LUND UNIVERSITY
School of Economics and Management

Master's Programme in International Economics with a focus on China

Impacts of Shortage in raw Materials for Electromobility:

Valuation of Automotive Stakeholders - Germany and China

Fiona Westermeier

fi7025we-s@student.lu.se

The implementation of emission targets in the worldwide automotive market has led to the application of more sustainable solutions. The market for Electromobility is booming, however, lithium-ion batteries depend to a large extent on critical raw materials. The access to these materials is crucial to the success of alternative drive concepts. The aim of this thesis is to collect, frame and evaluate the national differences between China and Germany on the scarcity shortage of Lithium and Cobalt. Furthermore, a specific focus on automotive stakeholder's perception of the threat of a potential scarcity. Currently, it is understood that there is a possible threat of raw material shortage for Electromobility. However, there is no standardized procedure, nor are there any standardized indicators for the measurement of criticality. Little knowledge exists about the special evaluation of scarcity from the automotive stakeholder's perspective. The thesis data collected is based primary data obtained from a survey of automotive stakeholders in both countries. Furthermore, secondary data were analyzed applying a mixed method approach and using cross-referencing with relevant theoretical conceptualizations and survey results to provide a reliable analysis. Based on the data analysis there is a reason to believe that in the near future Germany and China will experience a shortage of strategic resources discussed. Furthermore, the results obtained from the survey show that a disparity in understanding between selected countries exists, based on differences in perception of the severity of scarcity, differences in evaluation of government policies within respective countries and differences between the expected current supply.

Keywords: resource scarcity, electromobility, automotive market

EKHS51
Master's Thesis (15 credits ECTS)
June 2018
Supervisor: Sofia Teives Henriques
Assistant Supervisor: Luka Miladinovic
Examiner: Andrés Palacio
Word Count: 14.465

Acknowledgments

Firstly, I would like to thank my professors from the "International Economics with a focus on China". Special thanks to Professor Sofia Teives Henriques and Luka Miladinovic who have greatly helped me with the personal growth during the thesis writing process. Both invested a great amount of time into tutoring me, providing me with helpful guidance along the way and always giving me feedback, even when they were both super involved with work. Thank you so much for that!

Thank you also, Professor Ju Liu, for providing me with helpful insights on how to approach Chinese stakeholders and sharing my survey within your network. Without this support, I wouldn't have gotten such great feedback.

This journey would not have been possible without the constant support of my wonderful family back home. Thank you so much for always having my back, always believing in me and always pushing me to make the best out of anything. Thanks for making this study possible for me. Mom and Dad, I am beyond lucky to have you as my parents!

Special thanks to my "Korpa 2" family. I never had a place away from home that felt so much like "family" to me. Emily, Pontus, Jesper, Kim, Andreas, Luciana, Simon, and Stina – I am beyond grateful for your constant support. Charly, thank you for always keeping up with me, always having a minute for me and always making me smile again. Michael and Alexander, thank you guys so much for the support.

Thank you, Lund University, for this great experience.

Table of Contents

List of Tables

List of Figures

1 Introduction

In the modern age, changing climate, depletion of resources, and increased environmental activism has led to changing beliefs surrounding transportation in MEDCs (More Economically Developed Countries). The implementation of emission and fuel economy standards for setting emission targets have become a popular tool for regulation in many countries (Paltsev et al., 2018, p. 578). In the European Union, the Euro 6 (2014) Norm is the current standard and has been in the news lately, with the EU Commission suing Germany for the high nitrogen oxide emissions in the European Court of Justice (Berschens, 2018). Historical developments and recent initiatives have shown that a shift from archaic fossil fuel based means of transport, towards environmentally sustainable transport based on renewable energy sources are the future. (Grauers et al., 2013)

The feasibility of an electromobility[1] solution rests primarily on the ability of an electrically powered vehicle to store its energy in its power source; the battery (Grauers et al., 2013).

[1] Electromobiliy is the general term for the development and implementation of electric-powered driveconcepts (full electric vehicles, hybrid electric vehicles and hydrogen fuel cell technology). These driveconcepts are not only developed to minimize the usage of fossil fuel but also from carbon gas emissions (Grauers et al.,2013)

State of the art batteries depends heavily on specific critical raw materials[2], access to which are crucial for the success of the emerging technologies in China and Germany. Despite the obvious dependency on these strategic resources, the threat of depletion has rarely been considered an issue by the last stages of the value chain (consumers and secondary sector enterprises). Furthermore, there has been hardly any political agenda to prevent a possible shortage of scarce resources for Electromobility (Ziemann et al., 2013, p. 48). The discussion about a possible shortage of raw materials due to market exhaustion, restrictions, and geopolitical tension has been strongly influenced by China's control over rare-earth elements (REE) (Cox and Kynicky, 2018, pp. 9-10). China's intervention has been an eye-opener to industry and policymakers on a world-wide scale. Concerns about possible limitations and scarcity of these materials have caused science, policy, and industry to act. Governments have started to implement national plans concerning excavation of strategic elements and the feasibility of current excavation practices (e.g: excavation volume).

However, despite recent initiatives finally beginning to materialize, the current approaches still seem to be symbolic rather than practical. The actual execution seems to be questionable since information about the measurement of a potential shortage of scarce resources and the actual risks for the supply chain disruptions coming along with a shortage do not seem to be feasible for all actors, especially industry, yet.

---

[2] Raw material are defined as being critical, if the material is limited and has only few or no satisfactory c ompensation in its area of application. Furthermore, if there is a major chance for supply intermittence and such an disruption would have major influence on a countries industry (Ziemann et al., 2013, p. 47).

This study will focus on the supply of raw materials for batteries in electro vehicles. Specifically, lithium and cobalt as the main energy storage for Lithium-ion batteries. It will assess and contrast the scarcity in sourcing between China and Germany. Statistics and literature from both countries will be evaluated alongside opinions and views of automotive stakeholders. A primary point of interest is to evaluate the situation for each key stakeholder in the automobile industry within respective territories. Insight into the situation will be gained through the use of electronic surveys to allow for a comparison of attitudes, beliefs, and opinions. The comparison will focus on three key issues: characterizing the scarcity of the mentioned raw materials on quantitative terms, determining the qualitative assessment of criticality for Lithium and Cobalt in Germany and China and assessing the special valuation of automotive stakeholders of the perceived criticality of raw materials for both countries.

There is a reason to believe that studies into the supply of these materials are worthwhile given that recent initiatives are pushing towards electromobility, which is heavily dependent on the access to resources, such as cobalt or lithium.

In Germany, this development is supported by the German policymakers with an agenda called “Energiewende”, or “energy transition”. One aspect of this “green industrial policy” is to enhance a transition towards sustainability by promoting zero-emission vehicle engines via electromobility (Altenburg et al., 2017, p. 166). This attitude can be further illustrated by Germany’s goal of having 1 million electric vehicles in operation by 2020 (Ziemann et al., 2013, p. 48).

China, on the other hand, has a slightly more ambitious goal. In 2015 Chinas State Council published a national development plan “Made in China 2025”. One of the ambitious targets of this plan is to have 5 million Electric Cars driving on Chinas streets by 2020 (Newswire, 2017). Furthermore, Chinese manufacturers are enforced by the government to cover the worldwide market of “New Energy Vehicles” (NEV)- a term for fuel cell vehicles, battery-electric vehicles and plug-in hybrids- by 80 percent in 2025 (Retzer, 2017, p. 166).

1.1 Aim and Contribution of the Thesis

The primary intention of this thesis is to collect, frame and evaluate the national differences between China and Germany on the scarcity'shortage of Lithium and Cobalt, within the context of automotive stakeholders. This paper will incorporate data and insights from previous studies that have been investigating in the scarcity of sourcing in on a worldwide level and especially in Germany and China. A potential point of interest is that so far there has been no attempt at unifying the industry approaches to deriving and defining resource availability indicators which reduces the ability to compare different findings between different nations (Achzet and Helbig, 2013, pp. 435-436).

Little has been investigated into a comparison of both countries present situation and future estimated situation of scarce resources- Lithium and Cobalt; this study seeks to focus on the specific situation for both countries comparison and add the automotive stakeholder's specific valuation, which will be assessed throughout a survey.

As far as the author's knowledge goes, there has not been a valuation comparison of both countries situation and the special situation for automotive stakeholder's valuation yet.

The main research topics that will be addressed are the following:

1. To understand the quantitative assessment of criticality in the literature of the two mentioned raw materials at present times
2. To understand the qualitative assessment of the threat of a resource shortage for Lithium and Cobalt on a global market for electromobility and especially for Germany and China
3. To develop a clearer interpretation of the reality by combining insights gained from qualitative and quantitative research, and understand the effect on relevant Stakeholders' valuation of the criticality of mentioned resources.

The aim of this paper is to evaluate the differences in the perception of the scarcity of strategic resources, pertaining to manufacture of electro mobiles, between the nations participating in this study.

Furthermore, a specific focus on automotive stakeholder's perception of the threat of a potential scarcity. With the aim of elucidating the actual situation in both participating countries. The analysis of gathered information has shown that while both participating countries show concern to a degree (Germany seems to be more conscious than China) there is not enough information available to the respective automotive stakeholders to allow for full judgment of the question of scarcity.

1.2 Outline of the Thesis

This thesis is built up as follows; in the next chapter (Chapter 2), the literature that is essential for the investigation and theoretical contribution will be evaluated, with a major focus being put on the definitions of the quantitative approach used to understand scarcity, and how the lack of common definitions may impact the outcomes of quantitative research. It is at this point that the term "criticality "will be cleared out and the assessment of such made transparent.

The quantitative aspect of the research used is based on the work of Achzet and Helbig (2013), who attempted to define scarcity of resources in terms of certain indicators: the work of author has shown that the choice and definition of these indicators will lead to different insights into the material. The primary conclusion being that due to a lack of homogenous investigative approach prevents a specific conclusion that spends across participating countries.

Due to the seeming inconclusiveness of the quantitative approach, the qualitative approach will be discussed in detail. The qualitative approach will first explain the worldwide market for key resources (Lithium and Cobalt) and will then focus on the market within the nations participating in this study.

By using both types of research, the primary questions of interest within this thesis may be derived and can then be evaluated to steer the investigation within this thesis, to generate a contribution to the academic debate. The next section deals with the methodological approach and data (Chapter 3) which shall be utilized while investigating the study to answer the before mentioned stated research goal.

In the following section (Chapter 4) the empirical analysis of the investigated topic will be portrayed and results for the research questions presented with comparing the findings of the obtained survey and the literature review.

Finally, the thesis concludes with a summary of the results and future outlooks (Conclusion) and limitations that could be further investigated in the long run.

2 Literature review

This chapter will present the secondary data used to investigate the thesis topic. The chapter is divided into two sections; first, the literature that has been quantitatively investigated on the topic will be examined. Then, there will be the qualitative literature reviewed.

There is a broad variety of literature and studies executed by different institutions from policy, science, and industry, dealing with resource security and monitoring of critical raw materials. Major studies influencing this thesis will be described in more detail here. In the following, after giving a definition of the term criticality and reviewing an assessment approach of criticality, several papers will be revealed regarding their framing of present criticality and potential future criticality scenarios to give a picture of a potential shortage threat for Lithium and Cobalt worldwide and the special situation in Germany and China.

2.1 Quantitive Approach: Definition and assessment of criticality

The term "criticality" can be traced back to 1939, where it was used for the first time in line with raw materials. Back then, the American resource administration created a stockpiling of 42 raw materials for a military emergency case (Council, 2008). This stockpiling has been relevant until today and is an important tool for government reports, military technologies, and national economies. Nowadays the term "criticality" discusses scarcity of resources not only on a regional and global level but also for specific industries and for entire industry branches.

There have been multiple approaches of working groups on a worldwide scale to analyze impact factors for the assessment of raw materials. Problem with these studies is, that the definitions, choice of variables, and study methods are unique for every nation. Due to the manifold influences on raw materials, the methods of evaluating these are very disparate, there is no common approach yet. In their paper, Achzet and Helbig (2013) made it their main task to further investigate into 15 heterogeneous criticality assessment methods for supply risk evaluation (Achzet and Helbig, 2013, pp. 435-436).

Therefore, the authors split 15 criticality studies from the years 2006 until 2011 into four categories: selected target studies, entrepreneurial perspective, national-level studies and future technology studies. Studies within the same categories were compared to develop an understanding of how each category of analysis tackles the definition of "criticality". Each unique approach was then used to analyze the driving factors (the key variables of interest) in determining the raw material criticality from an ecological, economic and social perspective (Achzet and Helbig, 2013, pp. 435-436).

The criticality studies and their methodological approach were reviewed, and differences in variables, methodology and resulting conclusions were tackled by evaluating the studies based on three variables, that Achzet and Helbig (2013) found relevant. This was a three-step process. In the first step, the studies were evaluated on their inclusion of key concepts. The concepts could be generalized into "supply risks", "vulnerability" and "ecological risks" (refer to figure 1).

