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Lithium in Portugal. From an opportunity to a (hidden) threat?

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Lithium in Portugal. From an opportunity to a (hidden) threat?

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Dissertation

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Supervisor:

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Biographical Note

Elma Ticiana Silva Pereira, born in Mafamude, Porto district, on 26 June 1994.

Graduate student of Languages and International Relations, currently undertaking a Master in Environmental Economics and Management.

Trainee at the Portuguese Delegation to the OECD between September 2015 and March 2016, to where she came back last year to work in the area of Economic Diplomacy, for a one-year period. She is in charge of coordinating positions with different Ministries in Lisbon, drafting and preparing relevant documents, such as proposals, presentations, reports, and summaries of meetings as well as preparing speaking points for oral interventions and attending meetings.

In the meantime, during 2016 and 2017, she volunteered to work for AIESEC, an international non-governmental not-for-profit organization. Initially she worked in the Human Resources Team where she was responsible for coaching and talent and expectations management. Later she assumed the Public Relations Department Manager post where she had the opportunity to develop several assignments like being in contact with the Media, creating national B2C content, organizing and supervising events, managing the database and developing strategies to promote and present the Organization.

Co-founder of the NERI-UP, the *Núcleo de Estudantes de Relações Internacionais da Universidade do Porto*, she assumed the position of Responsible for the Culture and Solidarity Department, between September 2014 and June 2015, being in charge of the organization and supervision of charitable and cultural events.

In her free time she enjoys travelling and meeting new people, taking great interest in every day's social matters, arts and learning new languages.

Dancer, passionate environmentalist, blood donor and sports lover, Elma dreams of a better world, where people and Nature may live in harmony and balance.

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Abstract

The growing demand for lithium to feed electric vehicles (EVs) is a market in ascension and has potentiated the economic viability of some lithium deposits worldwide, as it is the case of Portugal.

The European market of EVs will be particularly relevant and significant for Portugal. Having the biggest lithium reserves in Europe, Portugal is in the position to take this momentum as an opportunity that will most likely trace the future of the country in terms of competitiveness.

The Portuguese Government is giving attention to this matter, having already created a working group to conclude if exploring this metal in Portugal is viable or not. However, the study only contemplates economic variables, briefly mentioning the importance of preserving the ecosystems and the environment. And, as is well known, an opportunity is always hand-in-hand with a threat. It is important to be aware of all the possible harms this massive extraction can generate to the environment and general public health.

A life-cycle assessment, in this case focused on the extraction phase, is thus a feasible tool to account the externalities caused by an extraction process and therefore formulate a strategy capable of contemplating all the associated variables, measuring their impact and consequently influencing the decision making process.

Through adaptation of literature, some environmental and health impacts are estimated for the Portuguese extraction of lithium case clearing the way for future, more realistic and more sophisticated research.

Keywords: Lithium, Life-cycle Assessment, Electric Vehicles, Portugal, Opportunity, Threat, Environmental and Health Impacts

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1. Introduction

In the light of the Paris Agreement, and taking into account that the world where we live is constantly changing, it is important to find smart solutions that accommodate the well-being of each and every individual.

During the United Nations Climate Change Conference, commonly known as COP21, countries agreed a rapid energetic transition is necessary as a response to the climate change threat (Baron, 2016). During the conference held in Paris the theme sustainable transport was heavily discussed as one of the ways to go on and fight for a new future, keeping in mind the need to find smart solutions and to invest largely in technology and research to meet the sustainable development goals, at the same time as the well-being of each and every individual are taken into account (Mellino et al, 2017).

Furthermore, the growing concerns about air quality, global warming, acidification and smog are a driving force to a transition to cleaner technology in what relates to transportation (Mellino et al, 2017). Believed to be the more environmentally friendly and suitable solution, there has been a growing investment in the electric powered vehicles industry in terms of research and new technology (Mellino et al, 2017).

However, remains the need to certify if all life-cycle of an electric vehicle is the cleaner option we may have, since these vehicles require a set of electronic devices that may bring new environmental problems.

In this regard, this dissertation will focus on the use of lithium to produce the electric batteries needed to power these vehicles, analysing all the life-cycle in using a resource (Epstein et al, 2011). Each stage in the life-cycle of a metal – extraction, transport, processing, use and final waste management – generates a stream of waste and carries health and environmental consequences (Epstein et al, 2011). These costs are considered "externalities" of the resource mining operation and disposal industry, having, sometimes, a cumulative action (Epstein et al, 2011). Examining all the mentioned stages is crucial to account all the inherent costs and to guide public policy and investment (Epstein et al, 2011).

A bibliographic and documental research will be carried out regarding the exploitation and use of lithium and its waste management, along with an analysis of lithium deposits and reserves present in the world and in Portugal, and some of its cradle-to-grave costs.

In order to guide the action of governments and the private sector, it is not only important to analyse the economic benefits of a certain activity, but also all the impacts it will have in the environment and society.

Based in this premise, this dissertation proposes a combined analysis of two studies to better understand how Portugal could benefit from its insights, regarding the fact that the Portuguese authorities received more than 30 requests from prospection and concession (GTL, 2017).

In chapter 2, this dissertation clarifies what a life-cycle assessment is along with some of its variants, emphasizing specifically the application of a life-cycle assessment to the case of lithium.

In Chapter 3, lithium is presented as a metal in terms of its mechanical and physical properties and main uses. The chapter focuses also the difference between a resource and reserve, the demand for lithium to be used in electric vehicles and the life-cycle of this resource.

Chapter 4 focus the specific case this dissertation analyses – the case of Portugal and more precisely the case of the Sepeda project. The potentialities of exploring lithium in Portugal are presented in this chapter along with Portuguese geological context. Details about the Sepeda Project are also presented as well as a section identifying the pros and cons of exploring lithium in Portugal, in an adaptation to the case of the mentioned project. It is also presented the methodology of work and consequent obtained results. This dissertation uses especially two papers, one from Epstein et al. (2011) in what concerns the life-cycle assessment and full cost accounting of coal, adapting it to the case of lithium; and another from EPA (2013), a life-cycle assessment of three lithium-ion batteries developed to identify which stage impacts the most the environment and human health, based on a cradle-to-grave approach.

The present dissertation seeks to call for attention about the growing demand of lithium that will have unpredicted consequences for Portugal, the most important country in Europe concerning lithium reserves, and the consequent possible impacts of its extraction for the environment and human health. It strives to broaden the view on the importance of implementing a life-cycle assessment and considering the impacts of all stages of a product manufacture, many times cumulative, to the environment, in an attempt to inform decision makers and make them assume responsibility for their informed decisions.

This subject is extremely interesting and future-oriented once it reflects an environmental trend: the way people and industries will deal with the growing need for this scarce resource and how to treat the resulting products and waste.

2. Framework

2.1 The Life-cycle Assessment as an Analytical tool

As the society became more and more concerned about the environmental impacts of some activities and resource depletion, companies are increasing their environmental awareness and responding to this consumer pressure with greener products, processes and services, and at the same time trying to minimize the impacts on the environment. Companies understood they have to follow consumers pace and respond to their needs and wills and they are day-by-day building new strategies and tools to undermine pollution and manage their environmental performance (SAIC & Curran, 2006). An analytical tool of this nature is precisely the Life-cycle Assessment (LCA).

The Life-cycle Assessment is an analytical tool widely used to assess environmental impacts across the full life-cycle of a product, process or activity, from materials acquisition, encompassing the extraction and processing of raw materials, to manufacturing, product design, transportation, distribution, use, final disposition and maeby recycling. At the same time, it assists the process of decision making and the settlement of environmental policies and regulations (Domènech et al., 2002; Almeida et al., 2010; EPA, 2013; Curran et al., 2016; Özkan et al., 2016; Mellino et al., 2017). It is capable of leading to an improvement in consumption and production (Fava, 2002; Levasseur et al., 2010). Figure 1 summarizes the stages involved in an LCA (SAIC & Curran, 2006).

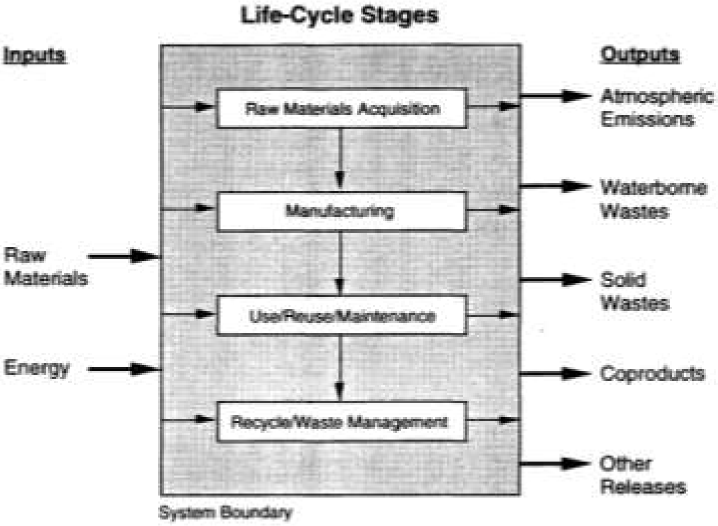

Figure 1: Life-cycle stages.
Source: Vigon et al. (1993), page 17

LCA evaluates all stages of a product's life and it considers all the stages are interconnected, enabling an estimation of the cumulative environmental and health impacts that result from all stages, including impacts not always analysed in the traditional studies, from the raw material's extraction and transportation to the disposal, thus providing a comprehensive view of all the life and all the environmental trade-offs and implications (Domènech et al., 2002; SAIC & Curran, 2006; Hossain et al., 2007; Levasseur et al., 2010; Graedel & Lifset, 2016; Byrne et al., 2017).

The concept and application of the life-cycle assessment tool has developed a lot over the past decades, from a mere energy analysis to a wide-ranging environmental analysis (Klöpffer, 2006; Guinée et al., 2010), gaining more impetus in the 21st century (Guinée et al., 2010).

Figure 2 shows the evolution in the number of articles mentioning LCA published in the Environmental Science and Technology Journal, since its first edition (Guinée et al., 2010).

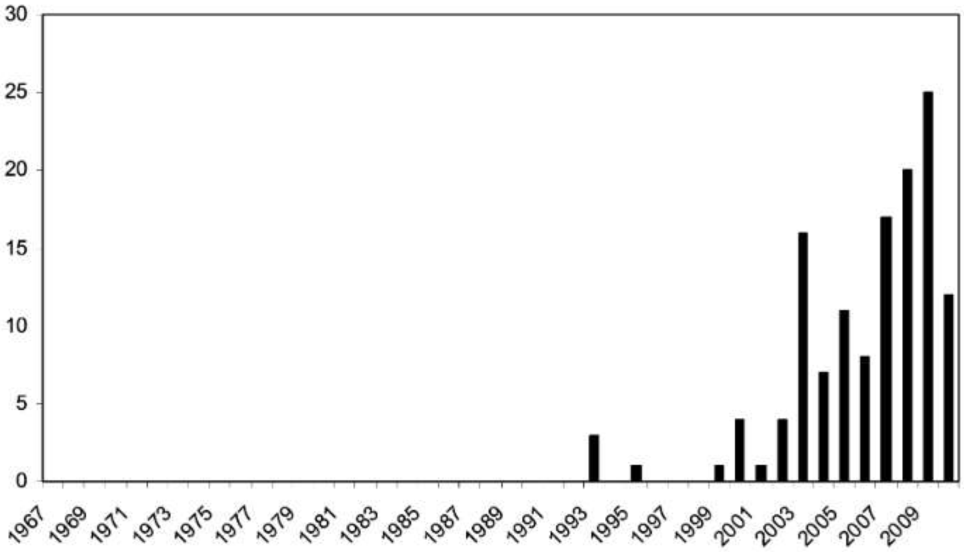

Figure 2: Histogram of the number of articles mentioning LCA in the Environmental Science and Technology Journal, since its first edition.
Source: Guinée et al. (2010), page 91

With the latest LCA developments came also the creative use of this tool, being applied to areas like military systems and tourism and expanded to non-conventional categories like noise, biodiversity and social impacts, a real "booming in application, breadth and depth" (Guinée et al., 2010, p. 90).

Actually, life-cycle assessments were being performed in many European and North American countries "before the name was coined" (Klöpffer, 2006, p. 116). The first analytical studies on LCA date from the late 1960s/early 1970s, a period in which there were efforts being made in terms of quantifying resources loss and when environmental impacts were getting public attention (SAIC & Curran, 2006; Guinée et al., 2010; Graedel & Lifset, 2016; Ling-Chin et al., 2016). During the 1970s and when the oil-crises took place this raising concern weakened but the interest rapidly grew in the early 1980s and so on, with a still not very well understood increase in the demand for impact studies (Klöpffer, 2006; Guinée et al., 2010). In the 90s LCA grew rapidly as well as its "relationship with industrial ecology" (Graedel & Lifset, 2016). These decades are known as the "decades of conception" of the LCA tool, characterized by "diverging approaches, terminologies and results", with a "clear lack of international scientific discussions and exchange platforms", without a common theoretical basis (Guinée et al., 2010, p. 91).

As for the 1990s to 2000s, the "decade of standardization and convergence", there were remarkable international efforts on coordinating scientific activities like forums and workshops and in the production of guidelines and handbooks, with the view of mainstreaming the tool to be widely used in the identification of possible environmental impacts of a product or system (Klöpffer, 2006;; Guinée et al., 2010; Ling-Chin et al., 2016). A result of this joint work was the "SETAC[1] Code of Practice" in 1993 (Klöpffer, 2006; Guinée et al., 2010; Graedel & Lifset, 2016). It focused on the "development and harmonization of methods", and the involvement of the International Organization for Standardization (ISO), more on the formal task of standardizing "methods and procedures" and defining the "methodological framework" (Guinée et al., 2010, p. 91). Two workshops were organized, one in the United States and the other in Europe in order to "bring together the groups working on life-cycle based assessment methods" once "methods were not really new but uncoordinated and far away from a harmonization" (Klöpffer, 2006, p. 116). After that, two international standards in what regards LCA were established, the ISO 14040 and the ISO 14044, with a last revision dating from 2006. These standards identified four interconnected LCA phases: 1) goal and scope definition, 2) life-cycle inventory (LCI), 3) life-cycle impact assessment (LCIA) and 4) interpretation of the results (Domènech et al., 2002; Guinée et al., 2010; Rostkowski et al., 2012; Ling-Chin et al., 2016; Byrne et al., 2017). Figure 3 schematizes these four phases:

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[1] Society of Environmental Toxicology and Chemistry (Guinée et al., 2010)

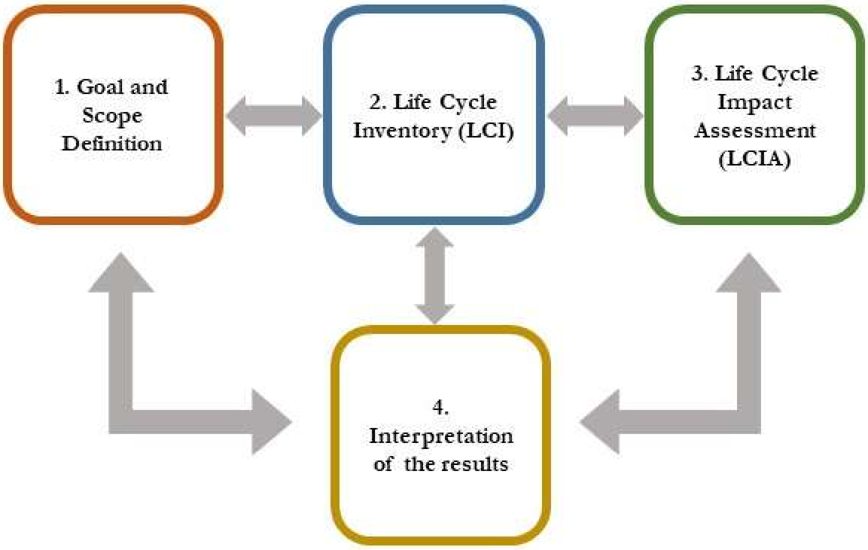

Figure 3: Life-cycle Assessment stages.

Source: Own elaboration based on information from Domènech et al. (2002), page 5518, and Guinée et al. (2010), page 92

1) The scope "depends on the subject and intended use of the study" (ISO, 2006, p. v) and its main function is to detail the study – functional unit, boundaries, assumptions, data requirements and quality, impact categories, LCIA categories and limitations, for example (Ling-Chin et al., 2016). In defining the goal, it is required to report very clearly the reasons for applying this methodology to the specific analysis, the intended application and the target audience (Ling-Chin et al., 2016);
2) The LCI analysis, the second phase, is "an inventory of input/output data with regard to the system being studied", involving the "collection of the necessary data to meet the goals of the defined study" (ISO, 2006, p. v). The LCA requires the compilation of an "inventory of relevant energy and material inputs and environmental releases", an evaluation of "the potential environmental impacts associated with identified inputs and releases" and an interpretation of "the results to help decision-makers make a more informed decision" (SAIC & Curran, 2006, p. 2). It is, in summary, an inventory of processes and flow of materials (Rostkowski et al., 2012);
3) The LCIA, the third phase, aims at providing "additional information to help assess a product system's LCI results so as to better understand their environmental significance" (ISO, 2006, p. v) and to calculate the quantities of inputs and outputs of the system and assess identified global impact categories (Domènech et al., 2002;

Ling-Chin et al., 2016). It is, indeed, a summary of impacts per category (Rostkowski et al., 2012);

4) The final phase, the life-cycle interpretation, is where all the inputs are converted in outputs to draw some conclusions after careful analysis (Ling-Chin et al., 2016). It constitutes "a basis for recommendations and decision-making in accordance with the goal and scope definition" (ISO, 2006, p. vi).

It is possible to run an LCA by performing only an LCI analysis and consequent interpretation, without the LCIA phase, what is usually called an LCI study (ISO, 2006).

During the first decade of the 21st century, "the decade of elaboration", attention on the LCA tool increased (Guinée et al., 2010, p. 92). The United Nations Environment Programme (UNEP) and the SETAC launched an International Life-cycle Partnership known as "the Life-cycle Initiative" aiming at "putting life-cycle thinking into practice and improving the supporting tools through better data and indicators" (Guinée et al., 2010, p. 91), and "to develop and disseminate practical tools for evaluating the opportunities, risks, and trade-offs, associated with products and services over their whole life" (Fava, 2002, p. 197). For the various impact categories, the Initiative aimed at establishing methodologies and guidelines and making results and recommendations available to users worldwide (Rosenbaum et al., 2008). In this context, identifying and quantifying the impacts on human health and on the ecosystems due to toxic substances is central for future work (Rosenbaum et al., 2008).

Also during this period, the environmental policy across the world became more life-cycle centred (Guinée et al., 2010), with the application of this analytical tool in the decision-making process (Fava, 2002). It was a period "characterized by a divergence in methods" once ISO never standardized in exact detail the LCA method and as there is "no common agreement on how to interpret some of the ISO requirements" (Guinée et al., 2010, p. 92). "These different approaches have the life-cycle basis in common, but they differ in methodological elaboration and in the question(s) they are addressing", remaining the need to "better structure the approaches to LCA" and "take into account more types of externalities and more mechanisms" (Guinée et al., 2010, p. 92).

While some changes and progresses are visible in terms of "implementing and integrating environmental and social aspects into decision-making", many decisions are taken with no consideration to all the possible impacts (Fava, 2002, p. 198).

It is known for many products the main environmental burden is not in the use phase but in its production, transportation, distribution or disposal phases (Guinée et al., 2010). For this reason, assessing just one phase "do not always lead to an overall reduction in environmental impacts", once we cannot focus only in a "single stage in the life-cycle of a product" (Fava, 2002, p. 197). Even recycling "has its own environmental effects" as it is an industrial process, but they are "generally smaller than those from primary production" (Gaines, 2014, p. 2). Life-cycle tools are then extremely vital for an ecological sustainability and development, and are being increasingly applied "to estimate the impacts of products throughout their life-cycle" (Fava, 2002, p. 197).

LCA is thus an unique tool capable of encompassing all processes, product design, resource consumption and environmental releases, helping to guide the environmental performance, identify opportunities for pollution prevention and choose the one with the lowest impact on the environment and biodiversity (SAIC & Curran, 2006; Hossain et al., 2007; Rostkowski et al., 2012; Curran et al., 2016). Information can be used in combination with other factors like cost and performance, recognizing the transfers of materials, energy and most of all impacts across the stages (SAIC & Curran, 2006).

However, to implement an LCA, we need not only significant time and effort for implementation, but also solid and valid data on the impacts, what is not always easy to acquire and collect (Levasseur et al., 2010; Basbagill et al., 2013). It is then important to bear in mind that many times the "hidden costs" could substantially raise the real cost of a product if we could account them all (Fava, 2002, p. 198).

"The beauty of LCA is not necessarily in its objectivity", but its capacity of making us think about the environment and the way we can affect it, "allowing us to consider our decisions more carefully and to tread a bit more lightly on the earth". (Schnoor, 2009, p. 2997).

2.2. Variants of the LCA Tool

As a tool to analyse the various stages of the life-cycle of a product, LCA can be applied from different perspectives that depend mostly on the definition of the boundaries.

