FINAL TECHNICAL REPORT

Study of critical materials' production chains: opportunities and threats of the circular economy

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Presentation

The CETEM (Centro de Tecnologia Mineral, [Centre for Mineral Technology]) and the IBICT (Instituto Brasileiro de Informação em Ciência e Tecnologia, [Brazilian Institute of Information on Science and Technology]), research units of the Ministry of Science, Technology, Innovations and Communications present below the results of the project as mentioned above, carried out between 2017 and 2020. A team of researchers from both institutions and experts assisted in the project, in addition to the support of researchers from the Joint Research Centre (JRC) of the European Comission, and operational and strategic support from the SEMPI/MCTIC team.

In Brazil and Europe, increasing interest on this topic has emerged, since among the basic proposals of the Circular Economy there is the objective of promoting the efficient use of natural resources by society, focusing on the material and environmental sustainability enhancement. The current economic model, i.e., Linear Economics, cannot deliver said attributes.

Concerning raw materials, certain mineral resources that have an important share in building the desired sustainability are considered critical for their economic importance and because their supply is subject to uncertainty. Brazil and the European Union have been partnering on this topic, aiming to cooperate in the reduction of the related risks, especially regarding critical raw materials. Brazil has been showing a great interest in reducing eventual uncertainties concerning the supply of minerals produced domestically to the international market, however critical they may be regarded. On the other hand, the European Union has sought to interact cooperatively to demonstrate their interest in partnering with Brazil regarding mineral resources, offering technical collaboration through the Joint Research Centre (JRC), and financial support for common interest studies.

The niobium case study illustrates that very well, as the EU considers it a critical raw material, in addition to the fact that Brazil is a leading producer of the mineral and some goods manufactured with it. From the point of view of the Circular Economy, niobium introduces properties into materials using it, while saving other natural resources in the process. For instance, using the niobium in the structural steeland in the transport industry promotes increased strenght while reducing the weight of constructions and vehicles, thus lowering the need for other materials, as well as fuel and power needed to transport Niobium is a metal that has various interesting chemical and physical properties. Worldwide, there is an intense PD&I activity being performed. This study introduces national and international advances in niobium-related innovations.

Social and Environmental Life Cycle Assessments (S-LCA and LCA)) can help cut down the uncertainties around critical raw materials' supply risks. The studies on actual production situations could only succeed thanks to the invaluable cooperation of the

Companhia Brasileira de Metalurgia e Mineração (CBMM), the world's largest producer of niobium. Expectations for the future are to have this collection being part of the National Life Cycle Inventory Database (SICV-Brazil), which is managed by the IBICT, and made available through the Life Cycle Data Network (LCDN), the European network of life cycle databases.

The report offers conclusions on the case study and its status within the Circular Economy design. Such findings do deserve deepening and corresponding measures such as, for instance, research aimed at improving niobium circularity aspects. Furthermore, the report also provides a methodology for the study of other Brazilian raw materials, within the context and idea of critical raw materials, the Life Cycle Assessment, and the Circular Economy.

Based on the success of this cooperation, in the case of Brazil, the expectation is to raise the interest in critical raw materials as a complement to government planning, relying on the desirable collaboration of the JRC, which manages the Raw Materials Information System (RMIS) platform.

CETEM and IBICT consider that the objectives of the experience enabled by the EU/Brazil Sector Dialogues initiative – managed in Brazil by the Ministry of Economy, the European Union Delegation in Brazil and the Ministryof Economics– have been fully achieved.

Finally, the members of the boards specially acknowledge the interest of the Ministry of Science, Technology, Innovation and Communications, which co- funded the project via their Secretariat of Entrepreneurship and Innovations, and the Companhia Brasileira de Metalurgia e Mineração, which actively collaborated with the performance of the activities planned under the partnership executed with the CETEM, enabling the information to support a significant portion of the results herein.

Fernando A. Freitas Lins
Director of CETEM

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Director of IBICT

Foreword

Critical raw materials for the European Union (EU) are materials with particularly high importance to the EU economy and, at the same time, with an increased risk of supply disruptions. The list of critical raw materials for the EU has been established for the first time in 2011 and has been since then updated every three years. The current list contains 27 critical raw materials, including cobalt, natural graphite, platinum, rare-earth, natural rubber, tantalum, and niobium, to name a few. Brazil is an important producer of several critical raw materials (e.g. natural graphite), the main global supplier of Niobium and has a remarkable potential for several other CRMs (e.g. REEs).

The transition to a more circular economy, where the value of products, materials, and resources is maintained in the economy for as long as possible, and generation of waste is minimized, is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource-efficient, and competitive economy. In its Circular Economy Action Plan published in 2015, the European Commission identified several measures across the stages of the life cycle of products, from production to production of secondary raw materials and for several priority areas. Brazil has also started its journey towards a more circular economy through the proclamation of National Policy on Solid Waste, in August 2010. Since then, other specific regulations have been published in specific reverse logistics areas, as follows: (i) Specific rule: Electronic equipment Decree No. 10.240/2020; (ii) Sectoral agreements: lubricant oil packages (2013), lamps (2014), general packages (2015), batteries (2019) and electronic equipment (2019), and (iii) Terms of commitment: batteries (before 2019).

Critical raw materials and circular economy are linked in multiple ways. First, the EU Circular Economy action plan included several actions to be undertaken in the priority area concerning Critical Raw Materials (CRMs). Moreover, recycling (one important strategy of Circular Economy) is seen in various criticality assessments (including in the EU and Japan) as a supply risk reduction factor. Other connections between critical raw materials and circular economy are explored in a 2017 JRC report.

The new European Commission (2019-2024) is likely to continue focusing on critical raw materials, and circular economy. Moreover, the recent European Green Deal communication, and the new Circular Economy Action Plan clearly stated that Europe needs to ensure strategic security and sustainable supply of raw materials for clean and digital technologies and to mobilize industries for a clean and circular economy. A new Critical Raw Materials list and Action Plan are expected to be launched in 2020. Moreover, worldwide, many critical raw materials will be necessary for the transition to a more sustainable, low carbon, resource-efficient, and competitive economy. For example, Niobium can be used to develop lightweight structures and bodies that can enhance cleaner mobility.

In such a context, this report summarizing the results of the project “Analysis of the supply chain of critical raw materials: opportunities and threats: the case of niobium” carried out in the context of the EU-Brazil Sector Dialogues and also with the financial support of the Brazilian Ministry for Science, Technology, Innovations and Communications is an important and timely contribution. Niobium is currently used in various high technology (e.g. medical devices) and lightweight applications (e.g. mobility) and brings key functions to materials. High-tech and mobility applications are very relevant for circular economy initiatives, being remanufacturing and recycling. Brazil is a crucial global supplier of niobium and other raw materials. The country monitors raw materials’ flows in a circular economy (through material flow analysis, circular economy indicators) and life cycle perspectives (through (social) life cycle assessments). Thus, Brazil contributes to a better understanding of future trends and possible actions. Moreover, this project contributes to the necessary international dialogue (as mentioned in 1) that will contribute to the widespread deployment of a more circular economy worldwide.

The Joint Research Centre of the European Commission has followed with high interest the joint work of colleagues from CETEM and USP and associated experts, and we congratulate them for the excellent results obtained. We also want to thank CBMM for their active support to this work, offering expertise and data.

Because the path to a circular economy is still long, the JRC remains available for possibly entering the relevant results into the Raw Material Information System and for discussing follow-up studies.

Gian Andrea Blengini
Fabrice Mathieux

Constantin Ciupagea

European Commission, Joint Research Centre,
Sustainable Resources Directorate
(ISPRA, Italy)

Acronyms and abbreviations

ABNT – Associação Brasileira de Normas Técnicas [Brazilian Association of Technical Standards]

LCA– Life Cycle Assessment

MFA - Material Flow Analysis

LCIA – Life Cycle Impact Assessment

ANM - Agência Nacional de Mineração [National Agency of Mining]

ASDF – Plataforma Economia Circular de las Americas [Circular Economy Platform for the Americas]

AT – Assistência Técnica [Technical assistance]

BLM – Bureau of Land Management

BNDES – Banco Nacional de Desenvolvimento Econômico e Social [National Bank for Economic and Social Development]

BSI – British Standards Institution

CBMM – Companhia Brasileira de Metalurgia e Mineração [Brazilian Metallurgy and Mining Company]

CD – Comitê Deliberativo [Decision-making Commission]

EC – European Commission

CEI – Circular Economy Index

CETEM – Centro de TecnologiaMineral [Centre for Mineral Technology]

CMOC – China Molybdenum Corporation

COLTAN – ore containing an association of columbite and tantalite minerals

COMIPA – Companhia Mineradora de Pirocloro de Araxá

CSMSC – Council Subcommittee on Critical and Strategic Mineral Supply Chains

CTU - Comparative ToxicToxic Unit

DA – Despesas Acessórias [incidental expenses]

DELBRA – Delegação da União Europeia no Brasil [European Union Delegation in Brazil]

DG - Directorate-General of the European Union

DG GROW – Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs

DN – National Directorate of the Initiative

DNPM – Departamento Nacional de Produção Mineral [National Department of Mineral Production]

DOD – Department of Defense

DOI – Department of the Interior

EC – European Commission

EOL – End of Life

EPR – Extended Producer Responsibility

ERA–MIN – Research & Innovation Programme on raw materials to foster a circular economy

EU – European Union

USA – United States of America

EURMKB – European Union Raw Materials Knowledge Base

FAPESP - Fundação de Amparo à Pesquisa do Estado de São Paulo [São Paulo State Research Support Foundation]

FINEP – Financiadora de Estudos e Projetos [Projects and Studies Funding Institution]

HHI – Herfindahl–Hirschmann Index

HHIWGI – Herfindahl Hirschman World Governance Index

HSLA – High strength Low alloyed Steel

IBICT – Instituto Brasileiro de Informação em Ciência e Tecnologia [Brazilian Institute of Information in Science and Technology]

LCI – Life Cycle Inventory

ILCD – International Reference Life Cycle Data System

ILO – International Labour Organization

INPI – Instituto Nacional de Propriedade Industrial [National Institute of Industrial Property]

IPP – Integrated Policy of Products

ISI – International Scientific Indexing

ISO – International Organization for Standardization

JRC – Joint Research Centre

KE – Key experts

L&C –Longevity and Circularity

LCA – Life Cycle Assessment

LCSA – Life Cycle Sustainability Assessment

MCI – Material Circularity Indicator

MCTIC – Ministério de Ciência, Tecnologia, Inovação e Comunicações [Ministry of Science, Technology, Innovation and Communications]

METI – Ministry of Economy, Trade and Industry

MFA – Material Flow Analysis

MI – Material Flow Analysis Indicator

MME – Ministério de Minas e Energia [Ministry of Mines and Energy]

MP – Ministério de Planejamento, Desenvolvimento e Gestão [Ministry of Planning, Development and Management]

MRE – Ministério das Relações Exteriores [Ministry of Foreign Affairs]

MSP – Multi-Stakeholder Platform

NEDO – New Energy and Industrial Technology Development Organization

NKE – Non-Key experts

NSTC– National Science and Technology Council

PAC – Plano de Ação Conjunta [Joint Action Plan]

PAF – Potentially Affected Fraction (PAF) of species

RDI – Research, Development and Innovation

PNM – Plano Nacional de Mineração [National Mining Plan]

PPP – Polluter–pays Principle

PSIA – Product Social Impact Assessment

RIR – Recycling Input Rate

RMIS – Raw Materials Information System

ROM – Run of Mine

SAM – Social Assessment Method

SEGEP – Secretaria de Gestão Pública [Secretariat for Public Management]

SELCA – Social and Environmental Life Cycle Assessment

SEMPI – Secretaria de Empreendedorismo e Inovação [Secretariat for Entrepreneurship and Innovation]

SETAC – Society of Environmental Toxicology and Chemistry

S-LCA – Social Life Cycle Assessment

SHDB – Social Hotspot Database

SIEI – Substitution Index for Economic Importance

SIP – Strategic Implementation Plan

TDR – Termo de Referência [Terms of Reference]

TIC – Tantalum-Niobium International Study Center

TL – Team Leader

UAT - Unidade de Acompanhamento Técnico [Technical assistance monitoring Unit]

EU – European Union

UN – United Nations

UNEP – United Nations Environment Program

UNIMEP – Universidade Metodista de Piracicaba [Methodist University of Piracicaba]

USGS – United States Geological Service

USP – Universidade de São Paulo [University of São Paulo]

UV – Ultraviolet radiation

VA – Value-added

WGI – World Governance Index

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Summary

1.

Critical and strategic raw materials

CARLOS CESAR PEITER

1.1 Introduction: Drivers and objectives of the research

Proposing this research project was enabled by a network of contacts and collaborations that occurred in advance among research institutions in Brazil, and in the EU via two bilateral initiatives, i.e., the EU-Brazil Sector Dialogues, and the EU-Latin America Dialogue on Raw Materials. In the context of the EU-Brazil Sector Dialogues, the IBICT (Brazilian Institute for Science and Technological Information), and the CETEM (Centre for Mineral Technology/ MCTIC) could work together in life cycle assessment exercises (Brazil-EU Sector Dialogues, 2014), e.g., the Brazilian production of ornamental granite. Moreover, IBICT and CETEM already counted on the partnership with the Joint Research Center (JRC). Within the context of the EU-Latin America, the common-ground interests emerged through a special diplomatic initiative of the EU for raw materials with Latin American producing countries (EC, 2015a).

The Ministry of Science, Technology, Innovations and Communications (MCTIC), through its Secretariat for Entrepreneurship and Innovation (SEMPI), allocated additional funds to the project, while making an effort to promote the project, thus offering a complement to the funds derived from the Sector Dialogues Program.

That partnership among the research institutions enabled us to advance a mutual interest study proposal on raw materials policies: the critical raw materials policies from Europe, and the strategic minerals' one from Brazil. With this project, we drove our efforts to benefit from that well-established network, from a knowledge base enhanced in prior works of life cycle assessment, and bilateral diplomatic discussions on mineral raw materials, with the CETEM participation in support towards the Ministry of Mines and Energy.

In 2017, we had the opportunity to present a proposal to the EU-Brazil Sector Dialogues Program. At the time, the IBICT, the CETEM, and the JRC expressed their interest in performing social and environmental life cycle assessment exercises for one critical raw material through a case study. The aim was to assess how such methodologies could contribute to the criticality assessment, which currently does not consider such intrinsic aspects of production chains and businesses. Figure 1 summarizes the EU methodology, where you can add the life cycle assessments to supply chains and the bottleneck analysis (Deloitte et al., 2017). Those assessments also make sense, based on the inclusion of sustainability aspects in the criticality evaluation.

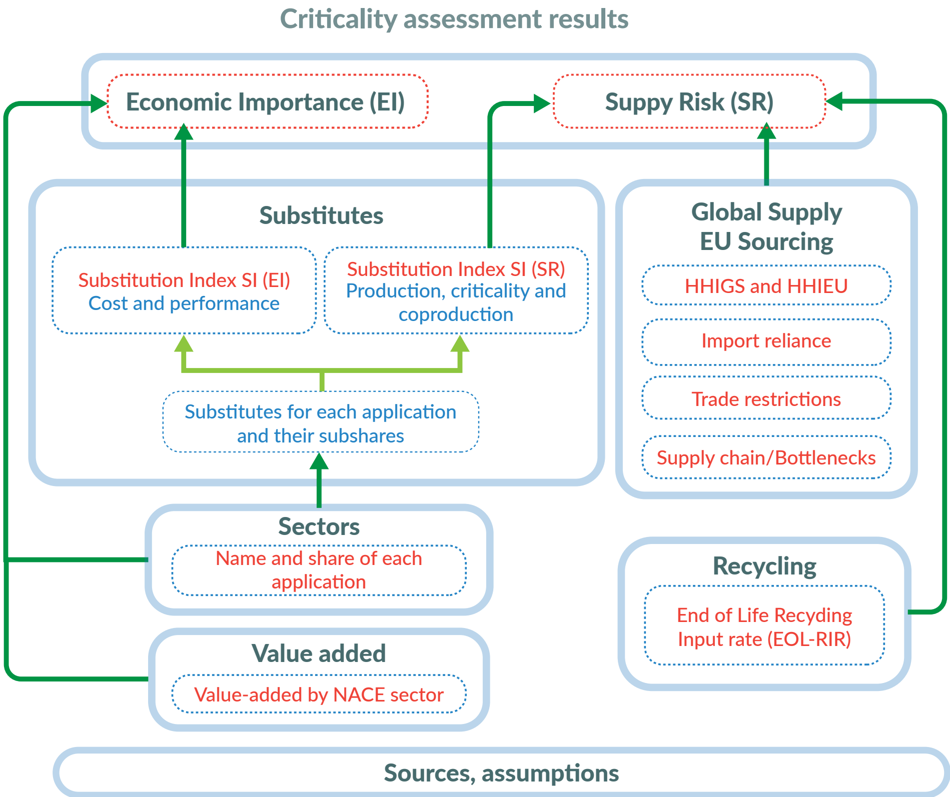

Figure 1. Flow chart of the critical raw materials' reviewed list study.

Source: Deloitte et al. (2017).

Upon the development of the proposals consolidated within projects No. 128 and No. 128-A, for the Nineth Call of the Program, the partnering research teams also considered that both the dynamics of innovations and the adoption of policies and models of a circular economy – across the value chains that depend on critical raw materials – influence or might influence the demands for primary sources. This is a key concern for producing or supplying countries, Brazil inclusively. Therefore, the critical raw material selected for a case study was the object of simulations to determine its circularity index. Besides, worldwide innovations dynamics were verified within a five year reference period (2014-2018), based on the analysis of a database of international patents and scientific papers.

In short, this study is intended to comply with two core demands:

- Provide the JRC life cycle assessments within a critical raw material case study, while evaluating the feasibility of obtaining the corresponding results, as well as their usefulness to complement raw materials' criticality studies.
- Providing CETEM and IBICT with an overview on the current international policies for raw materials, considering Brazil's strategic participation as a major producer, while discussing opportunities and challenges upon the adoption of the circular economy, and upon the dynamics of the innovations.

1.2. Critical and strategic raw materials

Raw materials supply has always been a concern for the countries and groups of countries. During the Cold War, groups of opposing countries sought to secure their supplies – both based on domestic production, and on imports and strategic stocking. Also, they aimed safety, using diplomatic endeavours, and even through actions across the domestic policies of the countries producing such raw materials. Geopolitics of raw materials has been challenging for all government administrations, and for the USA, in special, as reports Cuellar (2013). Cuellar also mentions authors envisaging that raw materials used in new energyproduction technologies could even replace fossil fuels as *commodities* deserving specific strategies (VERRASTRO, 2010 apud. CUELLAR, 2013, p. 87).

On the other hand, the 1980 and 1990s were marked by international trade openness, with the admission of several nations into global trading. The rising of China in terms of consumption, raw materials production and supply is worth to emphasize.

The resurgence of national policies for raw materials was probably a response to two new situations. That is, the international trade and economic competition for raw materials, and the emerging innovations depending on certain materials, which were not so relevant before, but whose availability depends on geological, geographical and political aspects.

1.2.1. Critical raw materials for the European Union

The concern with the above international scenario translated into policies; these, in turn, caused an intense production of studies, strategies and actions that the EC (European Commission) has been sponsoring in recent years.

The current topic of raw materials is based on *the Raw Materials Initiative* (EC, 2017a). The initiative reflects Europe's concern about the need to secure raw materials for their economy, and suggests three pillars to support the supply in the future:

1. Ensure access to raw materials from the international market under the same conditions as other industrial competitors.
2. Determine the appropriate structural conditions within the European Union to promote the supply of raw materials from European sources.
3. Drive resource efficiency and encourage recycling to reduce the need for raw materials from primary sources by reducing their dependence on imports.

This document determines that the most important Critical Raw Materials (CRMs) for the EU block of countries must be identified. The practical objectives of the initiative (EC, 2013a) are clearly stated in the Strategic Implementation Plan (SIP), as follows:

- Reducing the importation dependency, while encouraging production and exportations, by improving the EU supply conditions, diversifying the sources of raw materials and improving resource efficiency (including recycling), in addition to finding alternative raw materials.

The Strategic Implementation Plan (SIP) includes the European Implementation Plans (EIPs) (2013), which present the objectives, goals and actions that must be coordinated with the Member-States. Part II of the SIP includes 95 concrete actions, structured in seven priority areas (EC, 2013b).

To meet all these demands, the EC realized they would need a lot of information and actions. These, in turn, would be actionable through specific programs, derived from both public and private organizations, among which we highlight two European programs:

- The Raw Materials Information System (RMIS)[1], which is intended to support information for public policies and other initiatives involving raw materials (non--energy and non-agricultural).
- THE ERA-MIN program[2], which is a public fund financed by the EC to support research, development, and innovation projects, aimed at non-energy and non-agricultural mineral resources.

The Raw Materials Information System (RMIS), operated by the Joint Research Centre – JRC (Ispra, Italy), offers broad information on raw materials, especially those considered as critical by the EU, which are open for the public knowledge and can be regarded as the most detailed among those available internationally. *The Joint Research Centre* (JRC) is linked to the Directorate-General of the European Commission for Domestic Market, Industry, Entrepreneurship and Small and Medium-sized companies, or *DG GROW*. *The JRC's mission* is to put together and maintain this information system, and to coordinate studies and research that provide the EC with strategic information and forecasts. One of the most important attributions of the JRC is to periodically update the list of Critical Raw Materials (CRMs) for the EU, which will be addressed in detail below.

We emphasize the ERA-MIN because this is an opportunity to establish cooperation and research between consumer and raw material producing countries. Currently, this encompasses twenty-one research support organizations from EU countries and other continents, which are participating together, including FINEP (Projects and Studies Funding Institution), that is linked to the Brazilian Ministry of Science, Technology, Innovation and Communications (MCTIC).

On the other hand, JRC used studies and survey of information to enter into the RMIS platform, which led to the creation *of the European Union Raw Materials Knowledge Base* (EURMKB)[3], i.e., the EU raw materials knowledge database.

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1 RMIS - Raw Materials Information System. Available in: <http://rmis.jrc.ec.europa.eu/>.

2 ERA-MIN - Research & Innovation programme on raw materials to foster circular economy. Available in: <https://www.era-min.eu/>.

3 EURMKB – European Union Raw Materials Knowledge Base. Available in: <https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/knowledge-base_en>.

The critical raw materials outlook, however, should be regarded from other EC policies' standpoint, as the connections between them are clear. The so-called *Circular Economy Action Plan* (EC, 2015a), which addresses actions aimed at planning and adopting the circular economy in the EU, has a variety of connections – as seen from the European Parliament document, which has been disseminated in several European initiatives. The Circular Economy Action Plan is a broad and comprehensive policy. The plan is intended to change concepts in force within the economy, and also across social habits, aimed at reaching high levels of sustainability in Europe, with the reduction in consumption and use of natural resources at its core (EC, 2015b).

Consequently, critical raw materials fit this plan, as it guides actions aimed at reducing dependencies and supply risks, especially in primary resources. In the document "*Critical Raw Materials and Circular Economy*", the JRC presented their first contributions. They gathered information from several European projects and studies that associate elements from the circular economy with some of the critical raw materials analysed on a per sector basis, according to their usage: residues from extraction activities, landfills, electro-electronic materials, batteries, and from the automotive, renewable energy, defence, chemicals and fertilizers sectors (EC, 2017b).

With this information, it is possible to understand the connection across the European initiatives involving critical raw materials and to understand the proposals and results that can lead to substantial changes in the production chains and primary product markets.

1.2.2. Strategic minerals for Brazil

Brazil is a renowned leading producer and participant in the global market of mineral commodities, especially metallic minerals. Figure 2 offers a view of the key metallic mineral substances' exports in 2017, their destination, and their relevance within the worldwide market.

Brazil has its policies focused on natural resources, which gained major relevance, as can be seen from two plans: The National Mining Plan 2030 (MME, 2010) and the National Science and Technology Strategy 2016-2022 (MCTIC, 2016).

Metallic Product Type value (US$)				Metallic substance total value
Raw material	Semi-manufactured	Manufactured	Chemical compounds	
22,124,879,847.00	14,092,972,520.00	4,976,485,662.00	567,427,542.00	567,427,542.00

Percentage by exports destinations

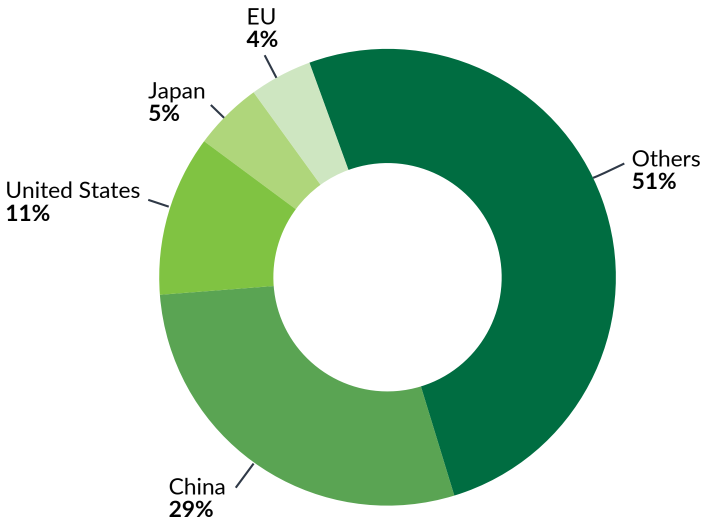

Figure 2. Brazilian exports of metallic substances (2017) and percentage participation of the main export destinations (US$ FOB values).

Source: ANM (2018a).

Strategic Minerals Management is among the strategic objectives of the National Mining Plan 2030 (MME, 2010), and it is defined as a set of mineral assets consisting of:

i. Minerals imported on a large scale, such as potassium, phosphate, metallurgical minerals, coal and minerals with potential for importation shortage, as it is the case of uranium.

ii. Minerals whose demand is increasing, and which should expand even further in the coming decades due to their use in high-tech products, as it is the case of rare-earth metals, lithium, tantalum, terbium and cobalt;

iii. Minerals that granted Brazil with a natural comparative advantage, and with international leadership, such as iron ore and niobium.

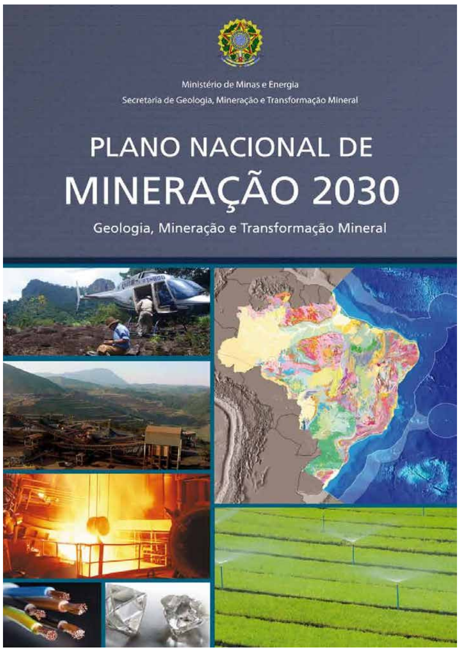

Figure 3. Government policy documents from Brazil addressing the issue of strategic minerals: National Mining Plan 2030 and National Strategy for Science, Technology and Innovation 2016-2022.

Source: MME (2010); MCTIC (2016).

The actions suggested in the document are as follows:

- creation of workgroups to monitor strategic mineral assets, focusing on the opportunities and threats of or from the international market.
- Inter-ministerial discussions with the production sectors towards the elaboration of long-term programs aimed at minerals needed by technologies considered essential to future country demands . The purpose of such programs would be the interaction between the Science and Technology Institutes (ICTs) and companies, targeted at the identification of competitive niches of action.