Figure 1: Target values used by each criticality study

Study	Supply risk	Vulnerability	Ecological risk	Target value aggregation	Supply risk aggregation
Graedel et al. (2012)	✓	✓	✓	Vector length	Weighted average
European Commission (2010a)	✓	✓	✓	Matrix	Multiplicative
U.S. National Research Council (2008)	✓	✓	Partially	Matrix	Maximum
Erdmann et al. (2011b)	✓	✓	Partially	Matrix	Weighted average
Frondel et al. (2006)	✓	×	Partially	Only 1 target value	Selective
Department of energy (2011)	✓	✓	×	Matrix	Weighted average
Duclos et al. (2008)	✓	✓	×	Matrix	Average
Thomason et al. (2010)	✓	×	×	Only 1 target value	Only 1 indicator
IW Consult (2009)	✓	×	×	Only 1 targetvalue	Weighted average
Oakdene Hollins (2008)	✓	×	×	Only 1 target value	Average
Behrendt et al. (2007)	✓	×	×	Only 1 target value	Average
Buchert et al. (2009)	✓	×	×	Selective[a]	Average
Rosenau-Tornow et al. (2009)	✓	×	×	Only 1 target value	Only partial aggregation
Moss et al. (2011)	✓	×	×	Only 1 targetvalue	Weighted average
Angerer et al. (2009)	✓	×	×	Only 1 target value	Only 1 indicator

[a] Buchert et al. (2009) additionally uses recycling restrictions and demand growth as target values.

Source: (Achzet and Helbig, 2013, p. 437)

Each criticality study surveyed, Achzet and Helbig (2013) used an individual set of criteria for each of these risks (see figure 2). In the second step, a "weighted average was applied to aggregate the criteria most frequently and to measure the final ratings of the three already mentioned risks" (Achzet and Helbig, 2013, p. 436). In simple terms, Achzet and Helbig (2013) were interested in seeing the overlap between the studies and found that most studies had the similar methodology, but few studies used advance means of calculating the scarcity of resources based on concepts (supply risks, vulnerability, and ecological risk) defined.

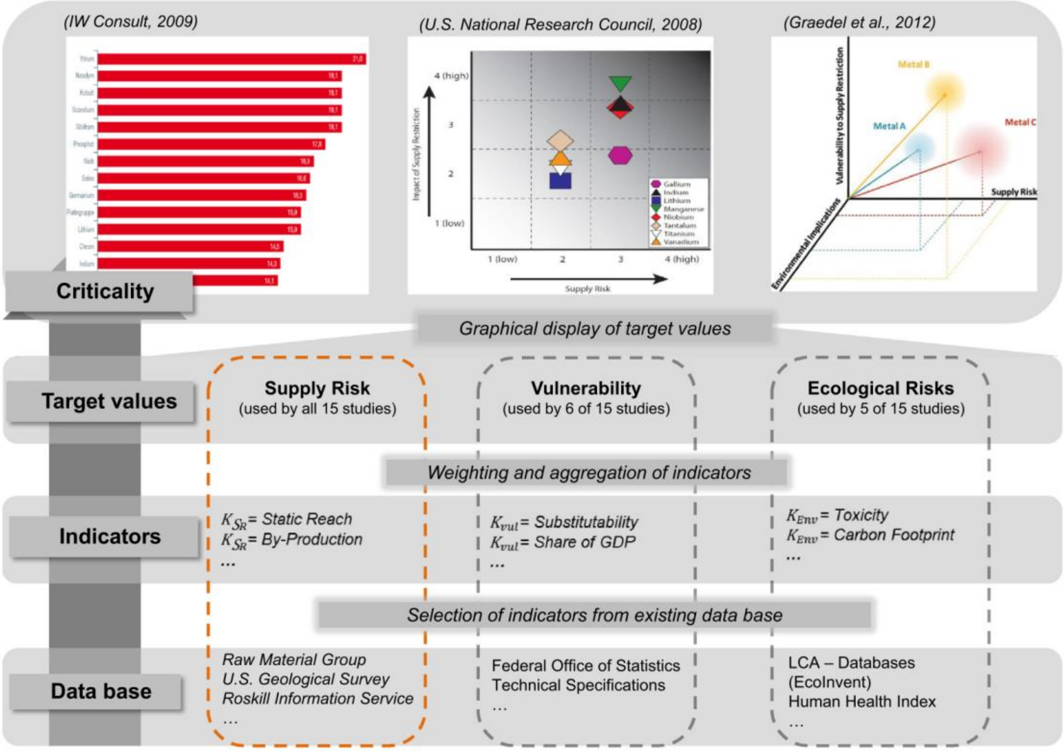
Figure 2: Number, frequency, unit and data base of the indicators for evaluation of supply risks in the selected studies.

Indicator	Frequency	Unit	Data base
Country concentration	12	[%], HHI	USGS, Raw Materials Group
Country risk	10	Index, qualitative	Expert assessment
Depletion time	9	[years]	USGS, Roskill Information Services, Raw Materials Group
By-product dependency	7	[%]	Raw materials group
Company concentration in mining corporations	5	[%]	Raw materials group
Demand growth	5	Qualitative, ratio	European Commission (2010b), USGS, projections
Recycling/recycling potential	3	[tons]	USGS, Graedel et al. (2011a)
Substitutability	3	Qualitative	Expert assessment, European Commission (2010b)
Import dependence	3	Ratio, net value	USGS, proprietary information, company questionnaire
Commodity prices	2	[Volatility], [USD/kg]	USGS
Exploration degree	1	[EUR]	Mining journals
Production costs in extraction	1	[EUR]	Mining journals
Stock keeping	1	[%]	USGS
Market balance	1	[tonnes]	USGS
Mine/refinery capacity	1	[%]	Raw Materials Group
Future market capacity	1	[%]	Raw Materials Group
Investment in mining	1	[US$/tonne]	Raw Materials Group
Climate change vulnerability	1	Qualitative	WBGU
Temporary scarcity	1	n/a	n/a
Risk of strategic use	1	Qualitative	Expert assessment
Abundance in earth's crust	1	[ppm]	USGS

Source: (Achzet and Helbig, 2013, p. 437)

Lastly, to get the aggregation of the final criticality values, Achzet and Helbig (2013), aggregated the measured target values of each study and plotted them on the linear or 3-dimensional matrix (see figure 3). Figure 3 shows the found differences in the approaches of particular sources, as an illustration of the non-standardization of the studies. One can see that the different types of risk identified by Achzet and Helbig, are not all represented in all of the studies (e.g.: vulnerability is measured in less than half of the surveyed studies). Likewise, indicators, although measuring the same factor, are wholly different. For example, vulnerability is measured by Substitutability (the ability to replace one resource, efficiently for another), or by the percentage share of GDP from the extraction of said resource. In operational definitions, these are different and are acquired through different means (via government, or via industry monitoring companies).

Figure 3: Evaluation of measurements of resource criticality for selected studies focusing on three target values: ecological risk, vulnerability and supply risk.



Source: (Achzet and Helbig, 2013, p. 440)

To further illustrate, regarding the indicators used to evaluate the" supply risk", a total of 20 indicators were identified, which were used in different frequencies within studies surveyed. Among these indicators, country concentration, country risk, depletion time and by-product dependency were the most common (see figure 2). Achzet and Helbig, further discuss the mathematical formulas behind these indicators and prove that each indicator works with different foundational data (sourced from various sources, depending on the study).

Lastly, each of the mentioned studies in figure 3, uses different information sources some of which belong to governments, some of which are research institutions, and as a result, the different sources have different reasons for steering information (institutional bias may need to be considered).

To summarize and reiterate, the selection of different indicators (quantitative) will lead to different conclusions based on the indicator used. It is often assumed that the criticality of each resource can be surveyed through the same indicators, however, since the individual dynamic of each element greatly varies, an informed and more appropriate selection of indicators ought to be made.

Indicator selection

Achzet and Helbig (2013), further comment on the indicator selection, which they find arbitrary; No clear reason for the selection of specific indicators was given in the surveyed studies, and other important indicators, according to Achzet and Helbig (2013), were completely disregarded. Naturally, the applied indicators will steer the particular outcomes of the research. It is also worth noting that the definitions heavily depend on the target audience for the end research, as no single stakeholder has the same interest in these resources, within the context of conservation. It would be more suitable for researchers to highlight how particular indicators were chosen, and for whom the research was conducted to help understand the reader the choice of these indicators.

Aggregation of supply risk indicators

Through calculating the weighted average, Achzet and Helbig (2013), achieve the aggregation of indicators (used within surveyed studies) was carried out. Keeping in mind, the lack of concrete explanation about the selection of indicators within the surveyed studies, the potential for information bias (due to different information sources), the studies will inevitably not lead to the same/similar conclusions. Same potential bias applies to the critical value in the evaluation of single indicators. There is an urgent demand for simplifying the indicator selection, the aggregation method while offering correct measurements for decision makers and industry.

Uncertainties of supply risk indicators

The applied indicators in the studies are difficult to be forecast. Especially the dynamic indicators- or variables/indicators that are constantly changing- like *substitutability* of raw materials. Furthermore, the information for production quantities and concentration have some major lacks, since there is still a transparency lack of how availability and price influences (Achzet and Helbig, 2013, p. 446).

There is a lack of consensus and understanding about which indicators are appropriate for a raw material supply risk assessment and how these indicators should be measured. In other words, there is no recognized standardized quantitative measure that describes “criticality”. Furthermore, there is no comprehensive database combining all raw material supply chain levels (mining, refining, life phase end and recycling). Based on this inexplicit assessment situation, the authors believe that uniform indicators should be adopted for the selection and evaluation of raw material bottlenecks. Future research into the selection of indicators, the accumulation of these indicators and their uncertainties during the supply risk evaluation should be invested in (Achzet and Helbig, 2013, pp. 445-446).

Given the identified irregularities within the quantitative approach, one needs to reconsider the approach and the resulting conclusions. For example, a study of 2013 on the scarcity of Lithium by Ziemann et al., shows that material flow analysis suggests that there is a threat of a shortage of lithium on a global scale (Ziemann et al., 2013). However, qualitative data conclusions, are only as accurate as the predictions, and definitions made at the start of the study. What is therefore needed is a qualitative approach to complement the information gained from quantitative analysis.

There seems to be no commonly used and recognized method of measuring and presenting supply bottlenecks and their consequences. This makes it even more important to understand what effects and indicators you might perceive (today), or perhaps have noticed in the past.

2.2 Qualitative Approach: Overview worldwide situation for Lithium and Cobalt for Electromobility

The currently known deposits of the scarce resources: Lithium and Cobalt and the quantities degradable and available for production define the worldwide market supply for these materials. The knowledge of the location of these scarce resources and how the current market situation it is crucial for the industry, institutions, and governments to supply their own market, for price volatility and commodity price uncertainties (NPE, 2016, p. 9).

As mentioned in the section before, study outcomes vary greatly from the indicators chosen by the researcher. Since there is no unified quantitative approach in literature, in this section qualitative review of reliable sources will be used to point out the situation for Lithium and Cobalt for Electromobility on a worldwide scale, in Germany and China.

In their paper, Hettich and Müller-Stewens (2014), caption the supply for Lithium on the global market at present as adequate. The outlook for sourcing of Lithium and Cobalt for big companies like Tesla is critical. According to their research, the ability of industry to satisfy the rising demand, especially with big shares of Lithium usage for competing for market just like smartphones, tablets, and other computing serviced products, might face some serious challenges. The supply for Cobalt is portrayed critically too, as the origin, the Democratic Republic of Congo is politically rather unstable (Hettich and Müller-Stewens, 2014)

In their paper, Helbig et al., (2018), talk about the supply risks associated with lithium-ion battery materials. For evaluation of criticality of scarce resources, the supply risk criteria model is utilized. At present times, the values for the risk of supply shortage are highest for cobalt and lithium. Manganese is portrayed as middle concerning. The authors do not present any future estimation but point out the necessity to further research the issue of increasing usage of assessment procedures for specific market conditions (Helbig et al., 2018).

In the next section, a more detailed look at the situation for Lithium and Cobalt will be provided. There are controversial opinions about the question if supply can meet demand in the future. This is due to different data about deposit concentration. Nevertheless, most sources assume that demand for the reserves will overtake supply (Olivetti et al., 2017, p. 4).

Lithium

Lithium is used to produce fabricants, glass, and ceramics to only name a few materials. The main usage nowadays is in the production of lithium-ion batteries, primarily for the automotive industry. Although geologists assumptions range from 33 to 64 million tons of lithium resources worldwide, and reserves range from 13 to 40 million tonnes, at the present stage only 36.000 tons of light metal are produced per year (Hajek, 2017).

The price of lithium on world markets has quadrupled since 2012. With the growing number of electric vehicles on the street, the demand for lithium-ion batteries grows steadily. The question is not only if there are enough resources but also if the production can keep up with the fast emerge of the market and meet the exponential demand of battery cell factories. Let alone the rapid consumption growth in the last years (from 2010 to 2014, 73 percent growth) be compared with the production growth of only 28 percent during the same time frame (Olivetti et al., 2017, p. 9).