When we are thinking about the LCA analysis *per se*, a whole life-cycle analysis, we are thinking about an assessment that begins in the extraction of natural resources from the ground and comprises the manufacturing of the product, transportation, actual use and finally ends at the disposal stage, an approach usually called "cradle-to-grave" (SAIC & Curran, 2006; Glavič & Lukman, 2007). This approach has the assumption of an "one-way", a "linear flow of materials" coming from extraction, transform them and eventually dispose them, knowing they can be recycled despite not being specifically designed for it (Braungart et al., 2007, p. 1337). It assumes "the transformation of resources into waste and the Earth into a graveyard" (Braungart et al., 2007, p. 1338). It is possible to extend the life of a product and "prolong the period until resources acquire the status of waste" by increasing the product's durability, reducing quantities, velocities and toxicity of the waste, or giving it a second use (Braungart et al., 2007, p. 1338).

This approach is commonly connected with the concept of "eco-efficiency" that echoes the need to "reduce the unintended negative consequences of processes of production and consumption" (Braungart et al. 2007, p. 1337). In the short-term eco-efficiency may really help on the reduction of ecological and resource consumption of a certain business activity and provide an opportunity to reduce costs, but in the long-term it is insufficient to achieve the objectives once it addresses the problems instead of the source (Braungart et al., 2007; McDonough et al., 2003).

As already pointed, when applying a cradle-to-grave approach we can analyse the impacts along the various phases and consequently avoid or minimize them, but we always create waste and we dispose it, losing value. In this context and as a response, a new concept emerged – the cradle-to-cradle approach, which is a life-cycle analysis of a product from the resource extraction, skipping the disposal phase and jumping to recycling, until the reintroduction of this recycled resource as a new input in the stream (Glavič & Lukman, 2007). It is indeed "the elimination of waste by recycling a material or product into a new or similar product at the end of its intended life, rather than disposing of it" (DuPont, 2008, p. 1). The term is often related to industrial ecology "because both terms are designed to mimic nature, where everything is used and nothing becomes a waste", maximizing "the material value without damaging ecosystems" (Glavič & Lukman, 2007, p. 1882).

On this premise, the book "Cradle-to-cradle: remaking the way we make things" from McDonough & Braungart published in 2002, defends that "the current paradigm of 'cradle-to-grave' product development is unable to provide a solution to the world's current ecological crisis" (Reay et al., 2011, p. 36). McDonough & Braungart, according to Braungart et al. (2007), introduced the notion of "waste as food" meaning waste is used as raw material – products after being used are considered food for other products or uses, an idea of recycling and reintroducing waste in the stream, giving it a second-life, turning it into a new product or giving it a new use (Braungart et al., 2007). It is the real and complete notion of a life-cycle assessment that includes reducing, reusing and recycling and that does not accept the notion of "waste" (Braungart et al., 2007).

The cradle-to-cradle approach is described by McDonough & Braungart, according to Reay et al. (2011), as an "industrial revolution", suggesting industry needs to address over-consumption and waste in accordance to the eco-effectiveness approach (Reay et al., 2011, p. 37). This approach is "an alternative design and production concept to the strategies of zero-emission and ecoefficiency" that seeks the "conception and production of goods and services that incorporate social, economic, and environmental benefit" (Braungart et al., 2007, p. 1337), under the condition of keeping the status of resources as "productive resources" throughout their life (Braungart et al., 2007, p. 1338). This eco-effective approach has the vision of zero waste, "even if enormous amount of waste were generated" (Reay et al., 2011, p. 37). All outputs, if we ensure their "quality and productivity" through "subsequent life-cycles", can become inputs in other process (Braungart et al. 2007, p. 1337). The primary objective is the "transformation of products and their associated material flows such that they form a supportive relationship with ecological systems and future economic growth", by increasing the value of the economic output and at the same time decreasing the adverse ecological impacts (Braungart et al., 2007, p. 1338). Moreover, it intends to design industrial systems "to be commercially productive, socially beneficial, and ecologically intelligent" (McDonough et al., 2003, p. 435A).

McDonough & Braungart, according to Braungart et al. (2007) rested their thinking in the nature and in its ability to regenerate, as there are some similarities between biological organism's metabolism and industrial activities: "the synthesis and breaking down of substance for the maintenance of life" (Braungart et al., 2007, p. 1342). It is based also on the premise that all human activities may have a positive impact, guaranteeing we are able to develop a more diverse cultural and ecological world (Reay et al., 2011, p. 36). In this context, biodegradable materials are good for the environment and have the characteristics to fulfil this eco-effective scenario as they are absorbed by the Nature even when they are disposed, but synthetic materials may also fit the requirements if they remain in "a closed-loop system of manufacture, recovery and reuse to maintain their material value through many cycles" (Braungart et al., 2007, p. 1343).

We can then compare these two variants of a LCA assessment, the cradle-to-grave and the cradle-to-cradle, and the two respectively connected approaches, the eco-efficiency and eco-effectiveness, the first focusing on the assumption of industry as 100% bad, the second on industry as 100% good (Braungart et al., 2007).

But there are some "middle ground" theories and approaches. One of them is the cradle-to-gate, a partial life-cycle assessment that examines the environmental impacts of some stages, beginning at the extraction of raw materials and going to the factory gate (before transportation), excluding, usually, the use and disposal phases (Jiménez-González et al., 2004; DuPont, 2008; Almeida et al., 2010; Robertson et al., 2012; Russell-Smith & Lepech, 2015; IWTO, 2016). It may be split into two domains: from raw materials production to supply or a gate-to-gate approach "which brings the opportunity to the analyst to classify, characterize, and evaluate the impacts separately in two domains according to the needs" (Hossain et al., 2007 pág. 8794). It is, in summary, the assessment of just part of the life-cycle of a product including the extraction of resources and production and excluding the use and/or end-of-life stages (WBCSD & WRI, 2011). It includes "all emissions and removals from material acquisition through to when the intermediate product leaves the company's gate" (WBCSD & WRI, 2011, p. 37). The use of the product is not considered and therefore "the process map ends when the studied product is a finished intermediate product, typically when it leaves the production stage" (WBCSD &WRI, 2011, p. 41). An analysis like this one, that excludes one or more stages, ignoring the full-range of impacts, upstream and downstream, is therefore very limited (UGB, 1996).

Figure 4 summarizes the three variants of an LCA in analysis.

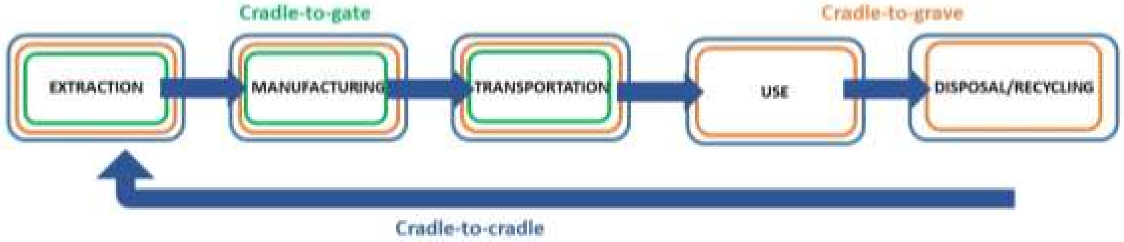

Figure 4: Summary of LCA variants mentioned in this work.

Source: Own elaboration.

There are even more variants of an LCA study than a cradle-to-grave, cradle-to-cradle and cradle-to-gate, all different in what regards the boundaries, but always with something in common – the goal of analysing the life stages of a product is to evaluate their single and cumulative impacts on the environment and therefore inform the public authorities and private stakeholders in order to implement measures to avoid, mitigate and compensate those impacts.

This LCA approach and its variants can be applied to many areas, as already mentioned, one of them being, of course, the lithium exploitation, theme of this work.

Uncertainties and risk assessment play an important role in the use of lithium in order to evaluate under what conditions environmental would offset the environmental benefits (Stamp et al., 2012). For this reason, the risk assessment on the use of lithium should be accompanied by a strict life-cycle management and auditing (Hawkins et al., 2013).

3. Lithium, the new gold[2]

3.1 The metal

Minerals can be divided into metallic (require a processing stage to create a concentrate; "the chief raw materials for the manufacture of metals") and non-metallic (can be used as extracted; "not used for the manufacture of metals") (Habashi, 2017, p. 1). Lithium is considered a metallic resource, more specifically an alkaline metal from the Group 1 of the Periodic Table. It was discovered in 1817 by Arfvedson, in Stockholm, and its name comes from the Latin lithos (rock) (Tarascon 2010a). Under normal conditions of pressure and temperature it is the lightest and less dense metal among solid elements, does not exist in nature in free form due to its high reactivity, is highly flammable, has a high specific heat and a high electrochemical potential (Tarascon, 2010a; Martins, 2011; Martins et al., 2011; Swain 2017). Table I in Annex summarizes some of lithium more specific characteristics.

Lithium, a scarce resource, is a natural component of the Earth with an average abundance of approximately 12ppm in the crust and 1.4ppm in the mantle (Lima et al., 2011a; Leite, 2017).

Due to its mechanical and physical properties, lithium is directly used in ceramics, in the form of concentrates, not only to lower the melting points but also to reduce the coefficient of thermal expansion and lower the viscosity, allowing the elimination of other toxic products (Lima et al., 2011a; Martins, 2011; Oliveira & Viegas, 2011; Leite, 2017). This market of ceramics requires steady and not high levels of lithium (Amarante et al., 2011)[3].

Besides this direct use of lithium, it can be processed for more specific and technological ends (Leite, 2017; Martins, 2011). Lithium is used in metallurgy and also in lubricating greases, due to its melting point and conservation of heating properties, lithium is used to thicken greases (Guberman, 2017; Ober 2018; Hocking et al., 2016). In air handling and air conditioning systems, lithium is used in the form of lithium chloride or lithium bromide, because it has the ability of keeping constant levels of humidity (Guberman, 2017; Ober 2018; Hocking et al., 2016).

Lithium is also used in aircraft manufacturing, in the military sector, in pyrotechnics and rockets propellants industry, in non-linear optics, medicine, chemistry and pharmaceutics, to produce vitamin A, act as mood-stabilizing drug and to treat the bipolar disorder (Tarascon,

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[2] The idea of the title was taken from *Tarascon, J. M. (2010a). Is lithium the new gold?, Nature chemistry, 2(6), 510*

[3] It is possible to identify some categories based on these levels of lithium: i) "feldspar high Li content", petalite, <0,5% Li2O; ii) "glass grade spodumene", 4-5% Li2O, and iii) "high grade spodumene", 7,5% Li2O (Amarante et al., 2011, p. 45).

2010a; Gruber et al., 2011; Swain, 2017). Figure 5 shows the demand for lithium by end and application, from 2013 to 2025.

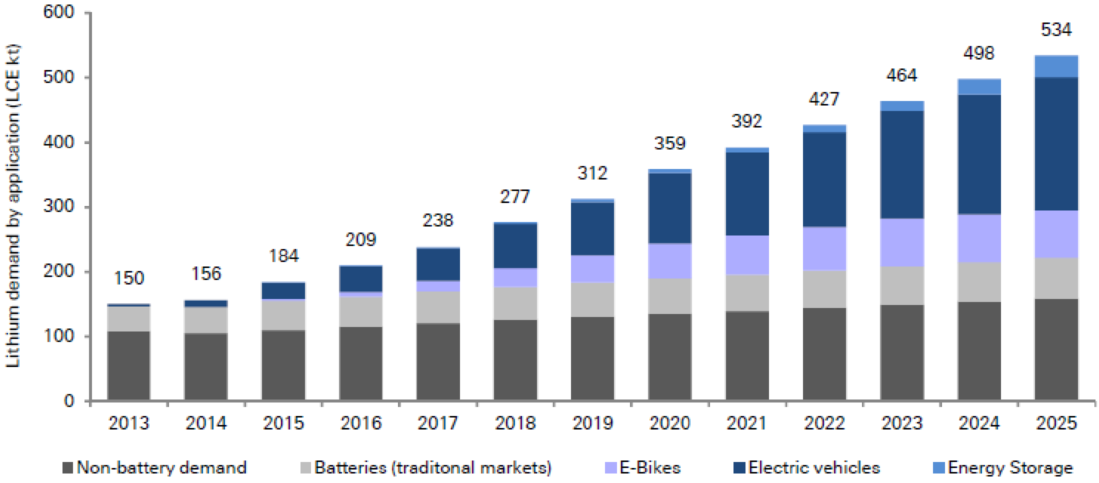

Figure 5: Lithium demand by end applications, from 2013 to 2025.
Source: Hocking et al. (2016), page 23

After understanding what is lithium and its uses, it is important to clarify from where it comes from.

3.2 Resources and reserves

The interest in lithium resources[4] suffered a dramatic change in mid-19th century and onwards "due to a series of innovations in the demand for portable energy" (Scrosati, 2011, p. 1624) and "the diffusion of consumer electronics" (Scrosati, 2011, 1626). Germany was the first producer of lithium from ores in Bohemia and Saxonia and later, in 1886, France initiated the production of amblygonite (Braga & França, 2011). In 1925, already on the 20th century, the German company Metallgesellschaft produced commercially metallic lithium from zinnwaldite and from 1930 and on, the USA started the production and commercialization of lithium by-products in North Carolina (Braga & França, 2011). A technological shift occurred in the 80s in the production of salts with lithium with the beginning of lithium carbonate production from evaporites with high levels of content, in Chile and Argentina (Braga & França, 2011). In Portugal, since 1990, the State became more

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[4] It is important to stress that in the context of this work the word "resource" does not have an economic sense, it is not "an economic or productive factor required to accomplish an activity, or as means to undertake an enterprise and achieve desired outcome (…)" (BusinessDictionary, 2018, accessed in 08/09/2018). In this context, a resource is "a concentration of naturally occurring solid, liquid, or gaseous material in or on Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible" (Ober, 2018).

active in the study and evaluation of mineral potentialities, assuming the responsibility on the riskier stages and technically helping and incentivizing enterprises to develop and modernize the sector (GTL, 2017).

As the interest in lithium is not new, it is important to understand its economical potentialities, and therefore it is important to make the distinction between a resource and a reserve. Broadly speaking, mineral deposits can be classified as resources, generally defined as "the geologically assured quantity that is available for exploitation", and reserves, "the quantity that is exploitable with current technical and socioeconomic conditions" (Vikström et al., 2013, p. 253). Reserves are important for production, while resources have little relevance for real supply, something that raises the importance of converting resources into reserves, meaning economically recoverable, before they can be produced and used by society (Vikström et al., 2013 GTL, 2017). It is also important to highlight that very few resources can be qualified as recoverable reserves. In what concerns lithium, the most known deposits are poorly explored, with no history of operation, many remaining to be discovered (Kesler et al., 2012).

The conversion of lithium resources into reserves will depend on "the degree of compartmentalization of reservoirs, the extent to which they can be recovered without dilution from recharge waters and degradation of salt-bearing reservoir rock, and whether other constituents, including potassium, magnesium, bromine and boron, restrict processing or the capacity of production to respond to changes in demand for lithium" (Kesler et al., 2012, p. 55).

Lithium deposits are of three main types: i) brine, a solution highly concentrated in salt and the most common deposit of lithium, ii) hard rock, known as pegmatites, and iii) sedimentary rock (Gruber et al., 2011; Martins, 2011). Figure 6 schematizes these informations.

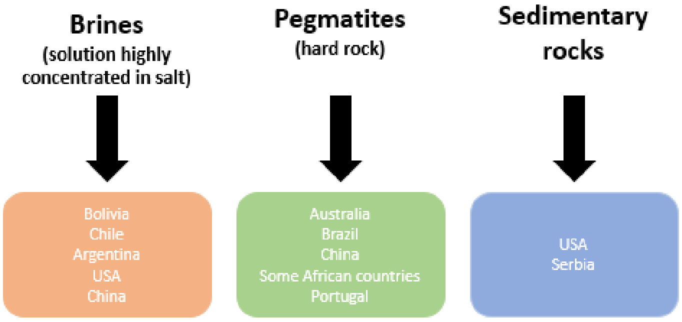

Figure 6: Types of lithium and main locations.

Source: Own elaboration.

Lithium exploitation from brines is more common and often considered a simpler and less costly extraction method, but generally with inferior results. Extraction of lithium from mineral deposits requires geological surveys and drilling through the rock, which can increase costs but also often results in higher product quantities (GTL, 2017). Figure 7 differentiates the processes associated with the treatment of lithium extracted from brines or pegmatites to produce lithium carbonate. In summary, this figure shows that the degree of complexity of the process of producing lithium carbonate depends on the type of deposit: extracting lithium from pegmatites to produce this carbonate is much easier than extracting it from brines.

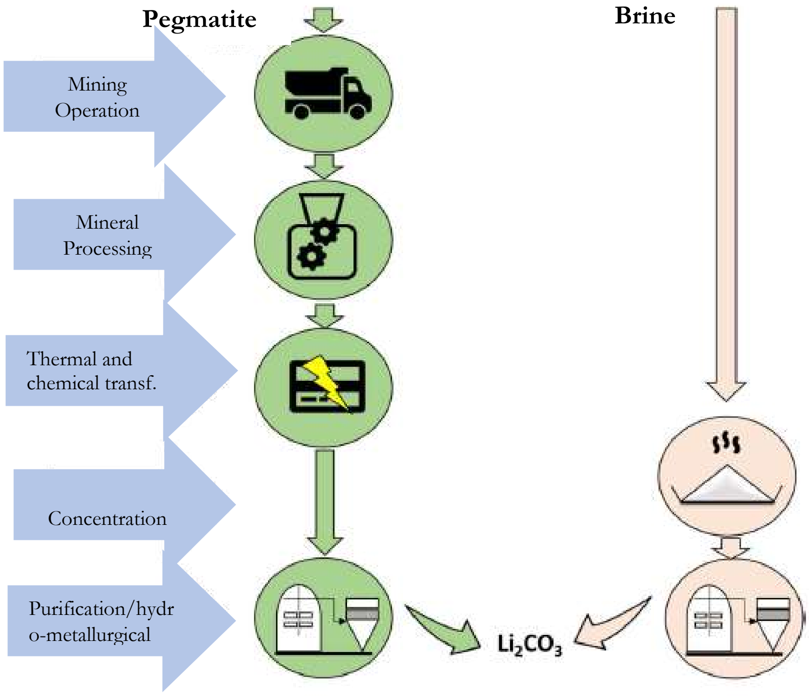

Figure 7: Production of lithium carbonate from pegmatites or brines.

Source: GTL (2017), chapter VII, page 2 (translation from Portuguese)

Brines can be found in the “Lithium Triangle” of Bolivia (*salar de Uyuni*, 10 000 km^2 unexplored), Chile (*salar de Atacama*) and Argentina (*salar del hombre muerto, Antofagasta de la Sierra*), and also in the United States and China (Hocking et al., 2016) (Figure 8). Here takes place the most economically profitable extraction (Narins, 2017; Martins, 2011). These areas represent approximately 70% of global lithium brine resources locations and they are, though, submitted to geostrategic and geo-economic bottlenecks – the duration of processing salt lake brines extraction and the consequent treatment is very long and inadequate to any short-term increase in the demand (Grosjean et al., 2012).

Pegmatites can be found in Australia, Brazil, China, some African countries and Portugal, and lithium in sedimentary rocks can be found in USA and Serbia (Gruber et al., 2011; Martins 2011; Martins et al., 2011; Swain, 2017) (Figure 8). The global distribution of these types of deposits is very disperse, and it is this wider geographic distribution of minor deposits and the low susceptibility to supply disruptions that allow them to remain of interest and capable to respond to market challenges (Narins, 2017)

Taking into consideration the major locations of the lithium deposits, Gruber et al. (2011) estimated that brines have 0.001 to 0.14% content in lithium, pegmatitic deposits 0.58 to 1.59% and sedimentary rocks 0.0087 to 0.27%.

Figure 8 presents a wide picture of lithium deposits around the world by deposit type and Figure 9 shows the lithium production in 2015, reserves and resources.

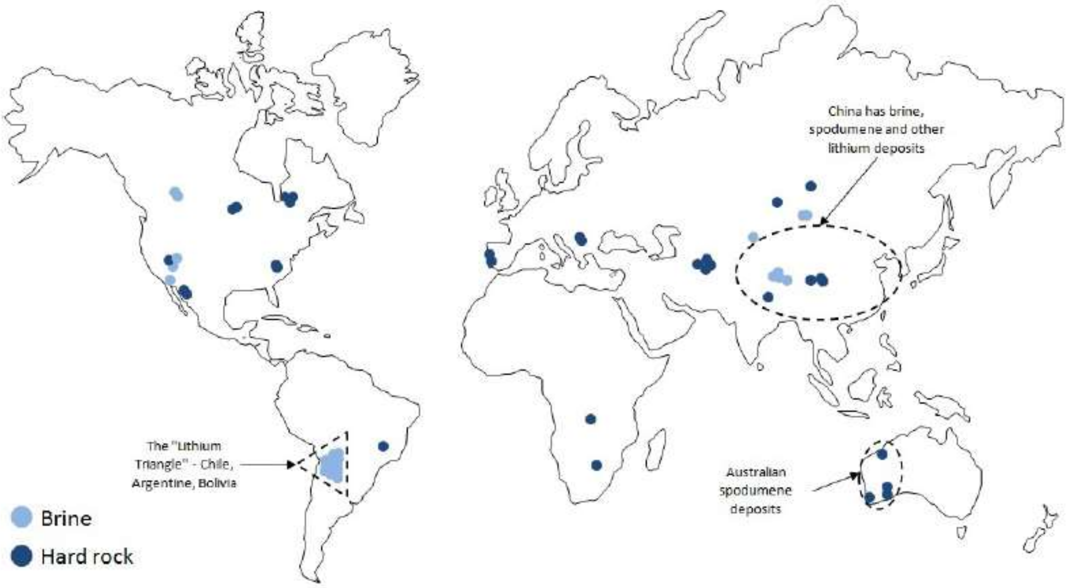

Figure 8: Lithium deposits in the world, by deposit type – brine and hard rock.

