Assessment of the Main Criticalities in the Automotive Battery Supply Chain: A Professionals' Perspective

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Abstract. The environmental transition has become a crucial element in the European Commission agenda. In this context, a key role is play by the electrification of the mobility that is viewed as a feasible alternative respect to the traditional fossil fuel paradigm, due to significant energy benefits. However, the scarcity availability of raw materials for producing battery packs and their concentration in few specific areas of the world, is determining high level of uncertainties and vulnerability in the supply chains of European car manufacturers. In particular, they are heavily facing the challenges that this transition is posing, specifically considering the reorganization and the structure of the associated supply chain. Therefore, this paper aims at capturing the perspectives of automotive industry about the different stages of the battery supply chain in the electric vehicle market. To this end, a questionnaire survey has been administrated to a set of identified automotive professionals. The obtained results underline that procurement, production and recycling of batteries are the most critical steps. On the contrary, the transport and the storage of the batteries are seen less crucial. This research is intended to stimulate future studies on innovative supply chains able to better manage batteries, and it is aimed at supporting car producers on designing more accurately their supply chain and to support decision makers in more effectively develop policy in the field of the electric mobility transition.

Keywords: Supply Chain, Battery, Electric Vehicle, Questionnaire.

1 Introduction

Transport that represents the core of all business and social activities at a worldwide level, is one of the most impacting agents for the environmental pollution, as about one-fourth of greenhouse emissions can be related to transport vehicles [1]. This is because the transport sector mainly depends on fossil fuels that discharge enormous amounts of greenhouse gases that are the primary basis of the climate change. Furthermore, the transport sector is a cause of the urban heat island phenomenon, resulting in emissions of fine particles, i.e. PM2.5, NOx, and SO2, into the natural environment. Air pollution has long been a focus of attention because of its adverse effects not only on the climate and national economies but also on human health. Therefore, according to the European Commission the sustainability of the transport has increasingly become a central theme [2].

In this context, the electrification of the mobility is considered a crucial element in achieving environmental sustainability goals due to significant energy benefits compared with conventional fossil fuel vehicles [3]. Even electric vehicles (EV) still suffer from a limited mileage, an underdeveloped charging network and lengthy charging times, the expected number of EV sold is projected to increase from 4 million in 2018, to 900 million in 2040. This will bring to a dramatic increase the demand for batteries that are currently the main element in powering EVs [4].

Moreover, car manufacturers have announced heavy investments in EVs, and a lot of new electric models are expected to enter the market in the next years [5]. In this context, Europe has been undertaking a strategy of climate neutral economy and EVs might play a crucial role in achieving this goal.

Car manufacturers rely on lithium-ion battery for powering the electric engines of the vehicles since this technology is able to offer an acceptable level of efficiency, high powers, good life cycle and high energy density [6]. This business environment is determining strong competition among players in order to have the availability and the steady supply of batteries together with the related raw materials. In particular, car manufactures are dealing with battery manufacturers that have a strong market position in the light of the scarcity of batteries [7]. In addition, the environmental transition in transport is determining relevant uncertainties in the automotive supply chain (SC) because of the massive technology shift related to product design, production process and more in general supply network structure. Other critical aspects might be referred to the limited availability of lithium, its spatial concentration in specific areas of the world and difficulties in implementing a sustainable and economically feasible recycling process.

Therefore, these complex relationships are leading vulnerabilities to EV SC, and the battery SC structure and the related organization are important drivers of procurement and cost reduction for a low impact vehicle [8]. In addition, the European Green Deal places European Union at the forefront of the green transition, and one of the main objectives is the decarbonization of the transport sector [9]. Thus, European car industries have embarked on a transition from the production of vehicles with internal combustion engines to the production of electric vehicles, which is leading to the reorganization of the existing automotive industry European sector [10].

Specifically, European Union seek to achieve a more than 80% share of EV by 2030 [11], and there is still an open debate about the decision of prohibiting the sale of traditional engine powered vehicles by 2035. Therefore, there is a strong policy pressure that is forcing the automotive industry to design and produce more environmental vehicles based on electric power. European Union, via the program so called European Battery Alliance has been trying to actually support the battery production within the European borders in order to better respond to the increasing investments borne by European car manufactures in the electric arena [12].

