted by the term 'Electric Vehicle' (EV).

Despite ambitious aims of several governments, worldwide only 665,000 cars out of more than 800 million in total were classified as EV at the end of 2014 [7]. But according to sale statistics, almost half of them were sold only in 2014, more than doubling 2012 sales. Strong distinctions between countries can be obtained: While in Norway more than 11% of all in 2014 sold cars were BEV, China and most other European countries exhibited a share of less than 1% for EV altogether. Only the Netherlands, Sweden and the U.S. (in particular California) reached EV sale quotas of 1% or more. As most important reasons for these differences, consumer financial incentives, offered by governments, and an available charging infrastructure were found statistically significant [8].

Learning effects and high research effort during the last years led to remarkable technical progress especially in the field of traction batteries, where the energy density (energy per space unit) has been increased and the battery cost (price per energy unit) has been reduced substantially. If this track can be retained and furthermore supported by a proper political framework, chances for a continued increase of market share are pretty good.

Again, for diffusion modeling two scenarios were generated. Starting with 800 million cars today, scenario 'Moderate' assumes an increase to 1.5 billion in 2050, based on an improved standard of living in fast-growing regions like China, India, Brazil, Mexico and Indonesia. This is substantially lower than the outlooks from IEA [9] and ExxonMobil [10], assuming 1.9 billion and 1.7 billion cars already in 2040 respectively. For end-of-life replacements a normal distribution with a mean of 15 years and a standard deviation of 2 is assumed. To calculate the number of EV, the chance of every car sold being an EV grows from a little more than 0% today to 40% in 2050. Fig. 3 shows the total stock of cars, divided in electric and non-electric. The annual sales volume of EV grows from 1.25 million in 2020 to 42 million in 2050.

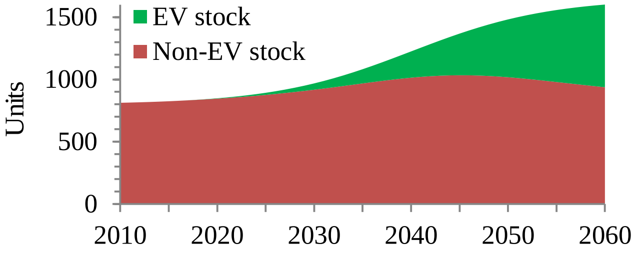

Fig. 3, Total stock of cars in scenario 'Moderate'.

In scenario 'Boost', a total car stock of 2 billion in 2050 is assumed. Furthermore, the mean of the vehicle life-time is lowered to 10 years (standard deviation stays at 2) and in 2050 three of four sold cars are electric (EV share grows to 75%). As can be observed in Fig. 4, this leads to a replacement effect, beginning in the 2030s. The annual EV production experience a boost, starting around 2025 with 10 million and reaching 150 million in 2050 – this is twice the quantity of today's total car production.

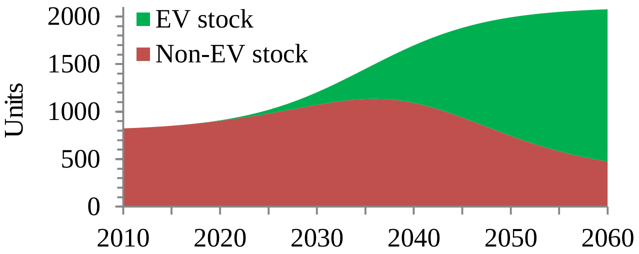

Fig. 4, Total stock of cars in scenario 'Boost'.

As a change of traction battery within a car's life-time seems to stay uneconomical, the number of produced traction batteries is equal to sold EV. However, in the average size of traction batteries, the scenarios differ. In scenario 'Moderate' it is assumed that PHEV of compact class size dominate, so the battery capacity of every sold EV is projected to be 20 kWh. In scenario 'Boost' an average capacity of 30 kWh arises from a higher share of BEV on the one side and large scale penetration of all kinds of cars, including premium models, on the other side. Fig. 5 shows the total demand for battery capacity.