Source: Hocking et al. (2016), page 79

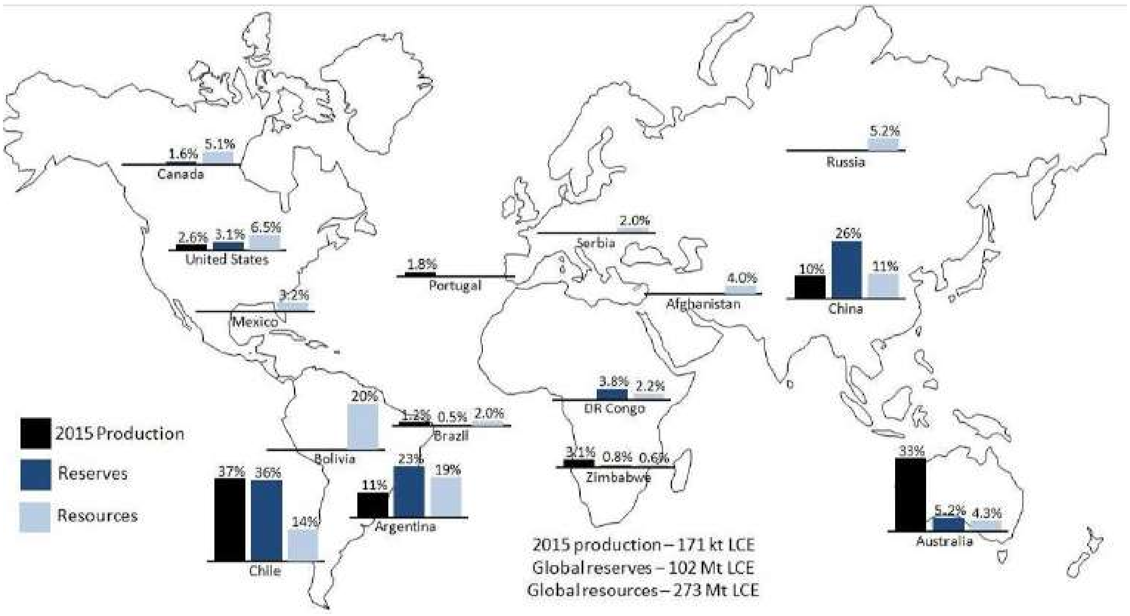

Figure 9: Lithium reserves and resources by country (2015).

Source: Hocking et al., (2016), page 79

A rise, already felt, in the price of lithium carbonate or hydroxide, induced by the growing demand for the mineral, will increasingly enable the referred less known and unexplored deposits to become economically attractive and viable, more specifically the pegmatitic deposits (Vieira et al., 2017). Moreover, new technologies are already being developed with the objective of reducing extraction, treatment and production prices in pegmatitic deposits (Vieira et al., 2017).

Figure 10 briefly summarizes lithium price evolution between 1990 and 2015 (Martin et al., 2017). According to the explanations in the figure, after a period of stable supply, in 1995 *Sociedad Quimica y Minera de Chile* (SQM) entered the lithium market, increasing the supply and therefore lowering the prices of lithium. From 1999 to 2002, prices and demand of lithium decreased due to the Asian economic crisis and the recession in North America. In the period between 2002 and 2007, the Chinese economy grew strongly and for that reason the demand increased, as well as the trade prices. After 2008, the demand dropped in response to the economic crisis, reaching its lowest point in 2010. The price has been recovering since that year, and by 2015 it had increased 56% (Martin et al., 2017).

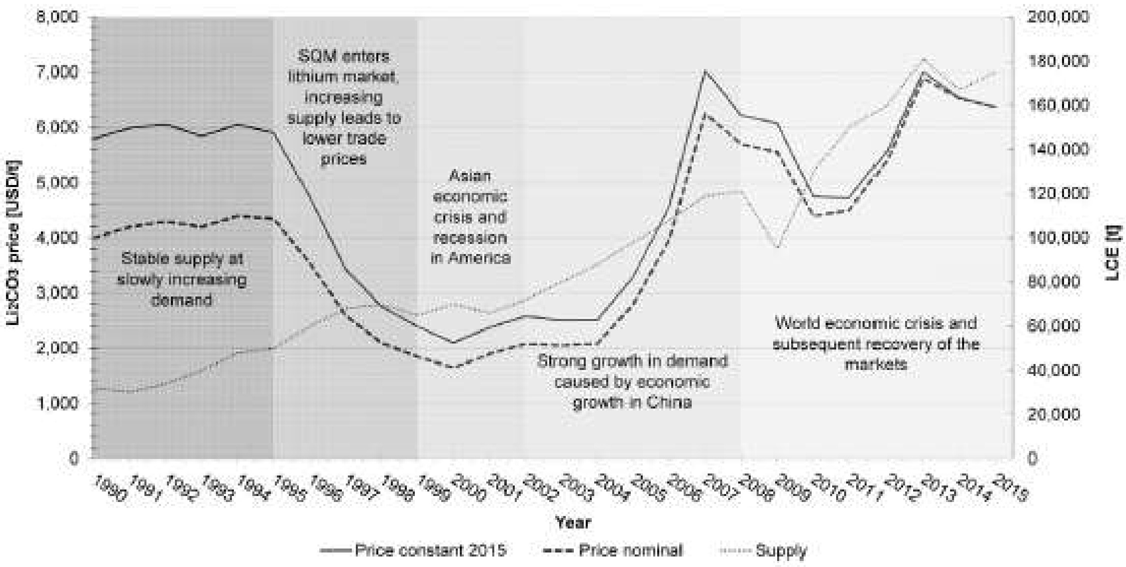

Figure 10: Lithium price history from 1990 to 2015

Source: Martin et al. (2017), page 178

Figure 11 shows some projections for the global lithium demand under three scenarios – basic, optimistic and pessimistic, until 2020.

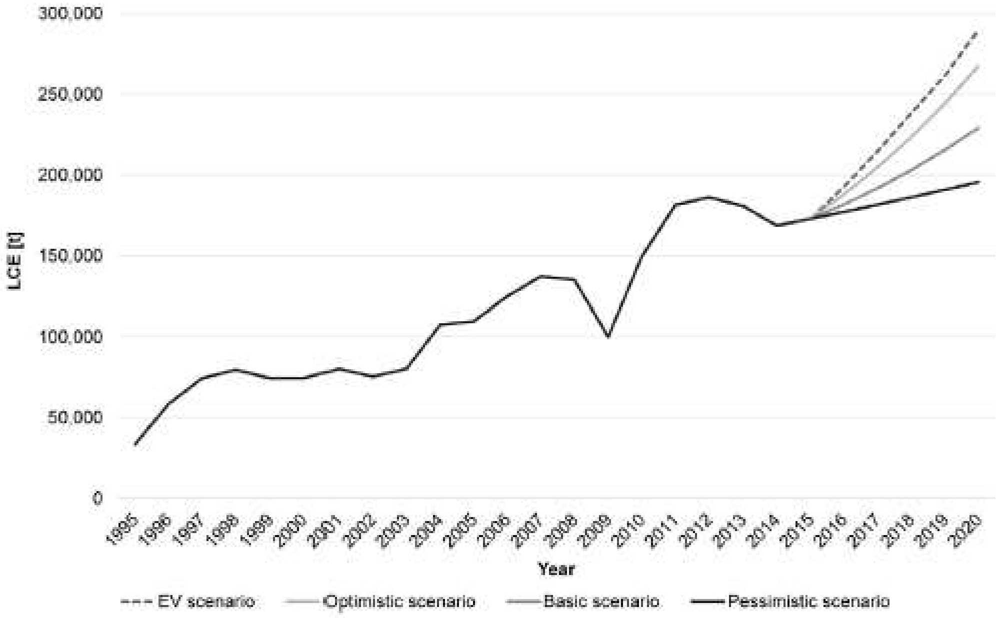

Figure 11: Global lithium demand under three scenarios – basic, optimistic and pessimistic, until 2020.

Source: Martin et al. (2017), page 176

Monitoring the price and availability of lithium was and is then very important once it allows the prediction of future trends and consequently the minimization of the environmental impacts of its extraction and processing mechanism (IEA, 2017).

Now that the principal locations of lithium minerals were presented, as well as its role, main locations, uses and price variability, it's important to narrow the research and focus on the use of lithium to feed electric batteries to power electric vehicles. Following this, it is also important to study the environmental impact of this exploitation as well as the treatment and destiny of batteries at the end of life (Schauerman et al., 2012).

3.3 The demand of lithium for Electric Vehicle's batteries

Due to its high electrode potential, lithium has become, in the last years, an important component of the electrolyte and one of the electrodes in batteries. Lithium consumption has increased significantly because of its intensive use in the rising market of portable electronic devices, increasingly being used in electric tools, electric vehicles and grid storage applications (GTL, 2017; Guberman, 2017).

Our 21st century society is facing three main challenges: 1) reducing CO_2 emissions in order to fight climate change, 2) improving the quality of air in big cities and 3) reducing the dependence on oil. In this line, the development of EVs (Electric Vehicles) is one of the alternatives to pursue the already mentioned objectives (Lamjom, 2012). They use lithium-ion batteries, so, in this context, it is important not to confuse lithium batteries with lithium-ion batteries. Lithium batteries are non-rechargeable and therefore they are disposable batteries (BGS, 2016). In these ones, lithium is part of the anode; they have a longer life than most other disposable batteries, being used in applications where a long life is important (medical devices, watches, cameras), they tend to be more expensive and they are smaller, in comparison with other batteries (BGS, 2016).

Lithium-ion batteries (Li-ion), on the other hand, are rechargeable and have a high energy density (BGS, 2016). Li-ion batteries, in comparison with other batteries, have high tension, high energetic density and potency, high numbers of charging and discharging cycles and low environmental impact (Rosolem & Beck, 2011; BGS, 2016; GTL, 2017). Li-ion batteries are, for these reasons, used in numerous applications – mobile phones, computers and other electronics, energy storage and, of course, in electric vehicles (BGS, 2016).

Li-ion batteries were introduced in the market in 1976 by Whittingham and their original design has been advanced ever since, especially since the 90s, when SONY started to commercialize Li-ion rechargeable batteries (Rosolem & Beck, 2011; Sonoc & Jeswiet, 2014), as well as the global mining production that has specifically increased since 1990s (Zhang et al, 2017).

A Li-ion battery consists of the cell (heart of the battery), composed of (1) cathode, (2) anode, (3) electrolyte, (4) separator and (5) safety structures (Lowe et al., 2010).

(1) Five major lithium metal oxides are used as cathodes (Lowe et al., 2010; Notter et al., 2010; Rosolem & Beck, 2011; Hocking et al., 2016). Table 1 briefly describes their main characteristics.

	Cathodes	**Chemical formula**	**Characteristics**
i	**LCO** (Lithium Cobalt Oxide)	$Li_{1-x}CoO_2$	*"Incumbent technology first introduced in 1991, high energy density but incurs longer charge times and shelf life of 1-3 years, can be dangerous if damaged."* (Hocking et al., 2016, p. 17)
ii	**LMO** **(**Lithium Manganese Oxide)	$Li_{1-x}MnO_4$	*"Low internal cell resistance allows fast recharging and high current discharging but 1/3 of LCO's energy capacity."* (Hocking et al., 2016, p. 17)
iii	**NCA** **(**Nickel Cobalt Aluminium Oxide)	$Li_{1-x}NiCoAlO_2$	*"High specific energy and long life span; safety and cost were historical concerns but these are now resolved; Tesla uses NCA."* (Hocking et al., 2016, p. 17)
iv	**NMC** **(**Nickel Manganese Cobalt Oxide)	$Li_{1-x}(NiMnCo)O_2$	*"Can be tailored to high specific energy or high specific power; most Japanese and Korean producers sell NMC into EV market."* (Hocking et al., 2016, p. 17)
v	**LFP** (Lithium Iron Phosphate)	$Li_{1-x}FePO_4$	*"LFP batteries offer a safe alternative due to thermal and chemical stability of the Fe-P-O bond compared to Co-O bond; the Chinese government is promoting LFP use in China over NCA/NMC."* (Hocking et al., 2016, p. 17)

Table 1: Types of cathodes and characteristics.

Source: Own elaboration, based on Hocking et al. (2016), page 17.

LCO batteries dominated the market as the first technology of its type ever being commercialized, but its market share has been declining in the recent years, and NCA and NMC batteries are the two leading technologies for electric vehicles (Hocking et al., 2016).

(2) In what concerns the anode, two types are used: highly crystallized natural graphite and randomly crystallized artificial carbon (Rosolem & Beck, 2011; Lowe et al., 2010).

(3) The electrolyte used is a mixture of lithium salt[5] and organic solvent[6] (Rosolem & Beck, 2011; Lowe et al., 2010).

(4) The separator is a micro-porous membrane made of either polyethylene or polypropylene, used to prevent contact between the anode and cathode and with a safety function called a "shutdown": "if the cell heats up, the separator melts and fills its micro pores to stop lithium-ion flow" (Lowe et al., 2010, p. 31).

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[5] Lithium Hexafluorophosphate, Lithium Perchlorate, Lithium Hexafluoroarsenate (Rosolem & Beck, 2011; Lowe et al., 2010).

[6] Polyethylene Oxide, Plyacrylonitrile, Poly Vinylidene, Poly Methyl Methacrylate (Rosolem & Beck, 2011; Lowe et al., 2010).

(5) Finally, there are internal safety structures, such as "tear-away tabs to reduce internal pressure, safety vents for air pressure relief, and thermal interrupters called positive for overcurrent protection" (Lowe et al., 2010, p. 31).

During discharge "lithium atoms ionize and de-intercalate from the anode, diffuse through the electrolyte, and intercalate in the lattice structure of the transition metal oxides in the cathode", and finally "electrons flow through an external circuit from anode to cathode" (Sonoc & Jeswiet, 2014, p. 290; Rosolem & Beck, 2011) not suffering, then, oxidation and reduction processes (Rosolem & Beck, 2011). During recharge, the opposite process takes place, "at any remaining capacity with no need for periodic full discharges without affecting the number of full cycles the battery will function" (Sonoc & Jeswiet, 2014, p.290).

"Cathodes, anodes, electrolytes, and separators account for roughly 26%, 9%, 6%, and 4% of the total manufacture cost of a lithium battery, respectively" (Hocking et al., 2016, p. 61). But since lithium is "the only active material in the battery", which means "increasing the battery's lithium content increases energy density", to select the perfect cathode and ensure the battery performance, we need to be aware of the "recharging times, discharge rates and stability" (Hocking et al., 2016, p. 17).

Currently, Li-ion batteries "are effective and affordable having few substitutes" (Swain, 2017, p. 389). Most major automobile companies are pursuing the development of electrified vehicles using these batteries once the mineral, compared to others, is "lighter, less bulky, and more energy efficient" (Gruber et al., 2011, p. 761). The major reasons for using Li-ion batteries are also the extensive experiences gained in the Information and Communication Technology (ICT) industry that has led to safe, lifelong, and affordable products. They almost don't require maintenance, they have no memory effect, little self-discharge rates and with no need of a scheduled cycling to prolong the battery's life (Notter et al., 2010; BGS, 2016). However, these batteries are more susceptible to fluctuations in temperature, raising concerns about safety and the risk of fire if overheat (BGS, 2016).

The consumption of lithium metal to build batteries is the highest among all end-uses of lithium and has increased in recent years – in 2017, the consumption of lithium to power batteries meant 39% of the total market compared to 35% in 2016 (GTL, 2017; Guberman et al., 2017; Swain, 2017). Figure 12 shows data from these two years in terms of percentage of lithium use per sector.

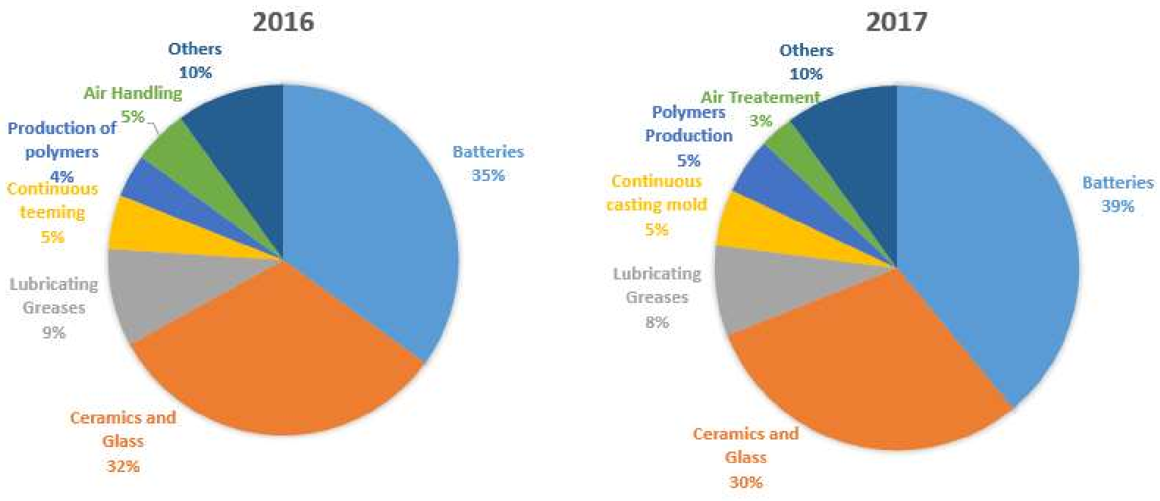

Figure 12: Estimated global market for lithium in various sectors for the years 2016 and 2017.

Source: Own elaboration based on Swain (2017), page 389

Figure 13 summarizes the demand of lithium to power electric vehicles in comparison with other markets, until 2025. By analysing figure 11 along with figure 13 it is possible to understand that there is a relation between the growing demand for lithium and the demand of this metal to power electric vehicles.

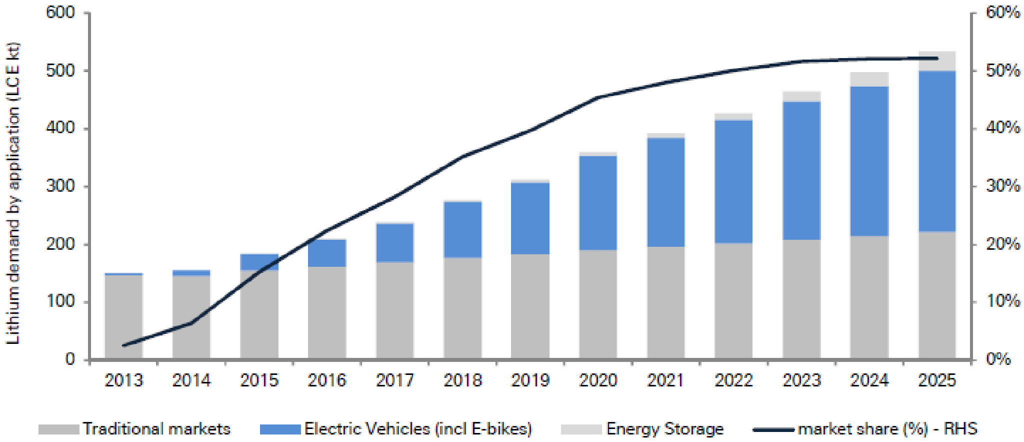

Figure 13: Lithium demand for EVs vs. other markets, until 2025.

Source: Hocking et al. (2016), page 24

Nowadays, the production of lithium in the market works as an oligopoly, with only five companies operating and controlling the supply - SQM, FMC Lithium, Albemarle/Rockwell, Ganfeng and Sichuan Tianqui Lihtium (GTL, 2017). They don't have the capacity to answer to all the demand, so there are some new players entering the market as the demand is grows.

The biggest enterprises responsible for the production of batteries to power electric vehicles are Chinese, Japanese and Korean. The top ten, arranged by business volume and production capacity, is composed by Panasonic, BYD, GSA Capital, LGChem, BPP-Beijing Pride Power, Samsung, Wanxiang, SK Group, Mitsubishi/GS Yuasa and Air Lithium (Lavrador, 2016; GTL, 2017).

The report produced by BCG (2016) and mentioned in Vieira et al. (2017) estimates the market of EVs will reach around $US 25 billion in 2020, with about 14 million EVs sold in China, Japan, USA and western Europe. Near 40% of the total lithium supply will be devoted to feed batteries of electric cars (Vieira et al., 2017).

Moreover, it is no surprise that the demand for lithium to feed these equipments will rise from a value of 0.3 million in 2015 to 11 million in 2025, and according to Bloomberg New Energy Finance the sales of electric vehicles will reach the 41 million by 2040, 35% of all the sold vehicles at the time (Vieira et al., 2017).

New technologies are being developed to store and extract lithium, with the objective of reducing extraction, treatment and production prices, especially in pegmatitic deposits (Vieira et al., 2017).

In what concerns the production of batteries in Europe, this continent has an installed capacity of 1,798 MWh (CEMAC, 2015) and some EU policies aim at supporting new production facilities and the technological development of Li-ion batteries (Vieira et al, 2017). As a result of the great international scandals, like Volkswagen, the biggest car manufacturers want a slice of the EVs market, once there is a pressure for environmental awareness and for green policies and they need to respond to it (Vieira et al., 2017). Tesla is a good example, but there are some European manufacturers also concerned and taking action, like Mercedes, BMW, Renault, Volvo and Audi, presenting more than 20 EVs and HEVs models (Vieira et al., 2017).