As a matter of fact, the cells that are the most relevant component in a battery pack, accounting for the 70% of the cost of a battery and up to the 40% of the cost of an EV are dominated by East-Asian companies with a European market share lower than 4% [13]. As a consequence, car manufacturers are called to carefully manage their SC, by precisely identifying the main critical stages, considering that the number of EVs produced in Europe is expected to increase up to more than 4 million by 2025 [14]. Thus, the perspective of European car manufacturers practitioners becomes particularly interesting to capture the most important challenges that this industry is facing in these uncertain periods.

To this end, the results of a questionnaire survey administrated to professionals working in the European automotive industry are here presented to understand the most critical stages of the battery SC in the European car industry. The paper is structured as follows: First an overview of the most relevant literature focused on the critical issues of the EVs markets and the related SC stages is shown. After that, the adopted methodology is described and the results presented. Finally, discussions and conclusions are traced.

2 Literature Review

Web of Science database was chosen to locate research works related to battery supply chain, especially in the automotive sector. The rationale for this choice is that this database is the oldest, global and multidisciplinary database that have the highest score in the visibility index global and is one of the world leaders in peer-reviewed journal ranking and evaluation.

To identify the trends, the database was asked to search for the following equation in title, abstract, and keywords: (battery/batteries) and (supply chain) from 1975 until 2022. The 879 results include 625 articles, 79 review articles, 179 proceeding papers, 25 early access, 7 editorial materials, 9 book chapters and 2 corrections. Within these results, we search for papers dealing with (vehicle) in title, abstract, and keywords to focus on the automotive sector, with the query (TS=(supply chain)) AND (TS=(batter*)) AND (TS=(vehicle)), and obtained a total of 343 results. We have preferred the word “vehicle” instead of “automotive” because more results were obtained (343 versus 57).

As we can see from the distribution of papers over the years on Fig. 1., even if the first paper dates from 1995, researcher’s interest really began in 2018, and in 2020 when we focus on automotive sector.

The literature shows many challenges, as the need to cope with the chip shortage and the scarcity of resources, the increasing transportation cost of EVB (electric vehicle battery) as those batteries are now registered as dangerous, the ensuring social welfare as the EVB market expands, and also a major environmental issue in every stage of the supply chain. Without embarking on a systematic analysis of the literature, we have sought to identify the issues associated with the main stages of the supply chain: procurement, production and use (including storage, and transport), and finally recycling in the broadest sense.