If estimations of 40 million electric cars worldwide by 2030 are true, up to 3 million tons of pure lithium will be needed, that is up to over half of the lithium demand worldwide. The concerns about potential supply chain bottlenecks continue to grow. For industry experts, it is unclear how such quantities of high-purity lithium could be produced until then (Hajek, 2017).

Countries like Germany, China, Japan and the USA are expected to take the lead in the production of these electric vehicles ((USGS), 2017). Broken down by region, the highest demand for lithium was generated in the year 2015 in China (40 percent), followed by Europe (21 percent), Japan (11 percent), South Korea (11 percent) and North America (8 percent) (Schmidt, 2017a, pp. 11-12).

However, the industry is adapting to the changing market situation. Recycling of materials is one of the potential chances to fight against possible disruptions. Still, with the lifetime of a Lithium-ion battery used in Electric Vehicles, recycling is more for a long run situation change but not for the short time (Olivetti et al., 2017, pp. 11-12).

Cobalt

Even more concerning is the situation for Cobalt, one of the metals in the positive (cathode) of the Li-ion batteries, according to Industry experts. The battery of an electric car contains about 3000 times more cobalt than that of a smartphone. Although there is a sufficient amount of cobalt in theory: the global reserves are 25 million tonnes; under the ocean up to 120 million tonnes of resources are suspected. Still, because there has not been any demand for cobalt before the boom of electric vehicles and this massive demand is relatively new, the dismantling and refining are not advanced enough yet (Hajek, 2017, pp. 3-4).

State of the art, the largest reserves of cobalt (half of the known reserves worldwide) can be found in the politically extremely unstable democratic republic of Congo. Around 3.5 million metric tons of cobalt reserves are estimated to be in located there. Even though industry heavily invests in this country, the exploration process lasts for years and the chances of not finding enough suitable material are high. With the unstable situation in Congo, it is almost impossible to run projects without illegal intermediaries and local militias ((USGS), 2017).

But not only the insecure resource locations are an issue. The current annual production of 124,000 tonnes Cobalt is not even going to fill up half of the industry's future annual demand for electric cars (Slack et al., 2017, p. 20). Therefore up to 400,000 tonnes of pure cobalt would be necessary to satisfy the demand for 30 million battery cars with a 90kwh battery. Furthermore, one must see that vast amounts of cobalt are also used for smaller electrical appliances such as lawn mowers, cordless screwdriver, laptops. In the long run cobalt in lithium-ion battery's must be replaced by other materials, as it won't be able to satisfy the mass car market (Hajek, 2017).

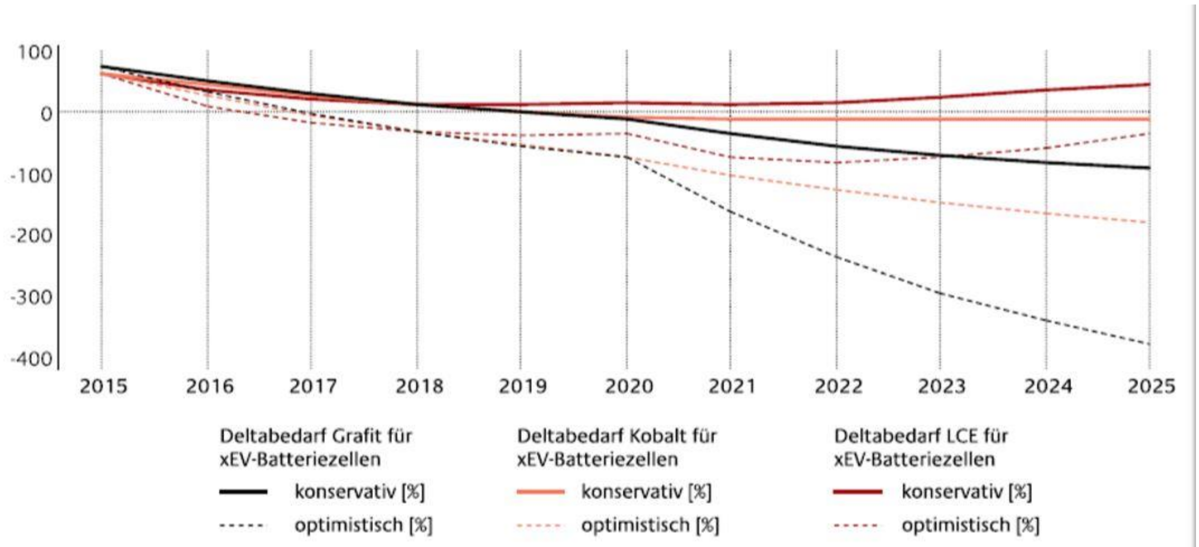
Cobalt itself is a by-product of Nickel and Copper production. The Cobalt Development Institute estimated in 2015, that 50 percent of cobalt production belong to the Nickel industry, 35 percent to Copper industry and the rest to other metals. Only a total number of 6 percent are traced back to primary Cobalt production. A drop in the demand for Nickel or copper would have major implications on cobalt supply chain as well (Slack et al., 2017, pp. 10-11).

2.2.1 Specific criticality Situation in Germany

The special market situation regarding the demand for the raw resources graphite, cobalt and lithium has been portrayed by the Nationale Plattform Elektromobilität (NPE), 2016. In their graph, they present two scenarios which are based on the needs of the respective materials: a conservative scenario, which assumes low demand and slow change to electric vehicles and an optimistic scenario, which emanates a rapid transition to the implementation of Electric vehicles in the German market (NPE, 2016, p. 30).

The relative gap between the assumed demand and the production adapted to the respective market developments is presented in figure 4 below.

Figure 4: Market situation regarding the demand for the raw resources graphite, cobalt and lithium (2015-2025)



	Grafit	Kobalt	LCE
Bedarf 2015[2)] [t] Produktion 2015 [t]	~9,800 ~37,100	~2,400 ~6,200	~5,200 ~13,200
Bedarf 2025[2)] [t]	~170,000 (~420,000)	~14,000 (~34,000)	~90,000 (~224,000)
Produktion 2025 [t]	~88,000	~12,000	~163,000

Bedarf bei konservativer Absatzprognose xEV (Bedarf bei optimistischer Absatzprognose xEV)

Source: (NPE, 2016, p. 30)

The graph portrays, that in all optimistic scenarios at the time of the preparation of the forecast in the year 2015, supply shortfalls have already been predicted for the years from 2017. The conservative scenario does not predict supply shortfalls for cobalt and lithium pre-products. There are only shortfalls reported from 2018 on in the case of natural graphite. This gap would be lockable by synthetic graphite.

More significant, however, is the consideration of the accessibility of these raw materials point of origin. Germany does not have any of these raw materials and has large deficits to sufficiently supply the trade. For example, there is a high dependence on the Democratic

Republic of Congo and China in the mining and refining of cobalt. A significant proportion of their production is exclusively related to the construction of lithium-ion batteries. Similar dependencies also apply to the other necessary materials mentioned above: Lithium, manganese, and nickel (NPE, 2016, pp. 30-31).

Furthermore, governments policies to prevent a resource scarcity. So far, the German government follows a political agenda called "Energiewende", or in English "energy transition". By promoting electric vehicles and setting goals of one million electric cars on the road by 2020, they want to implement the "green industry policy" (Ziemann et al., 2013, p. 48). Various loan programmes, cluster building support, research, and development support and sector-specific innovation are part of it. Unfortunately, no specific measurement and no specific action plans for securing the scarce resources have been implemented yet (Altenburg et al., 2017, pp. 166-199).

Lithium

When it comes to Lithium, NPE, 2016 describes the supply situation as slightly critical with decreasing tendency. At the present situation, there is a high concentration of countries controlling the lithium market. Market demand is strongly influenced by battery production. Due to available capacities for Lithium in Germany, there is probably no market deficit expected for 2020 (demand of about 85% of projected production 2020). In 2025, a slight market deficit could arise for refinery production, but this can be excluded by timely investment into market expansion (NPE, 2016, p. 31).

But once again different sources state different numbers. In his paper, Schmidt (2017) compares the different assumptions about total demand for Lithium Carbonate (LCE) in Germany for the years 2015 to 2017:

Table 1: Assumption of the total demand of Lithium Carbonate (LCE) in Germany for the years 2015 to 2017

Year	2015 Prognosis	2016 Prognosis	2017 Prognosis
macquaRie (2016)	173,750 Tons	184.600 Tons	203.400 Tons
stoRmcRow (2016)	193.750 Tons	213.125 Tons	233.100 Tons
Deutsche Bank (2016)	184.000 Tons	209.000 Tons	238.000 Tons

Source: Own presentation based on Michael Schmidt, 2017

The demand greatly varies from source to source. Macquarie, 2016 for example prognoses an increase of total demand for LCE by 6 percent over the year (2015 to 2016), and of almost 17 percent from 2015 to 2017 (Schmidt, 2017a, pp. 54-55).

StoRmcRow, 2016 expects a significantly higher demand than Macquarie (2016), with approximately 193,750 tons LCE total demand for the year 2015. For the year 2016, the analyst predicts a total demand increase by 11 percent and for the year 2017 even an increase by almost 20 percent in comparison to the year 2015 (Schmidt, 2017a, pp. 54-55).

The Deutsche Bank, 2016 quantifies the total demand for lithium somewhere along the lines of the previously mentioned analysists. For the year 2016 an increase of around 13,6 percent is proposed and in the following year, 2017 an increase by almost 30 percent compared to 2015 is proposed (Schmidt, 2017a, pp. 54-55). This presentation clearly shows how discordant analysts about the actual value are.

At present, the annual production of lithium is around 30,000 tons worldwide: far too little to meet the projected future demand. In the year 2035 alone in the most important sectors of the future the worldwide demand for lithium could be at 110,000 tons, the Fraunhofer researchers estimate.

In the demand for areas of application, lithium-ion batteries already made out 30 percent of the total lithium demand in 2017 (Schmidt, 2017a, pp. 54-55).

Cobalt

In their roadmap for electromobility, NPE, 2016 point out the supply for cobalt as very critical in Germany. According to their research, there is a very high dependence on DR Congo and China in mining and refinery production when it comes to cobalt. Already when the study was conducted in 2016, the total battery market demand for refined cobalt was already determined at about 45 percent by the worldwide battery market. According to their prognosis, due to the increase in battery demand, a supply deficit is already possible before 2020 (compare figure 4). The specific demand for batteries will be in a slight market deficit for 2020 (demand will be 115 percent of the projected production in 2020) and for 2025 a higher deficit is apparent (NPE, 2016, p. 31).

2.2.2 Specific criticality Situation in China

Due to the heavy air pollution and climate concerns, but also because of the abrasion of oil, the need to shift to more environmentally friendly transportation systems in China has to lead the government to implement extensive national development plans for electromobility in China. The ambitious plan to have 5 million Electric vehicles driving on Chinas streets by 2020 and to enforce Chinese manufacturers to rule the worldwide market for electric vehicles to 80 percent in 2025 were published in their national development plan “Made in China 2025” by the Chinese State Council in 2015 (Retzer, 2017, Newswire, 2017).

Industry experts evaluate China as one of the biggest users of the scarce resources for electromobility and predict them to be the primary ever-increasing user (Nassar et al., 2015). Alone in 2015, they were producing 2,002 tons of lithium for lithium-ion batteries (Schmidt, 2017b).

After China implemented their ban on rare earth export in 2010, government leaders of other industrialized countries developed political agenda to better mitigate potential consequences of shortages (Cox and Kynicky, 2018, pp. 9-10).

Experts that have been doing research about the threat of scarcity in the special case of China have been pointing out, that there has been limited research been made about a possible threat since nowadays the demand is still covered and many investments in the protection of the future coverage have been made. Thus, no specific agenda for the handling with a potential resource scarcity is on the market yet (Altenburg et al., 2017, pp. 166-199). Furthermore, post-consumer recycling of the raw materials is still very limited and environmental implications and supply risks don’t seem to be taken too serious in China yet (Nassar et al., 2015).

Lithium

Numerous studies have been conducted investigating in the global lithium supply-demand relationship for lithium-ion batteries (Hao et al., 2017). Most of these studies found a remarkable gap between supply and demand, especially in the case of China (Ziemann et al., 2012). At the current stage, Chile has the biggest reserves of lithium followed by China as the second biggest storage. In 2017 China was estimated to have around 3.2 million metric tons of total lithium reserves ((USGS), 2017).

As one of the main tools for policymakers and researchers to conduct the situation of lithium to measure policy implications, material flow analysis is conducted. In their research paper Hao et al., 2017 conduct the first material flow analysis for Lithium in China. A big discrepancy between production and consumption can be found (Hao et al., 2017, Schmidt, 2017a)

Cobalt

In the past two years, China had the leading consumer role for Cobalt. The local rechargeable Battery Industry consumed up to 80 percent of the total consumption. 48,700 metric tons of cobalt was refined produced in China only in the year of 2015, thereby China was the world's leader in the production of refined Cobalt. That is due to the fact that its refinery is globally mainly concentrated in China. Most of the material for the refined product is being imported from the Democratic Republic of Congo to China. These imports make up almost 40 percent of the total trade value. With their resources, they not only satisfy their own markets demand but are also the leading supplier of Cobalt imports to the United States (Olivetti et al., 2017, pp. 5-6).