It is also important to understand that the growing demand on lithium, mostly to power batteries of electric cars, is also a product of the fulfilment of the consumer needs and wishes: 1) affordability – the new electric vehicles based on lithium batteries have to be competitive in price, 2) clean energy – new sources of energy that are environmentally friendly and coming from renewable and clean sources, and 3) connectivity – need for a system that offers the possibility to recharge the batteries almost everywhere (Lamjom, 2012). But these customer needs and wishes have to be aligned with some market considerations that allow measuring the success of these Li-ion batteries: a) the cost of the battery – it is expected a reduction since there will be economies of scale as mass production of these vehicles starts, b) the standardization of the battery technology, in order to open up the possibility of the referred mass production, c) the production (itself) and disposal of batteries, accompanied by an expansion in facilities for manufacturing and recycling, d) the residual value of the battery and its development to enter secondary markets, e) the life expectancy of the battery, to bring attention to the need to continue to improve technology, and f) government regulations and legislation, as base to decide on making investment or not, and on recycling or not (Lamjom, 2012).

The amount of these batteries introduced in the global market is growing in comparison with other markets (Hocking et al., 2016; Swain, 2017), what consequently increases the production of end-of-life wasted batteries. The end-of-life waste, without recycling or treatment, can harm human health and the environment due to the potential toxicity of the materials (Swain, 2017).

The need to recycle or reuse the batteries is thus a very important issue. Umicore, a Belgian Company, has already a share in this market of recycling lithium batteries (Harland, 2016).The sites to store the waste are limited and from a management perspective, to meet the industrial needs and to reduce the carbon emissions and footprint and save energy to future demand, it is important to ensure the recycling of the major component of spent electric batteries, as a feasible and beneficial approach of supporting circular economy and preserving the environment (Swain, 2017) .

There are some new players entering the market as the demand is growing and taking into account the expected overall market evolution of Li-ion batteries products and the life of secondary Li-ion batteries, as well as the enormous projected demand for lithium to power electric batteries, we can conclude how the disposal of spent batteries will soon become a serious problem (Swain, 2017). For this reason, recycling becomes imperative in the view of the circular economy (GTL, 2017). Large quantities of waste will be generated every year and it will not only pollute the environment if not disposed appropriately, but also induce the loss of valuable resources if not recycled and reused (Li et al., 2014).

However, due to the low-cost exploitation, lithium from secondary sources had no significant impact on the total supply up to now (Martin et al., 2017). Swain (2017) estimate that Li-ion batteries will consume 66% of the total lithium produced by 2025. And even under the most optimistic scenario, supply will hardly meet the demand after 2023 (Swain, 2017). For this reason, recycling has a great potential, but by this moment only 3% of the batteries are being recycled and the rate of lithium being recycled is less than 1% (Vikström et al, 2013; Sonoc & Jeswiet, 2014; Swain, 2017).

We may have lithium in abundance and currently there is no urgent need to recycle concerning the question of scarcity, since there were no significant shortfalls or problems in supply, but the risk of a global shortage is rising (BGS, 2016). Therefore, substitution and recycling of batteries may begin to gain ground since if there is no material capable of replacing lithium or other battery system under development capable of offering similar or better performances, then Li-ion batteries will be at risk (BGS, 2016; Zhang et al, 2017).

This future supply crisis can only be prevented through 100% recycling of Li-ion batteries, designed with recycling in mind and to avoid certain materials (Gaines, 2014). Recycling will also have to guarantee 90% of lithium recovery, ensuring not only the metal economy and the green energy security but also the environment preservation (Swain, 2017).

Lithium "is completely recyclable and can be recycled repeatedly without loss of performance", but the economic incentive to recycle it from batteries in their end-of-life is very limited since the process to recover a small quantity is very expensive and supply the primary material is more cost effective (BGS, 2016, p.25). Despite it, there are some processes to recycle Li-ion batteries in the market, but they focus mostly on the recovery of other more valuable metals like cobalt and nickel, mainly due to the low price of lithium (Castillo et al., 2002; Kumar, 2011; Vikström et al., 2013; Martin et al., 2017; Swain, 2017; Zhang et al., 2017).

The situation can change as a consequence of EVs demand which means an increase in the number of batteries on the roads, that will eventually reach their end-of-life and will need to be substituted and recycled (Hamilton, 2009)

Currently, what drives the recycling of a Li-ion battery is the "general desire to reduce materials going to landfill, the avoidance of pollution from inappropriate disposal and the risk of fires in landfill sites caused by reactive battery materials" (BGS, 2016, p.26). There are some recycling companies recovering lithium[7], but their approaches have not yet been sufficiently scaled up on a commercial scale (Martin at al., 2017). At the same time, only a minor fraction of the spent batteries is appropriately disposed (Zhang et al, 2017). The recycling rate of spent Li-ion batteries, in Europe, was 18.03% in 2011 and 28.34% in 2012 (Zhang et al, 2017). When we talk about countries in development, the story changes dramatically with a rate of recycling of less than 10%.

But some actions are being undertaken, for example in Europe, where recycling and substitution concerns resulted in the 'Batteries Directive' (Directive 2006/66/EC – EU, 2006), adopted in 2006, aiming at increasing the collection and recycling of all types of

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[7] Accurec Recycling GmbH, AEA Technology Group, Batrec Industrie AG, Recupyl S.A.AS, Umicore (Harland, 2016; Martin at al., 2017).

batteries and setting out rules for their treatment and disposal (EU, 2006; European Commission, 2014).

A more circular economy with growing recycling rates will create value "by generating more employment and using less resources", having direct impacts in the waste management sector and indirect impacts in construction, maintenance and administration of the recycling facilities" (Probst et al. 2016, p. 7).

It is then important to have a life-cycle view of the use of a resource like lithium, in order to understand and anticipate potentially harmful impacts.

3.4 A Life-cycle Assessment of lithium

Some studies on the availability of lithium for use in electric batteries have reached the conclusion that there is sufficient lithium to meet the growing demand for the rest of the 21st century. Nevertheless, those studies have not looked into the deposits size and composition that will allow "the resources to be converted to reserves from which lithium can be economically produced" (Kesler et al., 2014). Studies have also not looked into the scale of adaptation of current production facilities, not reactive enough to follow real-time growth in lithium demand (Grosjean et al., 2012).

The question is how serious is the debate about LCA and how much control and oversight customers and policymakers believe that should be applied across production chains (Hawkins et al., 2013).

According to Mellino et al. (2017), studies using the LCA to analyse the environmental performance of electric vehicles powered by lithium-ion batteries (Li-ion batteries) are only a few and they only address the energy benefits and costs, while the other types of impacts are disregarded. This is particularly significant when we think about the potential toxicity of a battery and of its components (Mellino et al., 2017). It is then important to overcome the knowledge gap, to evaluate the environmental burdens of production, distribution and performance and not only the question of efficiency (Mellino et al., 2017). Governments should promote the improvement of electronic components in order to reduce the amount of metals and the emission of toxic compounds (Mellino et al., 2017).

Additionally, it is important to ensure a green and renewable electric mix capable of charging the battery, what is not the case of a lot of economies and national grids, once the mix of a country impacts greatly the environment and therefore is an important option for improvement (Mellino et al., 2017) and for the reduction in the overall cost of a battery

(Mellino et al., 2017). Therefore, it is important to have a sort of "certificate of origin" of electricity, in order to provide evidence on electricity production (Lamjom, 2012).

One of the biggest obstacles to a long-term lithium supply will also be the establishment of production facilities at the rate of the automotive industry demand (Gruber et al., 2011). Moreover, "creating strategic stocks, signing long-term supply contracts and exploiting in an environmentally friendly way the unexplored lithium deposits" will help the EVs industry to persist and last sustainably (Grosjean et al., 2012, p. 1744). At the same time, there will be not only the often mentioned increase in lithium demand to feed electric batteries, but also for other metals, with previously limited fields of application and many of them considered geochemically scarce (Stamp et al., 2012). This will raise a concern about their future supply.

EVs offer advantages in terms of "efficiency, maintenance requirements, and zero tailpipe emissions" in comparison to conventional vehicles, contributing to the reduction of air pollution relative to conventional internal combustion engine vehicles (Hawkins et al., 2013, p. 54). This has led to a general perception of EVs as an environmentally benign technology, but the reality is much more complex (Hawkins et al., 2013).

Electric vehicles can "exhibit the potential for significant increases in human toxicity, freshwater eco-toxicity, freshwater eutrophication, and metal depletion impacts, largely emanating from the vehicle supply chain" (Hawkins et al., 2013, p. 53). For this reason, improving the profile and performance of EVs requires engagement around reducing the supply chain impacts. Thus, the material requirements to produce an EV should focus on a strategy of evaluation of secondary sources and using alternative materials and recyclable components, so that they can be translated in effective recycling programs and improved EV lifetime (Hawkins et al., 2013). Sometimes, lower emissions during the use phase compensate the additional burden caused in the production of electric vehicles, depending, of course, on the electricity mix. However, it is not always the case (Hawkins et al., 2013).

The environmental performance of an electric vehicle powered by a Li-ion battery is critically dependent on the combination of the vehicle production and electricity production impacts, as well as energy use and battery and vehicle lifetimes (Hawkins et al., 2013). For this reason, it is counterproductive to promote this type of vehicles in areas where electricity is primarily produced from non-renewable sources (like coal, for example). On the contrary, combining EVs with clean energy sources has the potential to drastically minimize some environmental impacts in terms of air quality and preservation of fossil fuels, which should serve as motivation for cleaning up the regional and national energetic mixes (Hawkins et al., 2013). Moreover, EVs are seen as a way of moving emissions away from the road – with zero-emissions on the road, it is possible to aggregate emissions sources at a few point sources like mines and power plants, instead of having millions of mobile sources, which, theoretically, makes the control task easier (Speirs et al., 2014). However, the indirect nature of these emissions, embodied in internationally traded commodities like copper and nickel, challenges us as a society (Hawkins et al., 2013).

When it comes to waste management, it is important to consider recycling – "the low melting point (180°C) of lithium metal and the very low water solubility of its fluoride, carbonate and phosphate salts make its recovery easy" (Tarascon, 2010a, p. 510). While the life of an EV is relatively long, a significant number of battery packs will reach the end of their life (EOL), and they may still "have value for remanufacturing and secondary use" (Liu et al., 2016, p. 231). Some layers will "persist on the surface of electrodes deposit after a period of continuous cycling, possible causing the battery degradation and failure" (Liu et al., 2016, p. 231). Results of a study from Liu et al. (2016, p. 241) suggested the capability of "laser surface cleaning of the electrode to successfully recover degraded battery electrodes for battery remanufacturing". An alternative in the management of end-of-life Li-ion batteries is to (re)use them "to store excess baseload power generation during periods of low power demand, and then to supply this energy back to the grid during peak-demand times" (Anderson, 2009, p.34). This way it is possible to increase their lifetime and delay their disposal by giving them a new use.

But it is also important to separate the recycling rates of products and the recycled content in new products – a product can be recycled but there is no guarantee that it will be used at the same rate (Vikström et al., 2013).

Also infrastructure, maintenance and service have negligible shares of the environmental impact (Notter et al., 2010). In addition, the processes used to extract lithium are "very simple and have a low energy demand" (Notter et al., 2010, p. 6553).

Finally, it is important to think about some further issues. The world is currently largely dependent on oil exporting countries, and that creates the conditions to conflicts, but lithium reserves are situated in only a few countries (Vikström et al., 2003). According to Abell and Oppenheimer (2010), it is absurd to switch from one dependence to another since resources are finite.

Both the cradle and grave of lithium imply costs to society. The environmental consequences of its extraction, as a scarce resource increasingly demanded, and the accumulation of the costs of waste treatment or disposal have to be addressed by society. Time is limited and for this reason it is urgent to find means of enhancing the "cross-sharing of information between national programmes", so that concrete actions are taken in order to secure a bright future to our planet (Tarascon, 2010b, p. 3239).

As a battery is expected to last the lifetime of the vehicle and it usually has a life expectancy of ten years. For this reason, it is not seen as an urgent and immediate concern the establishment of economical and environmental recycling techniques that will be capable of reducing the need to extract raw materials or of importing raw material from abroad by recycling domestically (Gaines, 2014). There are many negative environmental impacts associated with the mining and processing (emission of pollutants) and they can be avoided by recycling (Gaines, 2014).

Every stage of the extraction and use of lithium and disposal or recycling of batteries have impacts on the economy and environment, positive and negatives, but one stage stands up as the one who will affect Portugal the most – the extraction of lithium.

4. Portugal. An opportunity or a threat?

Portugal is rich in many geological resources, but we need to import them because of the impossibility to constitute reserves due to low levels of mineral concentration, minerals complexity and technological mismatch (GTL, 2017). Nowadays, with the great demand for lithium, many locations with identified geological resources of lithium, like Portugal, prospection and exploitation become feasible (GTL, 2017).

Rosa (1976), in his technical report "*O lítio, recursos e potencialidades tecnológicas",* identified lithium as the fundamental raw material to diverse future technologies, particularly in what concerns energy production and storage, foreseeing that with this applications and growing demand it would be important to guarantee the supply and avoid shortages (Rosa, 1976). He recognized electrical propulsion as substitute to conventional internal combustions engines, with advantages in what regards savings in liquid fuels and environmental protection, anticipating the use of lithium as well in batteries capable of storing great amounts of energy, mainly the surplus on peak points and the energy produced by renewable sources (Rosa, 1976).

The first mining-metallurgical studies took place in 1992, by DGGM (now LNEG) and INETI. Between 1996 and 2000 IGM (now LNEG) recognized the high potential of the lithium deposits in *Covas do Barroso* (*Alijó, Veral* and *Adagói*) and approved the first mineral exploitation and research project of this type in Portugal (Leite, 2017; Oliveira & Viegas, 2011).

In out of about 20 minerals known to contain lithium, only four (lepidolite, spodumene, petalite and amblygonite-montebrasite) are known to occur in commercially sufficient quantities (Swain, 2017; Lima et al., 2010). Pegmatite bodies that occur in Portugal present these four types of lithium minerals, with petalite and spodumene as the dominant ones (Lima et al., 2010). The occurrence of each mineral is related with certain conditions of pressure and temperature which is translated in different stages of crystallization (Lima et al., 2010). Table 2 presents a summary of the physical and optical properties of the four lithium minerals mentioned. Furthermore, lithium exists in the form of a variety of chemical compounds but the most commonly used for industrial purposes is the lithium carbonate, as well as lithium hydroxide (Braga & França, 2011; Narins, 2017).

It is foreseen that petalite and spodumene will supplant in the coming years, in volume, the other lithium minerals (Lima et al., 2011a).

Name	Li* *(wt.%)*	C†	H†	D†	B†	CL†
Petalite One of the three most abundant minerals of lithium, occurring typically in crystals of reasonable dimensions, in the most internal parts of pegmatites, in association with quartz (Lima et al., 2010; Lima et al., 2011a)	2.0	colourless; white to grey, pink and green	6.5	2.4	vitreous, pearly	**{001}** *{201}*
Spodumene A pyroxene and one of the first mineral containing lithium described in Portugal (Lima et al., 2010; Lima et al., 2011a)	3.8	colourless; grey, pink, green and yellow	6.5-7	3.0-3.2	vitreous, pearly	**{110}** {100}
Lepidolite Usually associated with more crystalized granites (Lima et al., 2010; Lima et al., 2011a)	3.5	colourless; pinkish tones, yellow	2.5-4	2.8-2.9	vitreous, pearly	**{001}**
Amblygonite-montebrasite The first lithium mineral explored in Portugal, but for a very brief period. Occurs in small but well defined crystals, prismatic and in columns, with high density (Lima et al., 2010; Lima et al., 2011a)	3.5	colourless; white, grey and beige	5.5-6	2.9-3.0	vitreous, pearly	**{100}** {110} *{0-11}*

*Li$^+$ (values samples); †C – colour; H – hardness; D – density; B – brightness, CL – cleavage (**{perfect}**, {good} e *{imperfect}*).

Table 2: Brief summary of the physical and optical properties of the most common lithium minerals.

Source: Own elaboration based on Lima et al. (2010)

The already mentioned geological Portuguese context and its potential regarding lithium mineralization mainly in pegmatite deposits, aplitopegmatites and some quartz seams, contributes to a privileged position among other European countries (Amarante et al., 2011; Oliveira & Viegas, 2011; Viegas et al., 2012; Leite, 2017).

The pegmatitic mineralizations are associated with differentiated granitic magmas present in the centre and north of the country (Oliveira & Viegas, 2011). Traditionally, these mineral deposits have been explored to produce and trade mainly quartz and feldspar to feed, essentially, the ceramics and painting industries (Oliveira & Viegas, 2011; Viegas et al., 2012). But lithium concentrates – carbonate or hydroxide, must be seen as possible sources of lithium to the chemical industry and others (Lima et al., 2011a), especially in what concerns powering electric vehicles.

This market imposes growing technological requirements to products, rarely totally fulfilled by the minerals, what makes the beneficiation stage crucial to the valuation process (Amarante et al., 2011). Lithium ores from Portugal are technologically recoverable through the combined application of separation processes that guarantee the steadiness of lithium levels to ceramics and the production of concentrates with high levels of lithium content (Amarante et al., 2011; Leite, 2017). What we also observe in the pegmatite Portuguese deposits is the potential to not only explore lithium but also some other minerals with commercial value like rare earth elements, niobium, tantalum and tin. This way, it is possible to profit from one single mine to explore many minerals, with zero production of waste (Gomes, 2011; Lima et al., 2011a; Oliveira & Viegas, 2011; GTL, 2017).

In this context of growing demand for new uses of lithium, after ensuring the exploitation in their own countries, some foreign companies (Australians and Canadians) are trying to expand their business to Europe, and more concretely to Portugal (Vieira et al., 2017).

Figure 14 presents the biggest producers of lithium in the world for the years 2016 and 2017. It puts Portugal as the biggest European lithium producer and in 6th place in the world ranking, for both years (Vieira et al., 2017; Ober, 2018).

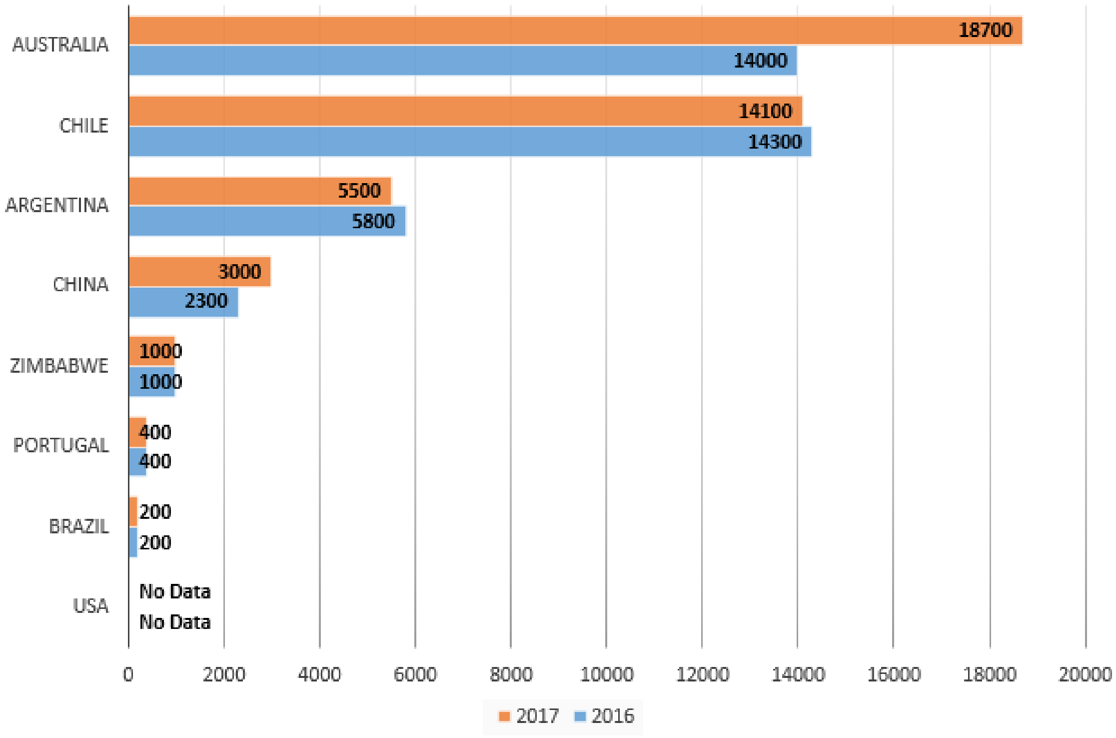

Figure 14: Biggest lithium producers in the world, for the year 2016 and 2017. Portugal in the 6th position (production unit: tones).

Source: Own elaboration based on data from Ober (2018), page 99

Ober (2018) have not presented the biggest producers of lithium worldwide for the year 2018 but he estimated the amount of lithium per country reserve (Table 3). Furthermore, and for the Portuguese case, he estimated an amount of 100,000 tons of lithium in terms of resources, accounting for 60,000 tons of lithium in terms of reserves (Ober, 2018).

Australia	Chile	Argentina	China	Zimbabwe	Portugal	Brazil	USA
2,700,000	7,500,000	2,000,000	3,200,000	23,000	60,000	48,000	35,000

Table 3: Lithium reserves (in tons).