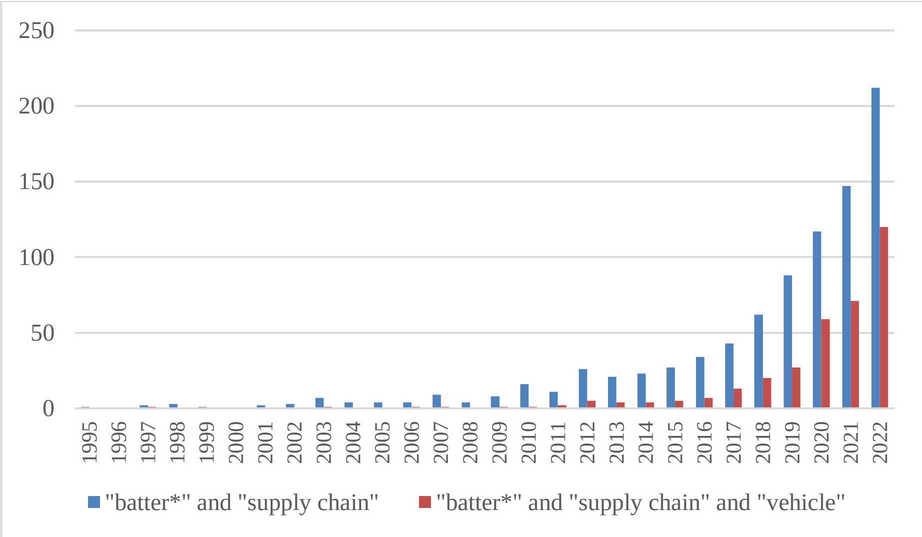

Fig. 1: Paper distribution in Web of Science database

It has come to light that the procurement of battery raw materials face several issues, due to the availability of the resources (lithium, cobalt, aluminum, copper…) and the extraction process. Indeed, the supply of copper and aluminum is the one emitting the most greenhouse gas, especially during the manufacturing of the cathode and anode. The battery market accounts for 22% of the lithium exploitation [15]. These above-mentioned aspects related to both economic importance and supply risk demonstrate the reason why these materials are critical for European companies [16]. [17] investigate the effects of key parameters on the equilibrium capacity allocation decisions and manufacturers' profits; they also show that to maximize social welfare, the upstream EV manufacturer should not supply batteries to its competitor if the procurement cost from the external supplier is low, which is contrary to the case of profit maximization. Some studies have compared make-or-buy strategies, such as Rafele et al. [8]; the authors draw a parallel between the purchase of complete batteries that implies the highest costs and CO2 emissions; on the contrary, buying single components helps improving these aspects, but it requires a certain level of vertical integration by the car manufacturer together with specific know how.

Moreover, it is shown that the production stage of electric vehicles has the biggest environmental impact due to the battery production. Already in 2012, [18] develop a lithium supply chain model that provides a framework with which to investigate the technical, geopolitical, and economic factors that impact the supply of lithium through different life cycle stages. The assessment of batteries' supply chain is also going to be integrated in low impact vehicles, focusing on location of the associated warehouse [3]. In the use stage, we can see the advantages that electric vehicles have compared to internal combustion engine vehicles, but we must keep in mind that the whole product lifecycle must be considered and thus the impact of the battery production must be reduced. In addition, it is important to underline that Europe accounts for only the 3% of global production of battery at an international level. This is a crucial aspect considering that a relevant number of electric and hybrid vehicle are sold in Europe [19]. Therefore, heavy investments are carrying out not only for supporting the production but also to implement reuse and remanufacturing processes, in order to reduce the European dependence from far-Eastern industries [20]. However, it is worth noticing that due to safety and performance reasons, battery should be stored and moved in warehouses and trucks with the control on humidity and temperature [21], with consequent negative impact on cost and on the environment. A recent study show that the conditions of the electric vehicle manufacturer’s product choice strategy depend on two thresholds related to the production cost of batteries, the manufacturing and assembly cost of EVs, the government subsidy and the range anxiety, while the conditions are independent of the EV manufacturer's market position and battery outsourcing decision [22].

In addition, the issue of recycling is very recurrent. Indeed, for instance in China, Zhao et al. [23] developed pricing strategies and emphasized the fact that the increase of government subsidies is correlated with the development of EVB recycling. Many authors developed studies regarding the EVB life cycle and it is clear that the battery lifetime must be extended as much as possible. According to the EU Battery Directive, the recycling of battery is expected to increase to 65% by 2025 [24]. Re-using batteries for other purposes could also restrict the waste as much as possible, as explained by Picatoste et al. [25]. The re-used batteries could have new lives as fast charging stations or even back-up power supplies. However, it would be important to assess the risk [26]. There are different recycling strategies, but centralized recycling facilities (with high capacity) offer great advantages. Using secondary materials (including scrap and residuals from production processes) could also be beneficial [27].

Overall, an effective framework to control the battery supply chain is required, to get a reliable circular or closed loop EVB supply chain [28]; [29]; [30]. Some authors review the external policy drivers and barriers for CE strategies for lithium-ion batteries and discusses how policy can be further developed. The results from [20] demonstrate that many manufacturers are pursuing CE strategies, mostly focused on repair, refurbishing, and repurposing. [28] studies a three-period electric vehicle battery recycle and reuse closed-loop supply chain consisting of a battery manufacturer and a remanufacturer; their result suggests that, comparing with new battery manufacturing, battery recycling and reusing would contribute to reduce raw material consumption hence reduce environmental impact, but may not gain financial benefits. Using game-theoretic models, [29] analyze process innovation strategies for green product remanufacturing in a closed-loop supply chain consisting of an upstream supplier and a downstream manufacturer; they conclude that (1) process innovation can effectively improve remanufacturing performance while increasing the recovery rate of the manufacturer, (2) although the cooperative mechanism is always beneficial to the supplier, the supply chain and the environment, it may not be favorable by the manufacturer; they also show that government subsidies can incentivize the manufacturer to adopt the cooperative mechanism, thereby achieving a win–win situation. [30] highlight the need for effective policy frameworks to foster a circular EV battery value chain. A life cycle sustainability assessment as well as a Product Sustainability Budget could also be useful tools [31].

3 Methodology

The research was carried out according to the following steps.