Concerning the inter-ministerial discussions, concrete joint actions were undertaken with the Ministry of Science, Technology, Innovation and Communications towards meeting the proposal from the Ministry of Mines and Energy. This interconnection between ministries can be seen in the document "Estratégia Nacional de Ciência e Tecnologia 2016-2020" (National Strategy for Science and Technology 2016-2020), of the MCTIC, 2016, which depicts two strategies:

i. Elaboration of the Science, Technology and Innovation Action Plan for Strategic Minerals.

ii. To promote research, technological development and innovation in strategic minerals, aiming at the production of final products based on these substances.

Figure 4. MCTIC Document on Strategic Minerals, and Call of the Funding Program for innovative projects, i.e., the INOVA MINERAL – a partnership between the FINEP and the BNDES.

Source: MCTIC (2016).

The Action Plan for Science, Technology and Innovation for Strategic Minerals (MCTIC, 2018), elaborated by the Secretariat for Technological Development and Innovation of MCTIC at the time, included the minerals suggested in the PNM 2030 (National Mining Plan), and identified challenges, proposing goals and actions. The focus of the plan lies on rare-earth elements, lithium, silicon, and graphite present in minerals (referred to as minerals for the future demands), the agricultural minerals – due to its growing relevance for the agribusiness in Brazil, and minerals like niobium and iron, due to their abundant availability and to the leading position of Brazilian companies in the international trade. Among the seven implementation strategies the plan depicts, there is an outline of the global cooperation relevance, which mentions the maintenance of the existing cooperation with Germany and the European Union, while proposing its expansion for other countries (MCTIC, 2018, p. 40).

To promote the RD&I, they have implemented concrete actions, e.g., the Inova Mineral Program, an initiative of the National Bank for Economic and Social Development (BNDES) and of the FINEP, which opened a joint public call for a BRL 1.2 billion (approximately EUR 280 million) fund for business plans involving research institutes and universities, by analysing proposals aiming research, development and innovation within the Brazilian mineral segment. Among other priorities, in this program, they mention as being of “major interest” the proposals on of minerals essential for future demands, specially those minerals containing cobalt, graphite, lithium, platinum group metals – molybdenum, solar grade silicon, thallium, tantalum, rare-earth, titanium, vanadium, and niobium. In 2017, Inova Mineral launched a publiccall for proposals, and approved – in a preliminary selection, 24 business plans amounting to R$ 727 million (FINEP, 2017).

1.2.3. Policies and strategies in other countries

The largest consumers of minerals, either the *commodities* or critical minerals, established specific policies to address raw materials deemed as critical, each following their respective guidelines. According to Bartekova & Kemp (2016), the European strategy is to interact with countries considered as being richer in terms of mineral resources. Japan and the USA tended towards research and development, while China and Australia have been focusing more on their domestic production, in addition to protecting their resources with protectionist policies.

Concerning its policies for minerals, China has evolved both as a major supplier – as it is the case of rare-earth, moving towards a value adding policy through industrialization and production of manufactured goods. At the same time, they also sought to secure their provisions of minerals less available domestically, by acquiring shares of companies and businesses across the world. Niobium is an example of such minerals. In this case, they acquired Niobras, a niobium minerals/ferroniobium mining and production company located in Ouvidor, Goiás, Brazil, through the CMOC - *China Molybdenum Corporation*.

European and USA documents emphasize China's relevance as a major source of key raw materials, specially minerals considered as critical worldwide (EC, 2017a, p. 14; FORTIER et al., 2018; USGS, 2018), as shown in Figure 5.

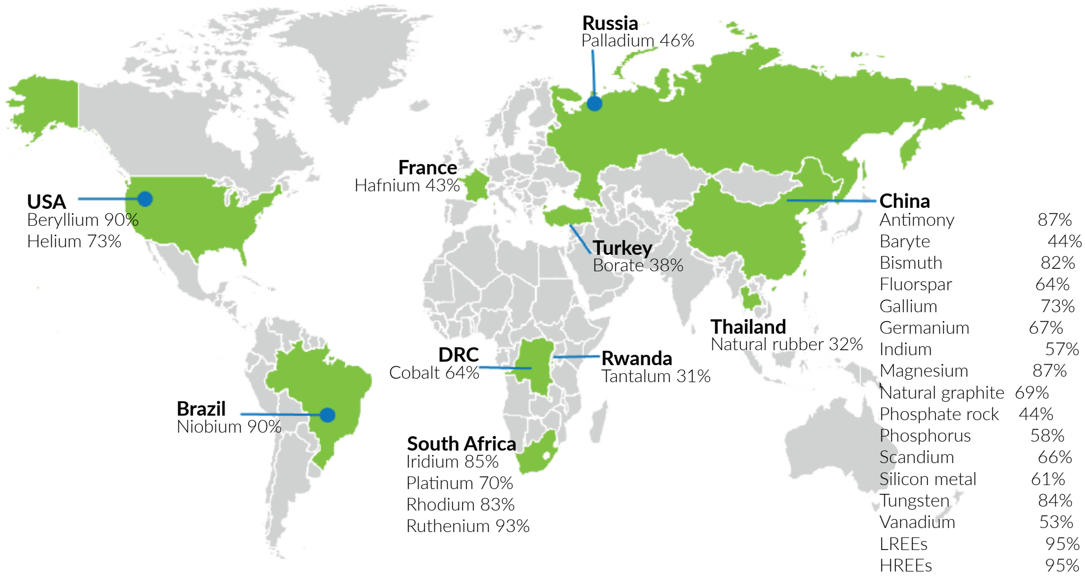

Figure 5. Percentage of critical raw materials' supply, according to the main supplying countries

Source: Deloitte et al. (2017).

For raw materials producing countries, it is very important to perform an economic and a political assessment of the consumer countries, since this enables them to take a stand – domestically, and externally – regarding their interests, while fostering discussions about their base of natural resources. If necessary, government authorities can engage in negotiations with domestic extraction industry representatives, both in terms of conditions and of the exportation to consumer countries, and regarding the optimization of the economic return for the companies and the country.

On the other hand, the USA keep growing its mineral production and participation in international trade (USGS, 2018).

In 2018, the USA Presidency Office requested an update to the list of critical minerals. The list was performed by a subcommittee *of the National Science and Technology Council*, which counted on the Subcommittee on Critical and Strategic Mineral Supply Chains, which, in turn, used an in-house method to indicate the critical minerals (NSTC, 2018).

> [...] As defined in the EO n. 13817, "Critical Mineral" is a mineral identified (1) as non-combustible or as a mineral material essential for the national and economic security of the United States of America; (2) as a supply network that is vulnerable to rupture, and (3) which serves as an essential function in the production of a certain product, whose absence could lead to serious consequences for the North American economy and safety.

The Department of the Interior carried out the *US Geological survey* to describe the minerals. Furthermore, they interacted with the *Bureau of Land Management* (BLM). They counted on the *Department of Defense* (DOD), the *Energy*, *State and Commerce*, and other members of the *National Science and Technology Council Subcommittee on Critical and Strategic Mineral Supply Chains* (CSMSC) (DOI, 2018). Table 1, below, features the list of critical minerals verified.

Table 1. Preliminary list of elements/critical minerals for the USA.

Mineral Commodities	Industries						Top producer	Top supplier	Notable example application
	Aerospace (non-defence)	Defence	Energy	Telecommunications and electronics	Transportation (non-aerospace)	Other			
Aluminum	X	X	X	X	X	X	China	Canada	Aircraft, power transmission lines, lightweight alloys
Antimony	–	X	X	X	X	X	China	China	Lead-acid batteries
Arsenic	–	X	X	X	–	X	China	China	Microware communications (gallium arsenide)
Barite	–	–	X	X	–	X	China	China	Oil and gas drilling fluid
Beryllium	X	X	X	X	–	X	United States	Kazakhstan	Satellite communications, beryllium metal for aerospace
Bismuth	–	X	X	X	–	X	China	China	Pharmaceuticals, lead-free solders
Cesium and Rubidium	X	X	X	X	–	X	Canada	Canada	Medical applications, global positioning satellites, night-vision devices
Chromium	X	X	X	X	X	X	South Africa	South Africa	Jet engines (superalloys), stainless steels
Cobalt	X	X	X	X	X	X	Congo[1]	Norway	Jet engines (superalloys), rechargeable batteries
Fluorspar	–	–	X	X	–	X	China	Mexico	Aluminium and steel production, uranium processing
Gallium	X	X	X	X	–	X	China	China	Radar, light-emitting diodes (LEDs), cellular phones
Germanium	X	X	X	X	–	X	China	China	Infra-red devices, fibre optics

(Table 1. Continuation)

Mineral Commodities	Industries						Top producer	Top supplier	Notable example application
	Aerospace (non-defence)	Defence	Energy	Telecommunications and electronics	Transportation (non-aerospace)	Other			
Graphite (natural)	X	X	X	X	X	X	China	China	Rechargeable batteries, body armour
Helium	–	–	–	X	–	X	United States	Qatar	Cryogenic (magnetic resonance imaging [MRI])
Indium	X	X	X	X	–	X	China	Canada	Flat-panel displays (indium-tin-oxide), specialty-alloys
Lithium	X	X	X	X	X	X	Australia	Chile	Rechargeable batteries, aluminium-lithium alloys for aerospace
Magnesium	X	X	X	X	X	X	China	China	Incendiary countermeasures for aerospace
Manganese	X	X	X	X	X	X	China	South Africa	Aluminium and steel production, lightweight alloys
Niobium	X	X	X	X	–	X	Brazil	Brazil	High-strength steel for defence and infrastructure
Platinum group metals[2]	X	–	X	X	X	X	South Africa	South Africa	Catalysts, superalloys for jet engines
Potash	–	–	X	X	–	X	Canada	Canada	Agricultural fertilizer
Rare earth elements[3]	X	X	X	X	X	X	China	China	Aerospace guidance, lasers, fibre optics
Rhenium	X	–	X	X	–	X	Chile	Chile	Jet engines (superalloys), catalysts
Scandium	X	X	X	X	–	X	China	China	Lightweight alloys, fuel cells
Strontium	X	X	X	X	X	X	Spain	Mexico	Aluminium alloys, permanent magnets, flares
Tantalum	X	X	X	X	–	X	Rwanda	China	Capacitors in cellular phones, jet engines (superalloys)
Tellurium	–	X	X	X	–	X	China	Canada	Infra-red devices (night vision), solar cells
Tin	–	X	–	X	–	X	China	Peru	Solder, flat-panel displays (indium-tin-oxide)
Titanium	X	X	X	X	–	X	China	South Africa	Jet engines (superalloys) and airframes (titanium alloys), high-strength steel
Tungsten	X	X	X	X	–	X	China	China	Cutting and drilling tools, catalysts, jet engines (superalloys)
Uranium	X	X	X	–	–	X	Kazakhstan	Canada	Nuclear applications, medical applications
Vanadium	X	X	X	X	–	X	China	South Africa	Jet engines (superalloys) and airframes (titanium alloys), high-strength steel
Zirconium and Hafnium	X	X	X	X	–	X	Australia	China	Thermal barrier coating in jet engines, nuclear applications

[1] The Democratic Republic of the Congo

[2] This category includes platinum, palladium, rhodium, ruthenium, iridium and osmium.

[3] This category includes yttrium and the lanthanides.

[X = applicable industry; – = not applicable]

Source: USGS (2018).

The US Federal Government has recently launched its policy for critical minerals, outlining six initiatives (*call for action*), in which the federal structure can lead or work in cooperation with the national private companies to reduce risks of supply or lack of the materials for its industry, including, obviously, the Homeland Security and Defense (USA, 2019).

In that document, it is worth to emphasize the changes regarding R&D investments, readiness for technology transfer, public labs for the private initiative, mining and exploration of critical minerals in areas under federal public control (national parks, environmental protection areas, *offshore* ocean areas). Furthermore, closer collaboration with major mineral producing countries stand out, e.g., Canada and Australia, and with global trade partners such as the EU, Japan, and Korea.

It is worth mentioning that the common concern about the critical raw materials drove the creation of a triple-sided initiative, involving the EU, the USA, and Japan, in terms of exchanging further information regarding the proper methodologies, and assessment. Since 2011, there have been yearly meetings, being the eighth event held in Tokyo, in 2018, which was sponsored by the METI (Ministry of the Economy, Trade, and Industry), and the Organization for New Power and Industrial Technology Development of Japan (NEDO) (METI, 2018).

1.2.4. List of critical raw materials for the European Union

The EC policies have been mainly based on the JRC and their partners, and contractors' studies, aimed at monitoring both the domestic and the international trade, and technologies connected to critical raw materials deemed as essential across the supply chains of the European industry. Initially, the method determined how to select and indicate the raw materials, which led to the first list, in 2011, with 14 items. Improvements made to the methodology increased the list to 20 items, in 2014, and to 27, in 2017.

The most recent list of critical raw materials can be found in the European Commission's document "*Study on the review of the list of Critical raw materials – Criticality Assessments*", dated June 2017, elaborated by the consortium comprising Deloitte Sustainability, British Geological Survey, *Bureau de Recherches Géologiques et Minières*, and the *Netherlands Organization for Applied Scientific Research* (Deloitte et al., 2017).

The discussion on screening and allocation of the raw materials is not part of this project. However, learning the essentials and applicability of the method enables us to understand certain economic and political choices of the EC. The methodology is featured and can be accessed both from the RMIS portal (RMIS, 2017), and in articles (BLENGINI et al., 2017).

The basis for the methodology is a bi-dimensional assessment of a broader list of non-energy raw materials with a focus, in the one side, on the risk of supply to the European market, and, on the other side, on the economic importance for European production chains.

The supply risk takes into accountthe level of expectation generated by the concentration of primary supply in countries with limited governance, added to market distortions and high dependence on imports.

On the other hand, economic importance is linked to the use of raw materials in manufactured materials that are essential for key European and global industries, where Europe expects to maintain or expand its market.

In summary, to determine the supply risk, the following equation can be used:

$$SR = HHI_{WGI}.(1 - EOL_{RiR}) \,.\, SI$$

In HHIWGI, HHI represents the Herfindahl Hirschman Index, which measures production concentration by country, WGI is the World Governance Index, and the EOL-RiR, which stands for End of Life Recycling Input Rate, while SI is the replacement index.

Below, please, see how the Economic Importance is measured:

$$EI = \sum_{s}(A_{s}.\, Q_{s})$$

Where A is the distribution of demand for raw materials by economic megasector (S), and Q is the contribution of the megasector to the GDP (gross domestic product).

Blengini et al. (2017) emphasize that the purpose of the equation on criticality is not to create an atmosphere of panic or fear that measures would be taken against suppliers and their countries. It is a tool to draw the attention of EU authorities and other *stakeholders* involved in the supply and production chains to take initiatives aimed at reducing the risks associated to in possible supply issues, whether political, economic, social or environmental.

In the 2017 EC list, out of the 61 assessed raw materials (58 of which assessed individually, and three groups of specific elements assessed separately), 26 were identified as critical by the methodology described above, as shown in Table 2, below.

Table 2. Critical raw materials identified in the 2017 EC list.

Critical raw materials – 2017 (26)		
Antimony	Hafnium	Platinum Group
Barite	Helium	Phosphate rock
Beryllium	Rare-earth (heavy)	Phosphorus
Bismuth	Rare-earth (light)	Scandium
Boron	Indium	Silicon metal
Cobalt	Magnesium	Tantalum
Fluorite	Natural graphite	Tungsten
Gallium	Natural rubber	Vanadium
Germanium	Niobium	

Source: CE (2017a).

Figure 6, below, provides a better definition regarding the specific status of each raw material, based on the results verified for the supply risk and economic importance, while allowing for comparisons, i.e., the group with the 26 elements classified as critical shows as red dots. The cut-off criterion for supply risk was greater than or equal to 1, and for economic importance, it was greater than or equal to 2.8.

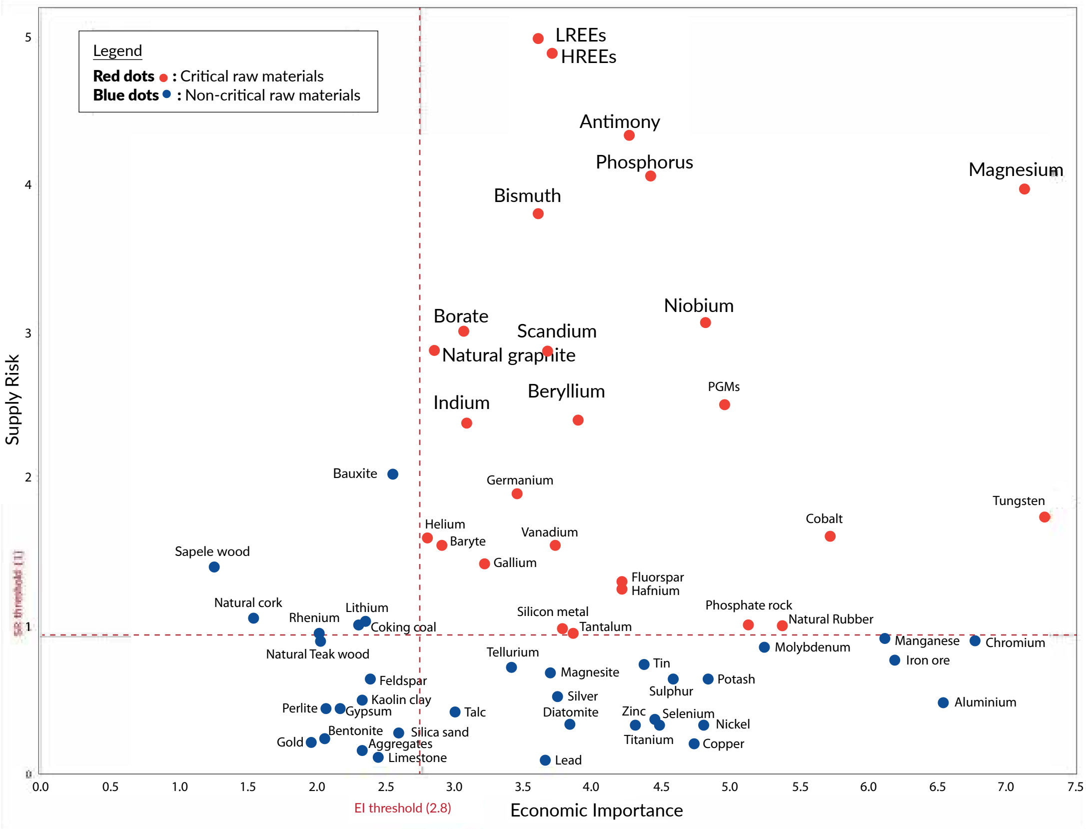

Figure 6. Critical raw materials' relative position, based on the risk of supply, and their economic importance in the European environment (CRM list 2017).

Source: RMIS (2017).

This result puts the critical raw materials at a higher level of concern, prioritizing them over the other plans and actions that the EC has implemented. Countless programs have been started, which have been bearing fruit, among which it is worth mentioning those connected to innovation, fostering research studies on the possible replacements or the search for alternative sources. Besides, they also draw attention to the relevance that the EC has been giving to the Circular Economy.

Circular Economy promotes the optimization of natural resources consumption and usage through the enhancement of their secondary sources. We further develop the subject in the specific chapter. The EC policy on this is featured in the document "*Closing the loop - an EU action plan for the Circular Economy*" (EC, 2015b).

Considering all elements across policies in mineral and natural resources' consumer economies, countries like Brazil should pay special attention to raw materials for their domestic consumption, as well as to critical ones, of which they are major producers and suppliers. Furthermore, new technologies and the adoption of circular economy practices may cause positive and negative impacts.

1.3. The choice of the case study

The case studies featured proposed for the Sector Dialogues program were on the niobium or some of the rare earth elements . Rare-earth elements are in the core of multiple interests, given their multitude of applications in current technologies and products, as well as innovations that have been changing the profile of important global economic sectors, such as energy. In the EC critical materials' study, as shown in the above Graph, both the group of light rare-earth elements (LREEs) and of heavy rare-earth elements (HREEs) are highlighted for their highest supply risk. Niobium stands out, and – although considered to be of lower supply risk – it is in a slightly higher position as to economic importance.

Brazil has considerable reserves of rare-earth and niobium-hosting minerals. Due to a coincidental geologic nature, i.e., one of the largest reserves of said raw materials - ever acknowledged in the country - is associated and located within the same mineral deposits in the municipality of Araxá, Minas Gerais. This deposit is operated by a single company, the Companhia Brasileira de Metalurgia e Mineração (CBMM).

Finally, the choice of niobium relates to the following factors::

- Niobium has a stand-out position in consumer countries' lists of critical raw materials due to the weight that the concentration of its production in few countries exerts on the variable supply risk.
- Brazil has a steady and consolidated production of Niobium ores and their semi-manufactured products, which does not yet apply to rare earth.
- Brazil is the world's largest producer of this mineral raw material, and CBMM leads this market.

1.3.1. The niobium: critical and strategic raw material

Earlier in this study, you could see that some raw materials considered critical are commonly subject to investigations and policies of more developed countries and blocks of nations. Comparing the lists from the EU and the USA, they have 19 raw materials in common, including the groups of rare-earth elements and the platinum group of metals, both a collection of several metal elements. Note that in the USA government list, China prevails as the main producer of 19 critical minerals out of the 33 ones listed (Table 1), and it also stands out as the main supplier of 13 minerals from the same list (USGS, 2018).

Moreover, note that there are common points between the methods used to indicate such raw materials, especially the supply risk assessment that considers the Herfindahl

Hirschman index-based approach, which seeks to measure the concentration of production per country. However, the EU method to measure the economic importance is different from the American one, although they have many critical raw materials in common.

Brazil appears as the main producer and supplier of niobium and semi-manufactured products in both lists, and is certainly among the world's largest suppliers of some others, such as tantalum and magnesite, in addition to vanadium, and graphite (ANM, 2018b). Among the non-mineral critical raw materials, natural rubber was outlined in the European list, of which Brazil is also a historical major producer and supplier. Emphasis should be given to the Brazilian rare-earth reserves, which, nevertheless, still do not have a market share consistent with their relevance, considering the international pricing practised by China, rare-earth elements main producer and supplier.

Figure 7, below, shows the most important Brazilian mineral reserves, compared to the global totals ever known[4].

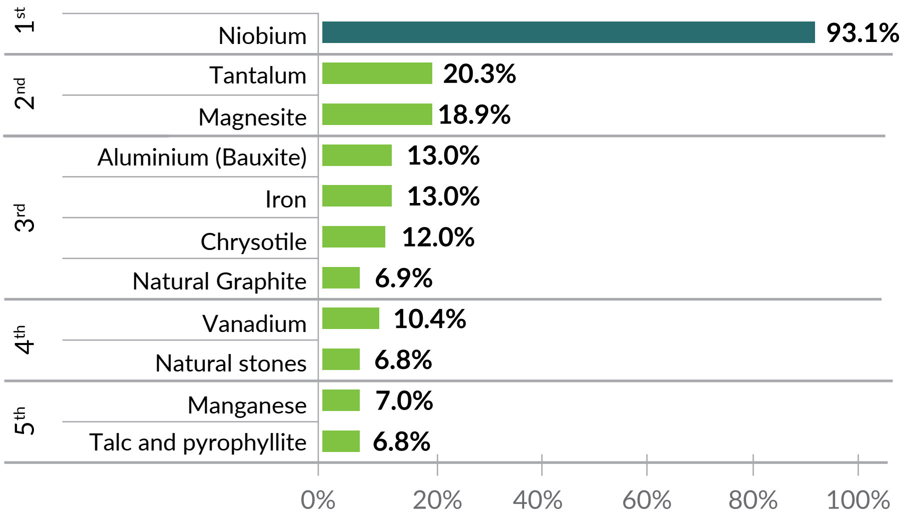

Figure 7. Brazilian participation and position in the global ranking of the main mineral reserves – in operation, and being explored (2015).

Source: ANM (2018b); USGS, 2018.

In the initial proposition for this research study, rare-earth and niobium came up as possible case studies. Rare-earth certainly came up for its growing relevance across a myriad of current products and technologies in the areas of energy and communications – with clear prospects for market growth, and in the face of the enormous mineral potential already known in the country. The niobium and its ores, in turn, are considered as strategic in the Brazilian Government plans due to various factors. Standing out among such factors, we have evidence on the location of the largest ore reserves of the world; the dynamic production sites already installed, both mines in

4 Concerning the niobium, the predominance of the Brazilian participation is questionable, while considering the deposits and occurrences featured in Figure 9, below.

operation'as well as metallurgical plants, including business expertise of the companies exploiting the resources supplying international markets. Also, these companies provide the population living nearby their operations with enormous economic and social benefits.

Niobium also stands out because of the benefits the materials using it offers to the global society. In turn, this makes us think that if the niobium was not present in nature, or if we did not achieve the scientific and technological development of its potential, the existing alternatives would probably be less efficient or effective, or would come at higher costs.

Another important factor leading to its choice was, undoubtedly, the potential for the Brazilian industry's cooperation, which was backed up by agreement established with Companhia Brasileira de Metalurgia e Mineração (CBMM), through a partnership executed with the CETEM.

1.3.2. Geology and occurrences of niobium

The main world reserves of niobium are within carbonatite ores complexes. The most relevant known deposits so far are in Brazil and Canada. However, there are at least 17 important occurrences already reported, as per the criteria for the disclosure of international reserve data (SIMANDL et al., 2018). There is also evidence of pegmatitic formations, like that of Lovozero, in the Kola peninsula, Russia. Figure 9 features a worldwide list of occurrences of niobium-rich mineralisation totalling 45 already identified.

The reserves with the best economic potential are in Brazil, within the Araxá complexes, in Minas Gerais State, and Catalão, in the State of Goiás. Equally important is one reserve in the State of Amazonas, known as "Morro dos Seis Lagos", which is of a different geological nature.

In carbonatites, the main niobium mineral is pyrochlore, whose formula is as follows: $[(Na, Ca)_2\ Nb_2O_6\ (OH, F)]$

Under a mineralogical standpoint, the association of niobium and tantalum is pretty ordinary, so much so that they were initially confused by the chemists, while their respective names maintain the similarity, as Tantalum and Niobium are father and daughter in the Greek mythology (GARATTONI & CORDEIRO, 2017). Figure 8, below, features a ternary plot of the super-group of minerals containing Nb, Ta, and Ti, which demonstrates multiple mineral associations, and, in turn, indicates that pyrochlore is the mineral with the highest content of niobium. At the same time, microlite is tantalum-rich, and betafite is titanium-rich.

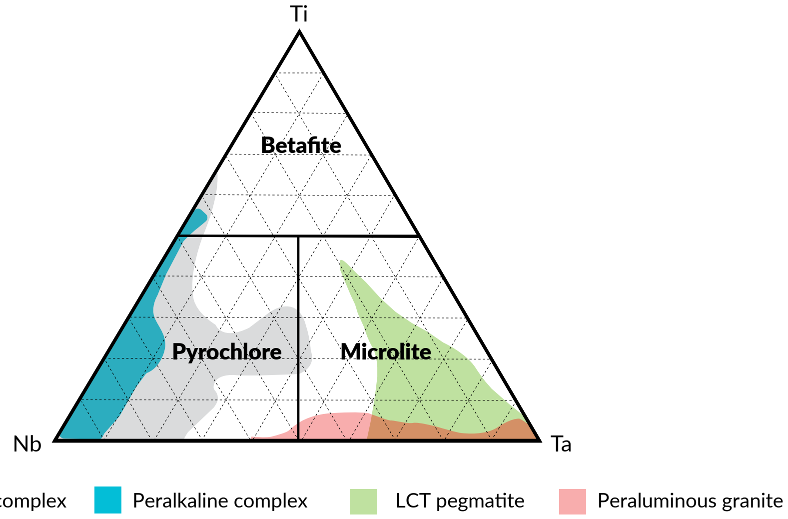

Figure 8. Composition ternary plot showing the allocation of the main minerals hosting for niobium, tantalum and titanium.

Source: SIMANDL and McKay, apud. SIMANDL et al. (2018).