Source: Own elaboration based on data from Ober (2018), page 99

There are at least 46 prospection and research requirements submitted to DGEG, 30 of them concerning lithium as primary substance, with the view of using this mineral to produce electric batteries for vehicles, involving a total investment of 3.8 million euros for the initial contract period (2/3 years) and an area of 2,500 km^2 (GTL, 2017). Figure 15 identifies these requests per location. However, there are other requests in DGEG having lithium as an accessory mineral substance and there are some prospection right holders that, aware of the economic potential of lithium, have expressed the will of explore and treat lithium minerals (GTL, 2017).

Trying to answer to this dynamism the Portuguese Government has commissioned a report. In this line, it was instituted the Working Group on Lithium (Grupo de Trabalho do Lítio), under *Despacho do Secretário de Estado da Energia* No. 15040/2016, published in Diário da República, series 2, of December 13, 2016, in order to identify and characterize lithium deposits in Portugal, as well as the respective economic activities and the possibility of producing metallic lithium in specific processing and beneficiation units (GTL, 2017; Vieira et al., 2017).

Figure 15: Lithium research and prospection requests to the Portuguese State.

Source: Vieira et al. (2017), page 524

This working group identified 11 lithium mineral deposits in the national territory: 1) Serra d'Arga, 2) Barroso-Alvão (Sepeda Projet[8]), 3) Covas do Barroso, 4) Murça, 5) Almendra, 6)

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[8] The next section will address this specific project.

Penedono, 7) Amarante – Seixoso – Veiros, 8) Massueime, 9) Gonçalo – Guarda – Mangualde, 10) Segura and 11) Portalegre (GTL, 2017; Viegas et al., 2012). (Viegas et al., 2012). Figure 16 presents these locations (GTL, 2017).

Figure 16: Identified Portuguese locations of requests and contracts.

Source: GTL (2017), chapter V, page 3

However, 9 of the 11 location are located in classified areas with great ecological and community value – 8 are *Rede Natura 2000* areas and 1 is a protected area, a natural park, as the *Liga para a Proteção da Natureza* (LPN) (2017) identified in the process of public consultation of the commissioned report. It is important to highlight that the report on lithium produced by the working group gives little attention to this big constraint and does not consider, in its financial analysis, the great importance of preserving the natural values, what suggests a depreciation of the importance of this resource (LPN, 2017).

The report also makes reference to the need of ensuring an economically, socially and environmentally sustainable exploitation of the geological resources, but all the recommendations and proposals focus only the direct economic sustainability of the projects. It was expected that a financial analysis of the costs associated with the minimization of the impacts was undertaken, not only in terms of ecological restoration at the surface, but fundamentally in what concerns contaminated waters and sludge, as well as sub-products with no potential for reuse (LPN, 2017). It was also expected to find an analysis of the ecological footprint, including greenhouse gas emissions associated to the thermic transformation process, the cost of which may represent 1/5 of the operational costs of producing lithium concentrates (LPN, 2017).

Due to the scarcity and high exploitation costs, the report makes reference to the importance of recycling end-of-life products, namely Li-ion batteries, by implementing a system of circular economy. But this recycling process is complex and costly, which means the recovery of end-of-life batteries is economically unviable *per se* – nowadays final consumers need to pay a green tax for this to occur (LPN, 2017).

The report of the working group suggests the establishment of a Geological Resources Fund aimed at supporting knowledge, conservation, protection and valuation actions of geologic goods (GTL, 2017). LPN (2017), on the other hand, suggests focussing the work in optimising the process for producing concentrated, not only for diminishing the associated costs but also to diminish the recognized environmental impact, related with the use of chemical reagents. LPN (2017) also considers that it would be a plus to draw some ways of creating value to the local and national population, without making the same mistake as in the contracts on hydrocarbons, in which the financial compensation to the Portuguese state accounts for only 10% of the profits, considering that it would be also important to establish the mechanism of Corporate Social Responsibility more as an incentive to act than as an obligation (LPN, 2017).

The working Group concluded that lithium mineral from Portugal is economically and technologically recoverable through the simple or combined application of two separation processes – dense media separation, optical separation or foam fluctuation (GTL, 2017). The Working Group also noted that the delay in adopting processing technologies for the recovery of lithium ores by producing high-grade concentrates was not due to any lack of knowledge of the applicable technologies or to any other less positive aspects of ores of national lithium mineral, but rather due to market constraints that until very recently have precluded the investment because of its unattractiveness (GTL, 2017).

Despite being a great tool to identify the potential opportunities and benefits of exploring lithium in Portugal, the report gave little attention to the environmental constraints, something that should not happen if Portugal wants to create a long-term strategy, capable of accounting all the costs associated with this new market.

4.1 The Sepeda Project in Barroso-Alvão

4.1.1. The area and critical raw materials

Portugal detains the biggest European lithium reserves, one of them located, in particular, in the region of Alto Barroso (GTL, 2017). For this reason, Portugal may find a market in European car manufacturers companies once with the growing demand for this mineral, European companies will need to be fed, and if there is no supplier in Europe, they'll have to buy outside. It is in this context of European development that the Sepeda Project[9] can play an important role as supplier of European factories that will have material "at the door", with visible and evident savings in terms of transportation costs and feasible supply deadlines.

If until 2016 the market was dominated by Asian raw material buyers, from 2017 it is impossible not to consider Europe – Daimler announced for 2017 the construction of an electric car batteries factory in Germany, as well as Volkswagen, Northvolt announced the same in Sweden and LGChem in Poland. Tesla also demonstrated interest in building a factory in Europe (Lusorecursos, 2018).

The EU, due to the growing demand for lithium and other metals, is putting in place some directives focusing the promotion of mining productions inside the European space, decreasing the dependence from the exterior. An example is the Raw Material Initiative, adopted in 2008 setting out a strategy to tackle the issue of access to raw materials in the EU (Blengini et al., 2017). The European Commission, under the Raw Material Initiative, launches regularly lists of critical raw materials, the last one dating from 2017 (Blengini et al., 2017; European Commission, 2017). This strategy on critical raw material aims at ensuring a fair and sustainable supply of raw materials in the global markets, with no distortions, promoting the supply of raw material within the EU, reducing the consumption of raw materials in Europe coming from outside and promoting recycling practices (European Commission, 2017). The denomination "Critical Raw Material" is due to their economical and significant importance to key sectors, risks of supply and lack of substitutes (European Commission, 2014).

It is also important to improve the efficiency of resources and the recycling processes at the European level, maintaining Europe in the leading front of technology and innovation. Lithium is commonly designated as the "new oil[10]", and in the Portuguese context "the national oil"[11], once Portugal owns significant reserves of this mineral, so important nowadays.

Barroso-Alvão is a good example of a location where we can find all types of lithium minerals described for Portugal (Lima et al., 2011a). The region where it is located comprises

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[9] This project and its main goals will be explained in the next chapter.

[10] Terminoly used by Peter Tertzakian, in its article "Lithium may be the new oil, but a double whammy looms for the battery market", published in the Financial Post, on the 26 July 2017. Available in (https://business.financialpost.com/commodities/energy/lithium-may-be-the-new-oil-but-theres-a-double-whammy-looming-for-the-new-energy-source).

[11] Lusorecursos, 2018.

the municipalities of Montalegre and Boticas (GTL, 2017). It is a mountainous region rich in raw materials, namely lithium[12] (GTL, 2017). It is bounded to the west by *Serra do Gerês*, to the northeast by Serra do *Larouco*, to the southwest by *Serra da Cabreira*, to the south by *Serra das Alturas*. It's a region rich in water sources, divided into two river basins – Cávado and Tâmega (Lusorecursos, 2018).

The cross-border region of Gerês-Xurés was declared by UNESCO, in 2009, a World Biosphere Reserve. It covers a land area of approximately 269,958 hectares divided into two protected areas, the *Parque Nacional da Peneda Gerês* and the *Parque Natural Baixa Limia-Serra do Xurés*. Besides the natural and cultural richness, this World Biosphere Reserve is also a touristic destiny (Lusorecursos, 2018).

Barroso-Alvão is located near Sistel, in *Arcos de Valdevez*, a location classified by the Portuguese State as a National Monument because of its cultural landscape (Decreto 4/2018 de 15 Janeiro) (Lusorecursos, 2018). It is also near the *Albufeira do Alto Rabagão* and consequently interferes with areas subject to the Forestry Regime – "the forester perimeter of *Barroso*", with the presence of spontaneous cork trees and sensitive to fires. The area is partially inserted in the territory of the Iberian Wolf (*Canis lupus signatus*), classified as an endangered species by the *Livro Vermelho dos Vertebrados de Portugal* (Cabral et al., 2005; Lusorecursos, 2018).

Adagói, in the region of *Barroso*, was already assessed according to a geochemical prospecting sensing method by the IGM, in 1999, along with Veral and Alijó (Lima et al., 2011b; GTL, 2017; Leite, 2017). In Adagói it was identified 110 kton of lithium (1.05% LiO_2) and in Alijó 400 kton (1.4% LiO_2) (Lima et al., 2011b; Leite, 2017). These high concentrations of lithium were and are still possible, a factor not only of attraction but also feasibility, once this lithium presents a great conversion potential into carbonate to feed the chemical industry and not only as raw material to the ceramics and glass industries (Lima et al., 2011a; Lima et al., 2011b; Leite, 2017).

4.1.2. The Sepeda Project

The *Sepeda Project*, the project in the most advanced phase approved by the Portuguese government, is a consortium between *Lusorecursos*, a Portuguese mining company and *Novo Lítio* (at the time called Dakota Minerals), an Australian mining company. Novo Lítio acquired from Lusorecursos "100% of the granted license and the exploration license applications on the grant of the applications" (Novo Lítio, 2016). Nowadays the two

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[12] There can also be found like feldspar, lithium, tungsten and tin.

companies are battling in the Portuguese courts and the transfer of licenses to Novo Lítio remains pending (Novo Lítio, 2016).

One of the reasons that made Novo Lítio invest in Portugal was the existence of infrastructures of energy and transport and at the same time the proximity between the raw material and the storage facility (Vieira et al., 2017). According to Lima et al. (2011a) it is an open-cast operation, in a first phase, and besides being almost non-pollutant, it will be limited in physical and temporal space, being associated with a manufacturing industry to be developed in the region, one of the poorest, as also a solution to the desertification.

The blocks leased to research and prospection in the area of Sepeda, identified in Figure I in Annex as Block A and B, are located in a sector where metasedimentary sequences from the Superior Palaeozoic emerge, composed by granites of two sin-tectonic micas (GTL, 2017; Lusorecursos, 2018).

The extracting activity will be conducted in phased modules – extraction and recovery of the area as soon as the exploitation is finished and moved to the next "piece of land" (Lusorecursos, 2017; Comissão de Avaliação, 2018.

Lusorecursos detains rights of prospection and research in the area of Sepeda, according to the contract nº MN/PP/046/12-Sepeda, celebrated with the Portuguese State on the 07/12/2012 (APA, 2018). Now the project is in its Preliminary Study Phase, on the assessment and quantification of the amounts of lithium in the location with potential to be extracted, to present the needed documents in order to have a license for the exploitation.

Under the Law nº 151-B/2013 the Company submitted a Proposal on Scope Definition of the project, the first phase of the Environmental Impact Assessment (EIA). Figure II in Annex shows the organization of the EIA for this specific project. The Portuguese Environmental Agency (APA) received the proposal and established an Evaluation Committee (*Comissão de Avaliação*) that has already emitted an opinion.

The Evaluation Committee (composition in Figure III in Annex identified several areas in which the Proposal of Scope Definition (PDA) needs further work and explanation. The Proposal of Scope Definition fulfils vaguely the legislative requirement. However, the Evaluation Committee considers that the PDA has significant gaps in the description of the project and the reference situation, namely the object and stage of the operation, the time horizon of the project, the form and the place of treatment, the solutions to be adopted for treatment/disposal of effluents and waste and the environmental and landscape recovery of the site, as well as other information on the evaluation of impacts methodology (Comissão de Avaliação, 2018).

Considering the lack of definition of the proposed mining project and the poor approach to several essential environmental aspects to be included in the EIA, Evaluation Committee considers there are insufficient elements to positively deliberate on the content of the PDA (Comissão de Avaliação, 2018).

Based on this opinion, APA emitted a decision about the Proposal on Scope Definition deciding, in January 2018, that there is the need for further work (APA, 2018). Figure IV in Annex summarizes the decision.

4.1.3 Opportunities and Impacts

This extraction in Portuguese ground is still in its initial phase, but once it is implemented, it would undoubtedly have positive and negative effects on local communities. If the opportunities will overcome all the threats remains to be seen (Figure 17).

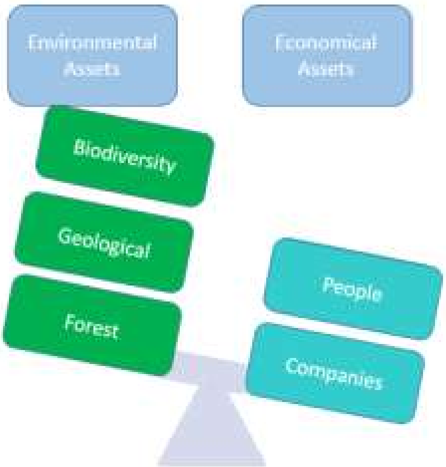

Figure 17: Opportunities vs. Threats of exploring lithium in Portugal.

Source: Lusorecursos (2018), page 113 (translated from Portuguese).

It is then important to acknowledge all the opportunities deriving from this exploitation of lithium in Portugal, and also the threats.

Lithium extraction in Barroso-Alvão may help to develop and promote the Barroso region in a local microeconomic innovative way, in order to supply energetic and strategic raw materials to the national and global macroeconomics. There is a big geological potential in *Mina da Borralha* and *Mina de Beça*, a touristic potential in Gerês Biosphere Reserve and of bio and sustainable agro-sylvo-pastoral production, as barrosã meat and montalegre smoked meat are known all over the country (Lusorecursos, 2018).

Valle & Holmes (2013) described in their work the benefits and threats of lithium exploitation in Bolivia, giving arguments that may fit the Portuguese situation. The revenues to the Portuguese Government could increase and they could be allocated to local opportunities and potentiate sharing of expertise in the manufacturing process with other countries and the signature of agreements with foreign companies to establish and bring the technology, capital and necessary infrastructures (Valle & Holmes, 2013). Portugal, as Bolivia, has the capacity to maximize the possible benefit of a promising natural resource and thus become a wealthier country, with more economic means to fight poverty and inequality (Valle & Holmes, 2013).

The mine will promote the creation of jobs and youth employment in different technological and industrial sectors accompanied with an increase in workers' incomes and boost of the region's development (Valle & Holmes, 2013; GTL, 2017). It will also promote the reinforcement of degrees and training offer in order to transfer the know-how from universities and institutes to the field (Lusorecursos, 2018).

According to Lusorecursos (2018) lithium exploitation in Barroso-Alvão has the potential to promote social cohesion and invert the desertification trend, by involving the community in projects marked by decentralisation and by promoting a multifunctional economy involving many activities. In this context, establishing partnerships between the government, population and all other social actors will be very important to encourage the occupation of lands and empty properties and therefore create an identity, a soul, a *"genius loci"*[13] to make people stay. And to answer people's needs, services like kindergartens, schools and health facilities will be built.

Moreover, and thinking ahead, the use of lithium in batteries reduces "their weight to energy ratio and thus enables fuel and energy savings", meaning that EVs have the potential to significantly reduce the CO_2 road emissions (BGS, 2016, p. 16). Thus, it enables a compensation in terms of emissions – relatively high emissions during the extraction but almost none in the use phase.

However, it is also important to acknowledge all the susceptible threats. By supplying foreign countries with lithium to power eco-friendly vehicles, Portugal will be impacting its own ecosystem (Valle & Holmes, 2013). Many benefits might become irrelevant for the local population needs because of damages in agriculture and water shortages (Valle & Holmes, 2013) Great quantities of toxic chemicals will be required to fulfil the need of lithium per year, chemicals that could be leaked by leaching, spilling and/or atmospheric emissions, causing not only the pollution of water, air and ground, but also putting the ecotourism in risk (Valle & Holmes, 2013).

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[13] Lusorecursos, 2018.

Lithium is not considered toxic to humans, however, a long-term or in large doses use can cause some health problems like "dehydration, diarrhea, vomiting, blurred vision, tremor, slurred speech, drowsiness, confusion, muscle twitches and/or unconsciousness" (BGS, 2016, p. 16). In terms of the processing and manufacturing stages, extracting lithium from hard rock impacts the environment in terms of energy use in the industrial unit, contamination by acids and chemical through leaching, emissions to air from high temperature processes, waste production from removing impurities, water usages and shortage and transportation (BGS, 2016, p. 16).

Each stage of the extraction process from hard rock, as it is the case in Barroso, will contribute to the entire and cumulative environmental impacts in terms of energy usage, development of infrastructures, landscape, noise and vibration, dust and emission of particles to the air, vehicles circulation and traffic, clearance of forest and removal of soils, depletion of ecosystems, use of hydric resources and potential shortages, production of waste and impacts on groundwater (BGS, 201).

In this context, and in order to minimize those impacts, Lusorecursos (2017) commits to analyse some factors and projected implications (Table 4).

a) Climate	Climatic conditions help explain the evolution of ecosystems, their behaviour in face of anthropic changes and their operation in extreme situations such as storms and/or abnormal values of precipitation. At the same time, climate can affect aspects related to air quality and water resources. For the climatic characterization of the region, the Company[14] commits to analyse precipitation, temperature, humidity, evaporation, evapotranspiration, wind and insolation variables, based on the monthly and annual variations recorded for the region.
b) Air Quality	An inventory of existing air pollutant emission sources in the project area will most certainly be undertaken, as well as the identification of sensitive receptors. The Company commits at running an analysis of i) air quality data obtained in two air quality monitoring stations, the ones that are closest to the location - Lomba, Lamas de Olo (Vila Real) and Frossos (Braga), and ii) air quality data obtained through an air quality assessment campaign carried out in the project implementation area through a passive diffusion sampling for the determination of nitrogen dioxide (NO2) concentrations in the environment. The intention is to calculate and estimate atmospheric pollutant concentrations of dust resulting from the dismantling, loading and movement of vehicles and exhaust gases resulting from the machinery to be used in the project. These emissions will be minimized through the implementation of dedusting systems in the Industrial Unit and implementation of irrigation systems in the quarry's internal accesses.
c) Noise	Characterization of noise is planned to be based on the identification of the noise sources in the area of the project under study, on the identification of sensitive receivers and on the study of the Noise Map of Montalegre and Plano Diretor Municipal (PDM).
d) Geology and geomorphology	Identification and characterization of the topography, geology and geomorphology of the area is intended to be based on the consultation of bibliographical elements considered relevant, such as geological maps, Atlas of the Environment and the Management Plans of the Hydrographic Basins of the Cávado and Douro rivers.
e) Land Use	The characterization of the soil and land use in the area of the project implementation is intended to be based on existing works and in the cartography available for the territory, namely in information on the Environmental Atlas, as well as information contained in the PDM of Montalegre and Management Plans of the Hydrographic Basins of the Cávado and Douro rivers.
f) Landscape	Concerning landscape, the mining area and the Industrial Unit will have a visual impact that will be less evident in embedded areas but will be more significant in hill areas or hillside areas. Thus, in order to evaluate the potential impact on the landscape aesthetics, visual simulations are intended to be carried out in the surrounding area of the quarry in relation to dwellings, properties and zones of higher elevation. These actions will allow the estimation of the importance of the landscape and the identification of measures to minimize the negative impact affecting its aesthetic value. In the phase of deactivation, the recovery of the areas affected by the extraction and the area of the Industrial Unit will be contemplated.

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[14] Lusorecursos, 2018.

g) Hydric Resources	In order to approach the current uses of surface and underground water resources, in addition to a bibliographic data collection, a collection of information from public entities shall be made. The main uses of water resources may also be identified, and pressures quantified, to understand the quality of the water in the area surrounding the project. Sources of pollution surrounding the project must also be identified and characterized, as well as the state of the water bodies and the potential pollutants arising from the installation, exploitation and deactivation of the mining. An inventory of water points and underground abstractions in the quarry environs must be undertaken and the vulnerability of aquifers to pollution has to be characterized. A monitoring program for Surface Water Quality shall be implemented.
h) Biotopes and Flora	For the characterization of the flora, biotopes and habitats (especially those identified by the Habitats Directive) on the project area, the whole area affected by the project shall be considered, as well as the surrounding 500m around it. In the two zones (project area and surrounding area), the different biotopes and habitats present must be identified based on two field campaigns (autumn and spring) as well as on the analysis of available works, reports or articles.
i) Fauna	An identification and characterization of the main faunal communities present in the Project's implantation area and surrounding 500m must be conducted. The characterization of the existing communities, their sensitivity and ecological relevance, as well as the forecast of the evolution of the current situation in the absence of a project, constitutes the base information for the subsequent identification, characterization and evaluation of impacts resulting from the implementation of the mine and industrial unit.
j) Spatial Planning	Lusorecursos shall carry out a characterization in terms of approved development strategies in force in the area, in order to anticipate eventual impacts resulting from the implementation of this mining extraction on the model of planning of the Municipality of Montalegre.
k) Archaeological and Archaeological Heritage	All research carried out should be based on the identification of findings (isolated or dispersed), constructions, monuments, collections, sites, topographic or other archaeological, architectural and ethnological indicators, regardless of their protection status or value.
l) Socioeconomic Environment	The Company intends to undertake an assessment on employment creation and diversification, as well as on the supply of labour.