- *Questionnaire Construction*: based on the literature review outcomes, a questionnaire survey was designed so that to seek information and insights from professionals working the automotive industry with regard to the main challenges that the automotive SC is called to face in dealing with the battery for new electric vehicles. Before its administration, a pre-test was conducted with the aim of highlighting criticalities associated with the ambiguity and redundancy of questions, consistency, and typos. After that, the survey was ready to be submitted.
- *Sample identification*: the initial survey sample was made of 80 potential respondents. In particular, they have been identified via a research on LinkedIn. The research was carried out by looking for professionals working on the European Automotive sector. Once the identified profile was selected, he/she was contacted and in turn invited to take part to the study, by sending him the cover letter and the link to the questionnaire.
- *Survey administration*: the survey was developed by means of Google Forms and then sent by e-mail to the potential previously identified respondents. Specifically, they received a mail, with a cover letter aimed a presenting the objective of the research, with the related link to the questionnaire and entered their answers in the Google Form system that saved them accordingly. Finally, the obtained responses were downloaded and coherently organized in an excel file so that to have a dataset suitable to the analysis. The administration period extended over a couple of months according to two different waves, in 2022 in November and December. The first one was the initial invitation to take part to the research, and the second one was the reminder. This last one was conducted, to increase the response rate.

The administrated survey was composed of two main sections. The first part asked for demographic aspects of the respondent. In particular, the age, the nationality, the educational level, and the years of working experience were investigated. In the second part, respondents were asked to rate the importance of a set of proposed issues about the management of the battery SC in the automotive industry. For all statements, a Likert scale scoring system was used, where 1= Not important; 2= Moderately important; 3= Important, 4 = Very important; 5= Extremely important. This scale is largely used in carrying out survey research for assessing questionnaire answers [32].

The first set of questions was focused on assessing the level of criticality of every stage of the battery supply chain. Specifically, the extraction and the procurement that are becoming very important in maintaining stable the SC due to the growing demand of the scarce raw materials [33]. The production, the transportation and the storage were investigated. The recycling was considered too, since it is one of the topmost challenges in the battery SC [34]. The focus was on these aspects as, according to previously discussed in the Literature Review section, they represent the most relevant stages in the battery SC. In fact, the assessment of this SC is crucial to understand the main criticalities that companies are going to face as soon as the market share of EVBs increases [35]. Also, the battery cost was taken into account, considering that is a relevant driver for an EVB [36]. This is still an open question. On the hand it could be expected a decrease on cost thanks to the increased capabilities of companies and thanks to the more exploitable economies of scale related to the higher production volumes. On the other hand, some studies indicate that the cost of raw material is expected to increase further [37]. These issues, highlight that there is the necessity of investigating the challenges in EV battery supply chain according to the opinion of experts [1].

Once the responses were collected, the obtained data were ready to be analyzed. In particular, the questions based on a 1-5 Likert Scale were semi-quantitatively analyzed, and the open questions related to the solutions of the critical aspects of the battery SC very carefully analyzed in order to gain meaningful insights.

4 Results

The questionnaire achieved 31 responses, with a final response rate equal to about 37%. The results related to the demographic questions are presented in Table 1.

Table 1. Demographics

Age	Less than 35	51,61%
	35-44	19,35%
	44-64	22,58%
	More than 65	3,23%
Level of Education	High School	6,45%
	University (Bachelor & Master)	70,97%
	Ph.D	19,35%
Years of Experience	Less than 5 years	38,71%
	Between 5 and 10 years	16,13%
	Between 10 and 20 years	19,35%
	More than 20 years	22,58%

More than 50% of the respondents are less than 35 years old, and only one is more than 65, meaning that especially young professionals decided to take part to the study. This result is coherent with the years of experience. As a matter of fact, 38% of the respondents had less than 5 years of working experience. 22.5% of them had been working for more than 20 years. Finally, by observing the level of education almost 70% of the respondents had a university degree, 20% of professionals got a Ph.D. and only 6.5% had a high school diploma. This result shows that in the field under study higher levels of education can be observed, and high skill professionals proved to be willing to take part to this study.