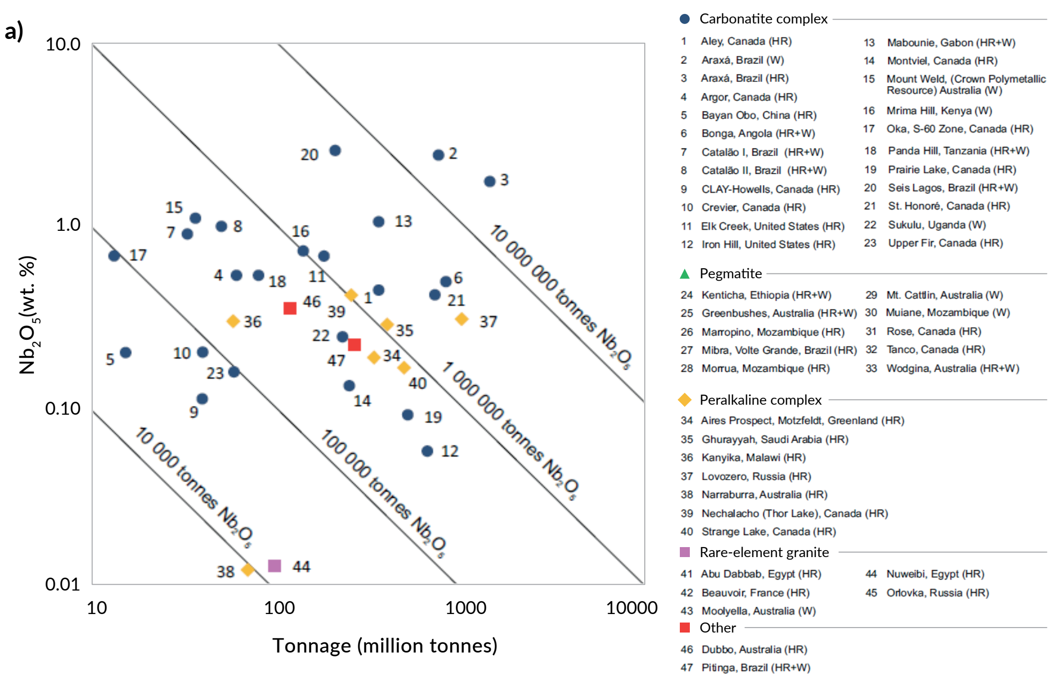

Figure 9. Mines, deposits and niobium minerals occurrences throughout the world.

Source: SIMANDL et al. (2018).

Another important minerals association is the COLTAN – short form for columbite--tantalite minerals combination. Relevant occurrences in Brazil are in the Amazonas State, e.g., the Pitinga mine, associated with the tin minerals. Columbite is also produced in the small mines within the region, which partnered together in cooperatives. The most important reserves in terms of coltan production are in the Republic of Congo, close to Rwanda. Said operations are in the middle of a conflictual dispute between anti-government groups and the Congolese army due to the various minerals of interest in the region.

1.3.3. The Niobium production in the world and Brazil

Mineral production and reserves of niobium ores are concentrated in Brazil, followed by Canada, as shown below (Table 3).

Table 3. World mining production and reserves.

World Mine Production and reserves: The information on the reserves in the United States, Brazil, and Canada have been revised based on the reports elaborated by niobium producing companies and the administrations of the respective countries.			
	Mine production		Reserves
	2017	2018	
United States	-	-	180,000
Brazil	60,700	60,000	7,300,000
Canada	6,980	7,000	1,600,000
Other countries	1,410	1,000	NA
World total (rounded)	69,100	68,000	>9,100,000

Source: USGS (2019).

A survey performed for the European project MSP-REFRAM (Multi-Stakeholder Platform for a Secure Supply of Refractory Metals), exclusively on refractory metals provides a chart on mines in operation and projects being developed on niobium and tantalum.

Table 4. Tantalum and niobium: Deposits, projects and mines in operation (2017).

Deposit Name	Company	Country	Status	Type of ore	Mining method	Commodity	Reserve Mt	% of Nb_2O_5	% of Ta_2O_5
Araxá	CBMM	Brazil	Operation	Weathered Carbonatite	Open pit	Nb	462	2,48	
Catalao - Boa Vista	China Molybdnum Co. Ltd.	Brazil	Operation	Weathered Carbonatite	Open pit	Nb	42	1,2	
Niobec mine	Magris Resources Inc.	Canada	Operation	Mineralized Carbonatite	Under-ground	Nb	630	0,42	
Aley	Taseko Mines Ltd. Corp	Canada	EIA process	Mineralized Carbonatite	Open pit	Nb	84	0,5	
Green-bushes mine	Global Advanced Metals	Australia	Operation	Pegmatite	Open pit + Under-ground	Ta ± Nb, Sn	68	0,023	0,026
Wodgina mine	Global Advanced Metals	Australia	Operation (disconti-nued)	Pegmatite	Open pit	Ta ± Be, Sn	28		0,042
Mibra / Volta Grande mine	Advanced Metallurgical Group	Brazil	Operation	Pegmatite	Open pit	Ta, Nb, Sn Li	6	0,009	0,038
Mt Cattlin	Galaxy Resources Ltd.	Australia	Operation	Pegmatite	Open pit	Li, Ta	10		0,015
Tanco	Cabot Corporation	Canada	Operation	Pegmatite	Under-ground	Ta, Cs, Li	2		0,22

Table 4. Continuation

Deposit Name	Company	Country	Status	Type of ore	Mining method	Commodity	Reserve Mt	% of Nb_2O_5	% of Ta_2O_5
Toongi / Dubbo Zirconia	Alkane Resources Ltd.	Australia	Developt-ment	Trachyte	Open pit	Zr, Hf, Nb, Y, Ta, REE	73	0,46	0,03
Pitinga Mine	Minsur / Mineração Taboca	Brazil	Operation	Peralkaline granite	Open pit	Sn, Nb, Ta	267	0,22	0,027
Kenticha mine	Elenílto Mining	Ethiopia	Operation	Pegmatite	Open pit	Ta, Nb	116		0,02
Tabba Tabba	Pilabara Minerals Ltd.	Australia	Operation	Pegmatite	Open pit	Ta	0,318		0,095
Kanyika	Globe Metals & Mining Africa (Pty) Ltd.	Malawi	Bankable Feasibility	Nepheline Syenite	Open pit	Nb, Ta, U, Zr	21	0,33	0,015
Abu Dabbab	Gippsland Ltd.	Egypt	Bankable Feasibility	Granite	Open pit	Ta, Sn, Feldspar	32		0,027
Several artisanal small-scale mines		Central Africa	Operation	Weathered Pegmatites	Open pit	Ta, Nb			

Source: MSP REFRAM (2017).

Below, we present the domestic production of niobium, as per the Brazilian Mineral Yearbook 2017 (ANM, 2018a).

Table 5. Gross mineral production[5] in Brazil by State (2017).

Substance	Quantity (ROM)		Contained		Average Content		
Niobium	23,575,307	t	142,324	t	0.60	%	Nb_2O_5
Goiás (pyrochlore)	12,507,212	t	61,062	t	0.49	%	Nb_2O_5
Amazonas (columbite-tantalite)	6,494,375	t	2,403	t	0.04	%	Nb_2O_5
Minas Gerais (pyrochlore)	3,032,878	t	78,554	t	2.59	%	Nb_2O_5
Rondônia (columbite-tantalite)	1,540,842	t	304	t	0.02	%	Nb_2O_5

Source: ANM (2018a).

Table 6. Production processed in Brazil (2017).

Niobium	Volume		Nb content		Average content		
State Total	165,624	t	83,166	t	50.21	%	Nb_2O_5
Minas Gerais (pyrochlore)	131,002	t	68,624	t	52.38	%	Nb_2O_5

5 According to Appendix A3 of the Brazilian Mineral Yearbook (2018), the mineral production figures refer to the information the companies provide to the National Mining Agency, through their Annual Reports on Mining Production . It is understood that the production value of a mine can be reported as the "transfer value", which quantifies the value of the ore transferred internally from the mine to the beneficiation unit.

Goiás (pyrochlore)	22,167	t	11,835	t	55.39	%	Nb_2O_5
Amazonas (columbite-tantalite)	8,901	t	2,403	t	27.00	%	Nb_2O_5
Rondônia (columbite-tantalite)	3,554	t	304	t	8.57	%	Nb_2O_5

Source: ANM (2018a).

Table 7. Production of niobium concentrate by State (2017)[6].

	Production processed			Total value (R$)
	Volume		Value (R$)	
State Total	170,541	t	635,629,056	635,629,056
Goiás (pyrochlore)	27,174	t	312,629,846	312,629,846
Minas Gerais (pyrochlore)	131,002	t	254,048,716	254,048,716
Amazonas (columbite-tantalite)	8,811	t	44,260,575	44,260,575
Rondônia (columbite-tantalite)	3,554	t	24,689,919	24,689,919

Source: ANM (2018a).

Table 8. Main companies producing ore (2017).

Company	State	Participation (%)
Niobras Mineração Ltda.	GO	49.18
Companhia Mineradora do Pirocloro de Araxá	MG	39.97
Mineração Taboca S.A.	AM	6.96
METALMIG Mineração Indústria e Comércio Ltda.	RO	1.44
Cooperativa Mineradora dos Garimpeiros de Ariquemes Ltda.	RO	1.12
Cooperativa de Garimpeiros MINERALCOOP	RO	0.73
Estanho de Rondônia S.A.	RO	0.47
Cooperativa dos Garimpeiros de Campo Novo de Rondônia	RO	0.12

Source: ANM (2018a).

Brazilian figures detail the country's leading position in the gross production of ores and concentrates (processed production), which demonstrates the predominance of the States of Goiás and Minas Gerais in pyrochlore ores. At the same time, Amazonas and Rondônia contribute with columbite-tantalite. Regarding the niobium production, Minas Gerais stands out due to a higher content of ores in its mines.

Table 5, 6 and 7 show a difference in terms of volumes, both regarding the ore and the concentrates production (processed production), as compared to those verified in Goiás and the Minas Gerais States. It is known that Minas Gerais is the largest producer of pyrochlore because its ore content is higher than Goiás'. The figures informed in the

6 The value of concentrate production also reflects the figures of mineral production indicated in Table 5, based on the information disclosed by the ANM from the Annual Reports on Mining Sites (RAL).

Annual Reports on Mining Production, as submitted to ANM by the companies, reflect their respective costs reality, e.g., the transfer value,what explains the difference.

The main ore producing companies – their processed and semi-manufactured products – based in Brazil are: Companhia Mineradora do Pirocloro de Araxá – COMIPA, partnership to the Companhia Brasileira de Metalurgia e Mineração (CBMM) and the Companhia de Desenvolvimento Econômico de Minas Gerais (CODEMIG); NIOBRAS, connected to China Molybdenum Corporation International (CMOC); Mineração Taboca (controlled by Minsur, Peruvian mining group). NIOBEC is based in the province of Quebec, in Canada. Table 9 features the main companies and their respective products.

Table 9. Major companies producing niobium in the world (semi-manufactured.

CBMM Companhia Brasileira de Metalurgia e Mineração	Ferroniobium Vacuum Grade FeNb and NiNb Oxides: high purity, optical grade, niobic acid (HY-340) and ammonium niobium oxalate (ANO) Niobium metal: reactor-grade, commercial-grade, RRR superconductor grade, and niobium zirconium
CMOC International Brasil NIOBRAS	Ferroniobium
Niobec UNE COMPAGNIE DE MAGRIS RESOURCES	Ferroniobium
TABOCA	Ferrotantalum & Ferroniobium

Source: Elaborated in-house.

Moreover, in Brazil, tin production brings, as a by-product the columbite-tantalite, which is mainly extracted and processed by Mineração Taboca, METALMIG, and also by the cooperatives of miners of Rondônia (Table 5, 6 and 7).

1.3.4. Uses and applications of the niobium

Table 10 features an overview of the uses and applications of the niobium for various materials (end products), as well as the characteristics and properties it confers on them.

Table 10. Characteristics of niobium, applications and the destination of the end products .

Characteristics	Applications	End products
Alloy refining element	High strength microalloyed steels	Pipelines for oil and gas Automotive exhaust systems Structural steels Automotive steels
Refractory metal	Stainless steels	Aircraft turbines Power generation turbines
Superconductors	Medical devices and scientific research	Superconductors wires for magnetic resonance imaging devices (NbTi) Particle Accelerator components (High purity Metal Nb)
Energy storage	Niobium-based cathodes and anodes of batteries	Safer and more efficient lithium batteries for electronics, energy storage systems and electric vehicles
Semiconductor	Advanced ceramics	Ceramic supercapacitors Electric and piezoelectric ceramics
Optical properties	Optical and vitreous devices	Lenses Special glasses
High acidity and surface area	Support for catalysts; additives for functional materials	Catalysts – production of organic chemicals, basic and automotive petrochemicals Ionic exchange resins

Source: CBMM (2018).

Different products should be produced from pyrochlore concentrates on meeting such demands, as shown in Figure 10.

Figura 10. Niobium products made from pyrochlore concentrates.

Source: CBMM (2018).

The main market for niobium is the steel industry that requires ferroniobium alloy for high strength microalloyed steel and stainless steel. The need for ferroniobium alloy (FeNb) – currently for 120 thousand tons/years – is split by application, with higher demand in the construction and automotive segments. The niobium content in steels is low, on average 0,3%, which implies a limited consumption scale.

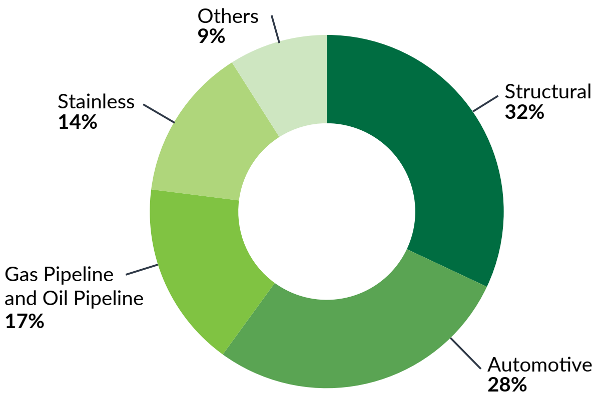

Figure 11. The world market for the ferroniobium according to its steel applications.
Source: CBMM (2018).

In the automotive sector, microalloyed steels (HSLA) provide vehicles' bodies with lightness, as they have higher yeld and tensile streght as compared to conventional carbon steels, thus promoting fuel economy and lower greenhouse gas emissions (GHGs) Figure 12 shows a car body, pointing out the different microalloyed steels used according to the structural requirements for parts, i.e., between 280 (pink) and 1,260 MPa (black) of yield strength values.

Figure 12. Vehicle body showing the different types of steels with niobium.
Source: CBMM (2018).

We can find high-tech applications in materials with special properties, like superalloys and superconductors. Superalloys are corrosion-resistant metallic materials. At the same time, they maintain their mechanical properties at high temperatures and are widely used in aeronautical and power generation turbines. Although not present at high contents (between 0 and 5%), we find niobium in several superalloys, e.g., INCONEL superalloys (TIC, 2016).

Regarding the superconductors, currently, the most commonly used ones are the niobium-titanium and niobium-tin, which can generate magnetic fields above 10 Tesla at very low temperatures when cooled in liquid helium, the first being the most common in magnetic resonance imaging devices (Figure 13).

Figure 13. Nuclear Magnetic Resonance Imaging device.
Photo: C. Peiter, in Phillips Medical Group, Netherlands.

Moreover, superconductors are neccessary for the scientific equipment known as particle accelerators, for the study of experimental particle physics. For example, the Large Hadron Collider (LHC)– of the European Nuclear Energy Commission – used 1,200 ton of NbTi filaments to build the ten supermagnets of the equipment (ROSSI, 2010).

The raw material used in superconducting alloys is the metallic niobium produced from pure niobium oxides. Interesting applications also appeared in the field of biomaterials, with metal alloys for orthopaedic implants, in jewellery and numismatics (special coins). Other important applications of niobium from its oxides are in catalysts, glasses, and optical lenses.

Innovative applications have been developed in the aluminium alloy fields for cast parts, and usage in the new lithium-ion batteries. This subject has been receiving special attention from the Brazilian company CBMM, in partnership with the Japanese Toshiba (energy TREND, 2018). Later, in section 4 of this report, which is devoted to innovations and new knowledge about niobium and products, we discuss the main trends observed nowadays.

1.4. Considerations and comments

The information gathered and described here points out evidence and expectations towards niobium, which is considered an important raw material in the world economy. Its usage shall continue growing across several economic segments, whether traditional or innovative, thus becoming increasingly important. This trend could increase its global demand, and enable new mining ventures, as well as accelerate the adoption of policies to reduce dependence on the existing producers, especially Brazil, as far as it is considered as critical raw material or mineral.

The initiative of Brazilian companies, such as CBMM, promoting and supporting R&D&I in collaboration with various international institutions and companies, has stimulated the expansion of the use of niobium. As the largest producer of niobium, Brazil can guide its specific policies, while increasing the participation of the National System of Science and Technology in the search for niobium-based innovations. Furthermore, Brazil can foster adhesion to international initiatives, such as the ERA-MIN program[7], with the participation of national companies to consolidate the leadership yet achieved.

Based on the recent movements observed in key consumer countries, the Brazilian government should pay special attention to the initiatives and policies on Critical Raw Materials (CRMs). Said movements demonstrate a recapturing of the strategic approach on raw materials while disclosing reactions to the growth of the importance of other global hegemonic poles. China, for instance, seeks to secure its raw materials requirements by producing or controlling a substantial part of the trade. Brazil's position should also consider that China is its largest business partner and importer of mineral goods, while keeping its own interests and policies.

On the other hand, the economic and geopolitical studies' motivations and methodologies – those present in studies and policies on critical raw materials, both in the EU and in the USA, offer interesting models for Brazil to further this matter. Now, it becomes clear how useful it is to have a specific study listing the minerals with outstanding critical aspects within the set of strategic minerals detailed in the current National Mining Plan. This supplementary information could allow for focused policies, thus complying with the realities and relevance of each group of minerals, while considering their importancefor the segments of the Brazilian economy.

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7 Program of the EU gathering other countries, including Brazil, aiming at the research and innovation in raw materials.

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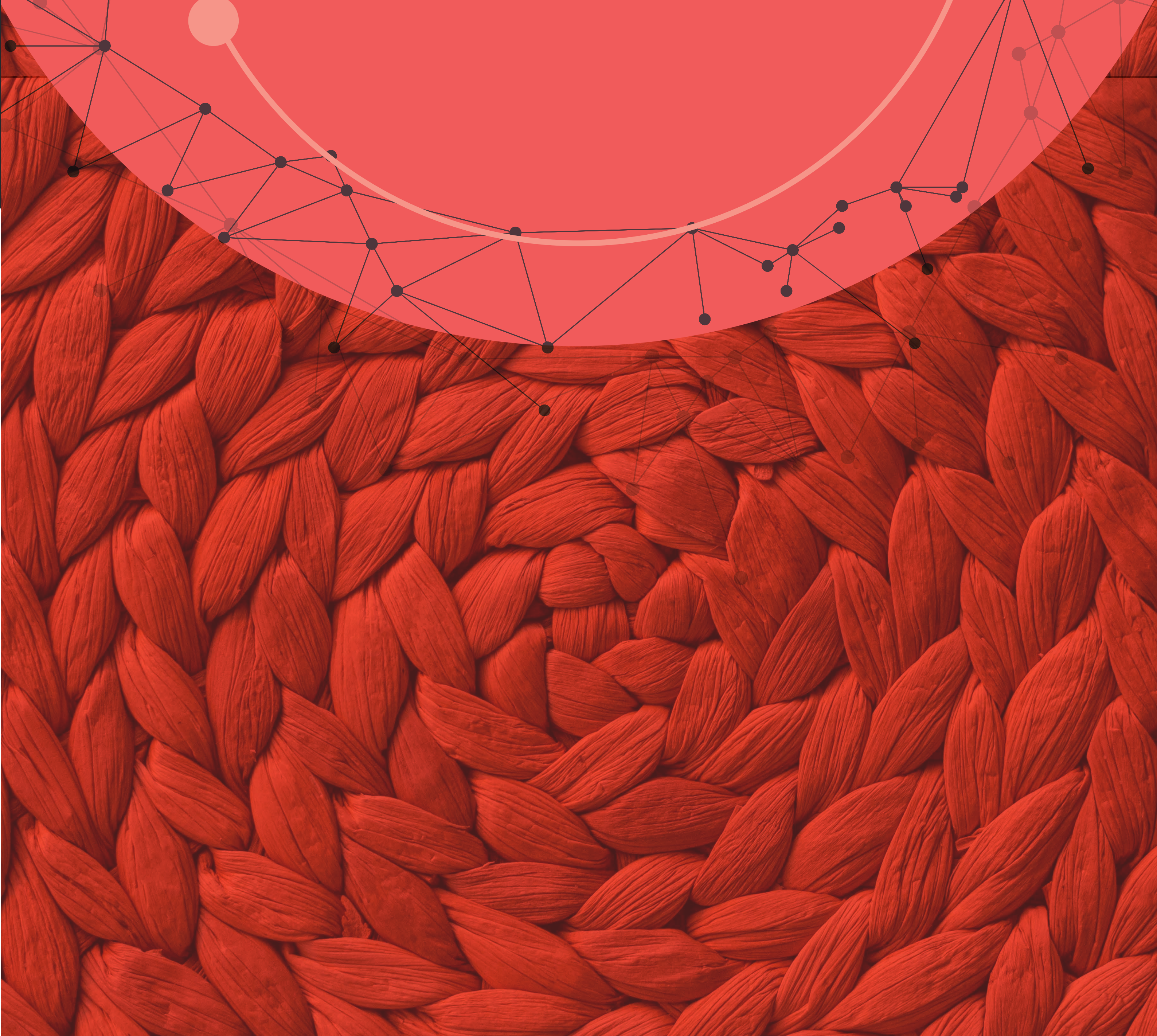
2.

Circular economy and its indicators

EFIGÊNIA ROSSI



2.1. The Circular Economy: grounds and proposals

Circular Economy (EC) can be regarded as an umbrella concept that, by definition, proposes to connect issues previously unrelated, as a way to focus on a particular quality or characteristic they share in common (BLOMSMA; BRENNAN, 2017). More than defining the Circular Economy (CE), it is necessary to mention its guiding principles, namely: The systemic vision, regenerative and restorative processes, the generation of positive impacts, collaboration, dematerialisation, long-term, and diversity.

In this sense, it is important to highlight two concepts: Eco-efficiency and Eco-effectiveness. Eco-efficiency advocates for value increase by reducing pollution levels and the use of resources, while Eco-effectiveness permeates the optimization of the benefits for ecological and economic systems (NIERO et al., 2017). The above concepts differ from one another. The first one seeks to minimize negative impacts, while the other one aims to strengthen the positive effects. Therefore, Circular Economy stands up as a new vision, and a development strategy that allows increasing the Eco-effectiveness, in the face of the currently adopted linear model.

Although some authors recommend the application of the Life Cycle Assessment (LCA) to the CE (Circular Economy) (ELIA; GNONI; TORNESE, 2017; LONCA et al., 2018; NIERO et al., 2017; SCHEEPENS; VOGTLÄNDER; BREZET, 2016), some of the CE strategies (recycling, reuse, repurposing, multi-functionality, co-production) are within the scope of unresolved problems in the LCA (BOBBA et al., 2018; MORAGA et al., 2019; REAP et al., 2008a, 2008b). Also, assessing the functions is challenging, as it triggers a consumption behaviour, e.g., sharing platforms can lead to a less cautious use when compared to ownership (TUKKER, 2015). Besides, the traditional LCA approach is not suitable for evaluating eco-effective products and processes, since its linear logic does not allow for optimization in the cradle-to-cradle context (BRAUNART; MCDONOUGH; BOLLINGER, 2007).

Overall, to be used in the context of the Circular Economy, the Life Cycle Assessment (LCA) needs to go from the context of a single life cycle to multiple life cycles, besides being able to incorporate positive impacts and work with the new circular business models. This change of perspective challenges how to transition the LCA approach from a linear context to a circular one. Some studies address a few of these challenges to incorporate the multi-functionality present in recycling (NIERO et al., 2016), measure the environmental gains in reusing products (CASTELLANI; SALA; MIRABELLA, 2015), and even propose new types of economic and environmental measurement for circular business models' cases (SCHEEPENS; VOGTLÄNDER; BREZET, 2016).

Moraga et al. (2019) proposed a framework to categorize the quantitative indicators of circularity found in the literature. The said framework is based on a matrix of six EC strategies in three scopes.

The strategies are:

1. Preserve the function of products and services from circular business models, such as sharing platforms, Product Service-Systems (PSS), and schemes promoting product redundancy and multifunctionality.
2. Preserve the product itself through lifetime increase with strategies such as durability, reuse, restore, refurbish, and remanufacture.
3. Preserve the product's components through the reuse, recovery and repurposing of parts.
4. Preserve the materials through recycling and downcycling.
5. Preserve the embodied energy through energy recovery at incineration and landfill facilities.
6. Measure the linear economy as the reference scenario or the absence of a preservation strategy to show the status, progress, or regress towards Circular Economy.

The scopes are as follows:

- Measure physical properties from the technical cycles without the life cycle approach, e.g. Recycling Rates.
- Measure physical properties from the technical cycles with a life cycle approach, e.g. the indicator of Reusability–Recyclability–Recoverability (RRR) in terms of mass includes the potential for the reuse of products, recycling, and energy recovery.
- Measure environmental, economic, or social effects in cause-effect types of models, e.g., an indicator of Reusability-Recyclability-recoverability in terms of environmental impacts.

The authors concluded that the reviewed indicators mostly focus on the preservation of materials (strategy 4), such as recycling. Circular Economy, however, encompasses many other strategies. Besides, no indicator evaluated the conservation of the product function (strategy 1), such as sharing platforms, product redundancy schemes, dematerialisation, Product Service-Systems (PSS) (use or result-oriented), and multifunctionality, present in the CE (MORAGA et al., 2019).

The contemporaneity of the topic under study is highlighted by many authors, aiming at the need for metrics in the Circular Economy (ELIA; GNONI; TORNESE, 2017; MAYER et al., 2019; MORAGA et al., 2019; PARCHOMENKO et al., 2019; PAULIUK, 2018; PIERONI; MCALOONE; PIGOSSO, 2019).

The circular economy seeks to incorporate the dimension of business models (KIRCHHERR; REIKE; HEKKERT, 2017). Figure 14 shows the interaction between business models and other facilitators in the circular business system. It becomes clear the need for a mindset change to provide changes among the other links in the chain, from business models to circular value chains (CONFEDERAÇÃO NACIONAL DA INDÚSTRIA, 2018).

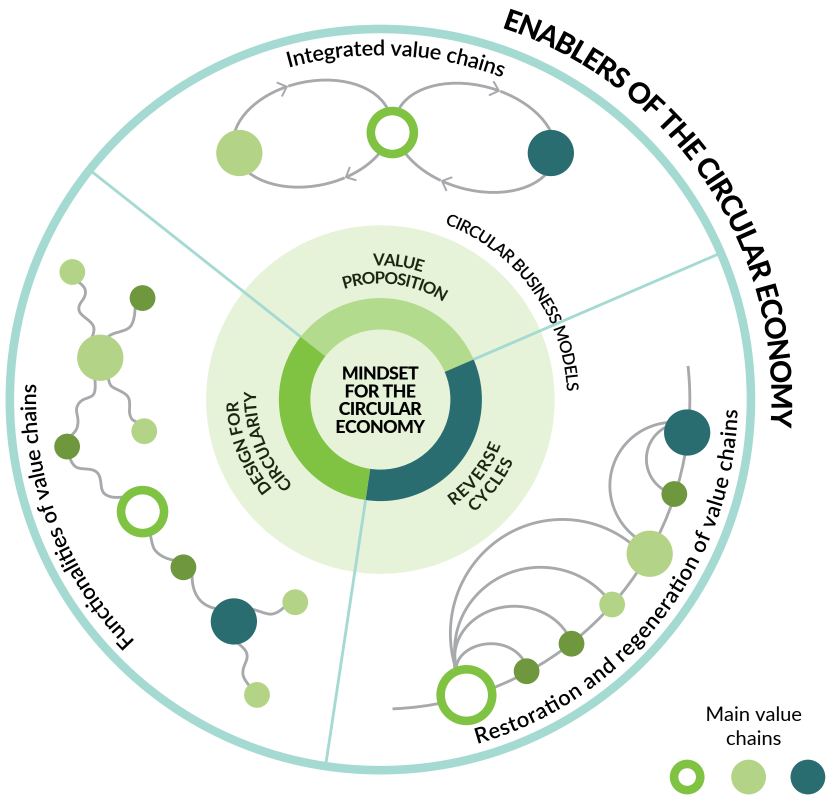


Figure 14. Circular business system framework.