Table 4: Factors and project implications.

Source: Own elaboration with information from Lusorecursos (2017)

Thinking about one impact alone, without considering the effects of the others, is not the most adequate approach since they have cumulative impacts that must be considered as a whole.

In the next section we will see the opportunities and threats of exploiting and processing lithium in Portugal.

4.2 Opportunities and threats of lithium exploitation in Barroso-Alvão

4.2.1. Methodology

The lithium market is growing, but there are consequences sometimes ignored. Each stage of the life-cycle of a mineral carries risks to the environment and to the population (Epstein et al., 2011). Accounting these externalities may double or triple the price of exploring it, potentiating recycling and second uses (Epstein et al, 2011).

Based on the premise of understanding the weight of the opportunities of exploring lithium in Portugal and the impacts associated with the extracting activity, this work focused on the analysis and adaptation of essentially two models. It tries to answer, then, the question: Is the lithium market an economic opportunity to Portugal or a big threat to the environment? If both, how to manage the situation?

The first model analysed is the one proposed by Epstein et al. (2011) in what concerns the life-cycle assessment and full cost accounting of coal. In their work, authors examined the many stages of the coal's life-cycle, using a framework of environmental impacts, not often taken into account in the decision-making process, and for that reason distorting the real results and costs (Epstein et al., 2011). The work tried to attribute a monetary value for the "hidden costs" associated with the mining, processing, transport and combustion of coal, sometimes with a cumulative effect (Epstein et al., 2011, p. 75). Those impacts affect individuals, families, communities, the ecological integrity and the global climate. The accounted damages, presented in 2008 US$, are the climate change, public health impacts from exposure to NOx, SO_2, PM2.5 and mercury, fatalities caused by rail accidents during coal transport, health burning due to mining, government subsidies and the lost value of abandoned mine lands (Epstein et al., 2011). Since it is always difficult to monetize damages, a scale of "low, best and high" was used. Despite it, this dissertation will closely look at the best scenario only.

Climate change impacts were monetized accordingly to the social cost of carbon, meaning "the valuation of the damages due to emissions of one metric ton of carbon, of \$30/ton of CO_2 equivalent (CO_{2e}), with low and high estimates of \$10/ton and \$100/ton"[15] (National Research Council, 2009 *in* Epstein et al., 2011, p. 75), for sensitivity purposes. In what concerns public health impacts due to exposure to air pollutants, two values for mortality risk were found, differing among them due to different concentration-response functions (Epstein et al., 2011). Mortality was valued using the value of statistical life (VSL), the most commonly used being 6 million in 2000 US$ or 7.5 million in 2008 US$. Regarding government subsidies for the coal industry, "the lower of the two values presented represents the low and best estimate, and the higher represents the high estimate" (Epstein et al., 2011, p. 75).

Epstein et al. (2011) focused on Appalachia (USA) and they first identified the impacts of the U.S. coal industry on the environment and society: "health and environmental hazards associated with coal stem from extraction, processing transportation and combustion of coal; the aerosolized, solid, and liquid waste stream associated with mining, processing, and combustions; and the heath, environmental, and economic impacts of climate change" (Epstein et al., 2011, p. 78). Those impacts were translated in some categories of impacts, summarized in Table 5. Thus, they analysed the available data and they attempted to monetize impacts (Table 6).

The coal industry feeds in a great part the American energy/electricity market. Based on the results, Epstein et al. (2011) concluded that impacts of coal industry are costing a third to over one-half of a trillion dollars annually – in another words, the price of electricity

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[15] National Research Council, 2009 *in* Epstein et al., 2011.

generated from coal, energy source that carries a heavy burden, doubles or triples when we account all the impacts (Epstein et al., 2011).

But the true impacts go beyond electricity and costs and are far greater than numbers suggest, not only because some impacts were not taken into consideration, but also because some of them, despite being identified, depend on the unstable climate or are not yet translated into numbers (Epstein et al., 2011). Accounting these impacts would make renewable energy sources along with investments in efficiency and storage methods economically competitive in relation to fossil fuels.

The second work used in the current methodology is a study carried out through a partnership – "the Li-ion Batteries and Nanotechnology Partnership", led by the Environmental Protection Agency (EPA), with the U.S. Department of Energy (DOE), the Li-ion battery industry and academics (EPA, 2013). This study is the first life-cycle assessment build on data collected directly from suppliers, manufacturers and recyclers, with the purpose of identifying which stage of the life-cycle assessment impacts the most the environment and human health, based on a cradle-to-grave approach (EPA, 2013). It filled the research gap at the time to "help to grow the advanced vehicle battery industry in an environmentally responsible and efficient way" (EPA, 2013, p. 19). It also used data from previously published studies.

The study "assessed three Li-ion battery chemistries for an electric vehicle (EV) and two chemistries for a long-range plug-in hybrid electric vehicle (PHEV) with a 40 mile all-electric range" (EPA, 2013, p. 1). For the Li-ion batteries, the study assessed LMO, NMC and LFP batteries chemistries.

EPA (2013) developed their work "to provide information to the advanced automotive battery industry to facilitate environmental improvements in Li-ion batteries, by identifying which materials or processes within the products' life-cycles are likely to pose the greatest impacts or potential risks to public health or the environment, including greenhouse gas emissions" (EPA, 2013, p. 16). The product systems evaluated in this study are Li-ion batteries used in electric vehicles, therefore the functional unit is the distance driven in kilometers. In addition, the study assumes the lifetime of a battery will be the same as the vehicle for which is used – 10 years, assuming one battery-per-vehicle (EPA, 2013).

EVs require higher energy density batteries which provides a higher range per charge. In this study, "the data were scaled to account for a 40kWh battery pack in the EVs", assuming "all components scale linearly into the battery pack to meet energy density requirements" (EPA, 2013, p. 44).

	Economic impacts	Human Health impacts	Environmental impacts	Other impacts
Underground mining	Subsidies of coal industry	Increased mortality and morbidity in coal communities due to mining pollution; Threats remaining from abandoned mine lands	Methane emissions from coal leading to climate change; Remaining damage from abandoned mine lands	
Mountaintop removal mining (MTR mining)	Tourism loss; Significantly lower property values; Cost for taxpayers of environmental mitigation and monitoring; Population declines	Contaminated streams; Direct trauma in surrounding communities; Additional mortality and morbidity in coal communities due to increased levels of air particulates associated with MTR mining (vs. underground mining); Higher stress levels	Loss of biodiversity; Sludge and slurry ponds; Greater levels of air particulates; Loss and contamination of streams	
Coal Mining	Opportunity costs of bypassing other type of economic development (especially for MTR mining); Subsidies of coal industry; Economic boom and bust cycle in coal mining communities; Cost of coal industry litigation; Damage to farmland and crops resulting from coal mining pollution; Loss of income from small scale forest gathering and farming (e.g., wild ginseng, mushrooms) due to habitat loss; Loss of tourism income; Lost land required for waste disposal; Lower property values for homeowners; Decrease in mining jobs in MT mining areas	Workplace fatalities and injuries of coal miners; Morbidity and mortality of mine workers resulting from air pollution; Increased mortality and morbidity in coal communities due to mining pollution; Increased morbidity and mortality due to increased air particulates in communities proximate to MTR mining; Hospitalization costs resulting from increased morbidity in coal communities; Local health impacts of heavy metals in coal slurry; Health impacts; resulting from coal slurry spills and water contamination; Threats remaining from abandoned mine lands; direct trauma from loose boulders and felled trees; Mental health impacts; Dental health impacts reported, possibly from heavy metals; Fungal growth after flooding	Destruction of local habitat and biodiversity to develop mine site; Methane emissions from coal leading to climate change; Loss of habitat and streams from valley fill (MTR); Acid mine drainage; Incomplete reclamation following mine use; Water pollution from runoff and waste spills; Remaining damage from abandoned mine lands; Air pollution due to increased; Particulates from MTR mining	Infrastructure damage due to mudslides following MTR; Damage to surrounding infrastructure from subsidence; Damages to buildings and other infrastructure due to mine blasting; Loss of recreation availability in coal mining communities; Population losses in abandoned coal-mining communities
Coal Transportation	Wear and tear on aging railroads and tracks	Death and injuries from accidents during transport; Impacts from emissions during transport	GHG emissions from transport vehicles; Damage to vegetation resulting from air pollution	Damage to rail system from coal transportation; Damage to roadways due to coal trucks
Coal Combustion	Subsidies for the coal industry; Damage to farmland and crops resulting from coal combustion pollution	Increased mortality and morbidity due to combustion pollution; Hospitalization costs resulting from increased morbidity in coal communities	Climate change due to CO2 and NOx derived N2O emissions; Environmental contamination as a result of heavy metal pollution; Higher frequency of sudden infant death syndrome in areas with high quantities of particulate pollution	Corrosion of building and monuments from acid rain; Visibility impairment from NOx emissions; Impacts of acid rain derived from nitrogen oxides and SO2; Environmental impacts of ozone and particulate emissions; Soil contamination from acid rain; Destruction of marine life from mercury pollution and acid rain; Fresh water use and in coal powered plants
Waste Disposal		Health impacts of heavy metals and other contaminants in coal ash and other waste; Health impacts, trauma and loss of property following coal ash spills	Impacts on surrounding ecosystems from coal ash and other waste; Water pollution from runoff and fly ash spills	
Electricity Transmission	Loss of energy in the combustion and transmission phases		Disturbance of ecosystems by utility towers and rights of way	Vulnerability of electrical grid to climate change associated disasters

Table 5: Life-cycle impact of the coal industry in the USA.

Source: Adaptation from Epstein et al. (2011), pages 78-80

	Results from the “Best Scenario” (millions US$)
Land disturbance	163
Methane emissions from mines	2,052
Public health burden	74,613
Fatalities due to coal transport	1,808
Emissions of air pollutants from combustion	187,473
Lost productivity from mercury emissions	1,625
Excess mental retardation from mercury emission	36
Excess cardiovascular disease from mercury emissions	3,536
Climate damages from combustion emissions of CO_2 and N_2O	61,679
Climate damages from combustion emissions of black carbon	45
EIA 2007 [16]	3,1778
AMLs [17]	8,775
Climate total	63,940
Total	345,309

Table 6: The complete costs of coal in 2008 US$.

Source: Adaptation of Epstein et al. (2011), page 91

EPA (2013) analysed three batteries of types LMO, LFP and NMC, using data from manufacturers, and modelled LFP batteries from secondary data to “provide a rough indication of how close the primary and secondary data sources correlate” (EPA, 2013. p. 22). This study is based in data collected directly from manufacturers between 2010 and 2011 (EPA, 2013). The study also assumes “any parameters that may change with time (e.g., availability of landfill space, recycling rates, recycling technologies) will be similar to current conditions, and will remain constant throughout the lifetime of the product system” (EPA, 2013, p. 27).

Authors evaluated the life-cycle environmental impacts from the following life-cycle stages: i) raw material extraction/acquisition, meaning the “activities related to the acquisition of natural resources, including mining non-renewable material, harvesting biomass, and transporting raw materials to processing facilities”, ii) materials processing, “processing natural resources by reaction, separation, purification, and alteration steps in preparation for the manufacturing stage; and transporting processed materials to product manufacturing facilities”, iii) product manufacture, “manufacture of components of battery cells and battery packs”, iv) product use, “use of batteries in EVs”, and v) final disposition/end-of-life, “recovery of the batteries at the end of their useful life” (EPA, 2013, p. 23).

This report focused on 10 impacts categories. Each of these 10 impact categories is described in Table 7, along with the formula, unit and description of each variable.

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[16] Energy Information Administration (Epstein et al., 2011).

[17] Abandoned Mine Lands (Epstein et al., 2011).

Impacts Category	Description	Formula and Unit	Variables Description	Source
ARD (Abiotic resource depletion)	Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve. It is, basically, the loss of resources for future generations.	$EF_{ADP}=\frac{DR/R^2}{DR_{Sb}/R_{Sb}^2}$ Unit: kg Sb-Eq.	**EF_{ADP}:** the abiotic depletion potential of material (unitless) **DR:** the global extraction rate of the material (kg/yr) **R:** the ultimate global reserve of the material (kg) **DR_{Sb}:** the global extraction rate of the reference material, antimony (kg/yr) R_{Sb}: the ultimate global reserve of the reference material, antimony (kg) **IS_{AD}:** the abiotic depletion impact score for the material (kg antimony-equivalents) per functional unit; **Amt:** the amount of material extracted (kg) per functional unit.	Guinée, 2002 (*apud* EPA, 2013) SAIC & Curran, 2006
GWP (Global Warming Potential)	Converts LCI data to carbon dioxide (CO2) equivalents. GWP can represent 50, 100, or 500 year potentials. GWP refers to the warming of the planet, caused by the levels of CO2 emissions, released to the atmosphere and causing adverse effects. It represents, indeed, the polar melt, soil moisture loss, longer seasons, forest lost/change and change in wind and ocean patterns.	$IS_{GW} = EF_{GWP} \cdot Amt_{GG}$ Unit: kg CO2-Eq.	**IS_{GW}:** the global warming impact score for the greenhouse gas (kg CO2-equivalents) per functional unit **EF_{GWP}:** the GWP equivalency factor for the greenhouse gas (CO2-equivalents, 100-year time horizon) **Amt_{GG}:** the inventory amount of the greenhouse gas (GG) released to air (kg) per functional unit	SAIC & Curran, 2006 EPA, 2013
AP (Acidification Potential)	Converts LCI data to hydrogen (H+) ion equivalents. It's the potential acidification impacts from inorganic air emissions that cause the increase in the acidity of soil and water, with the most visible manifestation being acid rain. It is characterized by building corrosion, water body acidifications, vegetation effects and soil effects.	$IS_{AP} = EF_{AP} \cdot Amt_{AC}$ Unit: kg H+ Mol-Eq.	**IS_{AP}:** the impact score for acidification for the chemical (kg H+ mole-equivalents) per functional unit **EF_{AP}:** the AP equivalency factor for the chemical (kg H+ mole-equivalents) **Amt_{AC}:** the amount of the acidic chemical (AC) released to the air (kg) per functional unit	SAIC & Curran, 2006 EPA, 2013
EP (Eutrophication Potential)	Converts LCI data to phosphate (PO4) equivalents. Nutrients (nitrogen and phosphorus) enter the water bodies, such as lakes, estuaries and slow-moving streams, causing excessive plant growth and oxygen depletion "It should be noted that results indicate negative net impacts because of the used data set that documents net negative emissions of inorganics, mainly because it appears to be accounting for the observation that input process water shows higher levels of these contaminants than the ultimate effluent water" (EPA, 2013, p. 77).	$IS_{EP} = EF_{EP} \cdot Amt_{EC}$ Unit: kg N-Eq.	IS_{EP}: the impact score for regional water quality impacts from the chemical (kg nitrogen-equivalents) per functional unit EF_{EP}: the EP equivalency factor for the chemical (kg nitrogen-equivalents) Amt_{EC}: the inventory mass (kg) of the eutrophication-inducing chemical (EC) per functional unit in a wastewater stream released to surface water after treatment, if applicable	SAIC & Curran, 2006 EPA, 2013
ODP (Ozone Depletion Potential)	Converts LCI data to trichlorofluoromethane (CFC-11) equivalents. It is, basically, the increase in ultraviolet radiation.	$IS_{ODP} = EF_{ODP} \cdot Amt_{ODC}$ Unit: kg CFC 11-Eq.	**IS_{ODP}:** the impact score for ozone depletion for the chemical (kg CFC 11-equivalents) per functional unit **EF_{ODP}:** the ODP equivalency factor for the chemical (kg CFC 11-equivalents) **Amt_{ODC}:** equals the amount of the ozone depleting chemical (ODC) released to the air (kg) per functional unit.	SAIC & Curran, 2006 EPA, 2013
POP (Photochemical Oxidation Potential)	Converts LCI data to ethane (C2H6) equivalents. It is, indeed, characterized by "smog", decreased visibility, eye irritation, respiratory tract and lung irritation, and vegetation damage.	$IS_{POP} = EF_{POP} \cdot Amt_{POC}$ Unit: kg O3-Eq.	**IS_{POP}:** the impact score for photochemical oxidation for the chemical (kg ozone-equivalents) per functional unit **EF_{POP}:** the POP equivalency factor for the chemical (kg ozone-equivalents) **Amt_{POC}:** the amount of the photochemically oxidizing chemical (POC) released to the air (kg) per functional unit.	SAIC & Curran, 2006 EPA, 2013
ETP (Ecological Toxicity Potential)	ETP helps characterizing the ecological impact of emissions on freshwater organisms.	$IS_{ETP} = CF_{ETP} \cdot Amt_{ETC}$ Unit: PAF m^3 day	**IS_{ETP}:** the impact score for ecological toxicity of the chemical (PAF m3 day) per functional unit **CF_{ETP}:** the ecological toxicity potential (ETP) characterization factor for the chemical (PAF m3 day)	SAIC & Curran, 2006 Rosenbaum et al., 2008 (*apud* EPA, 2013

			Amt_{ETC}: the amount of the ecologically toxic chemical (ETC) released to the air, soil, or water (kg) per functional unit	
HTP (Human Toxicity Potential)	Seeks to characterize the human health impact of emissions in terms of potential toxicity impacts to the general public, for example.	$IS_{HTP} = CF_{HTP} \cdot Amt_{HTC}$ Unit: cases	**IS_{HTP}:** the impact score for human toxicity potential (HTP) of the chemical (cases) per functional unit **CF_{HTP}:** the HTP characterization factor for the chemical (cases) **Amt_{HTC}:** the amount of the human toxic chemical (HTC) released to the air, soil, or water (kg) per functional unit.	SAIC & Curran, 2006 Rosenbaum et al., 2008 (*apud* EPA, 2013
OCH (Occupational Cancer Hazard)	Occupational hazard impacts are defined in the context of life-cycle assessment as relative measures of potential chemical hazard to workers in terms of toxicity. Assessments of potential occupational cancer hazard impacts rely on measures of chronic cancer toxicity, which are manifestations of carcinogenicity that occur as a result of repeated exposure to toxic agents over a relatively long period of time (i.e., years). Any chemical that is assumed to be potentially toxic is assigned a toxicity hazard value (HV).	$HV_{CA\ oral} = \frac{Oral_{SF}}{Oral_{SF,\ GM}}$ $HV_{CA\ inhalation} = \frac{Inhalation_{SF}}{Inhalation_{SF,\ GM}}$ The cancer HV for a particular chemical, whether it is from a slope factor or WOE, is then multiplied by the applicable inventory amount to calculate the impact score for potential cancer effects: $IS_{CHO\text{-}CA} = HV_{CA} \cdot Amt_{TC,\ input}$ Unitless	**$HV_{CA\ oral}$:** the cancer oral hazard value for the chemical (unitless) **$oral_{SF}$:** the cancer oral slope factor for the chemical (mg/kg-day)-1 **$oral_{SF,\ GM}$:** the geometric mean cancer slope factor of all available slope factors (mg/kg-day)-1 **$HV_{CA\ inhalation}$:** the cancer inhalation hazard value for the chemical (unitless) **$inhalation_{SF}$:** the cancer inhalation slope factor for the chemical (mg/kg-day)-1 **$inhalation_{SF,\ GM}$:** the geometric mean cancer inhalation slope factor of all available inhalation slope factors (mg/kg-day)-1 **$IS_{CHO\text{-}CA}$:** the impact score for chronic occupational cancer health effects for the ?chemical (kg cancertox-equivalents) per functional unit **HV_{CA}:** the hazard value for carcinogenicity for the chemical **Amt_{TC}**: the amount of toxic chemical input (kg) per functional unit for the chemical.	SAIC & Curran, 2006 SAIC & Curran, 2006 EPA, 2013
ONCH (Occupational Non-Cancer Hazard)	The non-carcinogen HV is based on no-observed-adverse-effect levels (NOAELs) or lowest-observed-adverse-effect levels (LOAELs) derived from laboratory animal toxicity experiments. Priority is given to the NOAELs or LOAELs used to calculate reference doses or concentrations (RfD/RfCs).	$HV_{NC\ oral} = \frac{1/\text{Oral NOAEL}}{1/\text{Oral NOAEL}_{GM}}$ $HV_{NC\ inhal} = \frac{1/\text{Inhal NOAEL}}{1/\text{Inhal NOAEL}_{GM}}$ The non-carcinogen HVs for a particular chemical are multiplied by the applicable inventory input to calculate the impact score for non-cancer effects: $IS_{CHO\text{-}NC} = HV_{NC} \text{ x } Amt_{TC,\ input}$ Unitles	**$HV_{NC\ oral}$**: the non-carcinogen oral hazard value for the chemical (unitless) **oral NOAEL:** the oral NOAEL for the chemical (mg/kg-day) **oral $NOAEL_{GM}$:** the geometric mean oral NOAEL of all available oral NOAELs (mg/kgday) **$HV_{NC\ inhalation}$:** the non-carcinogen inhalation hazard value for the chemical (unitless) **inhal NOAEL:** the inhalation NOAEL for the chemical (mg/m3) **inhal $NOAEL_{GM}$:** the geometric mean inhalation NOAEL of all available inhalation NOAELs (mg/m3) **$IS_{CHO\text{-}NC}$:** the impact score for chronic occupational non-cancer health effects for the chemical (kg noncancertox-equivalent) per functional unit **HV_{NC}:** the hazard value for chronic non-cancer effects for the chemical **Amt_{TC}:** equals the amount of toxic chemical input (kg) per functional unit for the chemical.	SAIC & Curran, 2006 EPA, 2013

Table 7: The 10 impact categories – brief description.