Table 2 shows the results of the administrated survey. Respondents almost fully agree on considering the battery as the principal cost driver in manufacturing an electric vehicle. This demonstrates that this battery should be deeply studied in the future in order to reduce its cost. Similarly, more than 80% of the respondent see the procurement a critical stage in the battery supply chain. Specifically, 74% strongly agree on viewing this SC stage as a critical one. This is coherent with the study developed by the European Union about the identification of critical raw materials for strategic sectors and technologies. In particular, it lists lithium, cobalt and graphite as largely needed in battery as critical ones [38]. As a consequence, there is a relevant level of procurement risk in the light that Chinese companies are the main supplier of anode material (graphite) and lithium-cobalt oxide cathode material [39]. By observing the production stage, about 50% strongly agree on its criticality, and about 20% of the respondents are neutral respect to this SC stage. This result might couch on an increasing strategy based on the internal manufacturing process for battery implemented by car manufacturers [40]. As a matter of fact, for batteries more and more companies are trying to pursue a make-strategy instead of a buy-strategy in order to lowering the cost, and internally develop and keep specific competences that will be more and more required in the future. Storage and transport stages are both considered less critical compared with the previous ones. This result is not aligned with the literature outcomes that underlines a certain level of criticality for these stages of the SC. A possible reason could be that companies have already established effective and efficient strategies for the inventory management and for the transport of their products and batteries, thus they are more easily able to deal with battery in these SC stages. Finally, more that 61% of the respondent strongly agree and almost 20% of them agree about the criticality of the recycling. In fact, the recycling of the battery is not a well-established process, and a lot of research has been undertaken in the field. Nowadays it often requires high quantity of reagents, high quantity of energy for separating rare and precious materials [41]. Therefore, it is still a huge challenge for car companies to efficiently manage this process.

Table 2. Survey Outcomes

Item		**1 strongly disagree - 5 strongly agree**				
		1	**2**	**3**	**4**	**5**
Battery as crucial cost driver for EVBs		0,00%	9,68%	12,90%	22,58%	54,84%
To what extend these stages can be critical in battery SC	Procurement	0,00%	6,45%	6,45%	12,90%	74,19%
	Production	0,00%	3,23%	19,35%	25,81%	51,61%
	Storage	3,23%	22,58%	38,71%	12,90%	22,58%
	Transport	9,68%	12,90%	22,58%	22,58%	32,26%
	Recycling	0,00%	0,00%	19,35%	19,35%	61,29%
The extraction of raw material in Europe can support battery SC		0,00%	0,00%	12,90%	22,58%	64,52%

Finally, respondents were asked to express their level of agreement with the potential support of extracting raw material in Europe. The obtained result is coherent with the opinion related to the procurement stage. There is a high level on agreement about the opportunity of having raw materials in Europe. The shared perspective is that this raw material proximity could become a lever to relieve the dependency from Far East companies and in turn to simplify the level of complexity of battery SC with positive effect for European car manufacturers and for their customers [42].

In the last part of the survey respondent could mention some relevant solutions and issues that should be undertaken in order to more effectively face the investigated challenges in the battery SC in Europe. The results show that four different areas of interest can be identified.

First, European Community should financially support applied research in the field so that to make more autonomous the local automotive sector: *"Searching alternative solutions (Hydrogen)"*. In fact, the Hydrogen is a quite promising solutions in the next years for powering electric vehicles, and it is expected that it could be more largely adopted from mid 2030s [43]:*"Massive investments from governments and EU"*. The European Commission already heavily support the EV market for the consumers' perspective and funds a lot of research projects aimed at developing innovative technological solutions in the field under study [44]. In addition, policy makers are called to simplify the administrative paperwork for the process of extracting raw materials: *"Make mining licenses less bureaucratic"*; *"faster permitting"*. Actually, it is worth underling that especially licensing processes require the acquisition of a large amount of data that need to be deeply analyzed in order to accurately evaluate the potential negative environmental impacts [45]. However, policy makers should always pay attention to social aspects associated with mining activities: *"mining in human conditions"; "Develop fair and sustainable extraction of these raw materials"*. Finally, the fourth aspect refers to the circular economy and to recycling processes: *"Battery technology with less rare materials"; "Increase local procurement and production"; "To assemble in house"; Circular business cycles, battery degradation reuse, research on how to recycle the batteries".* These issues have been gained growing attention from research, industries, and policymakers [46] since they are considered practices that can foster the reduction of the environmental effects and at the same time the maximization of the resource efficiency [47].