Source: CNI (2018).

The following stand out among circular business models: Product-as-a-service, sharing, circular inputs, resource recovery, the extension of product life, and virtualisation (CONFEDERAÇÃO NACIONAL DA INDÚSTRIA, 2018):

1) Product-as-a-service (PSS): Instead of selling the products, the company provides the service, offering the desirable functions to the service through a lease contract or solutions.

2) Sharing: The aim is to increase the efficiency of product use through monetized or non-monetized sharing.

3) Circular inputs: Based on restored, recycled, renewable, reconditioned, remanufactured, or uncontaminated materials.

4) Recovery of resources: Recover value and function of products, components, and materials within closed and open cycles.

5) Extension of useful life: Increase useful product life.

6) Virtualisation: Replace physical infrastructure and assets with digital services, and, therefore, deliver value through virtual means.

2.2. Definition of circularity indicators

The circularity indicators' state-of-the-art research was initially based on periodical publications of scientific journals accessed in the ISI databases, Web of Science (http://apps.webofknowledge.com), and Sci Verse Scopus (http://www.scopus.com) databases. Keywords used were "circular economy", and "indicators" or "metric". However, research was not restricted to those databases. Surveys were also carried out across reports from international organizations and consulting companies.

BSI Standard 8001 (2017) distinguishes six principles for Circular Economy:

1) Systemic thinking: Organizations must adopt a holistic approach towards understanding how individual decisions and activities interact and are parts of broader systems. In other words, systemic thinking allows us to understand the complex, non-linear and interconnected systems in which the organization is located (BSI, 2017).

2) Innovation: Organizations should innovate continuously to create value by enabling sustainable resource management through process design, products/services and business models. Circularity requires a new perspective on consumption and production, continuously challenging traditional business practices and methods (BSI, 2017).

3) Management: Organizations should manage the direct and indirect impacts of their decisions and activities through the broader system in which they are inserted. In this way, they should consider the social-environmental has implications of the entire product life cycle, including the origin of the raw material and the destination. Management allows you to identify whether the responsibility for managing your organization's decisions and activities will be shared or individualized, considering the value chain (BSI, 2017).

4) Collaboration: Organizations should collaborate internally and externally through formal or non-formal agreements to create mutual values. The Circular Economy implies progressive collaborations among businesses, governments, universities, civil society, and consumers. By overcoming the barriers from diverging motivations, cultures and requirements, the partnership must develop trust, effective communication, and shared vision (BSI, 2017).

5) Value enhancement: Organizations should maintain all products, components and materials at their highest value and usefulness all the time. In other words, reconsider what could be waste or losses in the system and identify opportunities for possible new uses from them. Also, increase the durability of the product, by using them in multiple cycles, and use other business models such as service and sharing (BSI, 2017).

6) Transparency: Organizations should be able to communicate their decisions and activities in a clear, accurate, timely, honest, and thorough manner. Overall, transparency should be favoured so that information can be accessed proactively or upon request (BSI, 2017).

Circular Economy can be applied in three levels: micro, meso and macro (YUAN; BI; MORIGUICHI, 2006). At the micro-level (companies and products), companies focus on strategies and actions aimed at eco-design and cleaner production, seeking to disclose the monitoring of their operation. At the Meso-level (between companies), there is the search to encourage the development of eco-friendly industrial parks and networks benefiting the regional economy and the environment. And, at the macro-level (between countries) there is the search for sustainability in production and consumption activities that seek the creation of a society focused on closing cycles (GENG et al., 2012).

Table 11 describes the main indicators at the micro-level.

Table 11. Indicators at the micro-level as per the literature.

	Indicator	Format	Reference
1	BIM-based Whole-life Performance Estimator (BWPE)	Calculation formulas	(AKANBI et al., 2018)
2	Building Circularity Indicators (BCI)	Dynamic Excel spreadsheet (contact author)	(VERBERNE, 2016)
3	Circular Economy Index (CEI)	Calculation formulas	(DI MAIO; REM, 2015)
4	Circular Economy Indicator Prototype (CEIP)	Dynamic Excel spreadsheet (contact author)	(CAYZER; GRIFFITHS; BEGHETTO, 2017)
5	Circular Economy Measurement Scale (CEMS)	Calculation formulas	(NUNEZ-CACHO et al., 2018)
6	Circular Economy Performance Indicator (CEPI)	Calculation formulas	(HUYSMAN et al., 2017)
7	Circular Economy Toolkit (CET)	*Website*	(EVANS; BOCKEN, 2013)
8	Circular Pathfinder (CP)	*Website*	(RESCOM, 2017a)
9	Circularity Calculator (CC)	*Website*	(RESCOM, 2017b)
10	Circularity Index (CI)	Calculation formulas	(CULLEN, 2017)
11	Circularity Potential Indicator (CPI)	Dynamic Excel spreadsheet (contact author)	(SAIDANI et al., 2017)
12	Closed Loop Calculator (CLC)	Computational tool (contact author)	(KINGFISHER, 2014)
13	Ease of Disassembly Metric (eDiM)	Dynamic Excel spreadsheet (contact author)	(VANEGAS et al., 2018)
14	Eco-efficientValueRatio (EVR)	Calculation formulas	(SCHEEPENS; VOGTLÄNDER; BREZET, 2016)
15	Economic-Environmental Indicators (EEI)	Calculation formulas	(FREGONARA et al., 2017)
16	Economic-environmental remanufacturing (EER)	Calculation formulas	(VAN LOON; VAN WASSENHOVE, 2018)
17	End-of-Life Recycling Rates (EoL-RRs)	Calculation formulas	(GRAEDEL et al., 2011)

Table 9. Continuation

	Indicator	Format	Reference
18	Input-Output Balance Sheet (IOBS)	Computational tool (contact author)	(MARCOCAPELLINI, 2017)
19	Longevity and Circularity (L&C)	Calculation formulas	(FIGGE et al., 2018)
20	Material Circularity Indicator (MCI)	Dynamic Excel spreadsheet (available online, free of charge)	(ELLEN MACARTHUR FOUNDATION; GRANTA, 2015)
21	Material Reutilization Part (C2C)	Calculation formulas	(C2C, 2014)
22	Mine site MFA Indicator (MI)	Calculation formulas	(LÈBRE; CORDER; GOLEV, 2017)
23	Multidimensional Indicator Set (MIS)	Calculation formulas	(NELEN et al., 2014)
24	Product-Level Circularity Metric (PCM)	Calculation formulas	(LINDER; SARASINI; VAN LOON, 2017)
25	Recycling Indices (RIs)	Computational tool (contact author)	(VAN SCHAIK; REUTER, 2016)
26	Recycling Rates (RRs)	Calculation formulas	(HAUPT; VADENBO; HELLWEG, 2017)
27	Resource Duration Indicator (RDI)	Calculation formulas	(FRANKLIN-JOHNSON; FIGGE; CANNING, 2016)
28	Reuse Potential Indicator (RPI)	Calculation formulas	(PARK; CHERTOW, 2014)
29	Set of Indicators to Assess Sustainability (SIAS)	Calculation formulas	(GOLINSKA et al., 2015)
30	Sustainability Indicators (SI)	Calculation formulas	(MESA; ESPARRAGOZA; MAURY, 2018)

Source: elaborated in-house.

Among these indicators, those that apply to the scope of this work are Circular Economy Index (CEI), Longevity and Circularity (L&C), Material Circularity Indicator (MCI), and Mine site MFA Indicator (MI).

The Circular Economy Index (CEI) is a quantitative value derived from the ratio between the material value obtained by the recycled product (market value) and the amount of the material entering the recycling company. In other words, the CEI measures the circularity in terms of the value of the recycled material (derived from end-of-life of products), compared to the total value of the material in the recycling process needed to produce new versions of the same product (SAIDANI et al., 2019). The data entered to calculate the indicator, provide detailed information about the values of the components and materials in each product that enters the recycler and how they turn into recycled raw materials. Thus, it has an economic focus and is mainly directed toward recycling (DI MAIO; REM, 2015).

The Longevity and Circularity (L&C) show a graph combining both indicators, i.e., the circularity that includes initial use, remanufacturing and recycling, and the longevity, which consists of the initial product life, the duration added due to remanufacturing, and the term added due to recycling. Both indicators have quantitative values as outputs (FIGGE et al., 2018).

The Material Circularity Indicator (MCI) is based on the Material Flow Analysis (MFA) and evaluates products predominantly. As entries to obtain the indicator, there is Percentage of reused or remanufactured raw material, percentage of recycled raw material, recycling efficiency, percentage of post-use that can be reused, and percentage of post-use that can be recycled. Besides, it includes the product's useful life and its functional unit. As an output to the indicator, there is a value between 0 and 1, where the higher this value is, the more circular the product is (ELLEN MACARTHUR FOUNDATION; GRANTA, 2015).

The Mine site MFA Indicator (MI) is a set of indicators applied in mining and created through the MFA. The work features the indicators considering production, recycling, waste generated, losses, material efficiency, impacted area, among others. Therefore, they seek to merge environmental and economic elements (LÈBRE; CORDER; GOLEV, 2017).

However, to select the indicators, the following attributes were assigned:

1) Relation of the indicators with the principles of the circular economy.

2) Applicability.

3) Practicality.

4) Ease of use.

5) Comparability of results

Therefore, they chose the Material Circularity Indicator (MCI) (ELLEN MACARTHUR FOUNDATION, GRANTA, 2015) for being an indicator whose entry data are compatible with the principles of the Circular Economy. Moreover, the output data (a quantitative value ranging from 0 to 1) allows a comparative scale between the products and the possibility of observing improvements to their circularity. Also, it has a dynamic Excel spreadsheet for calculations and can be applied to a diverse range of products.

2.3. Results

Using data from the literature, the MCI was calculated for the elementary niobium. Input data for the indicator were obtained from the "Study on Data for a raw material System Analysis" report, elaborated in 2015 (DELOITTE, 2015), which is part of the study on critical raw materials commissioned by the European Commission to the consortium in question. Hence, the data relating to Europe (Figure 15).

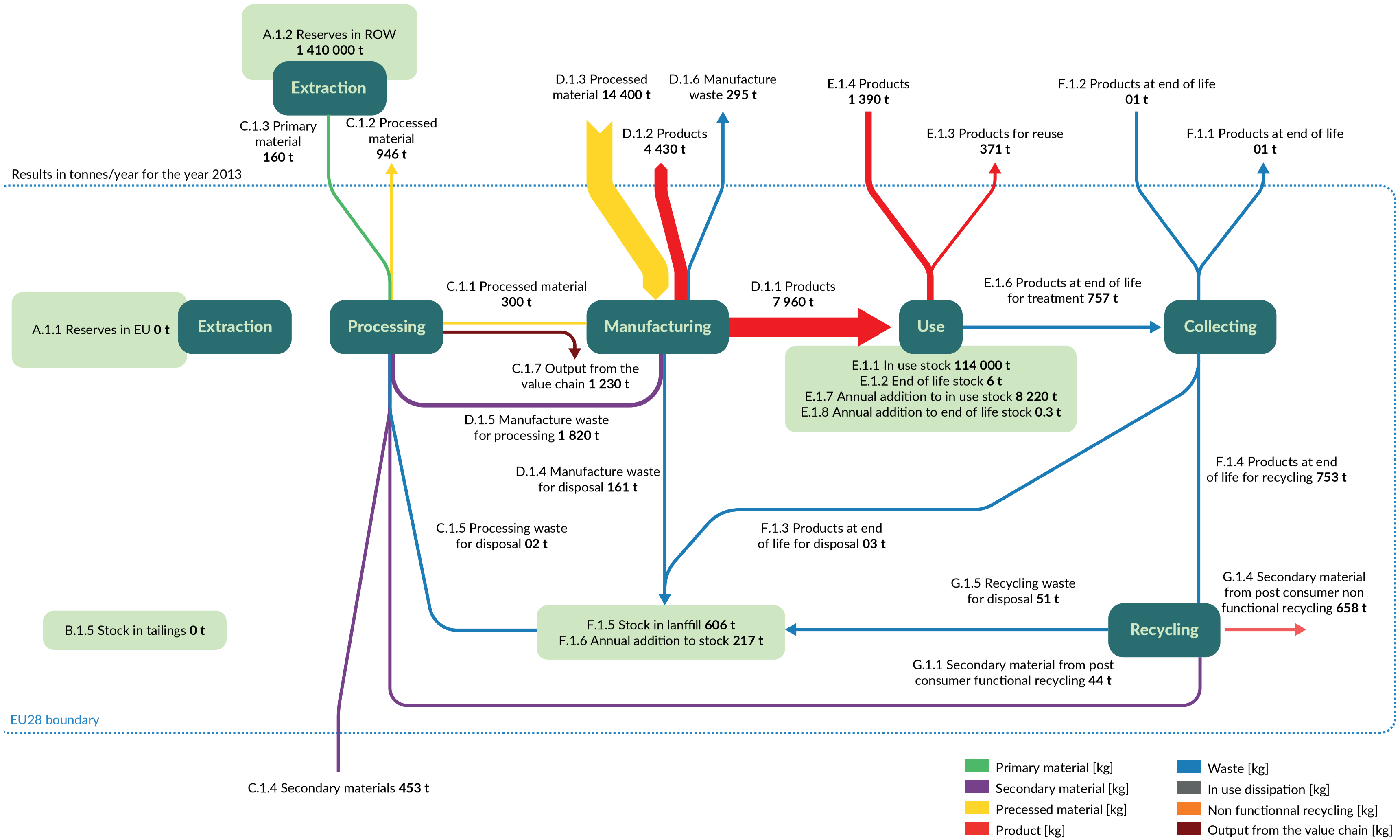


Figure 15. Sankey-type diagram for the niobium.

Source: Deloitte (2015).

The calculation of Nb input data in the MCI was obtained through the analysis in Figure 15 and is detailed as follows:

Raw material (%)

- Reused = 0%
- Recycled = C.1.4/(C.1.1+D.1.3)*100 =453/14700*100 = 3.08%

Post-use destination (%)

- Reused = E.1.3/D.1.1*100 =371/7960*100 = 4.66%
- = G.1.1/D.1.1*100 =44/7960*100 = 0.55%

Recycling efficiency (%)

- 50% (KURYLAK et al., 2015).

Durability (x industry average)

- 1 x industry average

Through a free routine (application), we used such data in the MCI, as described in Figure 16.

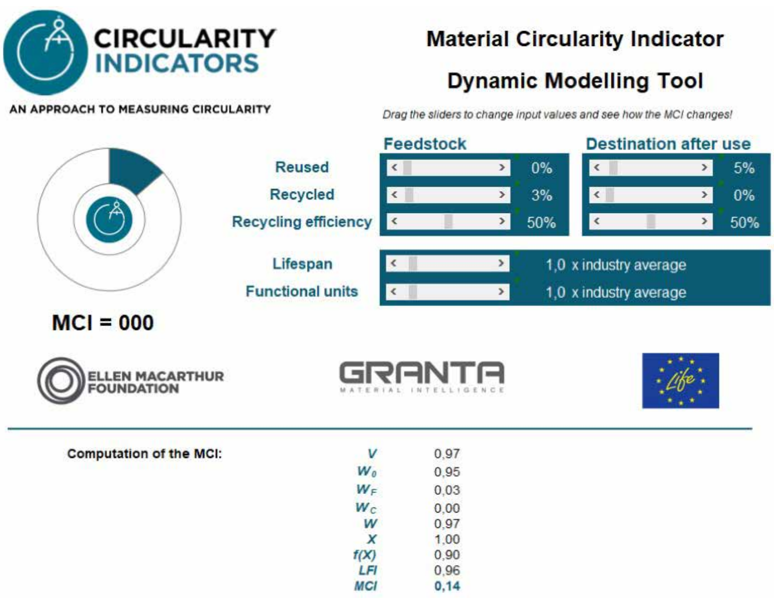


Figure 16. MCI calculation for generic niobium.

Figure 16. MCI calculation for generic niobium.

Note that the calculation verified a 0.14 value for the MCI, which shows a value of low circularity. This represents the reduced reinsertion of the niobium in its production chain, implying the need for the increasing demand for niobium from primary sources.

Using further data from the same report, "Study on Data for a raw material System Analysis" (DELOITTE, 2015), we also calculated the MCI for high strength low alloy steels (HSLA) containing niobium, having a car as the product base. We considered 300 grams (on average) of niobium per vehicle (DELOITTE, 2015). Thus, the following was found (Figure 17):

Raw material (%)

- Reused = 0%
- Recycled = 0%

Post-use destination (%)

- Reused = 0%
- Recycled = 33.33%

Recycling efficiency (%)

- 5,8%

Durability (x industry average)

- 1 x industry average

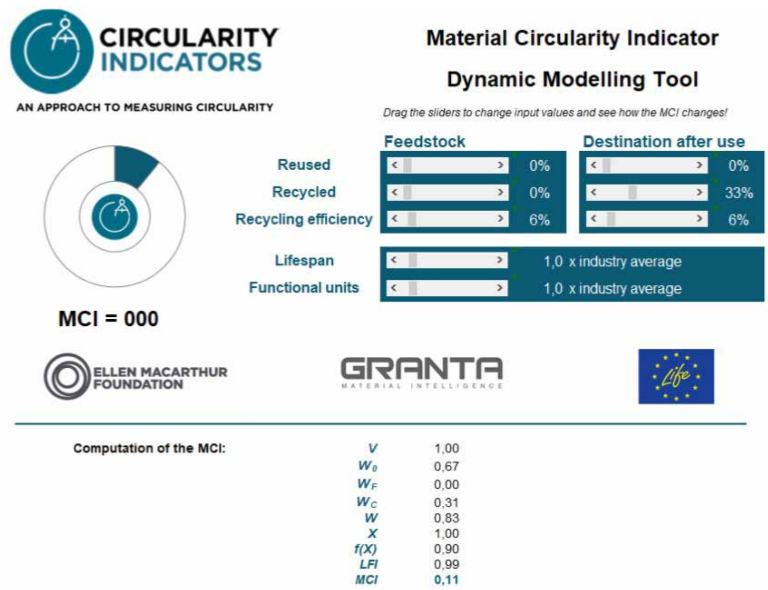


Figure 17. MCI calculation for niobium content in vehicles.

Source: Adapted from Ellen MacArthur Foundation and Granta (2015).

While considering that the durability of niobium steel is equivalent to the common carbon steel, note that a value of 0.11 was achieved for the MCI of the niobium steel of the automotive industry, which denotes a low circularity value. The reason for this lies in that the low reinsertion of the niobium in the automotive industry production chain implies the need for niobium from a primary source. On the other hand, if an increase in durability of 20% (1.2x industry average) is considered for niobium steels in the automotive application, as compared to common carbon steel, the MCI would reach 0.26, which shows a possible positive gain.

Due to the lack of data, it was not possible to calculate the MCI for the civil construction industry. However, it is known that the alloy used in Construction uses 0.03% of niobium, on average, and the durability of the construction is 80 years (DELOITTE, 2015).

The durability in service, as well as the extension of useful life, are positive aspects of materials and for their use meeting the Circular Economy notions. Examples of products using niobium-rich materials, whose useful life is extended, are the Nuclear Magnetic Resonance Imaging Equipment – whose superconducting material consists of niobium-titanium alloys or niobium-tin alloys. NMR equipment is subject to reconditioning processes by multinational companies, such as Philips[8], and Siemens.

In the oil and gas sector, there has been about 0,06% use of niobium in the constituent steels (DELOITTE, 2015) with a shelf-life expectancy of 30 years. However, the collection of niobium after the end of life of these products is practically insignificant, evidencing that it is not possible to calculate the MCI since linear Economics still predominates.

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3.

Circular Economy and Material Flow Analysis

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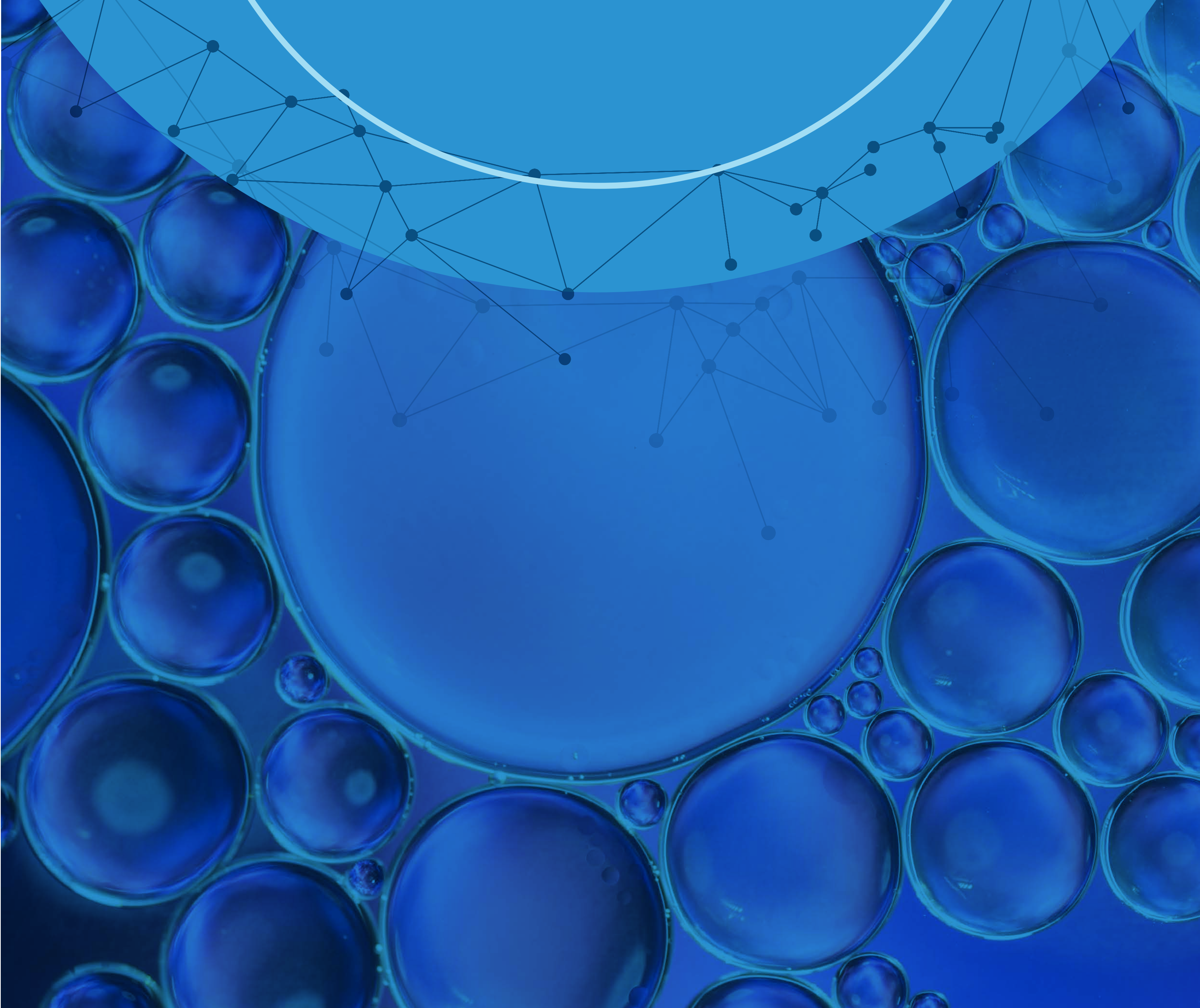

3.1. State-of-the-art

The Circular Economy concept has been gaining space in the business environment due to its contribution to sustainability. Originally developed in the academic environment, the idea is based on the reuse of products and materials (or secondary raw material), and currently covers a diversity of definitions and sustainable solutions.

The *British Standards Institution* (BSI) defines the circular economy as an "economy that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (PAULIUK, 2018).

Initially approached as industrial metabolism (AYRES, 1994) and industrial ecology (ERKMAN, 1997), the proposal for the closed-loop management seeks, concomitantly, to reduce the impacts of waste and to make the acquisition of inputs sustainable, while optimizing costs. The circular economy is based on these premises, and it has been backed by regulatory and normative instruments across different countries.

Among the most widespread practices are recycling, reuse, reconditioning, minimization of waste generation and recovery of materials.

Over the last decade, Europe is investing in strategies for the recovery and processing of materials considered critical that generally require the critical raw materials addressed in the previous section. Such materials are essential for high technological impact processes, and whose mineral reserves are not significantly available in industrialized countries.

3.2 Countries and Blocks' policies

Although the concepts behind the circular economy proposal have been long established, their regulation has only been consolidated in the last decade, focusing on specific areas such as waste management and prevention, power management, consumption and reduction of the use of materials (DAVIS & HALL, 2006).

The European Union is currently leading the circular economy initiatives in the world. It has, among several proposals, the Integrated Product Policy (IPP), the main objective of which is to create conditions for the acceptance of environmentally friendly products among EU Member-States. The European directives endorse the Polluter–pays principle (PPP) while focusing on three main areas: (i) packaging, (ii) electronic waste, and (iii) end-of-life vehicles.

According to Davis and Hall (2006), the IPP results in less environmental impact throughout its life cycles, from raw material mining to production, distribution, use and disposal at the end-of-life.

Japan, on its turn, has set the Top Runner program, which started in 1999, focusing on efficient energy management of products and enabled through products' labelling at the point of sale. This Japanese program is accompanied by the Ministry of the Environment, which can, among other actions, propose recommendations or impose fines on companies that do not meet the established targets.

According to Giurco et al. (2014), China's circular economy program was adopted in 2011 and prioritizes the improvement of the regulation, the establishment of Extended Producer Responsibility (EPR), financial support and the enhancement to recycling techniques. Before that, in China, the concept of the circular economy had been proposed in 2005 (WANG et al., 2005) and implemented through the Circular Economy Promotion Act in 2008, as "the general term for the activities of reduction, recycling and recovery of resources in production, circulation and consumption."

The United States, in turn, has no specific legislation for the circular economy. The principle of reducing, reusing, and recycling (3Rs) is adopted in some states, but not at the federal level, and PPP (Polluter-Pays Principle) has limited application. Most of the fifty states have reverse logistics programs or electronic waste based on EPR resources. California is the most engaged state in Environmental stewardship regulation. According to Davis & Hall (2006), the US does not have a federal law on e-waste, as it was considered a major challenge to fund a national program in this specific area of waste.

In Latin America, countries such as Chile and Uruguay have formal programs for the circular economy with the participation of other countries through the Circular Economy Platform of the Americas (CEP-Americas).

3.3. Material flow analysis

The Material Flow Analysis (MFA) method is a fit method for quantifying flows and stocks of materials and substances, based on the definition of economic or productive systems, aimed at monitoring flows (BRUNNER & RECHBERGER, 2004).