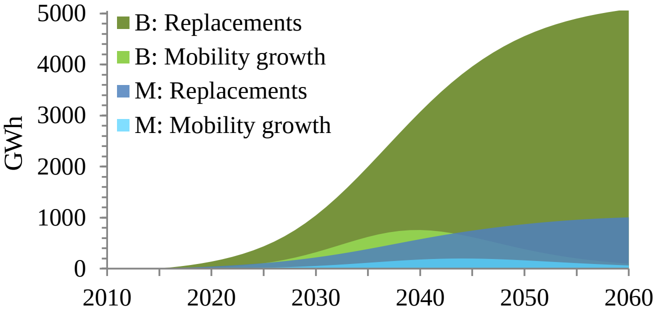

Fig. 5, Annually demanded capacity for EV traction batteries based on scenarios 'Boost' and 'Moderate'.

As can be observed clearly in both scenarios, most electric cars will originate from replacement sells: In times of major mobility growth, around 2030 to 2040, the EV sale quota is still low. When it gets higher, two effects appear: First, usual replacement sales become more and more electric. Second, many cars bought in the major mobility growth period reach their end-of-life and have to be replaced the first time. In sum, especially in the 'Boost' scenario, a heavy growth of annually demanded battery capacity, surpassing 4,500 GWh in 2050, results.

III. DEMAND FOR LITHIUM

Today, demand for lithium is mainly generated by industrial applications like ceramics and glass production, its use as lubricants, as well as by manufacturers of batteries for electronic devices like laptops or cellphones. In total, this made up for 33,000 tons in 2014 [11] with a positive trend. In this paper, an increase of 2% p.a. is assumed.

To convert possible future capacity of stationary energy storages and traction batteries into lithium demand figures, it is assumed that only lithium batteries will be produced. This can already be observed as a trend in EV production today, as many PHEV and all important BEV use a lithium ion battery system. For stationary energy storages, data from the 5MW/5MWh WEMAG/Younicos battery farm Schwerin (Germany) is available [12], while for EV a literature review was conducted [13,14]. For the purpose of this paper, it is assumed that 220 kg lithium per MW of stationary energy storage and 150 g per kWh capacity of an EV traction battery is required, which can be converted into 3 kg per EV in scenario 'Moderate' and into 4.5 kg per EV in scenario 'Boost'. To include technical progress in battery production, the required amount of lithium per battery unit of both applications is lowered by 1% annually.

In a first step, basic lithium demand and both stationary energy storage scenarios were calculated (Fig. 6). While basic demand doubles between 2014 and 2050, the scenarios reach their top level demand around 2040 with 3,000 tons p.a. ('Market Niche') and 12,000 tons p.a. ('Boost'), representing a maximum market share of 6% and 18% respectively.

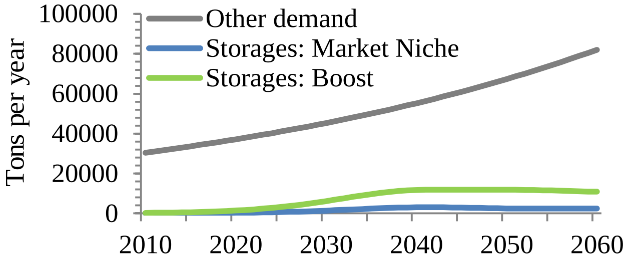

Fig. 6, Basic lithium demand and demand from stationary energy storage construction.

Then, the EV scenarios were calculated (Fig. 7). In scenario 'Moderate', lithium demand begins to increase notably in the 2030s, reaching 70,000 tons p.a. around 2040 and stabilizing at almost 100,000 ton p.a. in the 2050s. Already beginning in the 2030s, the lithium market would be parted into two parts about equally sized: One for EV and one for other applications, including batteries for non-traction use.

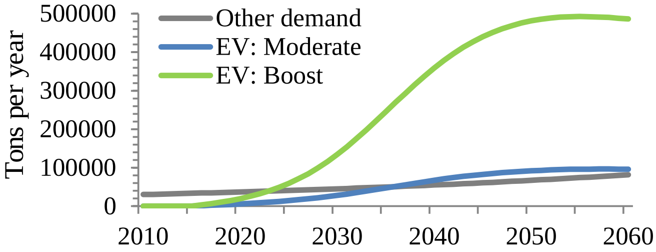

Fig. 7, Basic lithium demand and demand from EV manufacturing.