The potential threat of scarcity for Cobalt supply chain might be limitable by changes in the industry. Industry experts predict that with future development of extraction technologies there might be the chance to extract Cobalt as a primary product. Thereby changes in demand would be responded to more effectively (Olivetti et al., 2017, p. 8).

3 Research Design

This chapter of the paper will describe the specific techniques and strategy employed to answer the research questions delineated in Chapter 1 and for the collection of data. This chapter is build up as follows: it begins with an explanation of the conducted research and the data applied. The introduction will be followed by the clarification of methods that will be used to collect the data, frame the data and validate and interpret them. Finally, this chapter will end with the presentation of the reason for the methodical approach that has been chosen and limitations that are going to influence the contribution.

A multi-method approach for data collection and analysis will be chosen to investigate in the research question of this paper. In the first step, relevant literature and secondary data on the scarcity of raw materials: Lithium and Cobalt, for Electromobility in Germany and China will be located and analyzed. Existing studies on the scarcity of raw materials for Electromobility in both countries have been conducted using quantitive approach and qualitative approaches. Unfortunately, these quantitative studies have some lack of consensus and understanding about which indicators are appropriate for a raw material supply risk assessment and how these indicators should be measured. The according to qualitative studies had some limitations as well, such as assumption bias. Consequently, a mixed method approach was used, to limit potential bias.

Using a mixed method approach, the obtained data from qualitative and quantitative methods were designed and analyzed. The first stage identifies the scarcity of materials: Cobalt and Lithium on a global scale and for Germany and China. The second stage is the modification of before identified data and supplementation especially for the stakeholder's valuation in institutions and automotive industry in both countries, therefore an online survey was composed. The third stage is dealing with the construction of a dataset using the evaluated and compiled data of above-mentioned survey. Finally, in the last stage, the data will be analyzed through surveymonkey.com analyzation program. Triangulation will be used for the analyzation of results from the secondary data and the interview data. The quantitative and qualitative papers reviewed only show the situation for one country, but does not compare two countries and does not specialize in the situation for the automotive stakeholders. This information will be gathered through the survey.

3.1 Data and Methods

In this section, not only the data utilized for this thesis but also the research methods conducted for the data collection and analysis will be described in detail.

3.1.1 Data collection: Secondary sources

Secondary data is being elaborated applying the analysis of reliable sources. First of all, a classification of sources using quantitative approach and sources applying the qualitative approach to gather data was carried out.

The quantitative data presented in Chapter 2.1, was mainly a composition of the data provided by the US Economy National Research Council and the research papers of Achzet and Helbig. In his research paper, the author reviewed 15 criticality studies quantitive assessment methods for the evaluation of criticality for scarce resources.

The qualitative data presented in Chapter 2.2 was gathered from multiple sources.

Not only scientific papers from scientific research institutions such as the United States Geological Survey (USGS), International Organization of Motor Vehicle Manufacturers (OICA), Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM and the German National Platform for Electric Mobility (NPE) were contributing, but also research papers from leading experts in the field such as Hettich and Müller; Helbig et al.; Hayek and Olivetti et al., were only a few to be mentioned. Furthermore, professional journals were reviewed.

3.1.2 Identification of Automotive Stakeholders

In order to identify automotive stakeholders [3] from Germany and China that would be suitable for the collection of primary data, first of all, relevant secondary data was reviewed (Andriof et al., 2017). Automotive stakeholders are suitable for the conduction of this survey, due to their high-level competence and experience based on their professional occupation with the technology and the products in the automotive industry, hence have an intrinsic interest in future development, because not only are they affected in terms of their work content but also have a certain expected dependency on their work. For this study, the following attributes had to apply for a stakeholder to be invited to participate in the survey. First, the stakeholder should currently be employed in a job dealing with electromobility in Germany or China. Second, the job has to be in the either in the automotive industry (industry based) or research-

---

[3] A stakeholder is a person (employee, customer, or citizen) being involved with an organization, society, etc., consequently having interests and responsibilites towards it (Andriof et al.,2017).

based (not working for car manufacturers). Using data from research papers, trade fairs and automotive industry contacts the main participants were identified. Once the identification was finished, the contacts were classified according to what type of automotive stakeholder they were and which country they would provide information for. After this classification was done, the survey was sent out to them accordingly. In the end, around 80 automotive stakeholders were contacted via email to participate in the online survey. The response rate for the online survey was 25 percent.

3.1.3 Data collection: Online Survey

The collection of primary data for this thesis was carried out by an online survey. An Online survey offers a numeric description of rating and opinions by a specified audience (Creswell, 2014, p. 13). The topic of investigation was the criticality of Lithium and Cobalt, the specific audience were automotive stakeholders in Germany and China. For the collection of Data, with the intent to draw conclusions from the sample of individual automotive stakeholders to the target group of automotive stakeholders representing Germany and China, cross-sectional studies were implied. The cross-sectional study focuses on a particular group of people at a certain point in time (Creswell, 2014, pp. 13-14).

This online survey was not only sent out to a before specified network (Appendix A) but also shared on special groups for electromobility in the automotive industry on social networks like LinkedIn or Wechat (for the case of China). The tool used to create, share and analyze the survey was surveymonkey.com. Two surveys were created, one in English and one in Chinese as well, because the Chinese targeted audience was more likely to respond to the Chinese version, than to the English one (Appendix B).

The aim of the survey is to collect and frame content for the critical evaluation of raw material shortage for Electromobility in Germany and China. The questions asked in the survey are adequate to further invest in the special situation for automotive stakeholders anticipation of the invested topic. The survey template can be found in Appendix C.

Nevertheless, there are some limitations to online surveys. First of all, through the way the questions are formulated, the interviewer provides information in a predesigned place, the way the questions are asked can influence the participants to answer greatly. Furthermore, the interviewer is not present to clear the meaning of the question, the validity of the collected data depends on the perspective and intellectual knowledge of the participant individually (Creswell, 2014, p. 191). Especially while working with industry as a target audience, corporate policies might limit the participant's answers. The answers also vary on the audiences' willingness to answer the questions truthfully and not to skip questions. This hugely affects the precision, accuracy, and credibility (Sapsford, 2007, pp. 11-12).

To minimize the possibility of shortcomings for this thesis, the target audience was selected very carefully and individuals were contacted to confirm their eligibility.

3.1.4 Data analysis: Convergent parallel mixed methods

The design of this papers analysis is the *Convergent parallel mixed methods* approach, it is part of a *mixed methods* approach. It originates from the historic concept of the multimethod, multitrait idea from Campbell and Fiske (1995). In their opinion, the combination of different data forms would be most suitable to understand a psychological characteristic of investigation (Campbell and Fiske, 1959).

The *Mixed methods* approach combines research and data from qualitative and quantitative methods in the research study. Since qualitative data is relatively open-ended without hard numbers, quantitative data is rather closed-ended with clear answers. Mixed method approach is relatively new as a research approach. It can be traced back to the middle of the late 1980s. The idea of the mixed methods approach is, that both, qualitative as well as quantitative research approach have limitations and weaknesses. Through the implementation of a mixed methods approach, the limitation and biases of both methods could be limited (Creswell, 2014, pp. 14-15). The triangulation of data, which is described in the next section, developed from this approach.

In the *convergent parallel mixed methods* approach, the investigator collects both, qualitative and as well as quantitative data during the same time period. The overall results will be drawn a conclusion of the merge of both data sources, a comprehensive analysis of the research problem will be presented (Creswell, 2014, p. 19). The assumption is, that the collection of a diverse type of data will best provide a more complete understanding of the research question, than the application of either one of the two methods would give.

The process of convergent parallel mixed methods approach for this paper consisted of the following steps: after the automotive stakeholders were classified, an online survey was sent out for further data collection. The survey helps to collect detailed views from the participants to help explain the initial found data and draw a conclusion for future research. In the next stage, the data were analyzed using SurveyMonkey as an open source program industry standard measurement tool. After the data had been classified and analyzed accordingly, the visualization of the data was conducted with surveymonkey.com.

In the final step, the convergent parallel mixed methods approach was applied to make sure that the findings would fit within the scope of theoretical background and the reviewed literature to review and analyze the data. Furthermore, a SWOT Analysis was conducted.

3.1.5 Triangulation of the data

Triangulation is the utilization of multiple research approaches during the research process in order to get a richer picture while addressing one singular phenomenon. The aim of applying triangulation is by mixing different sources for the collection of data, reliability, validity and consistency of results, will be ensured while accessing the topic from a broader perspective using different methods and methodologies. Ir,-regularities that might not be taken into consideration while referring to one single approach, will be determined (Wilson, 2014).

The literature points out four unequal forms of triangulation:

Triangulation describes the usage of different sources. Different data sources were used to build an evidence from the sources and from that generate a conclusive rationale for themes (Wilson, 2014, pp. 74-75). Automotive stakeholders together with case studies of Lithium and Cobalt especially in Germany and China were the sources of data used for this research. These sources were combined to automotive stakeholders as the network, which was then further investigated in. The mixed method approach was applied to analyze the data. Data triangulation was used in this thesis to warrant validity and reliability.

Methodological triangulation is subdivided into ”within-method” and ”between-method” and refers to the use of more than one methodology in the analysis. ”Within-method triangulation” essentially means the utilization of various strategies to analyze the data of one method, whereas the ”between-method triangulation” is testing the degree of external validity by using a diverse set of methods for the analyzation of one unit (Jick, 1979, p. 603). This thesis is applying the ”between-method triangulation”. Qualitative analysis of the in literature perceived situation of criticality of Lithium and Cobalt and survey answers analyzation have been applied.

Theory triangulation, as the third approach, is the way of encountering the data using various theoretical frameworks. The theoretical framework applied in this paper to analyze data is a qualitative and quantitative approach (Wilson, 2014, pp. 74-75). The two mentioned theoretical frameworks correspond to one another. Despite their complementary interaction, different approaches are disclosed depending on the individual prerequisites classified in their corresponding literature sources.

Finally, Investigator triangulation describes the employment of more than one observer for the data gathering and data analyzation. Thereby, a broader range of information can be gathered, thus the chance of possible outliers can be minimized and the target audience better specified (Wilson, 2014, pp. 74-75). Unfortunately, time and sources were limited, so this triangulation could not be applied.

In this thesis, to guarantee reliability, three out of the four considerations of triangulation has been included and taken into account while performing the empirical analysis. Since in all triangulation designs weaknesses are encountered, the approach is to compensate these weaknesses by counter-balancing the positive aspect of the others (Jick, 1979). There are broad variations in definition and application of the triangulation approach. In this thesis, the opinion of Flick, (2014) who implies ”triangulation is less a strategy for validating results and procedures than an alternative to validation which increases scope, depth, and consistency in methodological proceedings” will be employed (Seale, 1999).

3.2 Ethical Considerations

While conducting the relevant data research for this paper, it was made sure that ethical issues that may arise during the process would be anticipated, and ethical integrity kept. The researcher has to respect the values, needs, and desires of the survey participant's. To protect the survey participants rights, the following procedures were employed:

Before conducting the survey, all participants were informed about the study aim and contribution (the informational letter was composed, Appendix B). In the information sheet, next to the general information about the study, the study scope and the time the study would take was mentioned as well. Furthermore, the participants were informed about confidential and privacy matters. For example, it was granted that while participating in the survey no corporate policy's would be violated and the stakeholder's anonymity would be kept. If information about one particular stakeholder would be shared, their name would either be changed (Stakeholder 1 (...)) or they would be asked for permission. The study holders were also given the chance to receive the study results upon request. Last but not least, the participant's rights, interests, and wishes would be considered at all times (Creswell, 2014, p. 92).

3.3 Rationale and Limitations for the methodological approach

When conducting a mixed method approach, all applied methods have their shortcomings which can weaken the entire research validity. In this paper, the limitations of the secondary data and primary data had to be taken into consideration. Regarding the secondary data, reviewing quantitative data, the main issue is, that there is no unified assessment of evaluation of criticality for raw materials in the literature yet. In terms of the review of the qualitative data, a special focus had to lay on the validity of the data and that it was stated from a reliable source.

But not only the secondary data had some limitations. Another limitation is the unity of the survey respondents. A lot of endeavors were undertaken to ensure, that the survey participant was well aware of the project scope and depth and the response format that was expected.

Nonetheless, the audience willingness to answer, knowledge level and accuracy must be taken into consideration. This has a magnificent effect on the accuracy, credibility, and precision of the survey (Sapsford, 2007, pp. 11-12). In addition, the interviewer's responsibility to communicate the questions clearly, for the audience to be understood correctly, also had to be focused on. These aspects were focused on, not only by choosing the targeted audience wisely according to their expected knowledge transparency but also while critically reviewing and checking the surveys effect on the audience with test participants before actually sending out the invitations.