Source: Own elaboration based on data from EPA (2013) and SAIC & Curran (2006*)*.

Moreover, since the report focus on 6 major life-cycle stages – (i) Material Extraction, (ii) Materials Processing, (iii) Components Manufacture, (iv) Product Manufacture, (v) Product Use and (vi) Average end-of-life, each impact category was analysed for each stage (EPA, 2013). EPA (2013) produced tables for each impact category, considering battery types and the life-cycle stage. In an attempt of simplifying data, this dissertation adapted data from

EPA (2013) for each type of battery (LMO, NMC and LFP), considering the life-cycle stage and each impact category. Tables 8-11 present these results.

The study concluded "the choice of active material for the cathode influences the results across most of the impact categories". NMC batteries rely on cobalt and nickel which indicate "significant non-cancer and cancer toxicity impact potential" (EPA, 2013, p. 102). On the other hand, LMO and LFP use metals less toxic like manganese and iron, with less impacts in terms of non-cancer and cancer toxicity.

Another conclusion is that LMO and LFP batteries use large amounts of aluminium in their various components, which is related with "higher potential for ozone depletion" in comparison with NMC batteries (EPA, 2013, p. 102).

It is important to clarify that the sum of 100% for each major life-cycle stages excludes the "average end of life" impact category. For the average end-of-life stage, the recovery of materials significantly reduces the overall environmental impacts by giving materials a secondary use. Values for this impact category are negative since it helps the environment instead of having negative effect.

Authors concluded: "batteries that use cathodes with nickel and cobalt, as well as solvent-based electrode processing, have the highest potential for environmental impacts (…) resource depletion, global warming, ecological toxicity, and human health impacts" (EPA, 2013, p. 2). The substitution of the cathode material and recycling of metals may reduce these impacts significantly (EPA, 2013).

Briefly analysing values from each table, it is possible to conclude that values for each type of battery induce similar conclusions in terms of which impacts contribute the most for the final result. By focusing especially on table 11, where the average values are represented, it is possible to conclude that the battery use phase dominates the majority of impact categories – 82.3% for ARD, 81.8% for Global Warming Potential, 82% for Acidification Potential, 82.3% for Photochemical Oxidation Potential and 83.7% for Human Toxicity Potential. On the other hand, impacts in the upstream materials extraction, processing and battery production are non-negligible in all categories. Moreover, materials extraction, the relevant stage for the Portuguese case as it is the one that occurs in the country, dominates in impact categories like Ozone Depletion (46.2%) Eutrophication Potential (46.4%), Occupational non-cancer hazard (69.8%), Ecological Toxicity Potential (94.3%) and Occupational cancer hazard (92.4%).

	ARD[18]	**GWP**[19]	**AP**[20]	**EP**[21]	**ODP**[22]	**POP**[23]	**ETP**[24]	**HTP**[25]	**OCH**	**ONCH**
(i) Material Extraction	6.97E-05 7.7 %	1.32E-02 9.7%	3.23E-03 5.7%	-2.93E-06 -24.8%	4.74E-10 64.3%	5.45E-04 6.7%	2.02E-03 97.7%	2.19E-13 7.5%	1.26E-01 69.1%	1.27E-01 58.2%
(ii) Materials Processing	1.18E-05 1.3%	1.27E-03 0.9%	5.87E-04 1.0%	3.57E-07 3.0%	1.03E-10 14.0%	1.73E-04 2.1%	1.01E-06 0.0%	3.99E-14 1.4%	3.77E-04 0.2%	4.07E-04 0.2%
(iii) Components Manufacture	8.98E-06 1.0%	1.76E-03 1.3%	6.32E-04 1.1%	5.35E-07 4.5%	1.13E-10 15.3%	9.92E-05 1.2%	7.33E-07 0.0%	2.90E-14 1.0%	3.75E-04 0.2%	6.78E-04 0.3%
(iv) Product Manufacture	2.74E-06 0.3%	5.16E-04 0.4%	1.67E-04 0.3%	9.00E-08 0.8%	3.75E-11 5.1%	4.27E-05 0.5%	2.38E-07 0.0%	5.40E-15 0.2%	1.02E-04 0.1%	1.70E-04 0.1%
(v) Product Use	8.06E-04 89.6%	1.20E-01 87.8%	5.23E-02 91.9%	1.38E-05 116.5%	9.80E-12 1.3%	7.32E-03 89.5%	4.66E-05 2.3%	2.63E-12 89.9%	5.57E-02 30.5%	1.70E-04 0.1%
(vi) Average end-of-life	-9.58E-06 -1.1%	-3.35E-03 -2.4%	6.27E-06 0.0%	-3.89E-07 -3.3%	-2.25E-10 -30.6%	1.39E-05 0.2%	-2.18E-05 -1.1%	-2.34E-15 -0.1%	-4.29E-02 -23.5%	-4.22E-02 -19.4%

Table 8: Impact category results per life-cycle stage for a LMO battery.

Source: Own elaboration based on EPA (2013).

	ARD	**GWP**	**AP**	**EP**	**ODP**	**POP**	**ETP**	**HTP**	**OCH**	**ONCH**
(i) Material Extraction	1.00E-04 9.9%	1.66E-02 11.1%	1.60E-02 21.9%	-9.10E-07 -6.1%	5.51E-10 80.9%	9.51E-04 10.5%	2.44E-03 97.9%	2.96E-13 9.3%	1.22E-01 66.5%	3.18E+00 97.0%
(ii) Materials Processing	2.38E-05 2.4%	2.83E-03 1.9%	8.39E-04 1.2%	5.91E-07 4.0%	6.60E-11 9.7%	2.40E-04 2.6%	2.04E-06 0.1%	8.79E-14 2.8%	1.20E-03 0.7%	9.42E-04 ~0%
(iii) Components Manufacture	1.41E-05 1.4%	2.06E-03 1.4%	7.18E-04 1.0%	5.73E-07 3.8%	4.28E-11 6.3%	1.08E-04 1.2%	8.15E-07 0.0%	3.26E-14 1.0%	7.69E-04 0.4%	1.07E-03 ~0%
(iv) Product Manufacture	6.25E-05 6.2%	7.17E-03 4.8%	3.03E-03 4.2%	8.71E-07 5.8%	1.11E-11 1.6%	4.53E-04 5.0%	2.95E-06 0.1%	1.47E-13 4.6%	3.91E-03 2.1%	5.65E-03 0.2%
(v) Product Use	8.06E-04 80.1%	1.20E-01 80.8%	5.23E-02 71.8%	1.38E-05 92.5%	9.80E-12 1.4%	7.32E-03 80.7%	4.66E-05 1.9%	2.63E-12 82.3%	5.57E-02 30.3%	8.96E-02 2.7%
(vi) Average end-of-life	-2.45E-05 -2.4%	-5.82E-03 -3.9%	-1.04E-02 -14.2%	-2.03E-06 -13.6%	-2.69E-10 -39.6%	-2.47E-04 -2.7%	-3.56E-04 -14.3%	-6.23E-14 -2.0%	-5.69E-02 -31.0%	-2.61E+00 -79.6%

Table 9: Impact category results per life-cycle stage for a NMC battery.

Source: Own elaboration based on EPA (2013).

	ARD	**GWP**	**AP**	**EP**	**ODP**	**POP**	**ETP**	**HTP**	**OCH**	**ONCH**
(i) Material Extraction	1.00E-04 9.7%	1.73E-02 11.1%	4.72E-03 7.7%	2.38E-06 4.0%	6.62E-10 29.6%	7.76E-04 8.2%	4.32E-04 69.2%	2.58E-13 7.8%	1.63E-01 73.2%	1.63E-01 62.9%
(ii) Materials Processing	2.38E-05 2.3%	2.85E-03 1.8%	5.91E-04 1.0%	3.94E-05 65.5%	4.92E-10 22.0%	1.39E-04 1.5%	1.56E-06 0.2%	8.71E-14 2.6%	9.73E-04 0.4%	8.19E-04 0.3%
(iii) Components Manufacture	1.15E-05 1.1%	2.23E-03 1.4%	7.47E-04 1.2%	6.05E-07 1.0%	9.10E-11 4.1%	5.37E-04 5.7%	1.40E-04 22.4%	1.92E-13 5.8%	5.52E-04 0.2%	8.87E-04 0.3%
(iv) Product Manufacture	8.92E-05 8.7%	1.26E-02 8.1%	3.09E-03 5.0%	3.98E-06 6.6%	9.81E-10 43.9%	6.52E-04 6.9%	4.64E-06 0.7%	1.39E-13 4.2%	2.44E-03 1.1%	4.76E-03 1.8%
(v) Product Use	8.06E-04 78.2%	1.20E-01 77.4%	5.23E-02 85.1%	1.38E-05 22.9%	9.80E-12 0.4%	7.32E-03 77.7%	4.66E-05 7.5%	2.63E-12 79.5%	5.57E-02 25.1%	8.96E-02 34.6%
(vi) Average end-of-life	-2.53E-05 -2.5%	-6.57E-03 -4.2%	-7.72E-04 -1.3%	-1.01E-05 -16.8%	-4.66E-10 -20.8%	-8.90E-05 -0.9%	-2.17E-05 -3.5%	-5.61E-14 -1.7%	-8.75E-02 -39.4%	-8.68E-02 -33.5%

Table 10: Impact category results per life-cycle stage for a LFP battery.

Source: Own elaboration based on EPA (2013).

	ARD	**GWP**	**AP**	**EP**	**ODP**	**POP**	**ETP**	**HTP**	**OCH**	**ONCH**
(i) Material Extraction	9.01E-05 9.2%	1.57E-02 10.7%	7.97E-03 12.5%	-4.88E-07 -1.7%	5.62E-10 46.2%	7.57E-04 8.5%	1.63E-03 94.3%	2.58E-13 8.2%	1.37E-01 69.8%	1.16E+00 92.4%
(ii) Materials Processing	1.98E-05 2.0%	2.32E-03 1.6%	6.72E-04 1.1%	1.34E-05 46.4%	2.20E-10 18.1%	1.84E-04 2.1%	1.54E-06 0.1%	7.16E-14 2.3%	8.48E-04 0.4%	7.23E-04 0.1%
(iii) Components Manufacture	1.15E-05 1.2%	2.02E-03 1.4%	6.99E-04 1.1%	5.71E-07 2.0%	8.21E-11 6.7%	2.48E-04 2.8%	4.71E-05 2.7%	8.45E-14 2.7%	5.65E-04 0.3%	8.77E-04 0.1%
(iv) Product Manufacture	5.15E-05 5.3%	6.77E-03 4.6%	2.10E-03 3.3%	1.65E-06 5.7%	3.43E-10 28.2%	3.83E-04 4.3%	2.61E-06 0.2%	9.70E-14 3.1%	2.15E-03 1.1%	3.53E-03 0.3%
(v) Product Use	8.06E-04 82.3%	1.20E-01 81.8%	5.23E-02 82.0%	1.38E-05 47.6%	9.80E-12 0.8%	7.32E-03 82.3%	4.66E-05 2.7%	2.63E-12 83.7%	5.57E-02 28.4%	8.96E-02 7.2%
(vi) Average end-of-life	-1.98E-05 -2.0%	-5.25E-03 -3.6%	-3.71E-03 -5.8%	-4.16E-06 -14.4%	-3.20E-10 -26.3%	-1.07E-04 -1.2%	-1.33E-04 -7.7%	-4.03E-14 -1.3%	6.25E-02 -31.8%	-9.13E-01 -73.0%

Table 11: Impact category results per life-cycle stage on average.

Source: Own elaboration based on EPA (2013).

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[18] kg SB-Eq./km = kilograms of antimony equivalent abiotic resource depletion through extraction per kilometre driven over base-case battery lifetime (10 year/193,120 km)

[19] kg CO2-Eq./km = kg CO2-Eq. = kilograms of carbon dioxide equivalent greenhouse gas emissions per kilometre driven over base-case battery lifetime (10 year/193,120 km)

[20] kg H+ Mol-Eq./km = kg H+ Mol-Eq. = kilograms of hydrogen ion molar equivalents per kilometre driven over base-case battery lifetime (10 year/193,120 km)

[21] kg N-Eq./km = kg N-Eq. = kilograms of nitrogen equivalents per kilometre driven over base-case battery lifetime (10 year/193,120 km)

[22] kg CFC 11-Eq./km = kg CFC 11-Eq. = kilograms of trichlorofluoromethane (CFC 11) equivalents per kilometre driven over base-case battery lifetime (10 year/193,120 km);

[23] kg O3-Eq./km = kg O3-Eq. = kilograms of ozone equivalents per kilometre driven over base-case battery lifetime (10 year/193,120 km)

[24] PAF m3 day/km = PAF m3 day = potentially affected fraction of species integrated over one day and one square meter per kilometre driven over base-case battery lifetime (10 year/193,120 km)

[25] Cases/km = unit increase in morbidity in the total human population per kilometre driven over base-case battery lifetime (10 year/193,120 km)

4.2.2 Results

"Consumers are increasingly interested in the world behind the product they buy. Life-cycle thinking implies that everyone in the whole chain of a product's life-cycle, from cradle-to-grave, has a responsibility and a role to play, taking into account all the relevant external effects." (Fava, 2002, p.196).

The study of Epstein et al. (2011), that focused mainly the cradle phase of the use of coal – coal mining and transportation, would be of great value for the Portuguese case, serving as a baseline to develop a similar analysis on the extraction of lithium and consequent human health and environmental impacts, by having a monetized perspective of the impacts, making it possible to inform public policy and private investment (Epstein et al., 2011). Epstein et al. (2011) calculated the share of total external costs specifically for the USA but their reasoning, analysis and methods, after proper adaptation, could be applied to other cases.

Epstein et al. (2011) estimated the social costs of coal mining and transportation having impacts in terms of increased illness and mortality due to mining pollution, government coal subsidies and cost of monitoring to taxpayers, climate change from GHG emissions, air pollution from the emission of particulates, loss of biodiversity, mercury contamination, decline in property values, infrastructure damages from mountaintop removal and mining blasting, acid rain caused by coal combustion and water pollution (Epstein et al., 2011).

Authors concluded that relying intensively on one source of energy is (obviously) a problem, since it weakens the position of a country in the market, leaving it vulnerable to changes (Epstein et al., 2011). In this context, this reasoning could be applied to the production of electricity mainly from coal, as Epstein et al. (2011) did, but also to the supply of lithium in the Portuguese context, that it is mainly intended to feed electric vehicles.

EVs are known to be environmentally friendly in their use phase, making it important to also minimize impacts in the first stage of the process and ensure they account for a real minimization of environmental impacts.

Keeping in mind that using lithium to power EVs will carry impacts along all the stages – extracting lithium, transporting and processing, using it in EV and disposing it, it is especially important to understand how impacts from the extraction and processing will affect the environment and human health, since it is the phase that will take place in Portugal.

In what follows, an exploratory analyses will be made by applying knowledges from the literature to an attempt of making a contribution to the evaluation of some environmental and human health impacts from lithium extraction in the region of Barroso-Alvão. We are aware of the limitations of this first attempt that will rely on strong assumptions.

First, we make an approximate estimate of how many batteries for EVs can be produced with the lithium from Barroso-Alvão.

The Portuguese working group on lithium (*Grupo de Trabalho do Litio*) identified an amount of 14 Mton of lithium corresponding to the sum of various aplitopegmatites structures. For the specific region where the Sepeda project is integrated – Barroso-Alvão, the working group identified 10.3 Mton of lithium (1.0% Li_2O) to be explored, classified as Inferred Mineral Resources[26] (GTL, 2017).

Following EPA (2013), we consider a battery size of more than 40 kWh (Table 12). This assumption is strict because the battery characteristics depend on the special type of EV and are not equal for all vehicles, but it is considered reliable and it is essential to make the calculations.

Vehicle Type	**Battery Size (kWh)**	**Power/ Energy Ratio**
HEV	1-2	>15
PHEV	5-15	3-10
EV	>40	<3

Table 12: General Battery Requirements.

Source: Own elaboration based on EPA (2013).

To connect the battery size and the content on lithium, we used the report produced by Oliveira et al. (2015) who refers that a battery with a size of 36 kWh contains 7.2 kg of lithium. Having in mind the information from EPA (2013) and Oliveira et al. (2015), it is possible, through some simple calculations, to assume that a battery with a size of 40kWh contains about 8 kg of lithium[27].

Using the analysed data produced by EPA (2013) and considering, based on calculations, that each battery contains an amount of 8 kg of lithium, together with all the data from GTL (2017) on the estimation of the amount of lithium to be extracted from Barroso-Alvão, it will be possible to produce 1,2875E9 batteries[28]. So, lithium from this particular Portuguese location may feed 1 287 500 000 EVs, that is, a little bit more than 1 billion cars, assuming the model characteristics of EPA (2013).

The Portuguese working group on lithium estimated a necessary investment in Barroso-Alvão of 150 000 000 euros (GTL, 2017, Cap. V, p. 8). Knowing this, the share of this

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[26] *"An "Inferred Resource" is one that is based on limited sampling and is based on reasonably assumed, but limited information. Samples might include those from outcrops, trenches, pits or drill holes. Previous geological maps may allow for reasonable assumptions about the size and scope of the resource."* (Geology for Investors. Available in https://www.geologyforinvestors.com/classification-of-mineral-resources-and-reserves/. 13/08/2018).

[27] 40x7.2:36=8 kg

[28] 10 300 000 000:8=1 287 500 000 batteries.

investment per battery/EV produced/fabricated, if all the lithium would be used to produce electric vehicles' batteries, is around 0.1165 Euros per EV/battery[29].

We can also estimate the value of the investment per kg of lithium, if all the lithium would be used to produce electric vehicles batteries, a value that will round 0.0146 Euros per kg of lithium[30]. Table 13 summarizes some values and calculation results.

Considering all the previous information, we intend in what follows to estimate and quantify the impacts per impact category, using the methodology of EPA (2013) and adapting it to the Portuguese context. We will use the average values calculated by EPA (2013) for each impact category, what corresponds to the values on Table 11, to apply to the Portuguese case, considering the number of batteries that could be produced with all the lithium from Barroso-Alvão and the estimated kilometers driven by all this potentially produced batteries. This estimation will only emphasize impacts in the materials extraction stage and materials processing stages, since they are the only stages that are predicted to take place in Portugal, at least by now.

It is important, then, to have as base scenario a battery and vehicle lifetime of 10 years, what means 193,120 km driven per one battery/EV, during its entire lifetime, according to EPA (2013). In this context, knowing that with lithium from Barroso-Alvão it is possible to produce 1 287 500 000 batteries, all these batteries/EVs will be expected to drive about a total of 4.48642E14 km.[31]

Table 14, in combination with data from table 11, presents the quantified impacts on the environment and human health, for the phases of materials extraction and processing, by impact category and for the 4.48642E14 km driven by all the potentially-built batteries. Basically, all values from the first two rows of table 11 (i and ii) were multiplied by the number of kilometers driven by all the batteries we could produce using all the lithium from Barroso-Alvão.

By analysing table 14 and comparing the extracting phase with the processing one, we conclude that the materials extraction phase dominates all the impact categories excluding the ecological toxicity potential.

Both phases will take place in Portugal and for that reason every impact, even low ones, are important. If more information were available, it would be very helpful to quantify the effects of these two phases in relation to health and environmental impacts following the methodology, for instance, of Epstein et al. (2011)).

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[29] 150 000 000:1 287 500 000 = 0.1165 Euros

[30] 150 000 000:10 300 000 000=0.0146 Euros per kg of lithium

[31] 193 120x1 287 500 000= 4,48642E14

Moreover, knowing which one has the greatest impacts may help in the process of creating a sustainable strategy on the exploitation of lithium.

Total mass of lithium in the region of Barroso-Alvão	10.3 million tons = 10.3E9 kg		GTL, 2017
Battery Size (assumption)	40 kWh	*EPA (2013) considered a battery size of more than 40 kWh. To simplify, we will consider the lower limit of 40 kWh.	EPA, 2013
Mass of lithium in one battery (result)	8 kg	*According to Oliveira et al. (2015), a battery with a size of 36 kWh contains 7,2 kg of lithium.	Oliveira et al., 2015
Number of batteries that could be produced using all the lithium from Barroso-Alvão	1,2875E9 batteries/ EVs		
Estimated investment for the region of Barroso-Alvão	150 000 000 Euros		GTL, 2017
Investment per battery, if all the lithium would be used to produce electric vehicles batteries	0.1165 Euros per battery/ EV		
Investment per kg of lithium, if all the lithium would be used to produce electric vehicles batteries	0.0146 Euros per kg of lithium		
Life expectancy of a battery (assuming one car = one battery)	10 years		
Number of km driven by one battery during its lifetime (assuming one car = one battery)	193,120 km		

Table 13: Summary of information and calculation results (1).

Source: Own elaboration.