When considering scenario 'Boost', the numbers increase sharply. Surpassing other demand already in 2023, EV demand reaches a level of 130,000 tons p.a. in 2030 and 480,000 tons p.a. in 2050. The demand side would clearly be dominated by EV traction battery manufacturers, making all other demand minor and expanding the market for lithium sixteen-fold between 2014 and 2050.

IV. POTENTIAL SUPPLY BOTTLENECKS

4.1. THE FEEDSTOCK OF LITHIUM

To analyze whether the supply side is able to cope with potentially soaring demand, the feedstock has to be examined. Today, two Chilean subsurface brine sites and an Australian mine account for the main supply [11], assisted by minor production sites in countries like China, Argentina, Zimbabwe and the US. Some 13.5 million tons are classified as reserves, of which 7.5 million tons are located in Chile, 3.5 million tons in China and 1.5 million tons in Australia. The world resources are estimated at 40 million tons, including 9 million so far untouched tons in Bolivia.

Comparing these estimates with Section III's lithium demand scenarios with the perspective 2050, no apparent shortage situation emerges. Cumulated basic demand requires 1.75 million tons until 2050, stationary energy storages 62,000 tons ('Market Niche') and 260,000 tons ('Boost') respectively. If EV scenario 'Moderate', which accounts for 1.5 million tons, is added to basic demand and stationary storage scenario 'Boost', a total consumption of 3.5 million tons until 2050 appears – leaving 10 million tons in situ.

If EV scenario 'Boost' is considered instead, accounting for a cumulated demand of 7.7 million tons until 2050, the bulk of reserves will have to be used. Combined with cumulated basic demand and the stationary storage scenario 'Boost', a total demand of 9.7 million tons emerges. Facing reserves of 13.5 million tons, it still leaves almost 30% in situ. However, almost 60% of the reserves are required for EV battery manufacturing, as shown by Fig. 8.

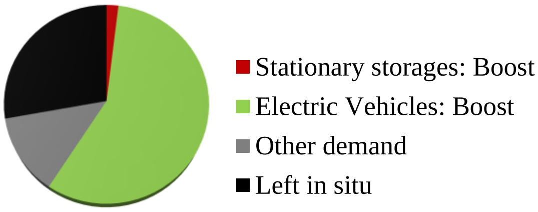

Fig. 8, Usage of reserves until 2050 with both 'Boost' scenarios.

Not only the demand site is uncertain, but also the stock of as reserves classified resources: Known and profitably mineable resources tend to rise with time and interest, as can be frequently observed at the market for oil, because new deposits are found and technical progress makes mining cheaper or even possible. Bearing that in mind, it might be likely that the available reserves of lithium will increase within the next decades, so that the share of reserves left in situ exceeds 30% and the danger of scarcity becomes less present.

Furthermore, particularly if EV traction batteries are widely distributed, a secondary market for recycled lithium could be established. Technically, a recycling rate of approximately 98% is possible already today [15], but due to low quantity and high cost no commercial lithium recycling system exists. But with increasing available quantities, an accepted collection system and a product design that pays attention to subsequent recycling, an effective re-use of wasted battery's lithium could be established. For installation, the well-functioning recycling system for acid car batteries, which covers in Europe nearly 100%, could serve as a guideline. Nevertheless, any recycling operation is time-lagged by nature: The initial amount has always to come from the primary feedstock. For this reason, it is appropriate to analyze the supply side with special focus on the flow perspective.

4.2. RISKS ON THE SUPPLY SIDE

Today, more than one third of lithium is supplied by Australia and Chile, respectively (approximately 13,000 tons p.a. each) [11]. But while Chile exhibits large assets of reserves, could be the prospects of expanding Australian supply narrowed. Particularly if EV experiences a boom within a short time period, raising lithium demand from 33,000 tons today to 180,000 tons in 2030 and further to 560,000 tons in 2050, other sources will have to be made accessible and developed quickly and simultaneously. But as can be well observed at the extraction of unconventional oil, large amounts of capital and know-how are required for large-scale projects. Adopting this to the extraction of lithium, several possible risks appear: The number of professionals could be insufficient, causing a 'bottleneck of know-how' and resulting in a slow speed of construction and increased costs for completion.