Based on the MFA analysis, it is possible to analyse sustainability performance, as well as identify opportunities for resources conservation and mitigation of impacts. The MFA has been often used in input application systems, wastewater treatment plants, to understand industrial metabolism, as well as environmental impacts on regional and urban scales (LEIGHTY & ANTONIIEWICZ, 2013; FISHER et al., 2017). The tool proposes to examine socio-environmental aspects, such as environmental and human health impact, job and income generation influencing the flows as a way of providing dematerialisation strategies with subsidies throughout material flow (AUGISEAU & BARLES, 2017).

In a more recent proposal, the MFA enables the understanding of the flows of materials and energy within the city that can be integrated into policy formulation and territorial planning (GUIBUNET et al., 2017).

The approach to the use of MFA for application in waste management is relatively more recent and results from the analysis of urban and territorial planning. According to Binder (2007), waste stream management in an economical system allows the identification of alternatives for materials recirculation.

The MFA was based on the model developed by the Waste and Resources Action Program (WRAP, 2011) to estimate the e-waste flows in the UK. The method consists of four basic steps: (i) Determination of the system model, including processes and materials, (ii) measurement of material flows, (iii) calculation of material flows and (iv) interpretation of results (CLARKE et al., 2019).

According to Islam and Huda (2019), MFA is one of the most widely used and accepted strategic tools in the application of the industrial ecology discipline, since it enables the analysis of complex models while serving as support for decisions. The materials balance (allowing the study of energy flow and economic value) is the core of the method enabling the comparison of inputs, stocks, and outputs in a process, and between processes relevant to the industrial ecosystem.

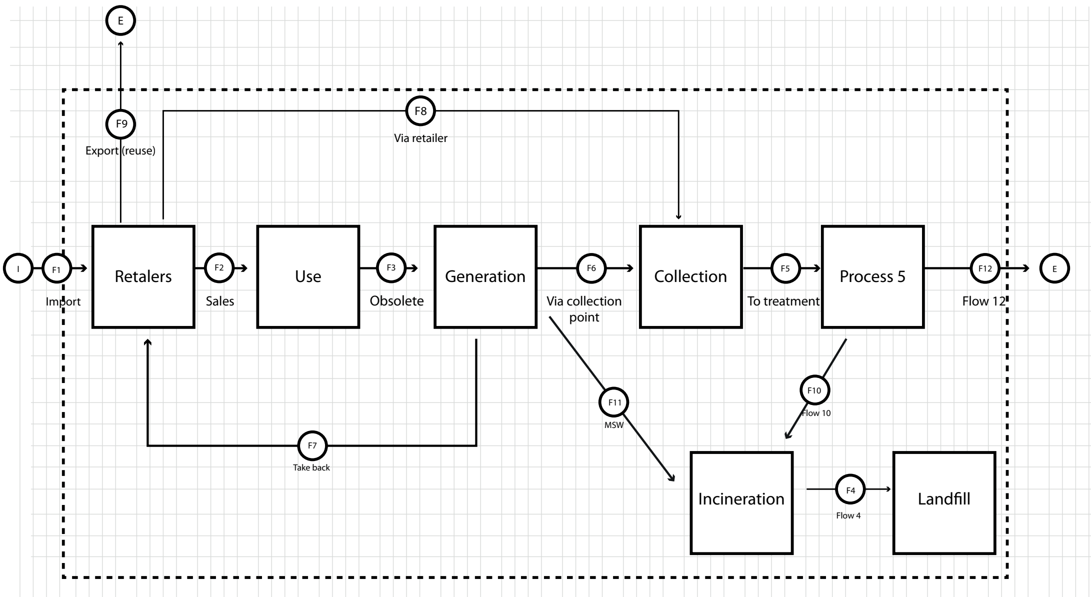

Figure 18. Generic MFA model for electro-electronic waste management in Switzerland (I = Import and E = Export).

Source: Islam & Huda (2019).

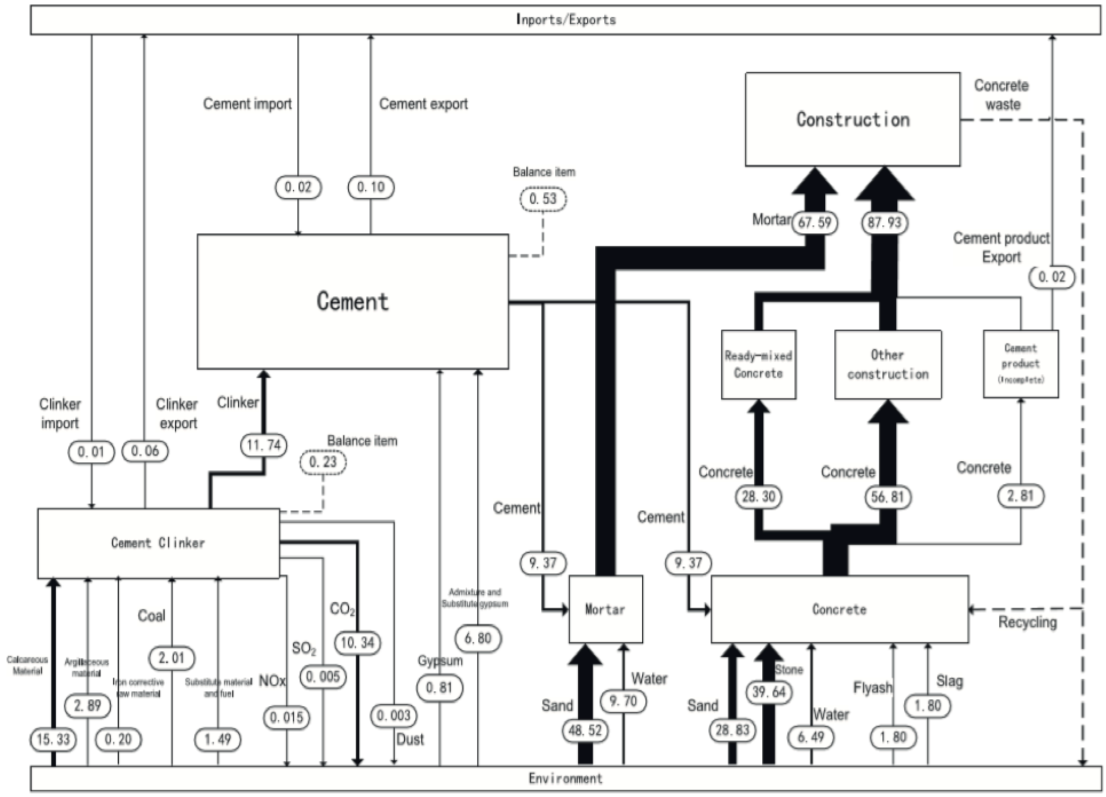

Figure 19. Cement industry MFA in 2010. (Unit 108 t).

Source: Wang et al. (2016).

The method has another advantage, i.e., the possibility of working generic (Figure 18) or more complex (Figure 19) models, depending on the availability of information or type of intended for the analysis.

3.4. Case studies: niobium and its use in the automotive industry

In this work, the Material Flow Analysis methodology is used as a support tool for the analysis of circular economy in the life cycle of different applications of niobium. The research focuses on the automotive industry, proposing an MFA model of the niobium industry and the automotive steel it uses as a ferroniobium input (FeNb). The model recompiles information and data connections, which could contribute to the construction of evaluation analysis and circular decision-making management.

Niobium is a metal (or raw material) considered critical for consumer countries, especially the USA and European Union countries, as featured in the “critical and strategic raw materials” section. Recent estimates of global niobium mineral resources show that they are not a limiting factor for the demand in this century due to their geological occurrence in different parts of the world (WERNER et al., 2017). Although there are numerous deposits known in several countries, products derived from niobium minerals are concentrated in Brazil and Canada, which the methodologies for assessing criticality construe as a real supply risk to the global market in the short and medium-term. However, recent studies have shown that there are materials that replace niobium in different applications due to their similarities with niobium (HALL, 2018).

The MFA can raise a new perception, that is, highlighting how this metal is currently used and where it builds up as a residual or potential resource. This study reviews niobium stocks and flows from the ore sources in Canada and Brazil to the end of the life cycle and recirculation of micro steel linked to niobium (High Strength – Low alloyed Steels) that uses FeNb in the automotive vehicle industry.

This study considers stocks and flows of niobium through a detailed dynamic analysis of the flow of materials at the product level (FeNb) to evaluate the quantities of niobium in manufacturing, use, productive process and end of life to reach conclusions on the potential in a circular economy.

3.4.1. Niobium material flow analysis

Performing a material flow analysis in scale entails the characterization of various stocks and flows throughout the life cycle of the niobium. Figure 20 shows a general life cycle for niobium. Stocks (shown in blue and green) represent places of interest for reuse as a future resource.

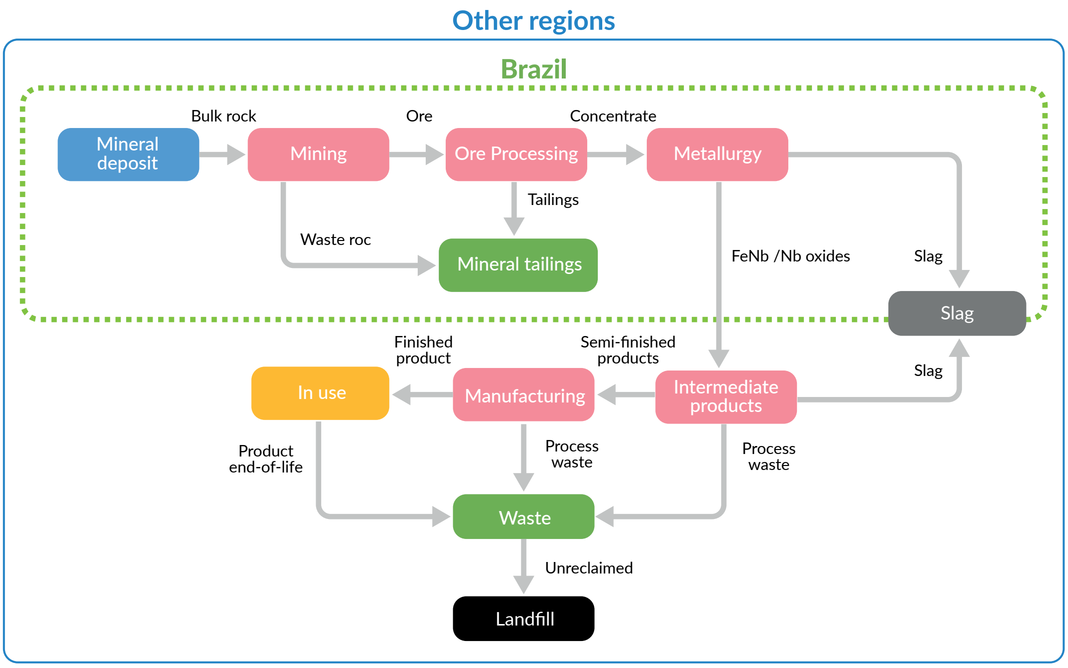

Figure 20. Domestic and international stocks flow and process considered in this study.

Source: Elaborated in-house.

Flows (grey arrows) are interesting because they determine stock accumulation rates. The stages shown in orange are processing steps in which the materials are transformed, which ends up affecting the direction and magnitude of the flows. The starting point of any metal cycle is its extraction (or mining) of stocks in the mineral deposits. The niobium mineral resources were determined using an estimated approach of niobium content in individual deposits in Brazil and Canada, according to the sustainability reports of Companhia Brasileira de Metalurgia e Mineração (CBMM), and NIOBEC (CBMM, 2018; NIOBEC, 2018), respectively, as well as information extracted from the National Mining Agency (ANM, 2018) and the United States Geological Survey (USGS, 2018) databases. Subsequently, the volume of marketed ferroniobium was calculated using historical import and export data (ANM, 2018; USGS, 2018; MINEM, 2016; ALICEWEB, 2018). Table 12 shows FeNb exports from the two world producing countries.

Table 12. Ferroniobium exporting countries (2017).

Country	Location	FeNb (tons) Exports
Brazil	Goiás (CMOC)	10,553
	Minas Gerais (CBMM)	65,801
Canada	NIOBEC	9,297

Source: Elaborated in-house.

Figure 21 shows the Brazilian participation in the mineral production of niobium, which represents 89% of the world production (USGS, 2018); COMIPA (a company that supplies ore to CBMM) represents 40% of the national participation.

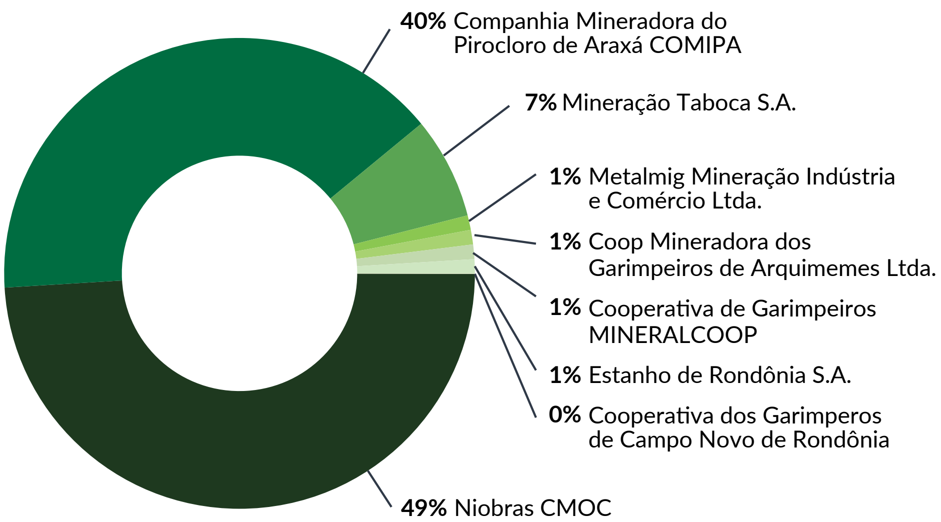

Figure 21. Distribution of the Brazilian companies' participation in the mineral production of niobium, according to the Brazilian Mineral Yearbook (2018).

Earlier in the previous section, we mentioned that the niobium has numerous applications. However, its main market is in the iron and steel industry – e.g., high strength and low-alloy steels, and stainless steels. Figure 22 shows the distribution of niobium across different applications concerning FeNb, with the material flow analysis for 2017.

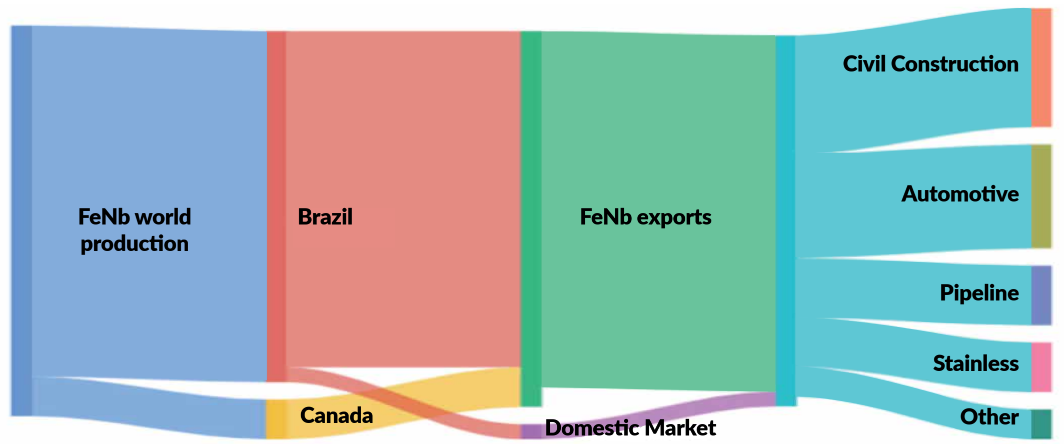

Figure 22. Generic niobium's Material Flux Analysis (MFA) from production to applications (2017).

Source: Elaborated in-house.

The previous figure shows the flow analysis of the main applications of niobium in steel, where the construction industry represents 32%, followed by the automotive sector 28%, fluid pipelines 17%, stainless steel 14%, and other applications 9% (CBMM, 2017). In 2017, Brazilian exportation of FeNb was of 76,669 tons/year, while the domestic market remained in 3,659 tons/year (CBMM, 2017).

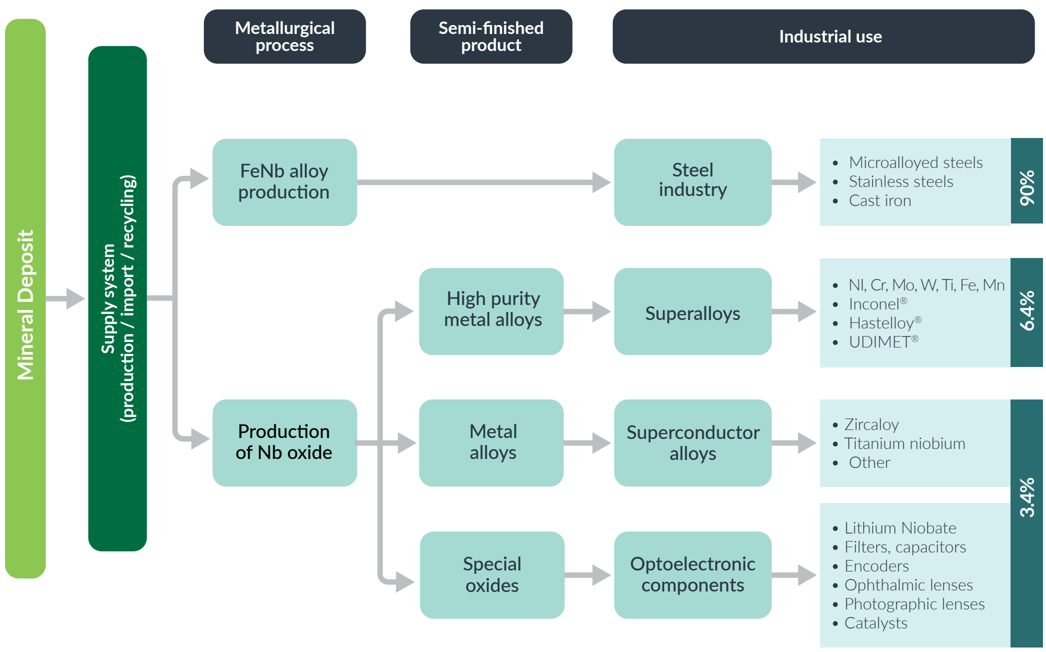

Figure 23. Product flow chart for niobium processing, with the FeNb route highlighted.

Source: Adapted from Lima (2010).

Table 13. Niobium main applications and markets.

Product	Main producers	% of total Nb incorporated in the products	Applications	Main markets
FeNb (Standard Grade) HSLA FeNb 65% Nb	- CBMM	90	High Strength Low Alloy Steel (HSLA	Automotive
	- IAMGOLD/ Niobec		Heat-resistant steels	Petrochemical sector
				Plants
				Oil/Gas pipelines
Vacuum Grade FeNb (VG FeNb) 99% Nb	- CBMM	3	Superalloys	Aircraft engines
				Power generators
				Petrochemical sector
Alloys and metal niobium (50%-65% Nb)	- CBMM	3.4	Superconductors	Particle accelerators
				Magnetic resonance imaging
Chemicals (99%) Nb	- CBMM	3.4	Functional ceramics	Optics
			Catalysts	Electronics

Source: ROSKILL Information Services (2009).

Figure 24 shows the sales volume of FeNb for consumer industries. The relevance of the automotive industry is noteworthy, as it is the second most important application, preceded by the construction industry, with 32%, and followed by pipeline used to convey flows, stainless steel, among others.

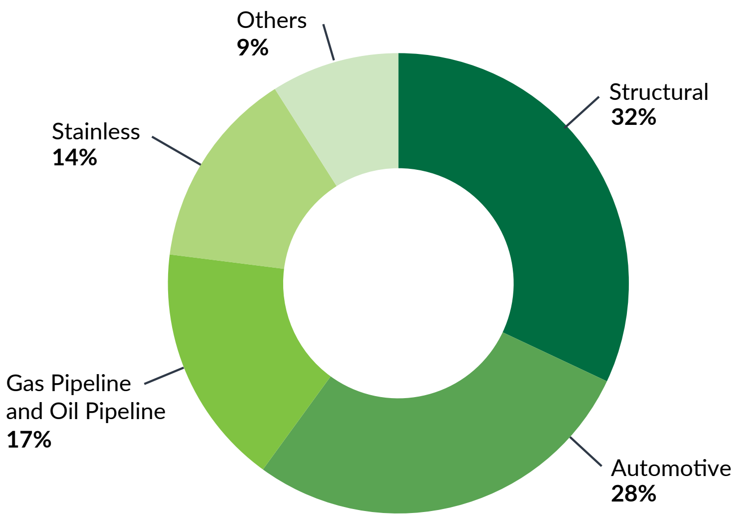

Figure 24. Participation in sales volume of ferroniobium for consumer industries.
Source: CBMM (2017).

Due to the representativeness of the use of FeNb iron alloy in the automotive industry steels, material flow analysis of steel containing Nb were carried out. In this analysis, we can see that recycling is a consolidated practise, which still does not occur significantly in some other segments.

3.4.2. Material flow analysis of steel used in the automotive industry

Figure 25 shows the niobium life cycle phases, from the deposits to its industrial use. The Steel industry uses ferroniobium alloy (FeNb). The FeNb enters in the composition of the High-strength low-alloy (HSLA) steels (or microalloyed steels) that are consumed by the oil, construction sector, maritime, aeronautics, tools making industries, as well as the one of interest here, the automotive sector, delimited in green colour.

In the automotive industry, the bodies of the cars become lighter, while maintaining their resistance. The weight reduction improves both combustion and electric engine-driven vehicles' efficiency. The flowchart in Figure 26 shows how stocks (in green) represent a resource that could be recirculated in the value chain in the future, also referred to as destination alternatives. The stocks (mustard colour) represent those that could enter in the reverse logistics, and the stock (in black). This material could hardly be reused or recirculated across the production chain.

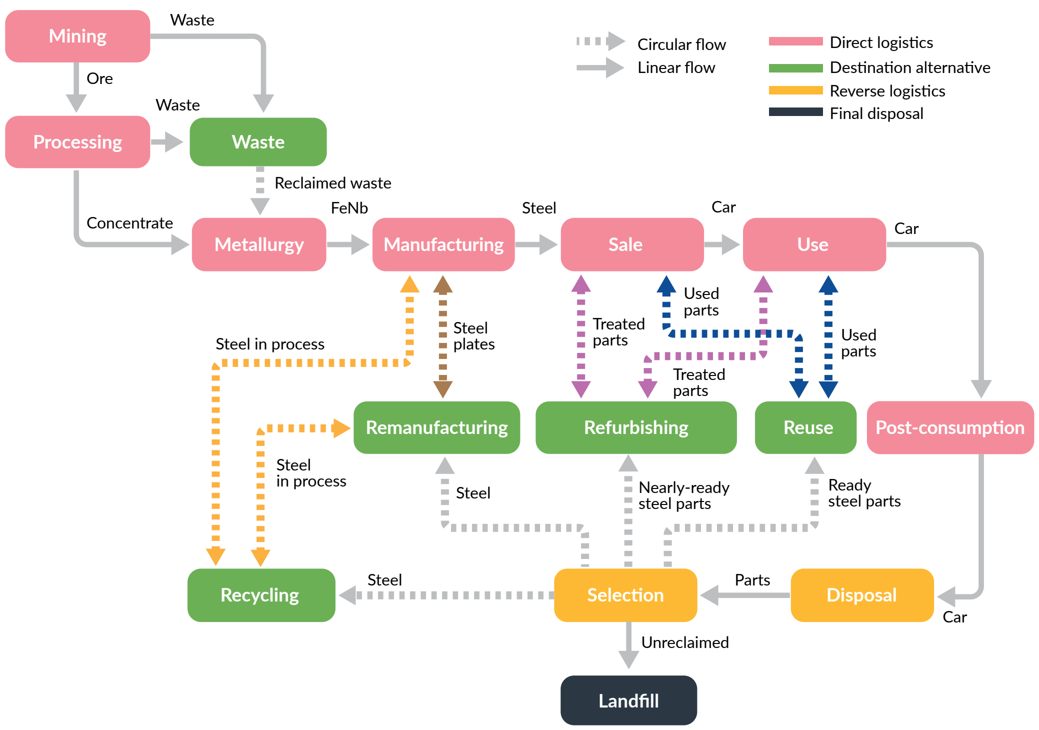

Figure 25. Steel flow diagram for the automotive industry.

Source: Elaborated in-house.

Flows (arrows) determine the inventory accumulation rates. The sequence of steps starting from the extraction of the inputs moves on to ore dressing and processing, until the consumption and post-consumption phases, which consist of direct logistics and is indicated by continuous arrows in Figure 27. The dashed flows represent the proposal of circularity for product recovery. In this model, a post-use step should be considered, indicating the time the motor vehicle is in circulation or use. Reuse phases were considered: waste recovery in the minerals processing (extraction, ore dressing and refining); remanufacture, where the steel is reused through physical or chemical treatment; reconditioning, where steel is reconditioned without physical or chemical transformation; the reuse of steel that was not processed before reusing phase. Screening phase separates the materials needing physical or chemical processing (recycling).

Furthermore, using Stan 2.6 software, flow analysis of the Nb was modelled for its entire value chain (Figure 26), by calculating the percentage of Nb in each of the flows between the steps of the model.

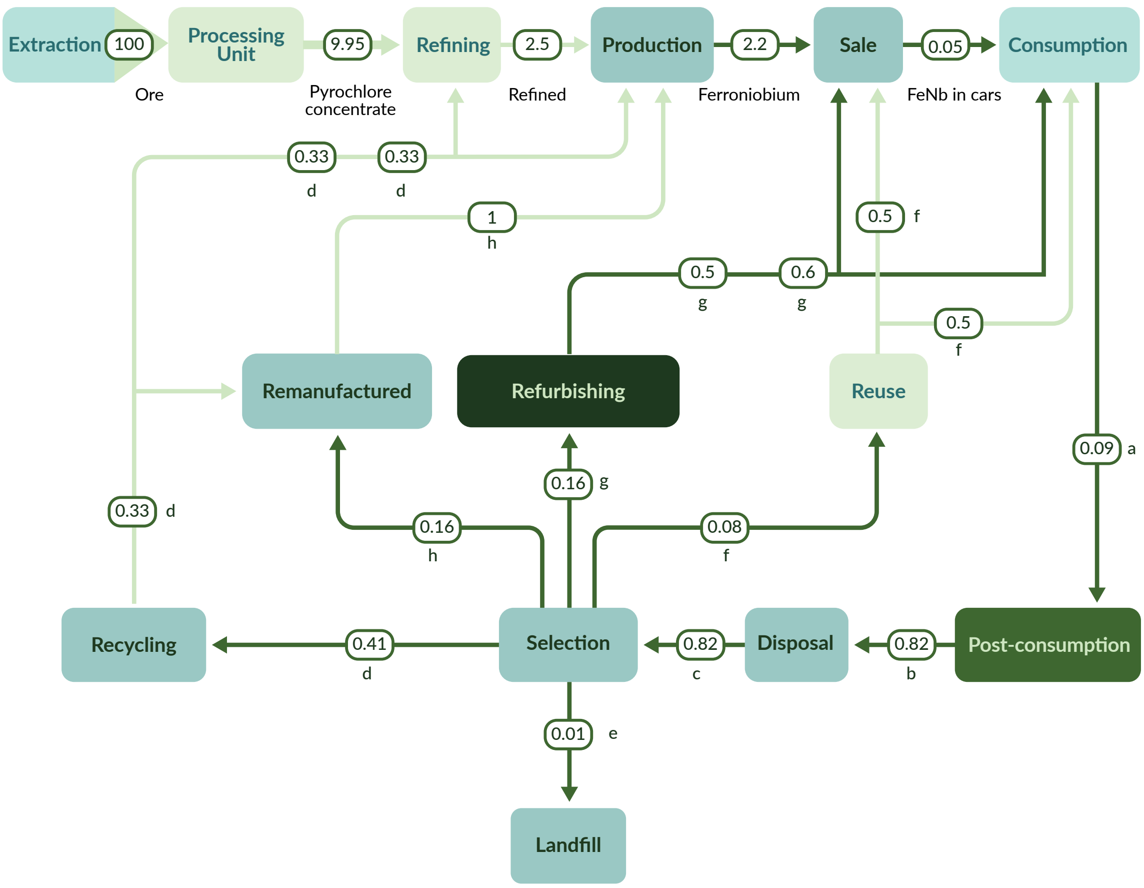

Figure 26. FeNb material flow analysis using Stan 2.6 software.