Another possible limitation was, after clarifying the targeted group of automotive stakeholders into groups of similar aspects, to find an equal number of all targeted audience members to participate in the survey. Particularly while working with automotive industry as the audience of choice, the limitation through corporate policies had to be taken into consideration. To minimize those, the interviewer tried to ask questions where as little as possible company/institutional knowledge was presented and ensured the audiences anonymity.

Overall, the methodology chosen in this study has certain similarities to other studies research design when it comes to specific case analysis. The certain level of similarities between the usage of certain methodological approaches in special case analysis provides researchers with a benchmark of literature for the cross-referencing of relevant studies in the same research field. Overall, Data triangulation and mixed method approach were chosen to minimalize bias and limitations.

4 Analysis and Discussion

In this chapter, the results will be pointed out, analyzed and discussed. This will be based on the analysis of the survey and the secondary research. This chapter is built as follows: Firstly, the analyzation of the survey results will be conducted. In the second step considering the research questions, the results of the survey as well as the secondary data results will be taken into consideration, analyzed and discussed.

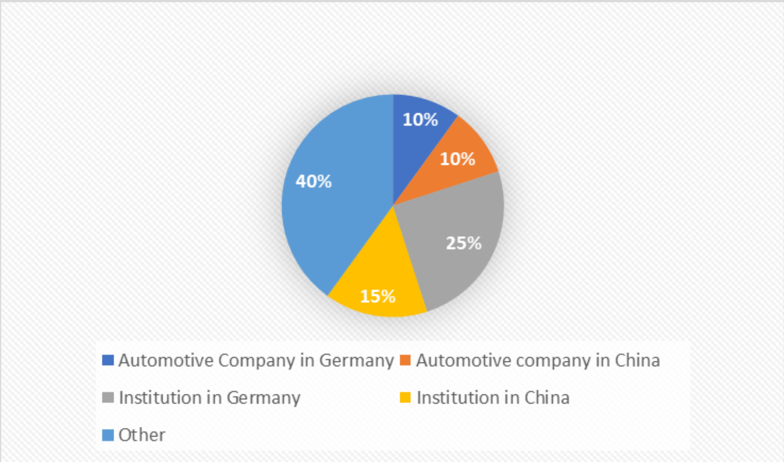
4.1 Results

In this section, the perceived situation of automotive stakeholder's valuation of a potential threat for electromobility by a criticality of resources in Germany and China will be pointed out and analyzed. The information was conducted in the before mentioned online survey. The entire survey can be found in the Appendix C. Out of the 80 participants of the targeted group contacted, 20 completed the survey. The completion rate is 25 percent.

Overview of the automotive stakeholders targeted for research (Survey Question 1)

Out of the around 80 participants of the targeted group contacted, nearly one-third of the participants are from the automotive industry, one third in automotive institutions and the rest in research positions and other forms of stakeholders. 11 answers came from Chinese and the remaining 9 from Germans. A weighting based on the ratio 55 percent from China vs. 45 percent from Germany gets considered. This was done with the intention to get a view about which stakeholder group would be most active in answering the questions (referring to question 1 in the survey).

Figure 5: Overview automotive stakeholders



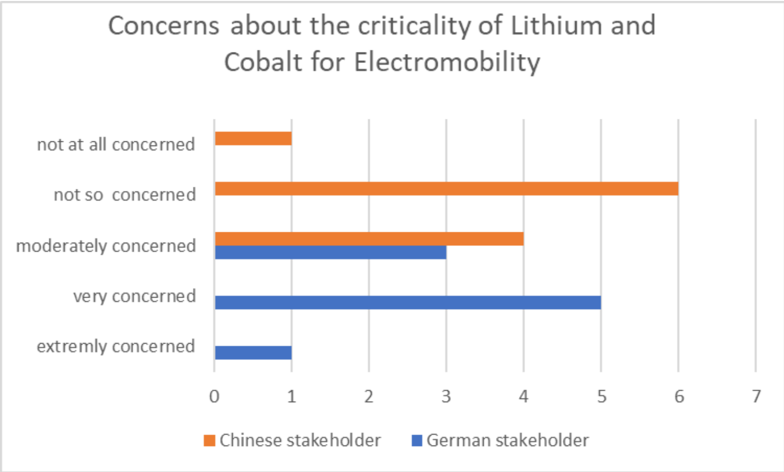
Source: Own survey

Portrayed in Figure 5 you can see that 40 percent of the people answering were referring to themselves as “Other” which was for example research employed, environmental scientists or a foreign association in China, the next biggest group answering were institutions in Germany with 25 percent. Third likely to answer were institutions in China with 15 percent. Equal was an Automotive company in China and Automotive Company in Germany with 10 percent each.

Concerns about the criticality of Lithium and Cobalt for Electromobility (Survey Question 2)

The second important question to be answered in this thesis is to understand the level of concern about the criticality of raw materials (Lithium and Cobalt) for Electromobility in Germany and China (compare Figure 6). A very clear trend can be seen: all Chinese stakeholders were “not at all concerned”, “not so concerned” and “moderately concerned”, whereas the German automotive stakeholders were in large parts “very concerned”.

Figure 6: Concerns about the criticality of Lithium and Cobalt for Electromobility

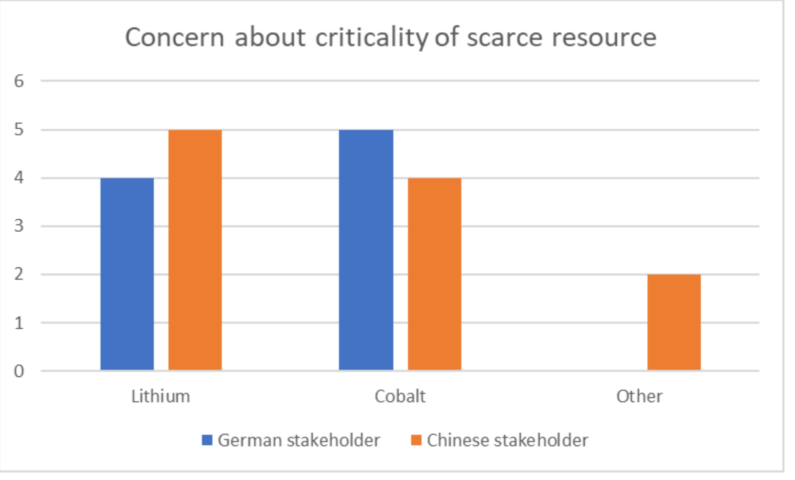


Source: Own survey

Country-specific assessment of the concern for Cobalt and Lithium (Survey Question 3)

Another important question to ask in this thesis is if there is a clear trend for one of the two materials being assessed more critical than the other in the specific countries. Understanding and evaluating the criticality threats for industry actors is necessary to ensure their business. Figure 7 does not present a clear conclusion for the criticality in both countries. The German stakeholders seem to be most concerned about cobalt, whereas the Chinese stakeholders are most concerned about Lithium. But looking at the small sample of this survey, the actual number is not representative in this case. The two participants that choose "Other" as an option stated, that they were indecisive about the answer.

Figure 7: Country-specific assessment of the concern for Cobalt and Lithium

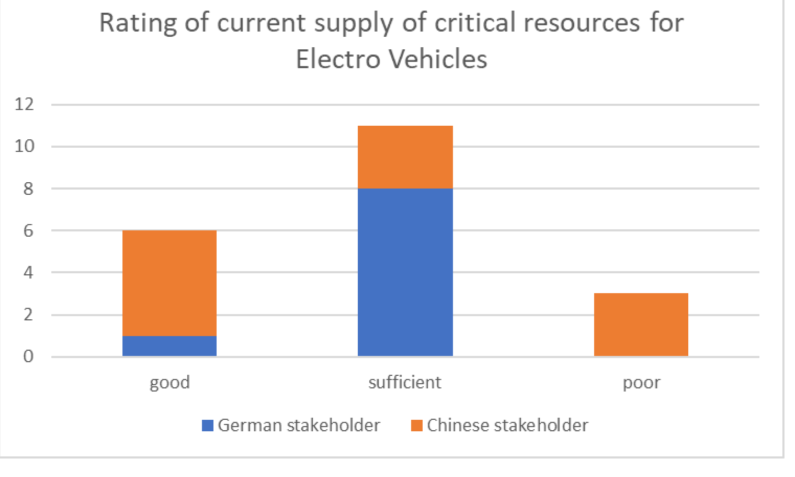


Source: Own survey

Country-specific rating for current supply of Lithium and Cobalt (Survey Question 4)

The current supply with the critical resources in Lithium and Cobalt is perceived as relatively sufficient by most of the German stakeholders. Chinese stakeholders seem very much divided on this point as reflected in Figure 8.

Figure 8: Rating of the current supply of critical resources for Electro Vehicles

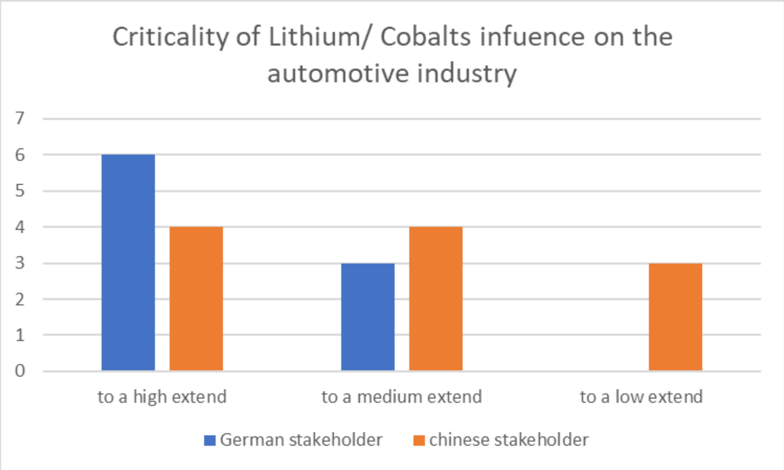


Source: Own survey

Extend of future Criticality of Lithium and Cobalt influence on the automotive industry in both countries (Survey Question 5)

The question how the scarcity of Lithium and Cobalt would influence the automotive industry in both countries was another topic of interest. The participants of the survey were asked to answer to which extent they would rate criticalities impact on the automotive industry. As portrayed in Figure 9, German stakeholders see a medium to high impact on the automotive industry by a scarcity of raw materials. The Chinese stakeholders have no common view on this subject.

Figure 9: Criticality of Lithium/ Cobalt influence on the automotive industry



Source: Own survey

Measures to prevent a criticality of scarce resources in the automotive industry (Survey Question 6)

Understanding that there is an actual threat of supply shortfalls for the two critical materials is one aspect, another one would be possible measures that could be taken to prevent such shortfalls. The answers of German and Chinese stakeholders for measures that should be taken to prevent a possible shortage greatly vary.

From the German side, suggestions like more direct investments in mines supported by guaranteed government Investments was one aspect pointed out. Another aspect was the point of recycling. One stakeholder answered that the development in the design for less material usage should be invested in, thus old equipment should be recycled more diligently. Vertical integration, long-term supply contracts, international political agreements, mining subsidies, tax exemptions and more investments in research funding was pointed out. Furthermore, the need for government and industry to set up long-term supply contracts and to invest more in finding alternative solutions for batteries instead of lithium-ion batteries.

One stakeholder's answer was very specific:

"The concern of a potential shortage is only warranted for the case of Cobalt. In this case, there is two bottlenecks (a) dominant supply from Democratic Republic Congo and (b) refining capacity focused in China. Without direct investment from leading battery and/ or automotive OEM's (original equipment manufacturer) there will be no alternative supply chains for Cobalt." (Source: German stakeholder's answer in the Survey)

Another stakeholder suggested not only to focus on Chinese producers and suppliers but to try and cooperate with other producers and build up new markets elsewhere.

For the Chinese stakeholders, the answers were quite similar. Next, to the development of alternative energy sources for the electric cars, they also suggested improving the acquisition and control of the material flows of Lithium and Cobalt. Furthermore, to invest more in recycling and saving of these materials. One participant stated:

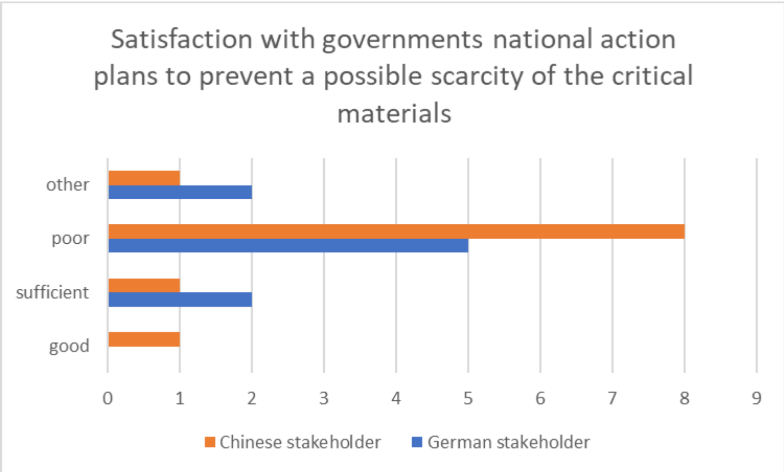
"We need to increase the collection and detection of raw materials; more investments need to be put into the improvement of battery recycling systems. The utilization of recycled batteries needs to be increased as well." (Source: Translated answer from Chinese Stakeholder from Chinese Version of the survey)

Stakeholders assessment of the government's implementation of national action plans to prevent a shortage of resources for industry functionality (Survey Question 7)

When it comes to the satisfaction with governments national action plans to prevent a possible scarcity of the critical materials, German and Chinese stakeholders seem to rate their functionality as rather poor as to be seen in Figure 10.