Moreover, large amounts of capital have to be allocated for long-term investments. To invest, actors need favorable surrounding conditions at political and economic levels. In the case of the brine lakes of Bolivia, disposing with approximated 9 million tons the world's largest sources, the political framework could become an issue. Recent acts of nationalization in the telecommunication and even energy sector and depreciative statements of the Bolivian government directed against foreign investors are likely to discourage engagement from outside. A possible result can be observed in allied Venezuela, where projects for the development of heavy oil resources achieve only little or no progress at all, because of missing know-how and capital. If this happens in times with strongly increasing demand for lithium, the risk for a supply shortage at the world market will be raised.

Another possible risk on the supply side is based on its geographic distribution [16]. Today, nearly 60% of the resource base is suspected to be located in South American countries, and due to high Chilean reserves even two-thirds of the reserves are South American. As most battery and car manufacturers are located in Europe, Northern America and Asia, it seems reasonable to expect a high export share for South American lithium. If one takes the oil market as a comparison again, one can observe that big net exporters allied and tried to join forces with the aim of gaining control of the market; they formed the cartel OPEC, which is responsible for several world oil crises with periods of lowered supply and high market prices. If South American net exporting countries unite with the aim of gaining market control and raising their profit, and establish a collaboration as well, another risk of reduced supply on the world market will appear.

In any case, if supply expansion cannot follow an increase in lithium demand, this can affect applications like stationary energy storages and electric mobility for two reasons. First, manufacturers have to cope with a restricted amount of lithium available, potentially leading to problems within the supply chain and resulting in production downtimes in the worst case. Second, the usual market result in situations of supply shortage is a growing price level. At battery manufacturer's level, this is represented by increasing costs for input factors. Especially for products that are being launched onto the market, this could become a considerable handicap, with price sensitive customers bailing out as soon as increasing input costs are forwarded. Today, the price development of lithium is quite stable [11], but this has not to last forever.

V. CONCLUSION

A simulation model was developed and possible paths of market penetration for two possibly large-scale applications of lithium ion batteries were generated. Due to the early market launch stage of both applications, the scenarios differed to a large extent. In all scenarios, a major phase of growing penetration was introduced, followed by a phase of leveling. In the case of stationary energy storages the yearly gross construction rate rises accordingly, with end-of-life replacements replacing net constructions. However, in the case of electric mobility two effects interfere with each other and cause a strong and massive increase of the production of electric cars. First, it is expected that the number of cars worldwide will grow substantially, resulting in EV net constructions. Second, the share of produced cars being electric increases over time. This causes the effect of partly replacing the oil fueled car fleet by electric vehicles, which is due to the high number of cars a large market as well.

Then, the resulting demand for lithium was calculated and confronted with today's lithium demand. It turned out that the lithium need for stationary energy storages could gain a sound market share at the world lithium market. Furthermore, and not surprising, the demand for EV traction batteries has the potential to revolutionize the lithium market, with being even the lithium requirements of scenario 'Moderate' more than all other demand summed up. If EV experiences a boom, the market will change completely and quadruple the first time until 2030 and another time until 2050.

Analyzing data of known lithium sources, this does not seem as a major risk in terms of exhausting world reserves, especially if a market for lithium recycling is introduced. But with possible strongly rising demand in mind, the authors see serious potential for risks on the supply side, which may result in temporary shortage situations and rising price levels at the lithium world market. First, input factor markets for the construction of depletion facilities could face a shortage, for example due to a lack of professionals. Second, an unfavorable investment framework particularly in Bolivia could delay a sufficient buildup of facilities as well. Third, a collaboration of net exports located in South America could try to take advantage of a high market share and ration supply to maximize profits and/or enforce political objectives.

To counteract those potential future risks, the market for lithium on the one side and applications for lithium technologies on the other side should be carefully observed. Furthermore, to keep the recycling option, starting today attention should be paid to product designs making subsequent disassembling and recycling as easy as feasible. To counter shortages in facility construction as well as the time lag between primary and secondary market, preparatory steps for future development of today unused deposits could be carried out already today. In addition, actors could work towards a more cooperative atmosphere to avoid Bolivian solo attempts in developing possibly crucial deposits.

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