These results show a high level of complexity associated with the SC for the batteries, especially in relationship with the procurement and the recycling stages. This complexity is quite difficult to be managed and it requires the involvement of a plethora of stakeholders as the respondents have underlined in the proposed questionnaire. In particular, the procurement can be made less critical via active programs implemented by the public policy maker that might support this process with easier administrative paperwork. On the contrary, research activities aimed at developing innovative technologies for both recycling and reusing should be carried out by automotive companies, together with universities and research centers that are increasingly interested in these topics. Another important aspect might be referred to the fact that the SC under study is not completely well established yet. Specifically, the battery SC is expected to have more companies operating in this industry, at different levels of the SC with a market less concentrated in the Far-East area.

5 Conclusion and perspectives

This paper is aimed at investigating the main stages of the battery supply chain in the electrical vehicle arena. To this end, a survey questionnaire was developed and administrated to an identified sample of experts. In particular, the objective is to capture the perception of professionals working in the European car industry about the level of criticality associated with the main stages of the SC at an issue. The results highlight a general relevant level of criticality and concern about the managing the SC in particular considering the procurement, the production and the recycling processes. On the contrary, transport and storage are viewed as less critical. In addition, it is worth mentioning the cost, still seen as a critical driver for electric vehicle. These results might also depend on the high volatility of market price for specific materials (e.g. lithium and cobalt) [23].

The proposed study can be considered as a support for car manufacturers for prioritizing their strategic actions to be aligned with the challenges in the battery SC. However, this support should be implemented in a systemic way, considering all the stages of the SC from the extraction of the raw materials to the final reuse of recycle of the batteries. In this sense, policy makers should include the critical SC aspects in designing their policies in order to support European car industry that is exposed to high level of uncertainties. In particular, attention needs to be given to applied research focused on exploring alternative materials to the lithium so that to reduce the European dependency from other continents.

Furthermore, it is crucial to have closer suppliers for rare, critical, and costly materials. This would make the SC more flexible, resilient, and efficient. In fact, several mining companies are emerging in Europe aiming at directly providing raw lithium to European car manufactures [48]. These companies should be effectively supported by European public authorities, not only from a financial perspective, but also in terms of leaner bureaucratic and administrative paperwork. In this way, the production of battery in Europe will be also able to create a relevant number of jobs. Specifically, European car manufacturers are expected to shift from a buy strategy, where batteries are purchased as finished product to a make one, in which industries develop vertical integration that allows to gain autonomy, to limit risks, and to increase the capability of human resources employed in these sectors. Consequently, the issue of dramatic job loss that is expected due to environmental transition could be relieved. This transition should consider both environmental and social impacts of the whole SC, such as the energy required to produce cells, the often-unregulated working condition, and the material extraction stage [49]. Finally, as a final crucial point to make easier the adoption of EVBs, policy makers are called to develop broad charging grids for effectively boost the market.

This paper originates both theoretical and practical implications. From a theoretical point of view, this study represents a contribution in the field of the study of the SC in the automotive sector focusing on the management of the battery. This is a very important research field with an increasing number of contributions. Indeed, this paper highlights the need to accurately design this SC, in the light of the massive transformation that this industry is facing, especially in Europe. Thus, it might stimulate further studies focusing on the most critical stages of the SC and on the alternative business models here highlighted.

From a practical perspective, the proposed research might increase the awareness about the criticality of the SC of the batteries in the electric transition of mobility. Thus, it can facilitate policy makers in more accurately design the policy related to the support to automotive industry that might be implemented at the different levels of the SC, and by using different drivers (legal, administrative, fiscal, economic). In addition, this paper might support car manufacturers in the design of a more reliable and less risky SC for the battery that is the most important component and highest cost element for an electric vehicle.

However, this paper suffers from some limitations. In particular, the survey items related to the literature review, considers the SC stage in a very general way, without entering more in detail in the main activities associated with every step. In addition, the sample size was limited to some car manufacturers professionals. Future studies will be addressed to more deeply investigate the processes related to the here considered SC stages, and to enlarge the sample size by including more respondents, and other professionals operating in companies producing batteries and battery's components. Moreover, other stakeholders will be included, such as public policy makers that in this industrial field have been played a crucial role.

6 Acknowledgement

This work was developed in collaboration with Paul Grieumard, Lea Issa and Valentine Pyt, master students at the Industrial Engineering Department of INSA Lyon.

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