One German stakeholder stated: *"There has to be done even more research on the efficient use and substitution of critical raw materials. Everyone seems to have an approximate idea of the threat, but no one knows for sure."* (Source: German stakeholders answer in the survey)

Figure 10: Satisfaction with governments national action plans to prevent a possible scarcity of the critical materials



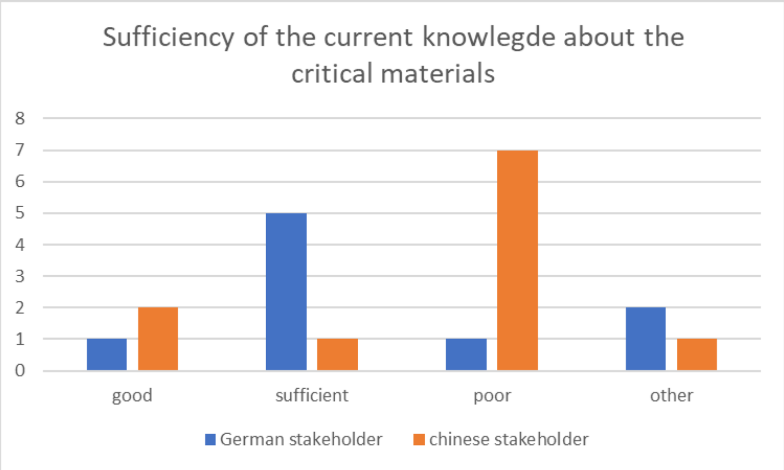
Source: Own survey

Sufficiency of the current knowledge about the critical materials (Survey Question 8)

The access to knowledge for the potential threat of a scarcity of the two materials is crucial for decision-makers and industry actors to ensure the markets inviolability. State of the art, this knowledge varies greatly to the country's government investments into research.

As reflected in figure 11, the Chinese stakeholders seem to find the knowledge transparency especially poor; most of the German stakeholders find it still sufficient. One German stakeholder stated: *"The knowledge about the criticality of the materials is particularly poor in case of Cobalt, for other materials like Lithium and Mangan it is sufficient."*

Figure 11: Sufficiency of the current knowledge about the critical materials



Source: Own survey

4.2 Discussion

An important aim of this thesis is to understand the interaction of all research factors and the dynamic of knowledge interaction. Understanding that there is no simple solution to the research questions is one aspect of the knowledge assessment. As discussed and pointed out in the literature review (Chapter 2), there is no common concerted solution to tackle the term criticality yet. Different framework and research goals are scattering displacement and elaboration of criticality (Achzet and Helbig, 2013). Therefore this section will try to sum up the main finding of each assessment to answer the research questions.

Quantitative assessment of criticality of Lithium and Cobalt for Electromobility (Research Question 1)

As addressed in Chapter 2.1., the problem with the quantitative assessment of criticality is, that no standardized quantitative measurement that describes criticality has been found yet. Different indicators are applied in various studies, no unified measurement has been adopted yet. Likewise, no database that combines every step in the supply chain of critical materials (mining, refining, life phase and recycling) has been established yet. Due to this inconsistent evaluation method, that mostly varies on different research goals and frameworks of each study individually, there can not be a clear solution for the criticality of the two materials found in quantitative research. Future research should focus on deployment of a selection of evaluation indicators, the collection of these and their shortcomings while evaluating. A unified method for the assessment of criticality would be necessary to invest into the criticality of Lithium and Cobalt for Electromobility in Germany and China.

Qualitative assessment of criticality of Lithium and Cobalt for Electromobility (Research Question 2)

When it comes to the qualitative assessment of criticality of both scarce materials for Electromobility, the opinions if the industry will be able to keep up with the rising market demand vary greatly. Different data about deposit concentration are the main reason for that (Olivetti et al., 2017). As a matter of fact, the currently known deposits of the critical resources, their degradable quantities, and production activities define the worldwide market for Lithium and Cobalt. Automotive stakeholders such as industry, institutions, and governments are dependent on this information of location and supply in order to estimate the current market values and future development (NPE, 2016). At the current stage, most sources agree that demand for both critical resources will overtake supply shortly.

As reflected in the reviewed literature, estimations picture supply shortages for both materials on a worldwide basis in the coming years. For Lithium it is the massive increase in demand, that will most likely not be possible to satisfy, because of refining and production not being able to adapt as fast. Besides, there is also a competing market for other industrial products, that must be satisfied at the same time (Olivetti et al., 2017, Hajek, 2017). In case of a fast adaption of the industry to this changing market situation, there might be a chance to satisfy the market.

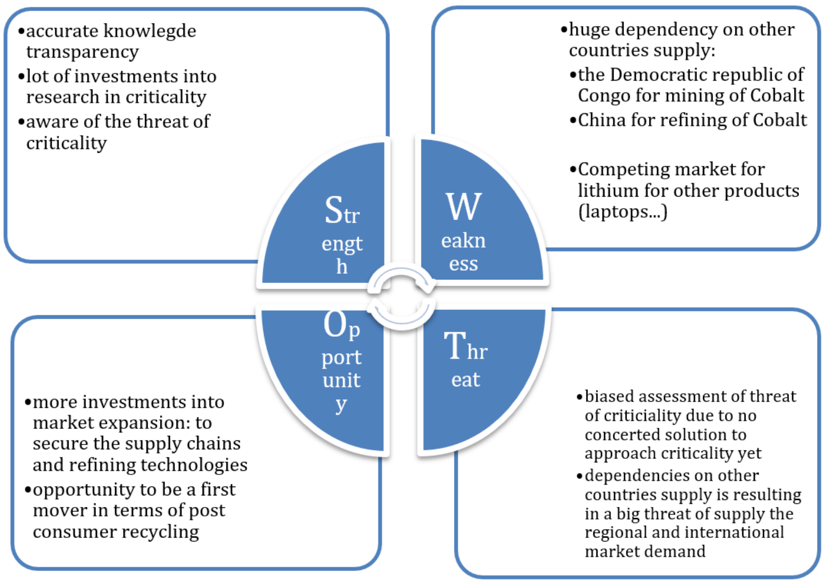
In case of Cobalt, there will not be the problem of reserve shortages, but more the issue of the not advanced enough refining and dismantling abilities of the industry yet (Hajek, 2017, pp. 3-4). Moreover, the difficult interaction with the Democratic Republic of Congo as the main provider for Cobalt products also influences the worldwide market greatly (Hettich and Müller-Stewens, 2014).

Special situation for Lithium and Cobalt in Germany and China (Research Question 2)

Another important question to be further investigated in of this thesis was about the special specific situation for Lithium and Cobalt in Germany and China. While doing the research about the specific situation in these two countries, it came to the attention, that the knowledge seems to not be transparent for all automotive stakeholders. The special valuation of the stakeholders will be further described in the next section. In this section, an overview of the country-specific situation will be pointed out using the SWOT Analysis tool. SWOT is a framework and approach for the analyzation of a market or company's strategic position. It has its roots at Harvard Business School and other American Business schools from the 1960s onwards. The name SWOT is an acronym for the words "Strengths, Weaknesses, Opportunities, and Threats". The aim is to find a good balance between internal and external factors. Internal qualities and characteristics (strengths and weaknesses) and external situation (threats and opportunities)(Hill and Westbrook, 1997, pp. 47-48).

In this case, it will be referring to Germany and China as the two markets strategic position to be investigated in, to present a clearer framework of internal and external factors influencing the two countries market situation. Figure 12 shows the SWOT-Analysis for Germany.

Figure 12: SWOT-Analysis Germany

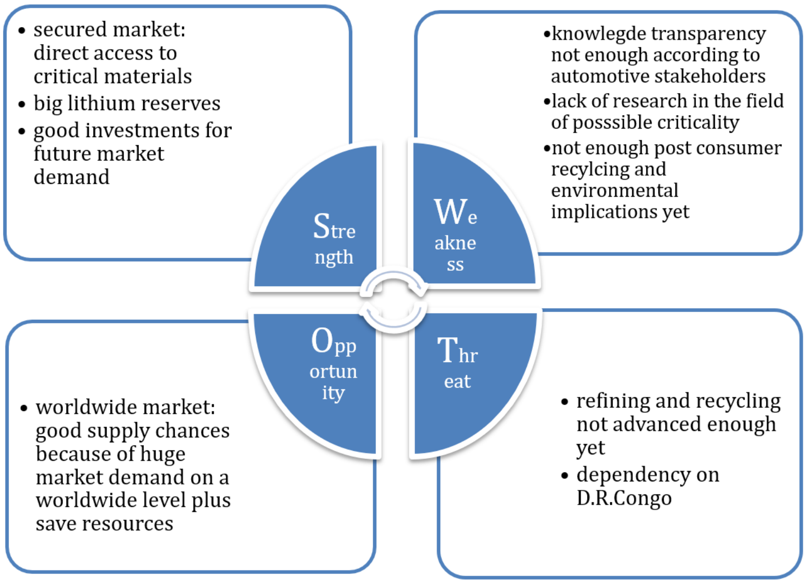


Source: own presentation based on (Hettich and Müller-Stewens, 2014, NPE, 2016, Achzet and Helbig, 2013) and own survey

The situation for Germany is as follows: The internal qualities are an accurate knowledge transparency, reflected in the literature review. Furthermore the paper of NPE,2016 pointed out that there are investments currently flowing into the research of criticality for the scarce resources. Furthermore, there is awareness of the threat of criticality, which is reflected in the survey results as well (Chapter 4.1). Internal weaknesses are first of all the supply dependencies on other countries. Since Germany does not have direct access to the critical material Cobalt and has deficits to sufficiently supply trade (NPE, 2016). The paper of Hettich and Müller-Stewens, 2014 reflected especially Germany’s dependency on the Democratic Republic of Congo for mining of Cobalt and on China for the refining of Cobalt (Hettich and Müller-Stewens, 2014). A supply deficit for Cobalt is already expected in 2020. Moreover, the internal competing market for Lithium in form of other products like Laptops and such is a weakness as well, although overall the market for Lithium is slightly critical with a decreasing tendency. No trade deficit is pictured for 2020, but for 2025 there is a market deficit predicted for refinery products of lithium (NPE, 2016).

External factors influencing the countries market situation for critical resources are Opportunities such as the possibility to invest more in market expansion. Literature has pointed out, that timely investment to secure the supply chain disruptions and into the improvement of refining technologies, possible supply bottlenecks could be prevented, new markets could arise (NPE, 2016). Moreover, the automotive stakeholder survey has shown, that there would be possibilities to be a first-mover when it comes to the market for post-consumer recycling (Own survey). External Threats that influence the market are the discordant analysis about the actual value share of the critical materials. The assessment of the possible supply bottlenecks are not unified yet, this information that will lead to decisions could be biased (Achzet and Helbig, 2013). As well as the dependencies on other countries supply can lead to internal supply shortages (NPE, 2016).

Figure 13: SWOT- Analysis China



Source: own presentation based on (Nassar et al., 2015, Schmidt, 2017a, Olivetti et al., 2017) and own survey

When it comes to China, internal qualities would be the relatively secured market of Lithium and Cobalt. Not only does China currently have the second biggest reserves of Lithium ((USGS), 2017), and consequently is aiming for the market control of lithium-ion batteries (Schmidt, 2017a), but also is it the leading consumer and producer for refined cobalt, with the biggest concentration of refinery located in China. Consequently one could say that the good investments for future market demand will secure the internal market. A weakness factor would be the fact, that according to automotive stakeholders the knowledge transparency within the country does not seem to be satisfying. Furthermore, the research about possible supply bottlenecks has been rather limited. According to experts, the current demand for both critical materials is covered and also for the following years, consequently research into the field of criticality have been neglected (Nassar et al., 2015). There have not been enough investments in post-consumer recycling and environmental implications either, due to the momentarily secured markets.

External factors influencing China market would be the opportunities to become a worldwide market leader for lithium-ion batteries because of enough resources to satisfy the market demand. China is already the biggest supplier of Cobalt for the USA (Olivetti et al., 2017). External threats would be that the huge demand in the worldwide market cannot be satisfied due to not advanced enough supply chains for refining and recycling of both materials. Furthermore the dependency on cobalt from the Democratic Rebulic of China.