Source: Elaborated in-house.

To draw the Sankey-type graph on the automotive steel, we considered niobium from the extraction phase up to its reincorporation into the steel production chain of small and large-sized automotive vehicles' production. For small-sized vehicles, we considered those weighing up to 1,337 kg, and for the large-sized, those starting from 1,338 kg, as shown in Figure 27.

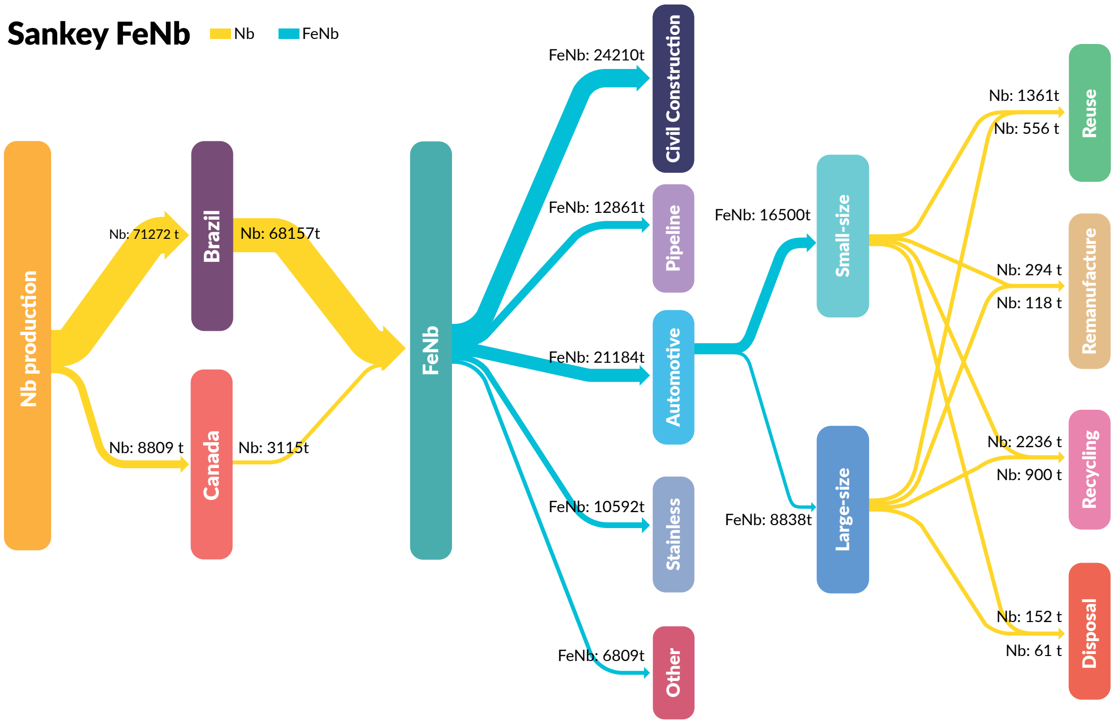

Figure 27. Sankey type graph of the niobium flow, from the extraction of the mineral to its application across different productive industries, with emphasis on the automotive industry.

Source: Elaborated in-house.

Figure 26 shows FeNb in average mass-volume quantities per year – mostly used in the construction industry, automotive industry, in pipelines, stainless steel, among others. Out of the yearly production of FeNb, 28% are for the automotive sector, each car with a weight of 0.3 kg mass of Nb for lightweight vehicles, and 3.75 kg for large-sized vehicles. Estimated 97.31 million vehicles are produced annually, light cars accounting for 71% of that production. After the life cycle of the vehicles, they are assigned for reuse (resale of used or resale of parts), remanufacture (reuse of steel without physical-chemical transformation), recycling (reuse of steel with physical-chemical transformation) and disposal. Figure 27 features the weight-mass approximate quantities of Nb for each destination.

It should be noted that when metallurgical processing occurs at the steel reuse phase, the quantities of Nb present in the steel composition are eliminated in that process. For this reason, Nb circularity index in the recycling step is irrelevant.

Figure 28 features a circularity proposal for microalloyed steels containing FeNb in the automotive industry.

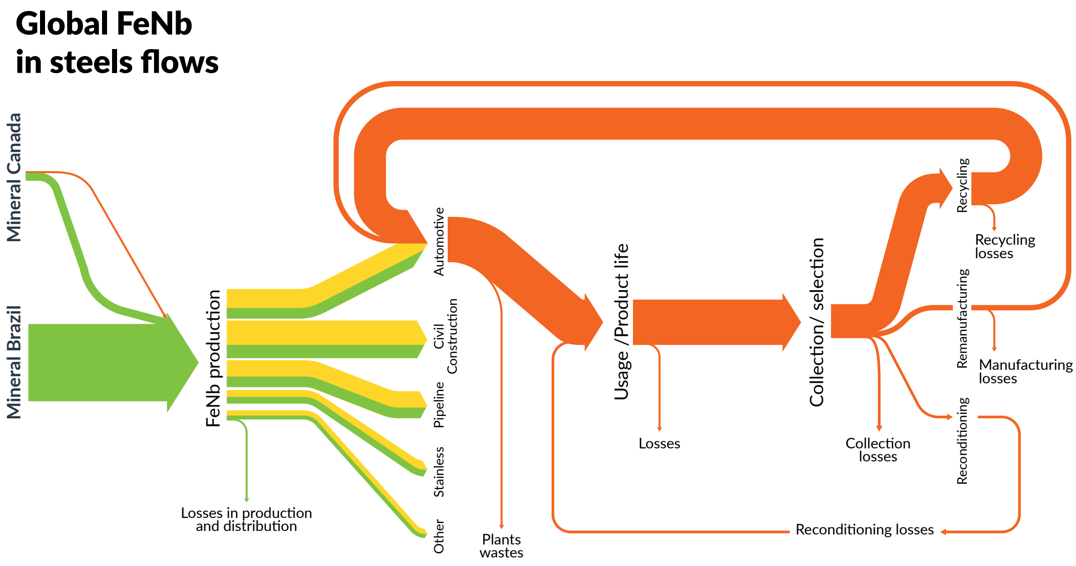

Figure 28. Circularity proposal for automotive steel.

Source: Elaborated in-house.

Figure 28 shows Nb flows represented in green, iron in yellow, and steel in orange steel. HSLA steel from vehicle wastes is of 1,106 kg per vehicle. The estimates are that 40 million vehicles reach their end-of-life in one year, which represents approximately 4 million kilograms of Nb for disposal. Out of that volume, 78% are assigned for recycling, 10% for remanufacturing, 5% for final disposal, and 5% for other destinations.

As Nb is lost in the recovery process, after the physical-chemical processing (remelting in electric arc furnace), it is observed that the material circularity is exclusive to steel.

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4.

Overview of innovations in materials and products involving niobium

ADELSON A. CASTRO
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4.1. Introduction

The search for innovation, including the use of niobium, may disclose dynamic aspects that allow us to infer and evaluate its future use. In this sense, the analysis of patents and scientific articles aims to help us understand the growth, stability or decline trends of this dynamics and, therefore, the effects on consumer markets, but also on the raw materials market.

The elaboration of this prospective study, aimed at meeting the specific objective, item B of the project proposal n. 128 A, approved by the EU–Brazil Sector Dialogues Program, i.e., "Presenting a framework of opportunities and threats to strategic or critical raw materials in a circular economy scenario, based on the assessment of changes' predictability versus the technology or knowledge available to materialize them for the actual case studies."

4.2. Methodology

To investigate emerging technologies, identify knowledge fields, and the market segments to be affected by future technologies, we used the keywords "niobium" (in Latin) and "nióbio" (in Portuguese) separately, as well as combined through Boolean words, in the Abstract field, both in patents, as in scientific papers databases. Choosing this search field aimed to identify the effective use of this element/mineral in the research that originated the selected paper or patent, since the Abstract must contain the summary information on the research and/or invention developed.

This was, therefore, a search with a general and indiscriminate scanning to find all available documents, even though niobium is not the focus for research or patent.

Also, we searched topics across patent database sites such as Espacenet (European Patent Office), USPTO (United States Patent and Trade Mark Office) and INPI (Instituto Nacional de Propriedade Industrial), using the *TotalPatent*[9] search tool, as well as websites of scientific paper's editions, such as the Web of Science, and Science Direct. The research study on the state-of-the-art of niobium use was limited to the extent of six years (2013 to 2018) across patents databases, and the period ranging from 2013 to 2019, across the scientific databases. This difference between search time extension is consistent if one consider the 18 months of non-disclosure for patents deposit.

9 Trial version used, license owned by LexNext.

4.3. Results

4.3.1. *Prospecting across scientific articles*

The search across scientific papers returned about 7,300 documents that, after the exclusion of individual duplicates of the publication, came down to 4,953 documents. In a preliminary analysis of these results, the recurrence of the terms "Alloy", "Oxide", "Steel", totalled 125 repetitions. On the other hand, the terms "Energy", "Anode"or "Cathode" totalled 50 and 95 occurrences, as shown in words cloud (Figure 29).

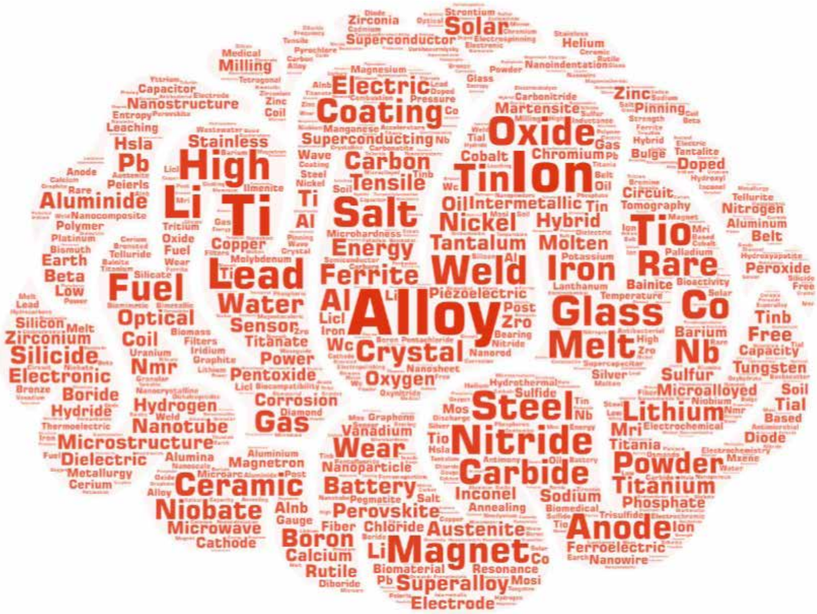

Figure 29. Words cloud with all keywords listed in the selected articles within the period ranging from 2013 to 2019.

Source: Elaborated in-house.

Given that said terms are within the set of keywords, we can infer the scientific interest in identifying the feasibility of using niobium in steels, and alloys and oxides in battery components, such as anode and cathode. Similarly, though with less evidence, our searching showed studies aimed at developing applications for this element in sensors for gases, supercapacitors, fuel cells and solar cells, as shown in Figure 30.

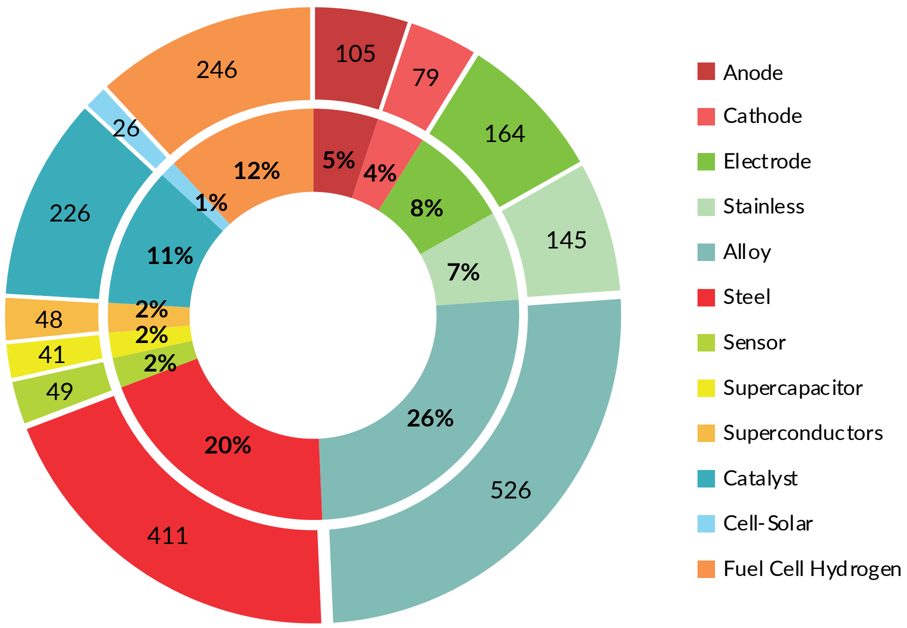

Figure 30. Quantitative and percentage ratio of papers published by field of use within the 2013-2019 period.

Source: Elaborated in-house.

In Figure 31, we can observe the annual distribution of publications in the field of metallurgy, with emphasis on steels, including stainless and superalloys. Note the almost constant contributions of the research studies, with a slight decline trend in terms of published papers.

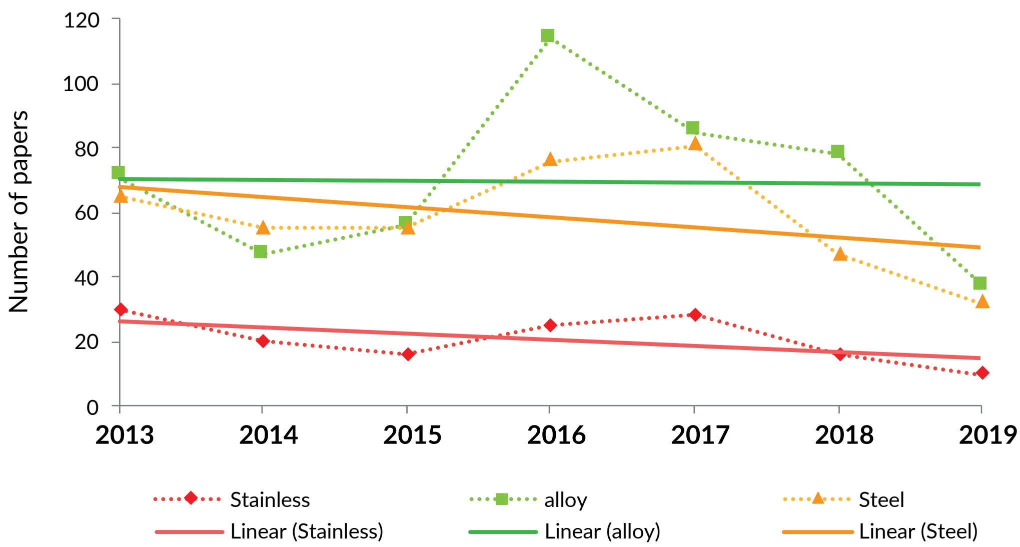

Figure 31. The quantitative ratio of scientific papers published per year in the metallurgy field (Stainless, Alloy and Steel) from 2013 to 2019.

Source: Elaborated in-house.

Figure 32 shows a clear growth trend in terms of studies related to the components of the anode/cathode/electrode for batteries. We identified the relevance of using niobium in the anodes of lithium-ion batteries, as power storages devices for vehicles.

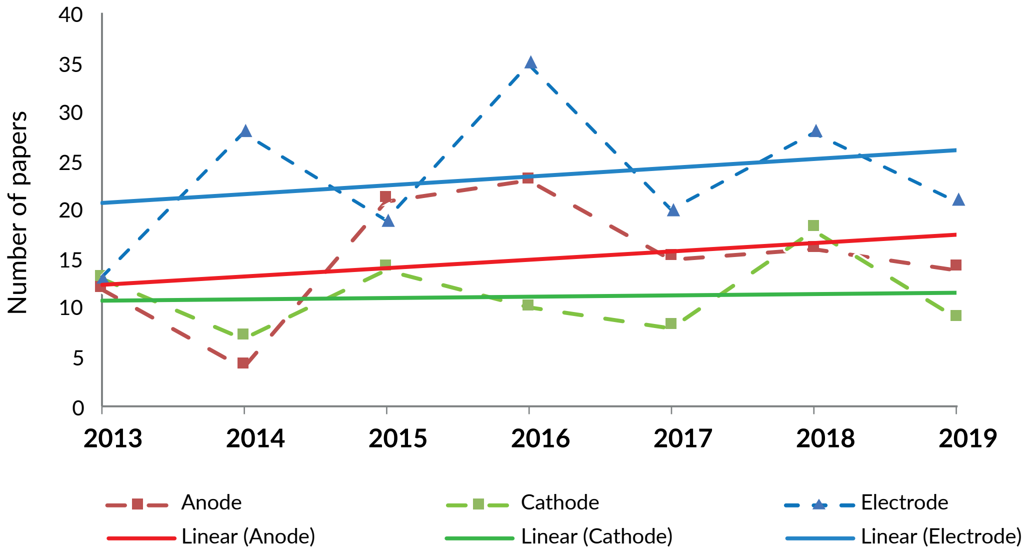

Figure 32. The quantitative ratio of papers per year with battery components' key words (anode, cathode and electrode) and their respective trend lines within the 2013-2019 period.

Source: Elaborated in-house.

Figure 33 shows the amount of papers related to the supercapacitors development studies. Note that there are just few occurrences of the terms when compared to those identified using "Anode, Cathode, and Electrode" individually. However, those are recent studies aimed at increasing the capacitance property.

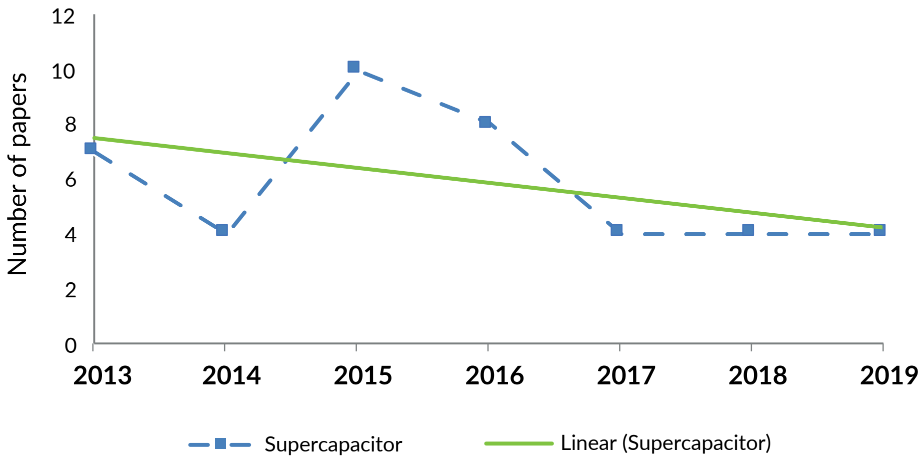

Figure 33. The quantitative ratio of papers per year related to supercapacitors' development and trend lines within the 2013–2019 period.

Source: Elaborated in-house.

Similarly, Figure 34 shows the occurrences of studies on superconductors.

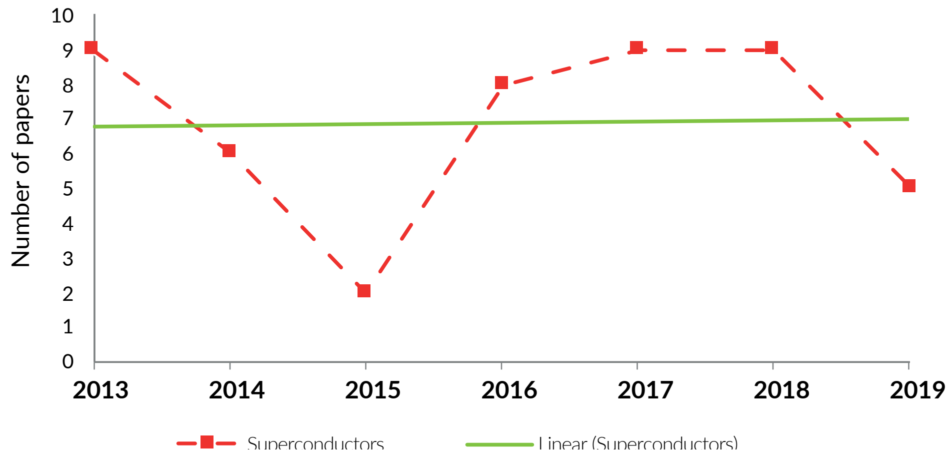

Figure 34. The quantitative ratio of papersper year regarding superconductors and trend lines within the 2013–2018 period.

Source: Elaborated in-house.

Both Figure 35 and Figure 36 show a slight downward trend in research studies to regarding catalysts, as well as for hydrogen fuel cells. However, the search for new sensors persists although the fewer published papers, what can be seen in Figure 37.

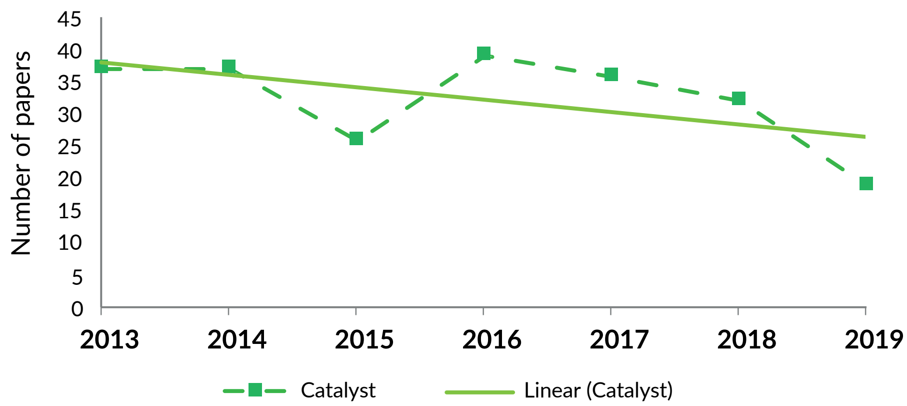

Figure 35. The quantitative ratio of the papers per year on catalysts for the 2015-2019 period.

Source: Elaborated in-house.

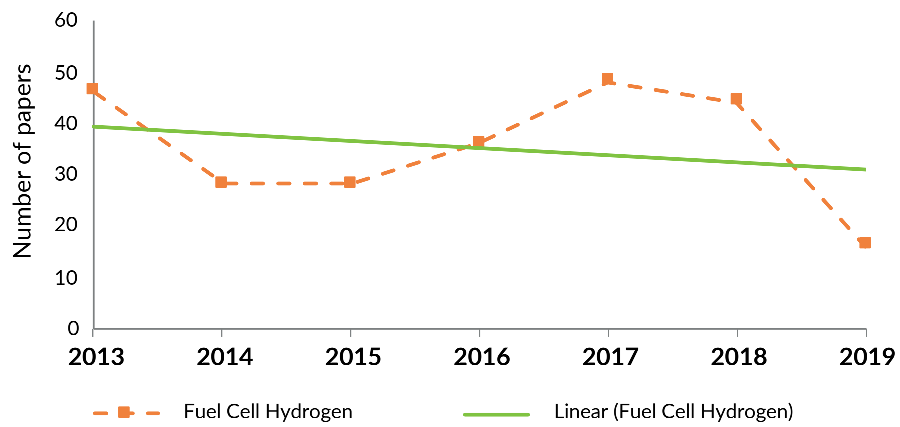

Figure 36. The quantitative ratio of papers per year containing fuel cell as key words for the period 2013-2019.

Source: Elaborated in-house.

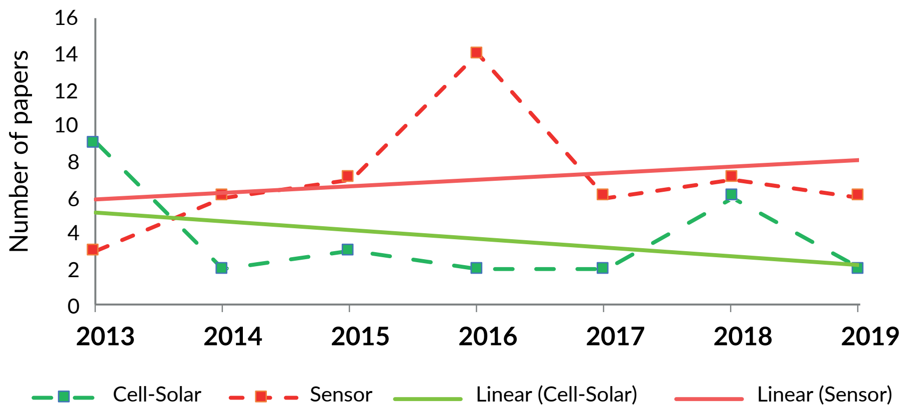

Figure 37. The quantitative ratio of articles with terms for steels from 2013 to 2019.

Source: Elaborated in-house.

4.3.2. Database search on invention patents

Patents databse search showed 3,375 patent filing applications for inventions. In Figure 38, we show the number and percentage distribution of patent filing applications per field of use dated within the 2013 to 2018 period.

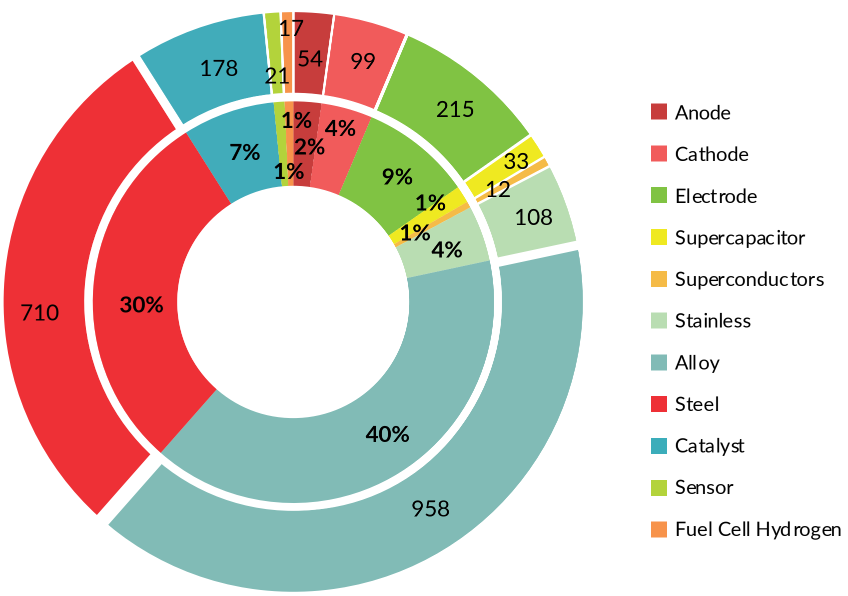

Figure 38. Quantitative search result of patent applications dated in the 2013 - 2018 period.

Source: Elaborated in-house.

Figure 39 features the patent filing applications in the metallurgy field (search subjects “steels”, “stainless steels” and “alloys”), where one can observe the same downward trend found with scientific papers around 2016-17 period, what may reflect the innovations maturity level of the related technologies.