	Material Extraction(i)	**Material Processing (ii)**	**(i) + (ii)**	Units
ARP	4.04E+10	8.88E+09	4.93E+10	kg Sb-Eq
GWP	7.04E+12	1.04E+12	8.08E+12	kg CO2-Eq.
AP	3.58E+12	3.01E+11	3.88E+12	kg H+ Mol-Eq.
EP	-2.19E+08	6.01E+09	5.79E+09	kg N-Eq.
OD	2.52E+05	9.87E+04	3.51E+05	CFC 11-Eq
POP	3.40E+11	8.26E+10	4.22E+11	kg O3-Eq
ETC	7.31E+11	6.91E+08	7.32E+11	PAF m3 day
HTP	1.16E+02	3.21E+01	1.48E+02	cases
OCH	6.15E+13	3.80E+11	6.18E+13	(unitless)
ONCH	5.20E+14	3.24E+11	5.21E+14	(unitless)

Table 14: Summary of information and calculation results (2).

Source: Own elaboration.

5. Conclusion

The growing use and preference for electric vehicles will undoubtedly have strong economic impacts, especially in the case of lithium and other metals needed to build batteries. This subject is extremely interesting and future-oriented, once it reflects an environmental trend: the way people and industries deal and understand the need of preserving and saving the Planet through the discarding of vehicles powered by fossil fuels, lightening the dependence on oil and mitigating climate change. But this altruistic trend and genuine concern has some perverse effects putting a lot of pressure in this scarce resource that is lithium and its capacity of answering to this demand.

The future of lithium extraction and processing will have to guarantee good corporate social and environmental responsibility, including environmental recovery and restitution of the area exploited to be enjoyed by the society, in compliance with the legislation in force (Oliveira & Viegas, 2011; Viegas et al., 2012).

Namely, it would be important not to concentrate the great amount of negative impacts of extraction and processing in only some locations and it is also important, mainly for car manufacturers, to vary the energy source feeding vehicles to avoid vulnerability in terms of supply shortages. The way forward is then to diversify the use of energy by using especially non-fossil fuels.

This dissertation analysed the work of Epstein et al. (2011) on the extraction of coal and consequent monetized environmental and health impacts as a reflection of what could be analysed if a similar study on the extraction of lithium in Portugal would be conducted. Epstein et al. (2011) concluded that relying on only one source of energy makes a country more vulnerable to changes. The same reasoning can be applied in this context of greening domestic transportation – relying intensively in lithium to feed car batteries has the potential to make the extractor country, in this case Portugal, vulnerable to market changes.

Epstein et al. (2011) estimated and monetized impacts in terms of increased illness and mortality due to coal mining pollution, climate change and air pollution, among others, a reasoning and categorization that could be applied to the Portuguese case (Epstein et al., 2011).

This dissertation, in a second moment, adapted the work of EPA (2013) to the Portuguese case, a study that intended to inform industry and provide an objective analysis and evaluation through the conduction of an LCA of the potential impacts of selected Li-ion battery systems, helping this way to identify areas for environmental improvement. Values estimated by EPA (2013) and data on the Portuguese lithium extraction were combined allowing the translation of some impact categories into numbers, trying to make a first contribution for a more objective view of environmental and health impacts.

On a long-term view it is also important to think about the impacts of the other stages of this lithium LCA, more specifically the disposal stage, since it encompasses batteries full of lithium. If a circular economy strategy is put in place, the extraction of lithium from Portuguese locations may have very positive consequences at local, regional and national level. However, an environmental preservation and valuation must be ensured through, for example, the production of electric and thermal energy from renewable sources – eolic, hydric, photovoltaic and biomass (Lusorecursos, 2018).

Future research should try to apply some already published methods and instruments as long as the extraction of lithium is not fully implemented, in order to analyse its environmental and health implications, neglected until the moment. The work of Epstein et al. (2011), briefly analysed in this dissertation, could be the basis, the starting point, for the study and monetization of impacts from lithium extraction in Portugal, by showing what could be done with the right information, and how should it be done.

This work is a very small contribute to the area of knowledge, simply trying to indicate a way forward, a possible path to follow. It seeks, therefore, to present a quantitative view of environmental and health effects of exploring this metal, by applying some data to the Portuguese case. It is far from a perfect quantification, and represents more a simulation and approximation of what could be done with more precise data and means. It intends to feed future research by giving some ideas of the way forward and of what could be done with the right information.

As Portuguese economic agents, we want our country to grow and to be more competitive, taking every opportunity. But as citizens of Portugal and from this Earth we must preserve it and sustain it and therefore weight the opportunities but also the threats of our actions.

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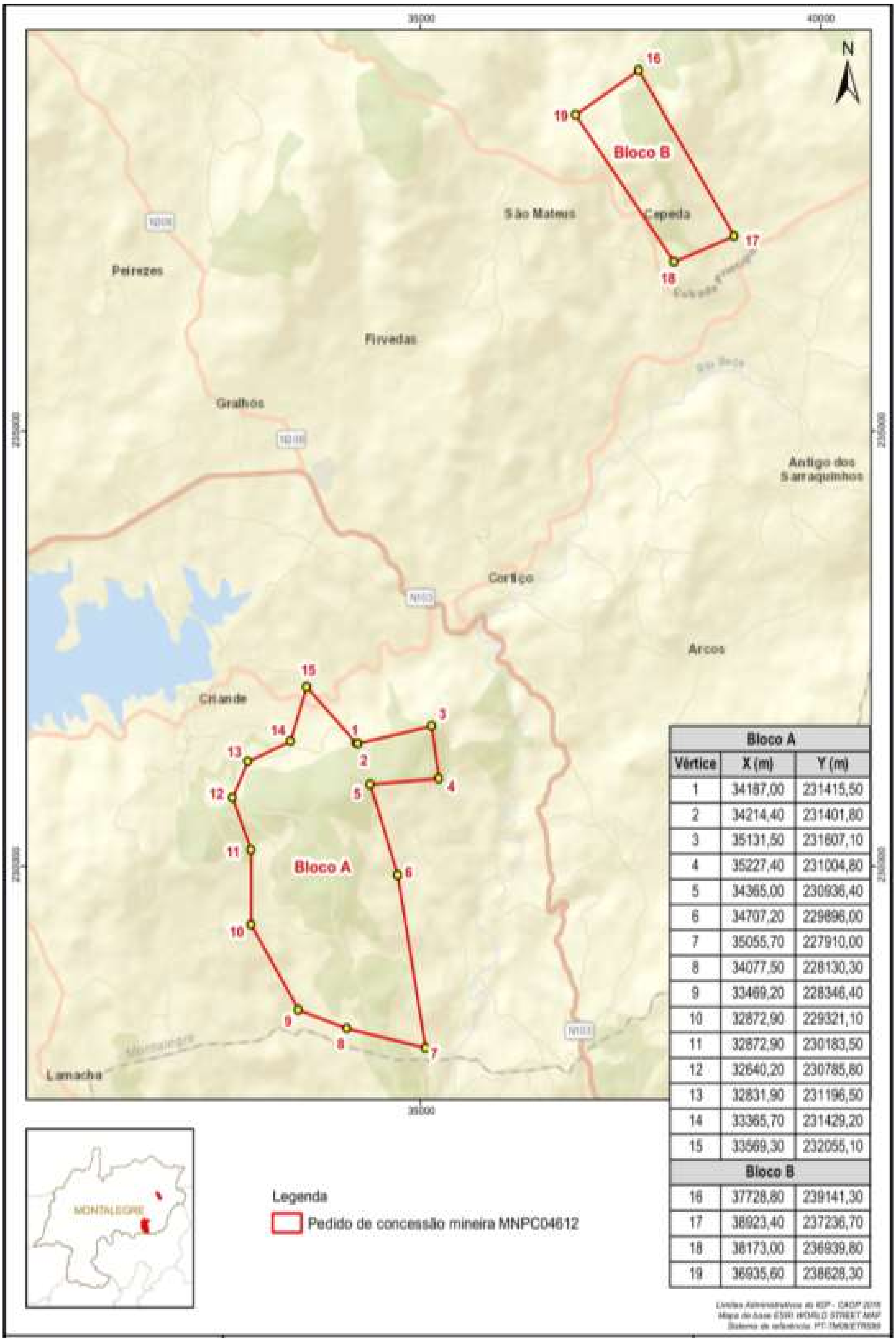
Annex

Table I: Lithium physiochemical properties. *Source:* Adaptation from Lusorecursos (2018).

Property	Value
Density	0.534 g/cm^3
Atomic Volume	13,1
Atomic Radius	1,56 Å
Ionic Radius	0,78 Å
Atomic Number	3
Atomic Mass	6,940 u
Stiffness (Mohs)	0,6
Melting Point	180 ºC
Boiling Point	1336 ºC
Ionisation Potential	5,36 ev

Figure I: Blocks leased to research and prospection in the area of the Sepeda. *Source:* DGEG, 2018.



Vértice	X (m)	Y (m)
Bloco A		
1	34187,00	231415,50
2	34214,40	231401,80
3	35131,50	231607,10
4	35227,40	231004,80
5	34365,00	230936,40
6	34707,20	229896,00
7	35055,70	227910,00
8	34077,50	228130,30
9	33469,20	228346,40
10	32872,90	229321,10
11	32872,90	230183,50
12	32640,20	230785,80
13	32831,90	231196,50
14	33365,70	231429,20
15	33569,30	232055,10
Bloco B		
16	37728,80	239141,30
17	38923,40	237236,70
18	38173,00	236939,80
19	36935,60	238628,30

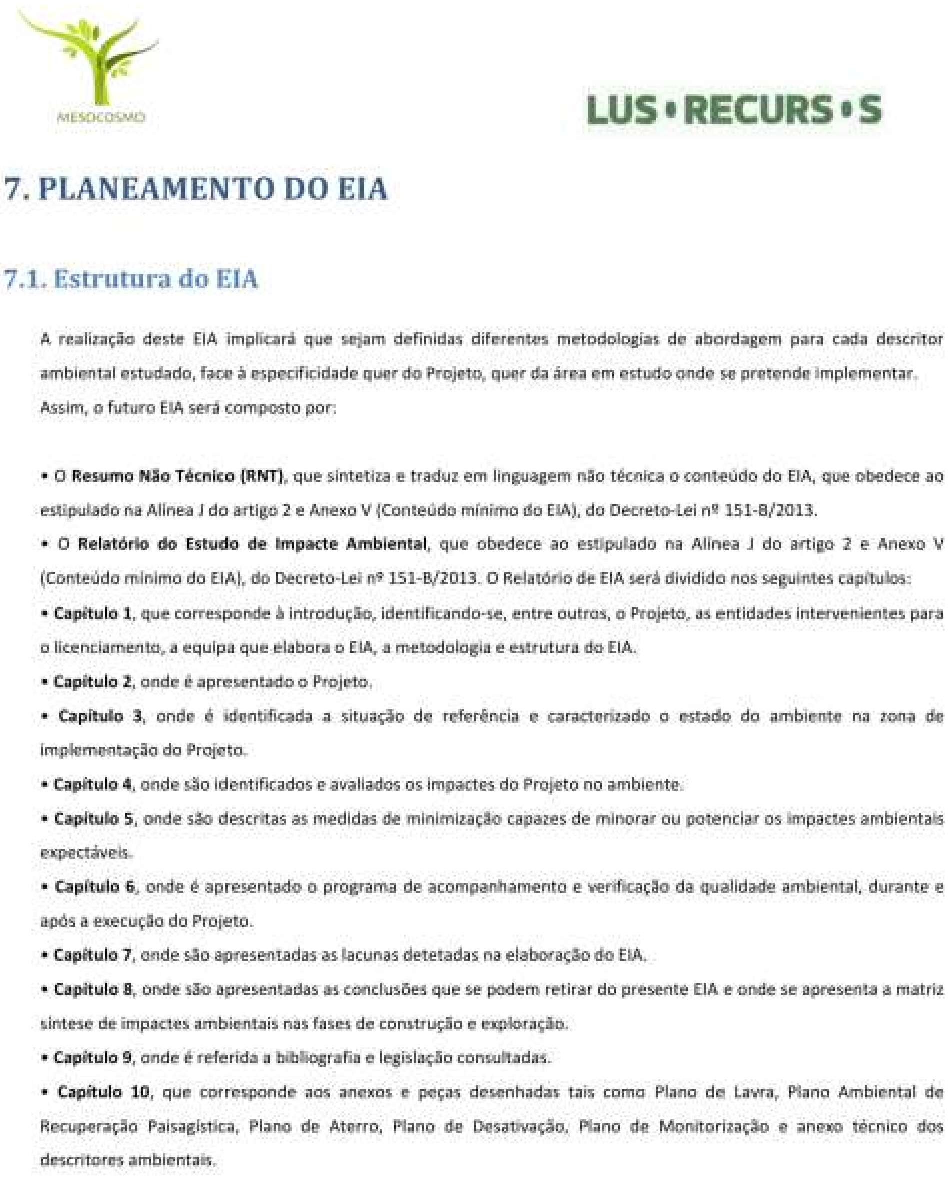


Figure II: Organization of the EIA for the Sepeda Project. *Source:* Lusorecursos, 2017.

MESOCOSMO

LUS•RECURS•S

7. PLANEAMENTO DO EIA

7.1. Estrutura do EIA

A realização deste EIA implicará que sejam definidas diferentes metodologias de abordagem para cada descritor ambiental estudado, face à especificidade quer do Projeto, quer da área em estudo onde se pretende implementar. Assim, o futuro EIA será composto por:

- O **Resumo Não Técnico (RNT)**, que sintetiza e traduz em linguagem não técnica o conteúdo do EIA, que obedece ao estipulado na Alínea J do artigo 2 e Anexo V (Conteúdo mínimo do EIA), do Decreto-Lei nº 151-B/2013.
- O **Relatório do Estudo de Impacte Ambiental**, que obedece ao estipulado na Alínea J do artigo 2 e Anexo V (Conteúdo mínimo do EIA), do Decreto-Lei nº 151-B/2013. O Relatório de EIA será dividido nos seguintes capítulos:
- **Capítulo 1**, que corresponde à introdução, identificando-se, entre outros, o Projeto, as entidades intervenientes para o licenciamento, a equipa que elabora o EIA, a metodologia e estrutura do EIA.
- **Capítulo 2**, onde é apresentado o Projeto.
- **Capítulo 3**, onde é identificada a situação de referência e caracterizado o estado do ambiente na zona de implementação do Projeto.
- **Capítulo 4**, onde são identificados e avaliados os impactes do Projeto no ambiente.
- **Capítulo 5**, onde são descritas as medidas de minimização capazes de minorar ou potenciar os impactes ambientais expectáveis.
- **Capítulo 6**, onde é apresentado o programa de acompanhamento e verificação da qualidade ambiental, durante e após a execução do Projeto.
- **Capítulo 7**, onde são apresentadas as lacunas detetadas na elaboração do EIA.
- **Capítulo 8**, onde são apresentadas as conclusões que se podem retirar do presente EIA e onde se apresenta a matriz síntese de impactes ambientais nas fases de construção e exploração.
- **Capítulo 9**, onde é referida a bibliografia e legislação consultadas.
- **Capítulo 10**, que corresponde aos anexos e peças desenhadas tais como Plano de Lavra, Plano Ambiental de Recuperação Paisagística, Plano de Aterro, Plano de Desativação, Plano de Monitorização e anexo técnico dos descritores ambientais.

Figure III: Composition of the Evaluation Committee. *Source:* Comissão de Avaliação, 2018.

Proposta de Definição de Âmbito N.º 200

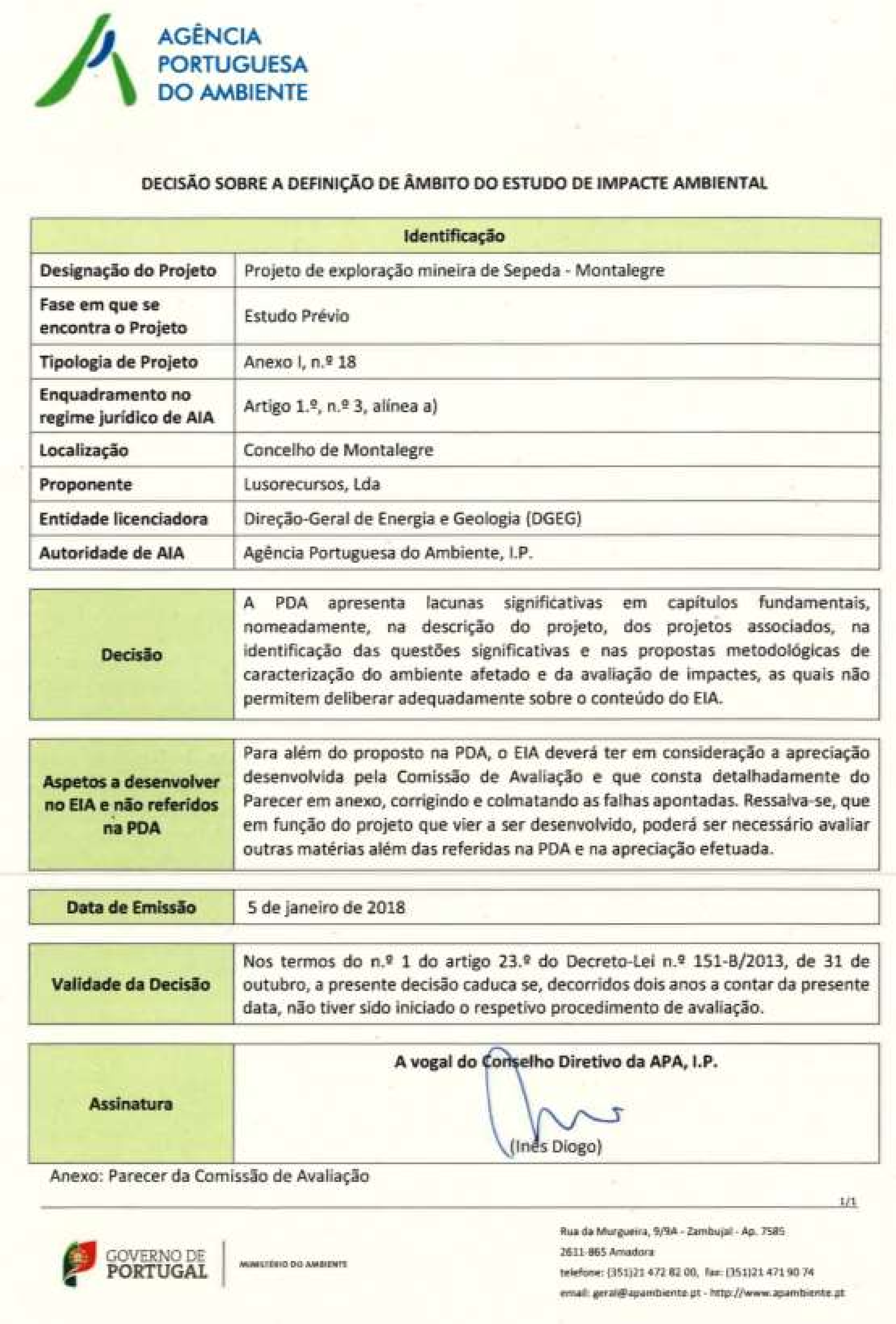
PROJETO DE EXPLORAÇÃO MINEIRA DE SEPEDA - MONTALEGRE

Parecer da Comissão de Avaliação

Janeiro de 2018

Agência Portuguesa do Ambiente, I.P.
Comissão de Coordenação e Desenvolvimento Regional do Norte
Direção Geral do Património Cultural
Instituto de Conservação da Natureza e das Florestas, I.P.
Direção Geral de Energia e Geologia
Laboratório Nacional de Energia e Geologia, I.P.
Centro de Ecologia Aplicada Prof. Baeta Neves | Instituto Superior de Agronomia

Figure IV: Decision on the Proposal on Scope Definition. *Source*: APA, 2018.



AGÊNCIA
PORTUGUESA
DO AMBIENTE

DECISÃO SOBRE A DEFINIÇÃO DE ÂMBITO DO ESTUDO DE IMPACTE AMBIENTAL

Identificação	
Designação do Projeto	Projeto de exploração mineira de Sepeda - Montalegre
Fase em que se encontra o Projeto	Estudo Prévio
Tipologia de Projeto	Anexo I, n.º 18
Enquadramento no regime jurídico de AIA	Artigo 1.º, n.º 3, alínea a)
Localização	Concelho de Montalegre
Proponente	Lusorecursos, Lda
Entidade licenciadora	Direção-Geral de Energia e Geologia (DGEG)
Autoridade de AIA	Agência Portuguesa do Ambiente, I.P.

Decisão	A PDA apresenta lacunas significativas em capítulos fundamentais, nomeadamente, na descrição do projeto, dos projetos associados, na identificação das questões significativas e nas propostas metodológicas de caracterização do ambiente afetado e da avaliação de impactes, as quais não permitem deliberar adequadamente sobre o conteúdo do EIA.
Aspetos a desenvolver no EIA e não referidos na PDA	Para além do proposto na PDA, o EIA deverá ter em consideração a apreciação desenvolvida pela Comissão de Avaliação e que consta detalhadamente do Parecer em anexo, corrigindo e colmatando as falhas apontadas. Ressalva-se, que em função do projeto que vier a ser desenvolvido, poderá ser necessário avaliar outras matérias além das referidas na PDA e na apreciação efetuada.
Data de Emissão	5 de janeiro de 2018
Validade da Decisão	Nos termos do n.º 1 do artigo 23.º do Decreto-Lei n.º 151-B/2013, de 31 de outubro, a presente decisão caduca se, decorridos dois anos a contar da presente data, não tiver sido iniciado o respetivo procedimento de avaliação.
Assinatura	**A vogal do Conselho Diretivo da APA, I.P.** (Inês Diogo)

Anexo: Parecer da Comissão de Avaliação

1/1

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