The perceived situation of automotive stakeholder's valuation of a potential threat for electromobility through resource criticality in Germany and China (Research Question 3)

The final question of investigation posed in this paper is the question of how automotive stakeholders in both investigated countries evaluate a potential threat for electromobility because of resource criticality. The findings present an inception from some of the reviewed literature assumptions in combination with the survey results. Each sub-question will be presented individually:

Overview of the automotive stakeholders targeted for research (Survey Question 1.)

Within the survey researchers and research institutions were more likely to respond and five opinions, while car manufacturers and other corporate stakeholders were more reluctant to give comments or move beyond the convenient "we do not know". An explanation for the reluctance to answer might be due to corporate policy's (non-disclosure), lack of awareness or like literature pointed out, different research designs lead to different conclusions and surveyed participants may be unaware of the shortage because the research they have, shows that scarcity is a non-issue (Newswire, 2017).

Concerns about the criticality of Lithium and Cobalt for Electromobility (Survey Question 2)

The question to be investigated it is concerned about the criticality of both materials for Electromobility in both countries. The results of the survey are expected and consistent with the literature. Overall the Chinese seem to have secured the market better for themselves. As pointed out in the reviewed literature, Germany is already facing supply shortfalls for cobalt from 2017 on. Furthermore, Germany does not have direct access to the critical material point of origin. They therefore have a high dependency on the Democratic Republic of Congo for mining Cobalt and on China for refining it. In case of Lithium, no deficits are predicted until 2025 (NPE, 2016).

Country-specific assessment of the concern for Cobalt and Lithium (Survey Question 3)

The next question to be asked is if there is a trend for Lithium or Cobalt to be perceived as more critical in one of the countries. The uncertainty that was presented in the Survey results, is also confirmed in literature. As mentioned in Chapter 2, literature offers no clear answer either, various sources state different numbers, which brings discordant analysis about the actual value. That the risk of a supply shortage is the highest for Cobalt and Lithium out of the raw materials, seems to be clear (Helbig et al., 2018). For both materials, with the boom for electric vehicles, the demand increased tremendously, according to literature the supply can only partwise keep up with this new massive demand (Olivetti et al., 2017). In case of the critical resource Cobalt, the global reserves are not only limited to only 25 million Tonnes but also are half of the worldwide reserves estimated to be in the unstable Republic of Congo. The massive increase in demand for Cobalt hit the market quite unprepared, dismantling and refining of Cobalt is not advanced enough yet (Hajek, 2017, pp. 3-4).

Literature confirms the evaluation of the survey participants, that both, Lithium and Cobalt are to be seen critical in Germany. For Lithium especially, there is no market deficit expected before 2020, but by 2025 already a supply shortfall could arise for refinery production. For Cobalt, the situation looks even more unstable, according to literature, since Germany has no direct access to the materials point of origin and therefore has a huge dependency on the Republic of Congo for mining and on China for refinery (NPE, 2016).

Even though the overall market position for China seems to be more secure, because of his huge Lithium reserves and leading producer position for refined cobalt but still, there seem to be some uncertainties here as well ((USGS), 2017, Olivetti et al., 2017).

Country-specific rating for current supply of Lithium and Cobalt (Survey Question 4)

The next question to be answered, was the question if there is a country-specific rating for the current supply of Lithium and Cobalt.

In literature information presented are pointing out, that there has been limited research about the possible threat of these materials especially in the case of China. A relatively stable market coverage, good investments for future markets are a reason for that, also postconsumer recycling of the materials and environmental implications are not too much in the picture yet

(Nassar et al., 2015). This could be reflected in the survey results evaluation as well, which presented rather distributed opinions.

The rating of the German stakeholders in the survey does not seem to match with the literature. According to most researchers, there are supply shortages with both, Lithium and Cobalt already, which would not confirm a sufficient supply pointed out by the survey participants (Olivetti et al., 2017, NPE, 2016).

Extend of future Criticality of Lithium and Cobalt influence on the automotive industry in both countries (Survey Question 5)

To which extent would a criticality of Lithium and/ or Cobalt influence the automotive industry in terms of electromobility in Germany and China, that was another question to be answered. Referring literature to this question draws a clear picture: the criticality of Lithium and cobalt will have a tremendous impact on the automotive industry. Estimations talk about nearly 40 million Electric cars worldwide by 2050. This means a demand for 3 million tons of lithium and up to 400.000 tons of Cobalt by 2050. The current annual production of Cobalt, for example, is only 124.000 tons, this would not even cover the demand of half of the future annual car production (Hajek, 2017).

To put it in other words, not only will the demand not be covered by the worldwide supply, but also will this have a significant impact on the market for electric vehicles. Results of the survey confirmed, that most automotive stakeholders felt that a criticality of Lithium and Cobalt would have a high extend an influence on the automotive industry.

Measures to prevent a criticality of scarce resources in the automotive industry (Survey Question 6)

The question of which measures could be taken to prevent a possible criticality of scarce resources: Lithium and Cobalt in the automotive industry, was another topic of interest. German government introduced some policy measures, these measures included various loan programmes, research and development support, cluster support and sector-specific innovation, especially for electromobility. No specific measures were implemented for securing or measuring the two scarce materials. In China, a variety of industrial policies are implemented in the industry. The development of battery-electric passenger cars is promoted. There is also a variety of subsidies for electric cars and regulations for non-electric vehicles. Just like in Germany, no specific agenda for the resource scarcity is implemented yet (Altenburg et al., 2017, pp. 166-199).

But how to implement these plans and make them feasible and workable seems to be questionable. Survey participants stated, that more direct investments in the supply chain steps should be taken. Furthermore, recycling of lithium-ion batteries should be further developed, Vertical integration, long-term supply contracts, international political agreements, mining subsidies, tax exemptions and more investments in research funding was pointed out. Furthermore, the need for government and industry to set up long-term supply contracts and to invest more in finding alternative solutions for batteries instead of lithium-ion batteries.

Stakeholders assessment of the government's implementation of national action plans to prevent a shortage of resources for industry functionality (Survey Question 7)

If the automotive stakeholders are satisfied with the government's implementation of national action plans to prevent a shortage of resources for industry functionality feasible and reachable, was another question of interest. The literature lacks a reflection of this topic so far.

The specific country plans are transparent: In Germany, it is called “Energiewende” or Energy Transition. Part of it is the promotion of electric vehicles via electromobility (Altenburg et al., 2017). The determined plan is to have one million electric cars on the German roads by 2020 (Ziemann et al., 2013). The Chinese plan implemented in the “Made in China 2025” national development plan is aiming for 5 million electric cars on the road by 2020 (Newswire, 2017). The government is also aiming for the Chinese manufacturers to cover the worldwide market for Electric Vehicles by 80 percent in 2025 (Retzer, 2017).

This knowledge in transparency is also reflected by the results of the survey. Most of the participants found the national action plans to be poor and were unsatisfied.

Sufficiency of the current knowledge about the critical materials (Survey Question 8)

The knowledge transparency about this topic is crucial for automotive stakeholders for their decision and plan making. State of the art, the knowledge transparency seems to variate greatly, thus the final question was about the sufficiency of the current knowledge about the too investigated critical material. The literature states that the problem with the current knowledge is, that there is no uniform solution to approach criticality. The survey resulted in most stakeholders finding the knowledge rather poor.

Conclusion

The final chapter of this paper reiterates the research aim and presents the conclusions and summaries of key findings. Lastly, future outlooks are commented upon, and additional future research is suggested.

4.1 Research Aims and Summary of Findings

The research aim of this thesis is to shed light on the special resource situation of Lithium and Cobalt for Electromobility purposes in Germany and China. A special contribution being the evaluation of Automotive stakeholders in both countries. The study was designed to understand the three main research questions which are: (1.) to understand the quantitative assessment of criticality in literature of the two mentioned raw materials at present times, (2.) to understand the qualitative assessment of the threat of a resource shortage for Lithium and Cobalt on a global market for electromobility and especially for Germany and China, (3.) to develop a clearer interpretation of the reality by combining insights gained from qualitative and quantitative reasearch, and understand the effect on relevant Stakeholders' valuation of the criticality of mentioned resources. The literature on the scarcity of both materials in the regarded countries is still rather limited, due to the no-standardized assessment of criticality indicators; however, a supply shortage is likely to occur. Very little is understood of how automotive stakeholders evaluate the scarcity of Lithium and Cobalt in both countries.

This study has shown that there is currently no standardized procedure, nor are there any standardized indicators for the measurement of criticality, despite the inherent dependency of conclusions on definitions, and assumptions made in the research design. A unification of indicator applied in future studies plus a worldwide data bank could be beneficial. Due to this inconsistent evaluation method, there can not be a clear solution for the criticality of the two materials found in quantitative research.

When it comes to the qualitative assessment of criticality, the evaluation of scarcity varies greatly. Some sources predict a material shortage sooner than others, but overall most sources agree, that in the near future Germany and China will experience a shortage of strategic resources. Supply shortage for both materials are predicted for the coming years, for the special situation of Germany, it is expected sooner than for China for both Lithium and Cobalt.

To understand the effect on relevant Stakeholders' valuation of the criticality of mentioned resources, an online survey was conducted. The results of the survey combined with the aforementioned analyzed secondary data show that a disparity in understanding between the selected countries exists. That is not only due to a difference in perception of the severity of scarcity but also due to differences in evaluation of government policies within respective countries. Last but not least the difference in rating and expectancy of current supply is an additional factor worth considering. Overall one could sum up, that automotive stakeholder found the current knowledge regarding the topic as not transparent/ accessible enough.

The contribution of this thesis is on the methodological level. The thesis contributes not only to the current debate of resource scarcity for electromobility but also explores the validity of the existing literature and its shortcomings. With its special methodological approach, it presents new insights into special automotive stakeholders rating. Methodological speaking, mixed method approach was combined with the findings of survey data and compared with intense data review. The result is a new insight on the special evaluation of the topic for both countries and the special evaluation of automotive stakeholders, which has not been conducted until now, with promising new research results and impressions for future research.

4.2 Research Objectives

In general, all applied methods within research have their shortcomings. For the choice of method in this paper, the mixed method approach, there are some limitations that can weaken the entire study outcome as well.

Using a combination of quantitative and qualitative sources for this paper, certain shortcomings have to be taken into consideration. For the quantitative secondary data, the non-standardized indicators for the assessment of the evaluation of criticality were one shortcoming. Regarding the qualitative secondary data, the validity of the data and reliability have to be taken into consideration.

For the qualitative primary data which were conducted in form of a survey a lot of impacts had to be taken into consideration as well. First and foremost, it has to make sure that reliable research participants were picked. Second of all, it had to be made sure, that the research participants were informed about the study goal and scope and that the study was accurate, credible and precise enough to answer the research questions. The research participant has to be willing and able to answer the survey questions and provide new knowledge for the research study. Furthermore, companies and institutions corporate policy's had to be applicable for participants to fill out the survey.

In order to minimize the impact of bias, and the informational limitations of the qualitative/quantitative approach respectively, Data triangulation, cross-referencing and Mixed method was adopted.

4.3 Practical Implications

Given the lack of clarity and transparency in information regarding the scarcity of the two materials, current research is limited due to non-standardisation of indicators. It is of common knowledge, that both, the industrial knowledge base and also the rating of automotive stakeholders influence the rating of a potential threat. This heterogeneity of assessment funding the knowledge base has to be considered while doing research on the investigated topic.

It is common knowledge, that a threat of a shortage is rather likely to occur. The division when it comes to the automotive stakeholder's knowledge base must be paid attention to while evaluating how the threat of scarcity of critical material Lithium and cobalt would influence electromobility in Germany and China. This thesis is mainly contributing to providing an insight into the two markets of Germany and China. This is done by providing an insight into the automotive stakeholder's evaluation of criticality for the two materials obtaining a survey. Given existing resources at the writing of this thesis, the special valuation comparison of both countries situation within the context of special rating of automotive stakeholders has not been conducted yet.

4.4 Future Research

Future research could be developed in:

First and foremost, by applying a non-standardized way of rating criticality the knowledge provided is limited. Currently, there is a significant amount of information when it comes to the assessment of critical raw materials for electromobility. The analysis of industry-specific markets with contrasting studies base in the same country has the chance of further expounding on the regional impact of the industries on the country market from the perspective of their industry knowledge base- literature for this aspect already exists on a high level. Contradicting studies have the capacity to delay the proclivity of governments to enact policies, may prolong the decision making time for key stakeholders and all-in-all worsen the future issue of scarcity.

Currently, the available knowledge is of heterogeneous nature. Therefore for future development of the topic, a more homogenous approach would be desirable. A consensus and understanding about the indicators that should be applied while evaluating supply risks and a comprehensive database combining all raw material supply chain levels (mining, refining, life phase end and recycling) would provide an even deeper analysis of the topic.

The second improvement for future research developments would be to increase the flow of key information between different stakeholders within the industry, to allow for comparisons, developments, and homogeneity in research approach.