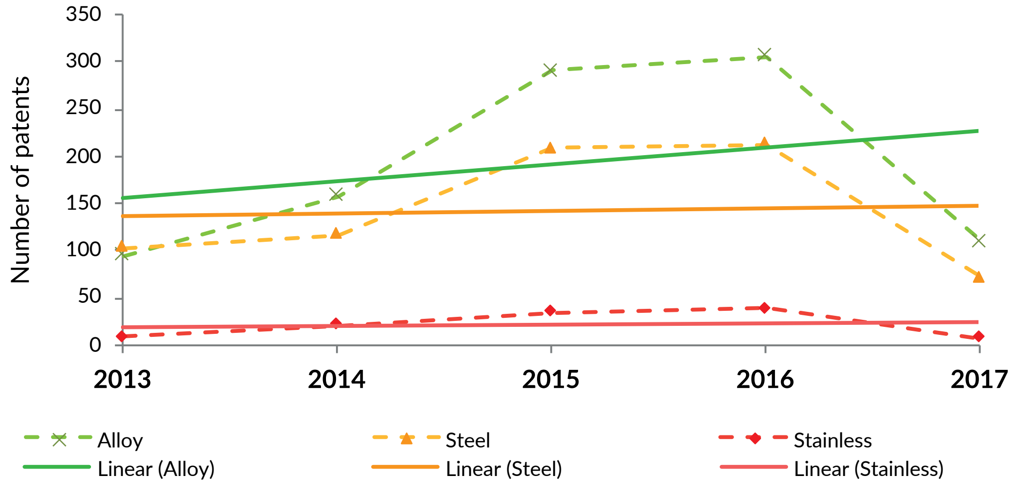

Figure 39. Patent documents mentioning niobium terms related to steel, with applications dated from 2003 to 2017.

Source: Elaborated in-house.

However, as featured in Figure 40, the slight patent filing trend upwards is not seen with scientific related to battery components (anode, cathode, electrode).

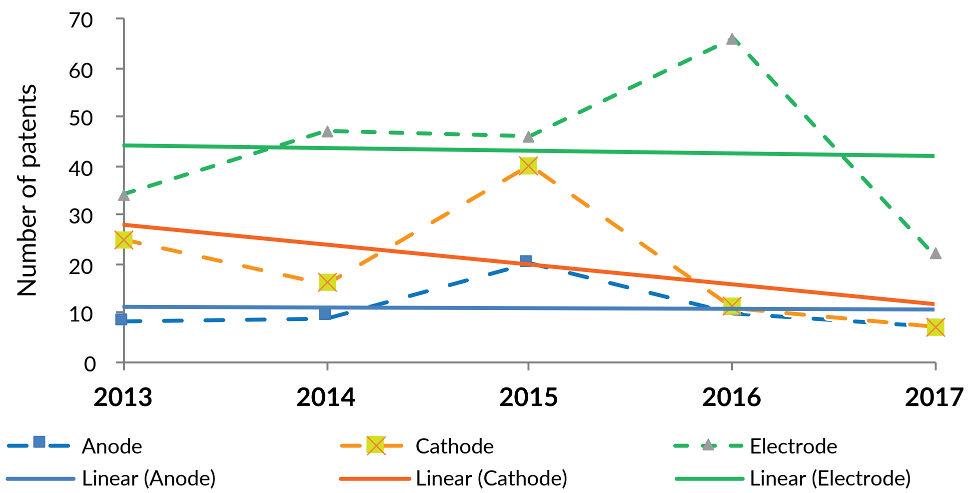

Figure 40. The quantitative ratio of patent applications per year using terms related to cathode and anode dated between 2013 and 2017.

Source: Elaborated in-house.

Figure 41 shows a dropping bias in patent applications in catalysts having niobium content after 2016. At the same time, Figure 42 represents a continuous trend of the patent applications related to supercapacitors and superconductors subjects although being the fields where fewer papers and patents were found out.

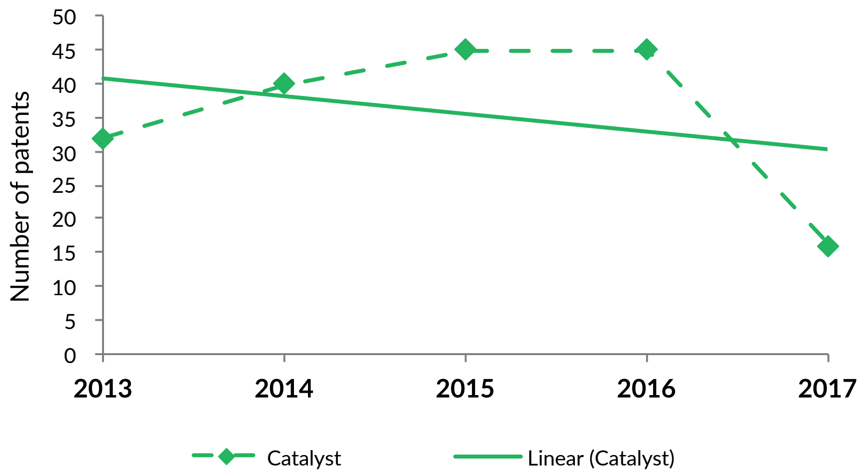

Figure 41. The quantitative ratio of catalysts patent applications documents dated from 2013 to 2017.
Source: Elaborated in-house.

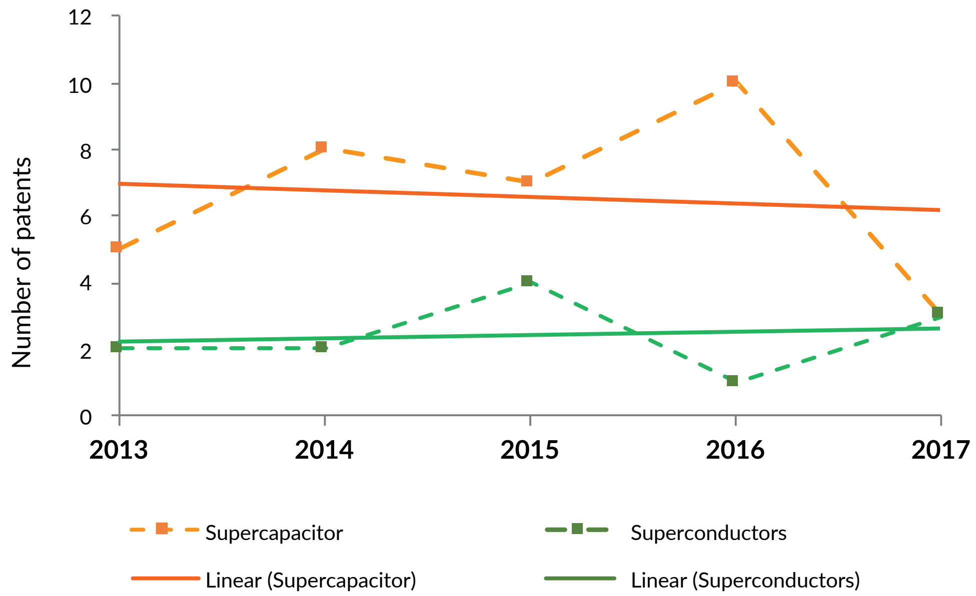

Figure 42. The quantitative ratio of patent applicationss related to supercapacitor and superconductor, dated between 2013 and 2017.
Source: Elaborated in-house.

Figure 43 shows the behaviour for the use of niobium in solar cells, sensors and fuel cells with perspectives of a drop. Given the small number of identified issued documents, trends may be considered as inconclusive.

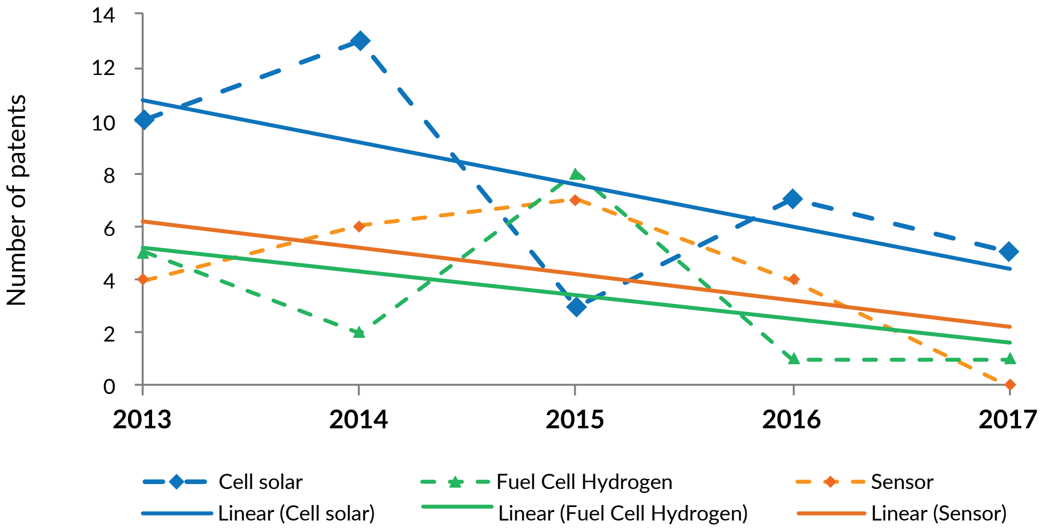

Figure 43. The quantity ratio of patent documents (solar cell, sensors and fuel cell) with patent pledge requests dated from 2013 to 2017.

Source: Elaborated in-house.

4.3.3. Patent distribution by country

The review on the number of patent applications allows identifying the countries of origin in which a the intellectual property to protected technology has been filed. Figure 44 shows a representation of the percentage distribution of the patent applications filed per country, compared to the total number of documents identified from 2013 to 2017.

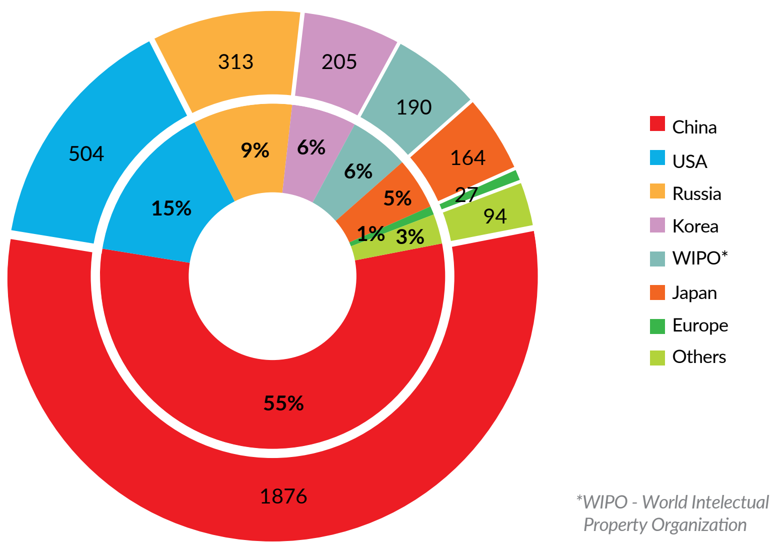

Figure 44. Patent applications by country from 2013 to 2017.

Source: Elaborated in-house.

In Figure 45, we show the percentage of patent applications by residents and per object related to energy storage devices, such as components of a battery, as well as supercapacitors. Interest in using niobium in anodes and/or cathodes in China, the USA and Russia are noted, with emphasis to cathode by the latter.

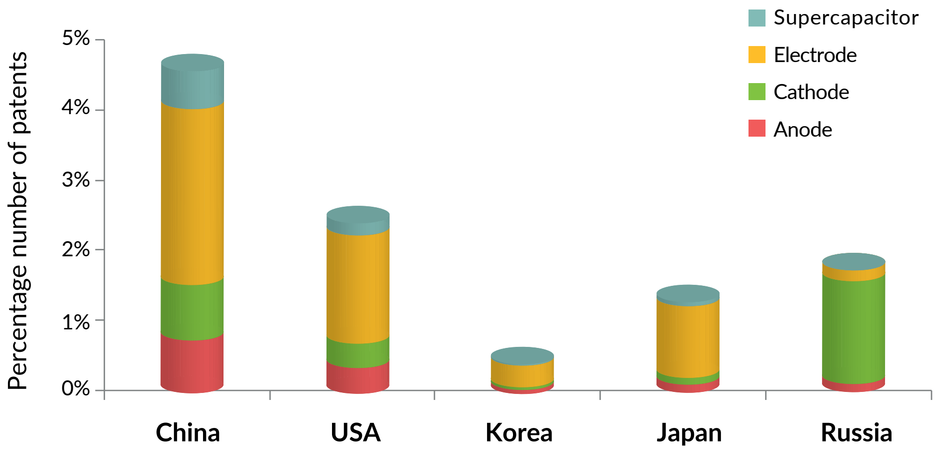

Figure 45. Percentage of energy storage devices-related patent applications (Supercapacitors, electrodes, anodes, and cathodes) per country, from 2013 to 2017.

Source: Elaborated in-house.

In Figure 46, it is showed the percentage of patents applications filed between 2013 and 2017 by residents per object (stainless steels, alloys, steels and catalysts). This review discloses the predominance of patent documents in the field of steels and alloys with the superior predominance of applicants in China .

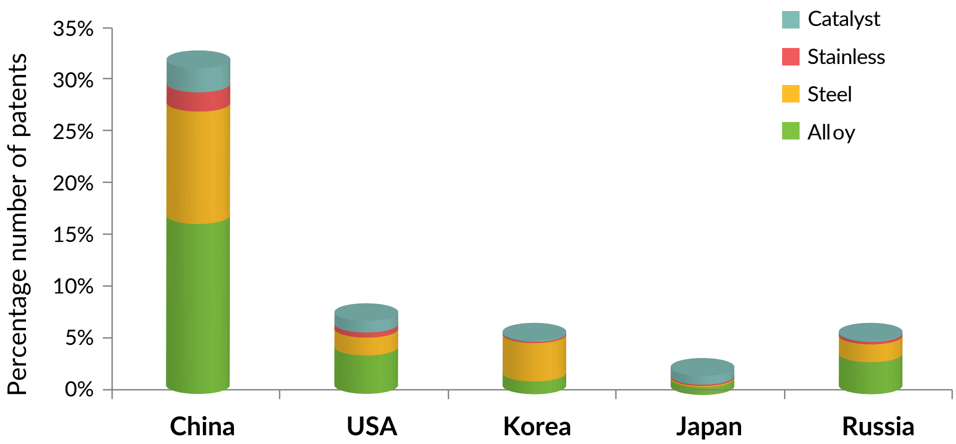

Figure 46. Percentage of patents applications having niobium as a content related to stainless steel, steels, alloys, and catalysts per country, from 2013 to 2017.

Source: Elaborated in-house.

Figure 47 features the low percentage of documents on patents for superconductors, sensors and solar cells, which still shows China's strong interest, followed by Korea and Japan in the patent filing on solar cells.

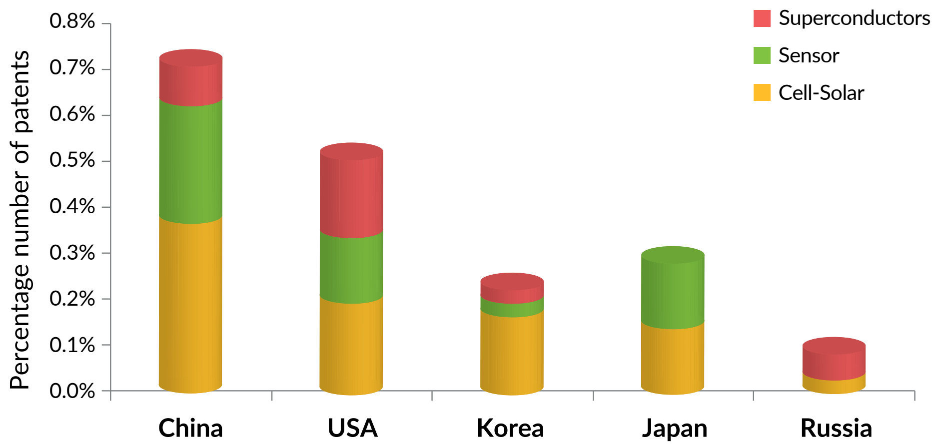

Figure 47. Percentage of patents applications related to superconductors, sensors, and solar cells per country, from 2013 to 2017.

Source: Elaborated in-house.

4.4. Conclusion

In terms of research and development having niobium mentioned on published papers and patent applications with repercussions on intellectual property, the major field is metallurgy (alloys and steels), concentrating 18,9 % of the papers, and 40,0 % of patents. We identified a trend of using niobium in anodes, cathodes, and battery electrodes from 2015 to 2019, as well as research, although much less important, to obtain materials for supercapacitors. This reinforces the interest in the use of the niobium as a component for energy storage devices.

The study reveals the bias towards a slight decline in the protection by patent applications, as compared to the growing number of published papers, which may reflect the development of innovations in energy devices that are being kept under secrecy

The results show the prevalence of applications in the metallurgy field (steels and superalloys), in a 7/1 ratio regarding energy-related devices, whether for generation or storage purposes.

Assessing the innovation dynamics requires further studies such as for other metals or elements competing with niobium, searching a broader amplitude for other refractory metals. However, the gross quantities found, and the diversity of research topics indicate that there is still a diversified and growing interest in the uses of niobium.

China has the largest number of patents applications mentioning niobium between 2013 -2017 showing its leading position in innovation.

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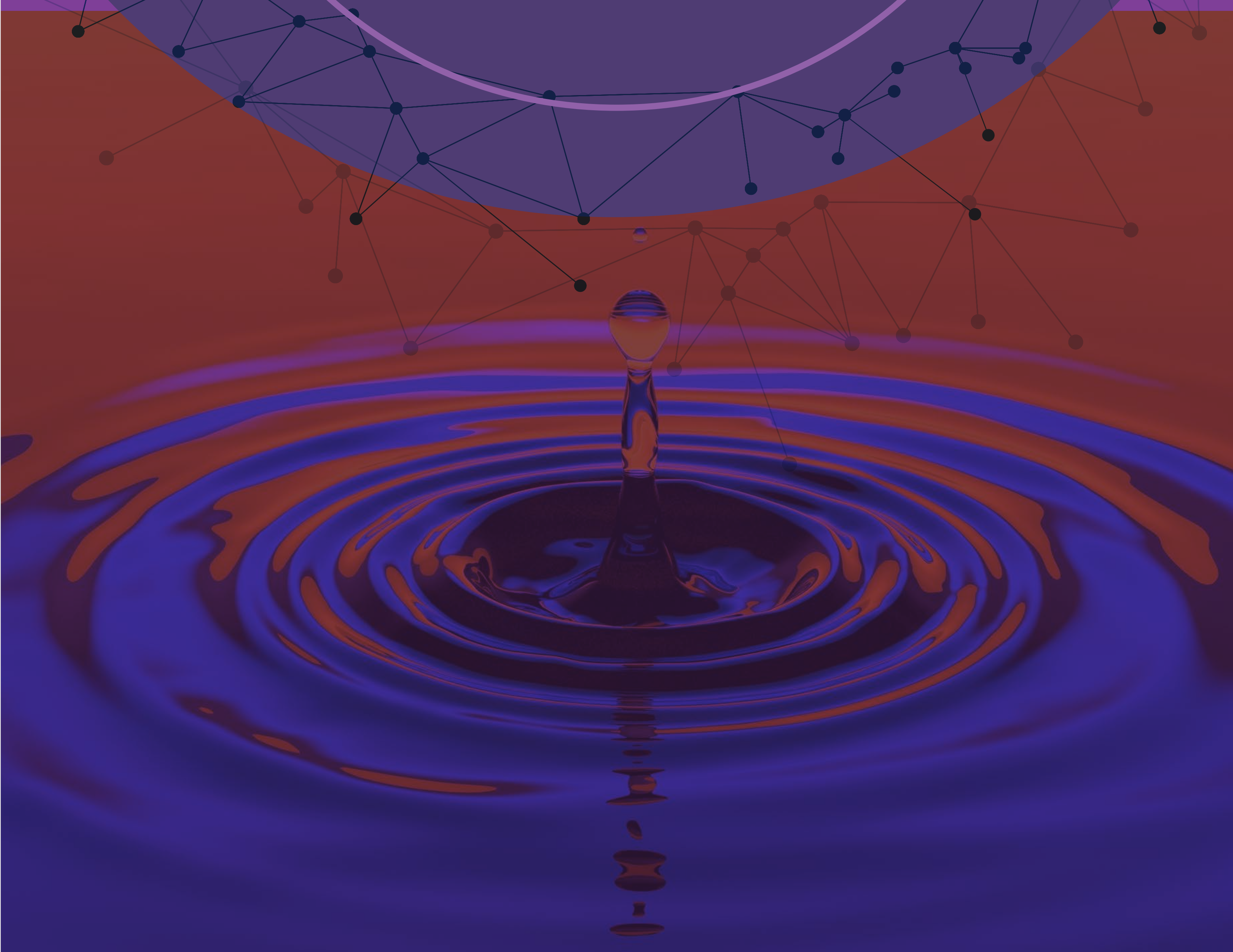
5.

Life Cycle Assessment (LCA)

EFIGÊNIA ROSSI



5.1. Introduction

Life Cycle Assessment (LCA) is a technique that quantifies the environmental impact of a product or service through its entire life cycle (UDO DE HAES et al., 2004). LCA comprises four phases: Objective and scope Definition, Inventory, impact Assessment and Interpretation (ABNT, 2009a, 2009b), Figure 48.

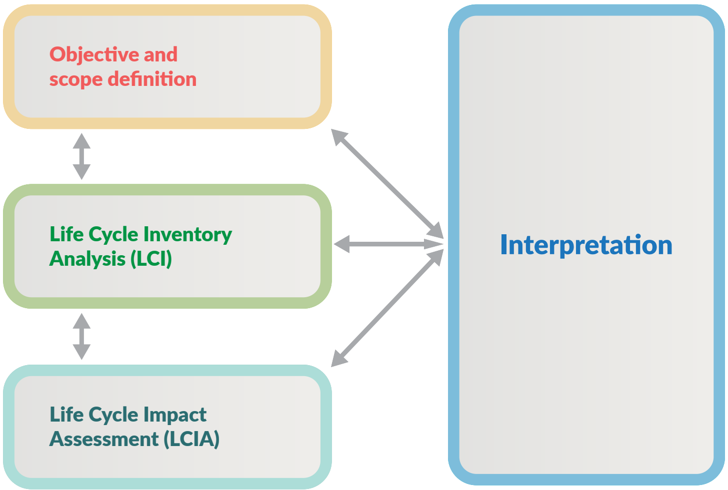


Figure 48. LCA phases.

Source: Adapted from ABNT (2009a).

The first phase of the study is the basis of all others, and there will be the objective of the study that will permeate the definition of the application and purposes, the limitations and scope, the reasons for its realization, the target audience and other actors involved. The scope of the study covers the following items(EC, 2010):

- Delimitation of the product system, its function, functional unit and reference flow;
- Type, quality and source of data;
- System borders and cut-off criteria;
- Impact categories;
- Methodology for Life Cycle Impact Assessment (LCIA);
- Critical review.

The product system refers to the interconnected processes of its life cycle. The function and functional unit represent, in qualitative and quantitative terms, the target object of the LCA. The function determines its performance characteristics, and the functional unit is the size expressed in quantitative terms towards the function of the product (EC, 2010). The reference flow is the measurement of the output of a process necessary to perform the function expressed by the functional unit (ABNT, 2009b). For example, since fuel is a product, its function is to move the vehicle, its functional unit is given in km driven, and its reference flow is the amount of fuel per km travelled.

The impact categories indicate which of these will be included and which methodologies to be used. Examples of categories are Global warming potential, Eutrophication, Acidification, etc. Regarding the methods, there may be several methods, namely: CML 2001, E-I99, EDIP 1997, IMPACT2002+, among others. The critical review should be performed by specialists not directly involved in the study to ensure the quality, credibility and value of the study (ROSSI, 2013).

The second phase of the study or Life Cycle Inventory Analysis (LCI) permeates the preparation for data collection and data validation. The preparation for the collection permeates the planning for obtaining the data. The collection can be carried out using Quizzes applied directly to the organization to be studied, seeking to list the main primary sources. Data validation is carried out through mass and energy balances to verify whether elementary processes comply with the law of conservation of mass and energy (EC, 2010).

The third phase of the study or LCIA is divided into three sub-phases: selection of impact, classification and characterization categories. The selection encompasses the definition of the categories to be studied. The classification denotes the correlation of LCI results (environmental aspects) within the selected categories. At the same time, the characterization refers to the quantitative contribution of each environmental aspect per each category through standardized comparative bases (ABNT, 2009b). For example, the methane gas emissions are an environmental aspect of the inventory classified in the Global Warming Potential category, and their characterization implies its quantification in terms of equivalent CO_2.

The final phase of the LCA is the Interpretation, which enables assessing significant environmental issues, the previous steps taken and verifying if the conclusions are sufficient in the light of the proposed objective.

5.2. Objective and scope

This report is based on ABNT 14040 and 14044 (ABNT, 2009a, 2009b). Ferroniobium is the object of the study. Brazil has the largest niobium ores reserves in the world in operation, followed by Canada, Australia, Egypt, among others (BRAZIL, 2016). Besides, it is also the largest producer, with 90% of the global production, followed by Canada, with 9%. Chapter 1 presented information on the main Brazilian and global reserves.

The objective of this study is to quantify the environmental impacts of the initial phases of the ferroniobium life cycle, indicating the hotspots. Ferroniobium is mainly used in the production of high-strength microalloyed steels, stainless steels and high-temperature resistant steels (CBMM, 2018). The main reason to perform the study lies in the verification of environmental impacts, from extraction to the exit gate of the plant, i.e. cradle-to-gate, aiming at improvements to the product system of choice. Thus, the study is classified as non-comparative LCA, and the target audience is the industrial and mineral sector, in a general manner.

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Below, we describe the scope of this study:

- Function

  Producing ferroniobium: when ferroniobium is alloyed with iron, it confers resistance and tenacity to iron.

- Functional unit and reference flow

  The functional unit and the established reference flow are a ton of ferroniobium.

- Impact assessment method

  As reviewed, the LCIA method to be applied in the study should include the 2011 International Reference Life Cycle Data System (ILCD) (EC; JRS; IES, 2011), supplemented by the EDIP method 1997 (WENZEL; HAUSCHILD; ALTING, 1997), as they are consistent with the Brazilian reality (EC; JRC; IES, 2011; MENDES; BUENO; OMETTO, 2016) (see Table 14).

Table 14. Scope of application in Brazil of impact categories from the main existing LCIA methods.

Legend: (✓) applicable (Brazil); (×) not applicable (Brazil); (– –) not found in the literature.