Further studies on the threat of criticality of Lithium and Cobalt for the automotive stakeholders with a special focus on relevant countries can provide further development of literature, which would create more knowledge transparency and enable cross-referencing to strengthen newly formulated theoretical conceptualizations. The literature reviewed is quite contemporary compared to other studies literature. This paper aim is the contribution of our understanding of the impact of criticality of Lithium and Cobalt for the automotive industry in two specific countries. Generalizations may arise as key knowledge is accessible to a few key stakeholders, who view the whole situation through a constricted view. Thus, further research into other countries automotive industries with distinct knowledge bases especially in the field for the two critical resources would make it possible to provide a bigger resource base. Within this growing body of sources, more and more industrial knowledge would be able to be benchmarked and cross-referenced to further enhance our knowledge base and understanding of the impact of criticality of these raw materials on different countries automotive stakeholders and industry.

References

(USGS), U. S. G. S. 2017. *Countries with the largest lithium reserves worldwide as of 2017 (in metric tons)* [Online]. Statista. Available: https://www.statista.com/statistics/268790/countries-with-the-largest-lithium-reserves-worldwide/ [Accessed 24.04.2018].

ACHZET, B. & HELBIG, C. 2013. How to evaluate raw material supply risks—an overview. *Resources Policy,* 38**,** 435-447.

ALTENBURG, T., FENG, K. & SHEN, Q. 2017. Electric mobility and the quest for automobile industry upgrading in China. *Green Industrial Policy*.

ANDRIOF, J., WADDOCK, S., HUSTED, B. & RAHMAN, S. S. 2017. *Unfolding stakeholder thinking: theory, responsibility and engagement*, Routledge.

BERSCHENS, R. K., SILKE; NEUERER, DIETMAR 2018. *EU verklagt Deutschland wegen überhöhter Stickoxidwerte* [Online]. Handelsblatt.com. Available: http://www.handelsblatt.com/politik/deutschland/luftqualitaet-eu-reisst-der-geduldsfaden-klage-gegen-deutschland-wegen-ueberhoehter-stickoxidwerte/22578980.html [Accessed 20.05.2018].

CAMPBELL, D. T. & FISKE, D. W. 1959. Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological bulletin,* 56**,** 81.

COUNCIL, U. E.-N. R. 2008. Minerals, Critical Minerals. National Academies Press, Washington DC.

COX, C. & KYNICKY, J. 2018. The rapid evolution of speculative investment in the REE market before, during, and after the rare earth crisis of 2010–2012. *The Extractive Industries and Society,* 5**,** 8-17.

CRESWELL, J. W. 2014. *Research design : qualitative, quantitative, and mixed methods approaches*, Los Angeles, Calif. : SAGE, cop. 2014, Fourth edition, international student edition.

GRAUERS, A., SARASINI, S. & KARLSTRÖM, M. 2013. Why electromobility and what is it?

HAJEK, S. 2017. Bremsen Rohstoff-Engpässe das Elektroauto aus? . *Wirtschaftswoche*.

HAO, H., LIU, Z., ZHAO, F., GENG, Y. & SARKIS, J. 2017. Material flow analysis of lithium in China. *Resources Policy,* 51**,** 100-106.

HELBIG, C., BRADSHAW, A. M., WIETSCHEL, L., THORENZ, A. & TUMA, A. 2018. Supply risks associated with lithium-ion battery materials. *Journal of Cleaner Production,* 172**,** 274-286.

HETTICH, E. & MÜLLER-STEWENS, G. 2014. TESLA Motors: Business Model Configuration.

HILL, T. & WESTBROOK, R. 1997. SWOT analysis: It's time for a product recall. *Long Range Planning,* 30**,** 46-52.

JICK, T. D. 1979. Mixing Qualitative and Quantitative Methods: Triangulation in Action. *Administrative Science Quarterly,* 24**,** 602-611.

NASSAR, N. T., DU, X. & GRAEDEL, T. E. 2015. Criticality of the Rare Earth Elements. *Journal of Industrial Ecology,* 19**,** 1044-1054.

NEWSWIRE, P. R. 2017. China New Energy Vehicle Report. *Reportlinker-Energy.* Y.

NPE, N. P. E.-. 2016. Roadmap integrierte Zell-und Batterieproduktion Deutschland: AG - Batterietechnologie.

OLIVETTI, E. A., FU, X., CEDER, G. & GAUSTAD, G. G. 2017. Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals. *Joule,* 1**,** 229-243.

PALTSEV, S., HENRY CHEN, Y.-H., KARPLUS, V., KISHIMOTO, P., REILLY, J., LÖSCHEL, A., VON GRAEVENITZ, K. & KOESLER, S. 2018. Reducing CO2 from cars in the European Union. *Transportation,* 45**,** 573-595.

RETZER, S. 2017. Electromobility in China–a development pathway to climate protection, sustainable transportation and economic strength. *Netzintegration der Elektromobilität 2017.* Springer.

SAPSFORD, R. 2007. *Survey research,* London ; Thousand Oaks, Calif. : Sage Publications, 2007, 2. ed.

SCHMIDT, M. 2017a. Rohstoffrisikobewertung – Lithium. *DERA Rohstoffinformationen 33.* Berlin: Deutsche Rohstoffagentur (DERA) in der Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).

SCHMIDT, M. 2017b. Rohstoffrisikobewertung – Lithium. *DERA Rohstoffinformationen,* 33.

SEALE, C. 1999. Quality in Qualitative Research. *Qualitative Inquiry,* 5**,** 465-478.

SLACK, J. F., KIMBALL, B. E. & SHEDD, K. B. 2017. Cobalt. *In:* SCHULZ, K. J., DEYOUNG, J. J. H., SEAL II, R. R. & BRADLEY, D. C. (eds.) *Professional Paper.* Reston, VA.

WILSON, V. 2014. Research methods: triangulation. *Evidence Based Library and Information Practice,* 9**,** 74-75.

ZIEMANN, S., GRUNWALD, A., SCHEBEK, L., MÜLLER, D. & WEIL, M. 2013. The future of mobility and its critical raw materials. *Revue de Métallurgie–International Journal of Metallurgy,* 110**,** 47-54.

Appendix A

Appendix A- Automotive stakeholder (Online Survey)

Type of Automotive Stakeholder	Company	Location	Importance
Automotive company in Germany	Bosch Daimler Litarion GmbH Mercedes-Benz Energy GmbH e-motors		
Automotive company in China	Sur-ron China Nio China Festo (China) Ltd. Zhejiang EGE Battery Manufacturing Co., Ltd. SINOPEC Shanghai Engineering Company Limited (SSEC)		
Institution in Germany	Fraunhofer ICT Rohstoffallianz BDI Sicherheit und Rohstoffe Deutsche Lithium GmbH Technische Universität Bergakademie Freiberg Deutsche Rohstoffagentur (DERA) Bundesministerium für Wirtschaft und Energie GIZ German Development Institute Technische Universität München (TUM) Bundesverband emobilität Bundesverband Energiespeicher Deutsch-Chinesischer Automobilclub im AvD Roland Berger Fraunhofer-Institut für System- und Innovationsforschung ISI Nationalen Plattform Elektromobilität		
Institution in China	Tsinghua University (THU) Econet China VDA China		
Other	Electrek ChinaAutoWeb Wirtschaftswoche Emo Berlin-Berliner Agentur für Elektromobilität Center of Automotive Management		

Source: Own survey

Appendix B

Appendix B.1. – Email Invitation to Online Survey – English Version

Survey about shortage of raw materials for Electromobility

Dear Sir or Madam,

A potential **scarcity** of Lithium, Manganese and Cobalt seems to **threaten the success of Electromobility.** How do automotive stakeholders in Germany and China collect and process relevant market information about the **scarce resources** for **Electromobility**?

As a master student of Lund University, I am carrying out a scientific study on exactly this question in my thesis. I would appreciate your support by participating in my survey.

Please follow this link: **https://de.surveymonkey.com/r/RH3N8XJ**
The survey takes less than 5 minutes and will be open for participation until May 10th , 2018.

The intention of this thesis is to collect and frame content for the critical evaluation of raw material shortage for Electromobility in Germany and China.

Any information from you will of course be treated in strict confidence. The evaluation contains only aggregated data, which in principle does not allow conclusions on individual companies or persons.

The compiled results of the survey will be available to you upon request.

For further inquiries please contact me via LinkedIn:
www.linkedin.com/in/fiona-westermeier-0a432bb7

Thank you for participating in this survey,

Fiona Westermeier
Source: Own survey

Version: 2018-05

Appendix B.2. – Email Invitation to Online Survey – Chinese Version

LUND UNIVERSITY
School of Economics and Management

关于电动汽车原材料短缺的问卷

亲爱的先生/女士，

我是瑞典隆德大学（Lund University）的硕士生 Fiona Westermeier，目前正在进行毕业论文的数据收集工作。

我的论文是针对目前电动汽车行业原材料，如锂、锰和钴的稀缺问题，研究德国和中国汽车行业的利益攸关方如何收集和处理电动汽车稀缺资源的相关市场信息。

欢迎点击以下链接参与问卷：https://www.surveymonkey.com/r/NQDBHSX
所用时间不会超过 5 分钟，截止时间为 2018 年 5 月 20 日。

感谢您的大力支持。任何来自您的信息都会被严格保密处理，评估只包含汇总数据，不会对公司或个人作出结论。

如有需要，我愿意与您分享问卷结果。

如需进一步咨询，欢迎通过 LinkedIn 与我联系：www.linkedin.com/in/fiona-westermeier-0a432bb7

再次感谢您参与本次调研。

Fiona Westermeier
隆德大学经济与管理学院研究生
2018 年 5 月 5 日
Source: Own survey

Version: 2018-05

Appendix C

Appendix C.1. – Online survey – English Version

Impacts of Shortage in raw Material for Electromobility: Valuation of Automotive Stakeholders - Germany and China

Your Responses will be treated with confidence and at all times data will presented in such a way that your identity cannot be connected with specific published data.

OK

1. To which of the below organization do you belong?

- [ ] Automotive Company in Germany
- [ ] Automotive Company in China
- [ ] Institution in Germany
- [ ] Institution in China
- [ ] Other (please specify)

2. How concerned are you about the scarcity of raw materials (Manganese, Lithium, Cobalt) for Electromobility?

- ○ extremly concerned
- ○ very concerned
- ○ moderately concerned
- ○ not so concerned
- ○ not at all concerned

3. In case there is any concern about the scarcity of raw materials, which scarce resource are you especially concerned about?

- ○ Lithium
- ○ Mangan
- ○ Cobalt
- ○ Other (please specify)

0 of 9 answered

(4) How do you rate the current supply with scarce rare materials (lithium, manganese, cobalt) for the production of Electric Vehicles in your country?

- ◯ good
- ◯ sufficient
- ◯ poor
- ◯ Other (please specify)

(5) To which extend would a lack of scarce resources (Lithium, Manganese, Cobalt) influence the Automotive industry in terms of Electric Vehicles in your country?

- ☐ to a high extend
- ☐ to a medium extend
- ☐ to a low extend
- ☐ Other (please specify)

(6) From your point of view: Which measures to prevent a lack of raw materials (Lithium, Manganese, Cobalt) in the automotive industry could be taken?

(7) In your opinion, how does the governments implemententation of national action plans to prevend a possible exhaustion of scarce resources for industry work? (please answer according to the country you are working for)

- ◯ good
- ◯ sufficient
- ◯ poor
- ◯ Other (please specify)

0 of 9 answered

8. Do you think that the state of knowlegde about the criticality of the before mentioned raw materials is sufficient to take appropriate measures in the automotive industry?

- good
- sufficient
- poor
- Other (please specify)

9. Would you be interested in receiving the compiled results of this survey, once the analysis has been done? If so, please insert the email address that you want to be contacted with.

DONE

Source: Own survey

Appendix C.2. – Online survey – Chinese Version

调查：原料短缺对电动汽车的影响：德国和中国汽车利益攸关者的评估

1 你属于下列哪个组织？

- ◯ 中国的汽车公司
- ◯ 中国机构
- ◯ 其他（请注明）

2 您对电动车原材料（锰，锂，钴）的稀缺有多担心？

- ◯ 及其担心
- ◯ 非常担心
- ◯ 中度担心
- ◯ 不太担心
- ◯ 完全不担心

3 如果有任何担心，那种稀缺资源特别引起你的担忧？

- ◯ 锂
- ◯ 钴
- ◯ 其他（请注明）

4 您觉得贵国稀贵稀有材料（锂，钴）对电动汽车生产的供应情况是？

- ◯ 良好
- ◯ 充足
- ◯ 较差

0 个问题已回答（共 9 个问题）

5 缺乏稀缺资源（锂，钴）对贵国汽车行业中电动汽车的影响是?

- 大
- 中
- 小

6 从你的角度看：可以采取哪些措施来防止汽车行业缺乏原材料（锂，钴）？

7 您认为，政府对预防稀缺资源耗尽的工作做得怎么样?

- 良好
- 充足
- 较差
- 其他（请注明）

8 你认为贵国汽车行业对这些原材料重要性的理解如何?

- 良好
- 足够
- 较差
- 其他（请注明）

9 请问您是否希望在统计调查和数据分析完成后，得到整理后的最终结果?如果是，请在此处给出您方便联系的电子邮件地址。

Source: Own survey