Method	Major impact categories	Scope of application in Brazil*
CML 2002	Depletion of abiotic resources	✓
	Depletion of biotic resources	✓
	Land use	✓
	Climate change	✓
	Depletion of stratospheric ozone	✓
	Human toxicity	✓
	Freshwater aquatic ecotoxicity	✓
	Marine water aquatic ecotoxicity	✓
	Terrestrial ecotoxicity	✓
	Photo–oxidant formation	×
	Acidification	×
	Eutrophication	✓

Table 10. Continuation

Method	Major impact categories	Scope of application in Brazil*
Eco-Indicator 99	Climate change	✓
	Ozone depletion	✓
	Combined acidification and eutrophication	×
	Ecotoxicity	×
	Land use	×
	Mineral resources	✓
	Fossil resources	✓
EDIP 1997	Global warming	✓
	Ozone depletion	✓
	Acidification	✓
	Nutrient enrichment	✓
	Photochemical ozone formation	✓
	Human toxicity	✓
	Ecotoxicity	✓
	Resources consumption	✓
EDIP 2003	Global warming	✓
	Ozone depletion	✓
	Acidification	×
	Terrestrial eutrophication	×
	Aquatic eutrophication	×
	Photochemical ozone formation	×
	Human toxicity	×
	Ecotoxicity	×
EPS2000	Human health	✓
	Consumption of natural resources	✓
	Exhaustion of reserves of elements	✓
	Depletion of fossil reserves (gas)	✓
	Depletion of fossil reserves (oil)	✓
	Depletion of fossil reserves (coal)	✓
	Depletion of mineral reserves	✓

Table 10. Continuation

Method	Major impact categories	Scope of application in Brazil*
Impact 2002+	Human toxicity	×
	Ozone depletion	×
	Photochemical ozone formation	×
	Aquatic Ecotoxicity	×
	Terrestrial ecotoxicity	×
	Aquatic acidification	×
	Aquatic eutrophication	×
	Terrestrial acidification and eutrophication	×
	Land use	×
	Global warming	×
	Use of non-renewable energy	×
	Mineral extraction	×
LIME	Global warming	✓
	Ozone depletion	✓
	Human toxicity	×
	Ecotoxicity	×
	Acidification	×
	Eutrophication	×
	Photochemical oxidants formation	×
	Land use	×
	Mineral consumption	×
	Power consumption	×
	Consumption of biotic resources	×
LUCAS	Climate change	✓
	Ozone depletion	✓
	Acidification	×
	Photochemical smog	×
	Aquatic eutrophication	×
	Terrestrial eutrophication	×
	Ecotoxicity (aquatic and terrestrial)	×
	Human toxicity	×
	Land use	×
	Destruction of abiotic resources	×

Table 10. Continuation

Method	Major impact categories	Scope of application in Brazil*
ReCiPe	Climate change	✓
	Ozone depletion	✓
	Terrestrial acidification	×
	Eutrophication (fresh and marine water)	×
	Human toxicity	×
	Photochemical oxidants formation	×
	Formation of particulate matter	×
	Ecotoxicity (terrestrial, freshwater, marine)	×
	Use of agricultural soil	×
	Urban soil use	×
	Depletion of fossil resources	✓
	Depletion of mineral resources	✓
	Depletion of freshwater resources	✓
Ecological scarcity	Climate change	×
	Ozone depletion	×
	Photochemical oxidants formation	×
	Water consumption	×
	Sand/gravel consumption	×
	Loss of biodiversity due to land use	×
TRACI	Ozone depletion	✓
	Global warming	✓
	Smoke formation (smog)	×
	Acidification	×
	Eutrophication	×
	Human health (carcinogenic)	×
	Human health (non-carcinogenic)	×
	Human health (pollutants)	×
	Ecotoxicity	×
	Fossil fuels depletion	✓
	Land use	×
MEEuP	Acidification	×
	Human toxicity	×
	Particles formation	×
	Aquatic eutrophication	×
USEtox	Human toxicity	✓
	Freshwater aquatic ecotoxicity	✓

Table 10. Continuation

Method	Major impact categories	Scope of application in Brazil*
ILCD 2011	Climate change	✓
	Ozone depletion	✓
	Human toxicity	✓
	Respiratory particulate/inorganic material	--
	Ionizing radiation	--
	Photochemical ozone formation	×
	Acidification	×
	Eutrophication	×
	Ecotoxicity	✓
	Land use	×
	Depletion of resources	×

Source: Adapted from EC; JRC; IES (2011) and MENDES, BUENO and OMETTO (2016).

5.2.1. Impact categories selected

The categories selected of the ILCD 2011 (EC; JRC; IES, 2011) were: Climate change, ozone depletion, human toxicity and ecotoxicity. The EDIP 1997's were (WENZEL; HAUSCHILD; ALTING, 1997): acidification, nutrient enrichment and photochemical ozone formation.

Climate change

The Earth's atmosphere absorbs part of the energy emitted as infra-red radiation, and this causes it to warm-up. This effect can be considered natural and is responsible for the maintenance of life on the planet (WENZEL; HAUSCHILD; ALTING, 1997).

However, as anthropic activities enabled the marked emission of greenhouse-effect gases, this effect escalates, raising the global average temperature, and other sudden climatic variations. Among some of these greenhouse-effect gases (GEEs), there are (STRANDDORF; HOFFMANN; SCHMIDT, 2003): Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), halogens associated with carbon chains, tetrachloromethane (CCL_4), 1,1,1- trichloroethane (CCL_3CH_3), and carbon monoxide (CO). It should be noted that CO_2 and CH_4 contribute more than 80% of global warming. Global warming is considered as a global impact, reason for which the LCI result should be expressed in terms of carbon dioxide-equivalent ($CO_{2\text{-eq}}$), corresponding to the characterization factor of the category (ROSSI, 2013).

Ozone depletion

The impact category results in an increase in the amount of ultraviolet rays reaching the surface of the earth, caused by an increase in the concentration of certain gases in the ozone layer, derived from atmospheric emissions generated by human actions. The reduction of the ozone layer can lead to disease growth, ecosystem interferences, and damages to various types of materials. It is measured concerning the effect of 1 kg CFC-11 (IBICT, 2019).

Human toxicity

Specifically concerning human toxicity, the contribution of chemical substances caused by anthropic activities via human exposure to the environment is evaluated. Human toxicity is a category of regional/local impact; anthropic activities can emit substances that can negatively influence human health.

The characterization factor corresponds to the volume of the affected environmental compartment (air, water or soil) necessary to neutralize or dilute the toxic substance so that its effects do not harm men (WENZEL; HAUSCHILD; ALTING, 1997). It is expressed in comparative toxic units (CTU), providing an estimate of the increase in total human mortality per unit of mass of the chemical emission (cases/kg emitted) (MENDES; BUENO; OMETTO, 2016).

Ecotoxicity

Anthropic activities can emit chemicals that contribute to ecotoxicity if they alter the structure of ecosystems and cause toxic effects on living organisms. Ecotoxicity is a regional/local impact category and is inserted in the context due to the emission of substances such as hydrocarbons, metals, persistent organic pollutants (POPs), etc. (ROSSI, 2013).

It is expressed in comparative toxic units (CTU), providing an estimate of the potentially affected fraction (PAF) of species over time and volume per unit of mass of an emitted chemical (MENDES; BUENO; OMETTO, 2016).

Currently, ecotoxicity is represented only by the toxic effects on freshwater species in water columns. Impacts on other ecosystems, including sediments, are not reflected in current practice (EC; JRC; IES, 2012).

Acidification

When compounds can be emitted and converted into acids emitted into the atmosphere, due to the hydrological cycle, they can be deposited back into water and soil, causing pH reduction and favouring the acidification of the environment. Consequently, the disappearance of forests, decline of the fish population, corrosion of architectural monuments, among other results may occur (WENZEL; HAUSCHILD; ALTING, 1997).

Acidification is mainly caused by atmospheric emissions of NH_3, NO_2 and SOx (EC; JRC; IES, 2012). This category fits on the regional/local scale and is connected to the study by the potential acidification-generating compounds also resulting from incomplete burning of fossil fuels. The characterization factor makes up sulphur dioxide (SO_2) (ROSSI, 2013).

Nutrient enrichment

Eutrophication is the enrichment of nutrients in the water or soil, mainly by phosphorus and nitrogen compounds. It affects ecosystems, but mostly the aquatic environments, since the decrease of oxygen concentration in the waters, because of the decomposition of these nutrients may lead to the extinction of fish and other organisms. The characterization factor used in EDIP 1997 is kg of NO_3-eq (ROSSI, 2013).

Regarding terrestrial and marine aquatic eutrophication, only nitrogen concentration is the limiting factor. Concerning eutrophication in freshwater aquatic environments, the limiting factor considered is phosphorus (EC; JRC; IES, 2012).

Photochemical ozone formation

It occurs when solvents and other volatile organic components are emitted into the atmosphere and are usually degraded in a few days by oxidation. In the presence of nitrogen oxides (NOx), this reaction may result in the formation of ozone (O_3). This reaction is called photochemical ozone formation since it occurs with the aid of sunlight. O_3 is a beneficial gas in the stratosphere because it protects the Earth from ultraviolet (UV) radiation. However, in the troposphere, it can cause many problems to live beings (WENZEL; HAUSCHILD; ALTING, 1997).

This category of impact fits the regional/local scale was chosen because it results from the incomplete combustion of fossil fuels. The characterization factor makes up the Ethene (C2H2) equivalent, representing the potential for the photochemical ozone formation that would be caused by the Ethene. The EDIP method divides this category into two: High NOx and Low NOx. In this study, we adopted the values for the high NOx (ROSSI, 2013).

5.2.2. Product system

The product system to be analysed corresponds to Figure 49.

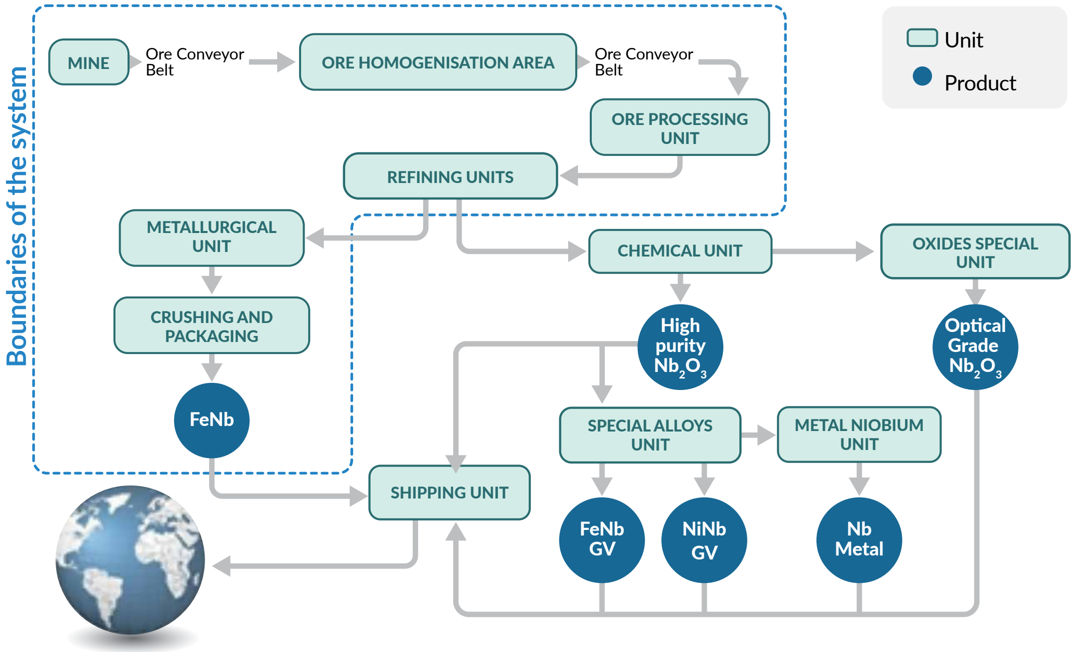

Figure 49. Product system.

Source: Adapted from Santos et. al. (2017).

Allocation

The allocation was avoided, mainly by using the process subdivision through technical criteria (mass).

Boundaries of the system

The product system limits permeate "from the cradle to the gate of the factory" or cradle-to-gate basis. Therefore, we considered the transport and production of raw materials needed for the company's internal processes.

Cut-off criteria

The cut-off criterion adopted was 1% by mass of each substance concerning the total inlet flow of each step. It is worth noting that, if the substance is considered environmentally overwhelming, it will be computed in the LCI, even if it does not fit into this cut-off criterion, referred by its mass.

Data requirements

The data to be analysed in this study were predominantly primary, obtained through the studied company. Secondary data were obtained through the Gabi, Ecoinvention and scientific articles databases (ALVES; COUTINHO, 2019; NUSS; ECKELMAN, 2014). It is worth noting that the company has not provided us with historical data due to confidentiality issues, so we could not make the recommendations described in the Qualidata guide (IBICT, 2017).

Representativeness of the data

Primary data geographical representativeness refers to the region of Minas Gerais, Brazil. Technological representativeness refers to the production process, which is commonly used in niobium mining facilities. Temporal representativeness identifies data assessed for 2017.

Regarding the secondary data, they vary in relation to the geographical representativeness, since national and international data are used. Technological and temporal representativeness may also vary.

Limitations

Due to the company's confidentiality policy, the data were aggregated into three processes. Moreover, no historical data sets were provided to us, but only data from 2017, so we could not follow the criteria in the Qualidata guide.

Critical analysis

The critical analysis could be performed by professionals from IBICT (Portuguese acronym for "Brazilian Institute of Information in Science and Technology").

Report type and format

The report was written in the classical format, detailed, and features specified text with Graphs, Charts, and Figures, and it is intended, preferably, for internal use.

5.3. Inventory

From January 14 to 18, 2019, we visited the niobium metallurgical and mining operational units of CBMM, in Araxá (MG) to collect the data for the inventory anticipated at previous steps. The visit consisted of meetings with the company's board and technical staff, as well as obtaining the data directly from their ore extraction, processing and shipment processes.

With this visit, we could elaborate the questionnaire to collect inventory data, which was formally submitted to the company's agent in charge on January 31st, 2019. The Quizzes for the mineral production and refining units can be seen in Appendix I and II.

On May 7, 2019, the company sent the answered Questionnaires to the research team. As of that date, we ran modelling using the Gabi Thinkstep, v.7.3.0.40, software, and the Gabi Database (v.6.115), as well as the Ecoinvention 3.3 databases (GABI, 2017) to accomplish the two last phases of the LCA, i.e., the LCIA, and interpretation. Below, we present the respective results and assessments.

5.4. Impact assessment

5.4.1. Modelling considerations

Mining site

The input data for the amount of "sterile+ore" mined at the mine were initially calculated using data from the literature (ALVES; COUTINHO, 2019). Using mass balance calculations for the specified functional unit, the total was of 45,487 tons. However, after contacting the company, that value was recalculated, thus totalling 51.07 t of ore/FeNb t, and 1.73 t of pyrochlore concentrates/t of FeNb.

Diesel consumption for bulldozers was another consideration. Primary data received indicated consumption of 0.136 kg of diesel/m^3 of material. The data used for the modelling based on the Gabi database used 0.173 kg of diesel/m^3 of material, figuring that they are given the same magnitude, thus justifying their use due to the greater detail of the processes.

The following parameters regarding the transport from the mining site to the beneficiation unit were used:

- Truck capacity: 20 m^3
- Distance travelled: 2 km
- Usage rate: 0.53 (FALTENBACHER; HENGSTLER, 2019)
- Euro 3 – Fleet: 2000 (FALTENBACHER; HENGSTLER, 2019)

Beneficiation Unit

For the new water consumed, we considered the total of 21,000 kg of water consumed/t of FeNb, as follows:

- 5,187 kg of drinking water.
- 5,859 kg of clarified water.
- 504 kg of demineralized water; and
- 9,450 kg of water without treatment.

As in the Gabi database, there was no distinction between drinking water and clarified water; these values were added (11,046 kg).

Besides, another important data used was the sum of the amount of amine with the surfactants, due to the limitations of the software to distinguish between them.

Some considerations for the transportation of inputs from the ore dressing unit:

- Truck capacity: 25 m^3
- Distance travelled: 450 km
- Usage rate: 0.55 (FALTENBACHER; HENGSTLER, 2019)
- Euro 3 – Fleet: 2000(FALTENBACHER; HENGSTLER, 2019)

Refining

Considerations on the transportation of inputs from refining (Table 15).

Table 15. Transport considerations.

Input	Truck capacity	Distance travelled	Usage rate	Fleet
FeSi	30 t	427 km	0.61	Euro 6 - 2013
Al	34 t	600 km	0.61	Euro 6 - 2013
CaO	20 t	217 km	0.53	Euro 3 - 2000
Sodium hydroxide	18 t	10 km	0.53	Euro 3 - 2000
LPG	15 t	350 km	0.53	Euro 3 - 2000
Coke	12 t	550 km	0.51	Euro 3 - 2000

Source: Adapted from Faltenbacher and Hengstler (2019).

Limitations

The following topics describe some of the limitations of the modelling:

- Due to confidentiality policies, we grouped the three main processes for modelling purposes (Figure 50). It is worth noting that the company's available data on power consumption are measured globally at the beneficiation plant. In other words, for the mining site, the individual processes include the excavation and the transport of the material. For the beneficiation unit, we included the data on homogenization, beneficiation (comminution, magnetic separation, flotation, thickening and filtration) and pumping. Refining was grouped into the following individual processes: Desulphurisation, dephosphorylation, metallurgy, crushing and shipping, including the production of inputs and transportation.

Figure 50. Individual processes grouped.

Source: elaborated in-house.

- We could not quantify the impacts of the transportation processes, as data are missing for the following items from the supply chains: refractories, flocculants, bentonite, charcoal, graphite, iron, fluorsilicic acid, amine and surfactants.
- The non-inclusion of their tailings dam's construction processes is evidence of high consumption of diesel, which the company addressed in their Sustainability Report. These processes can be configured as possible future work if all the construction aspects of the dam are quantified.
- The radionuclides figures from the production process were not informed by the company, which recorded that these elements are monitored by the National Nuclear Energy Commission, as per the protocols in force.
- Some data corresponding to the production of inputs and their transportation was not considered due to the limitations of the database used in the software.

5.5. Results

5.5.1. General

We calculated the impacts after modelling, as shown in Figure 51.

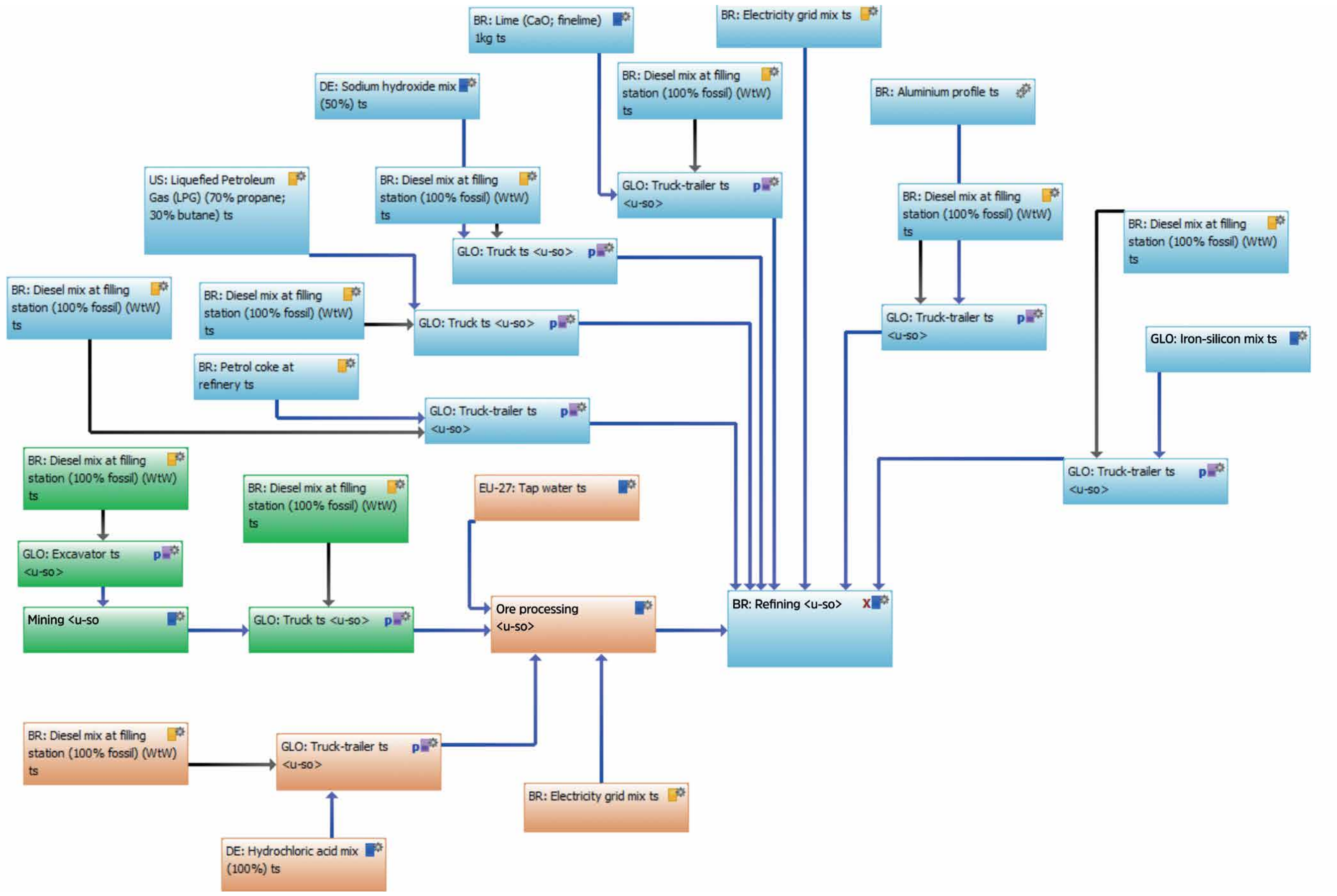

Figure 51. Modelling.

Source: elaborated in-house.

The calculated impacts can be seen in Figures 52, 53, 54, 55, 56, 57, 58, as well as in Table 16.

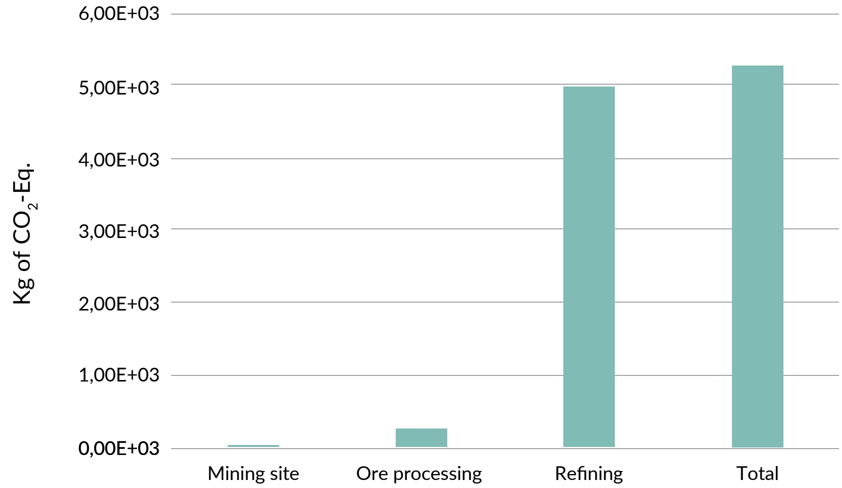

Figure 52. Climate change.

Source: elaborated in-house.

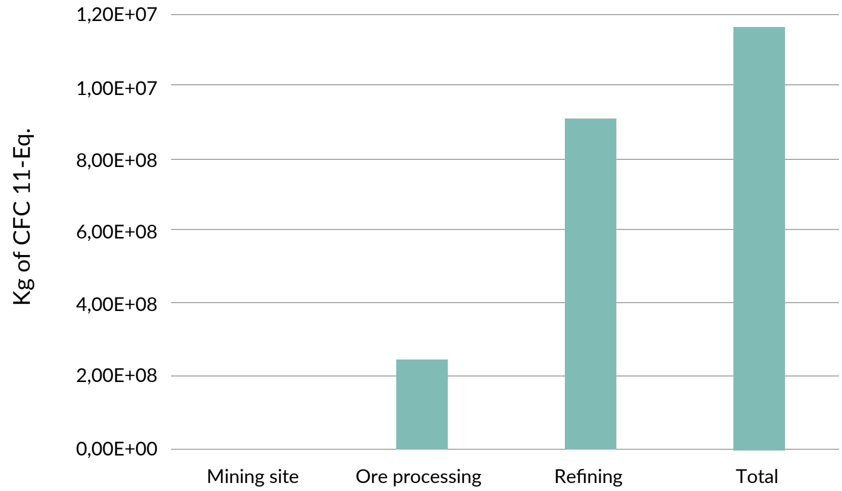

Figure 53. Ozone depletion.

Source: elaborated in-house.

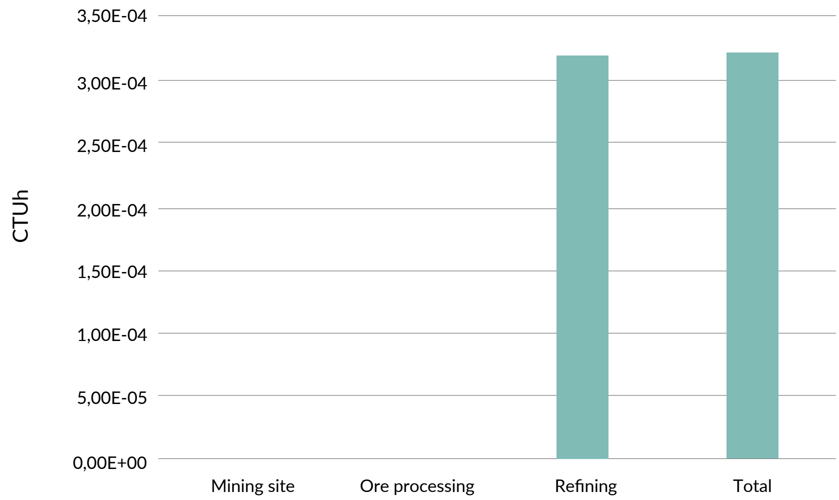

Figure 54. Human toxicity with carcinogenic effects.

Source: elaborated in-house.

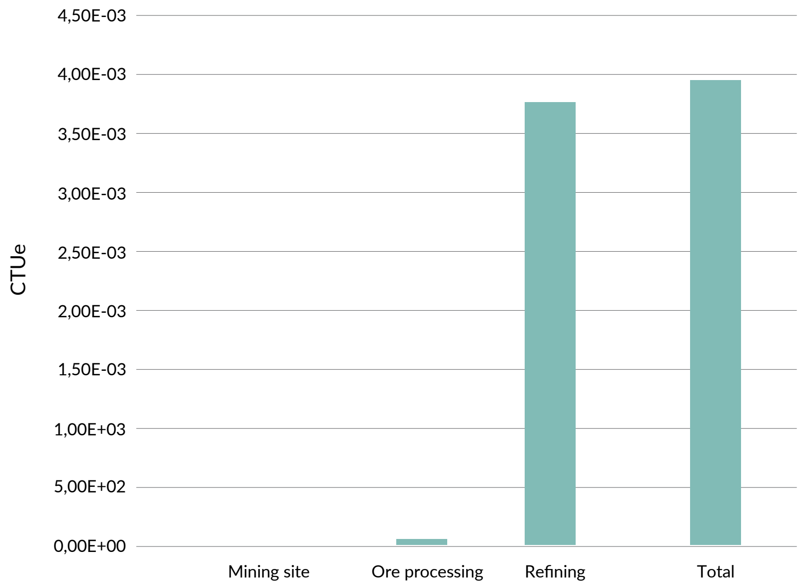

Figure 55. Ecotoxicity (freshwater).

Source: elaborated in-house.

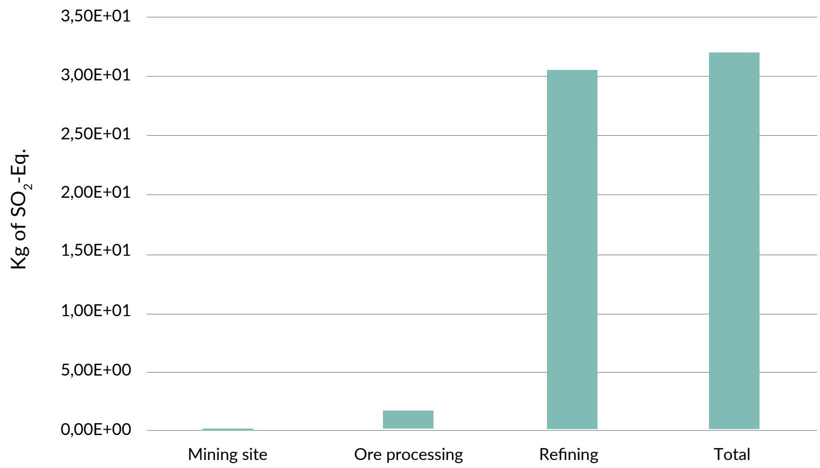

Figure 56. Acidification.

Source: elaborated in-house.

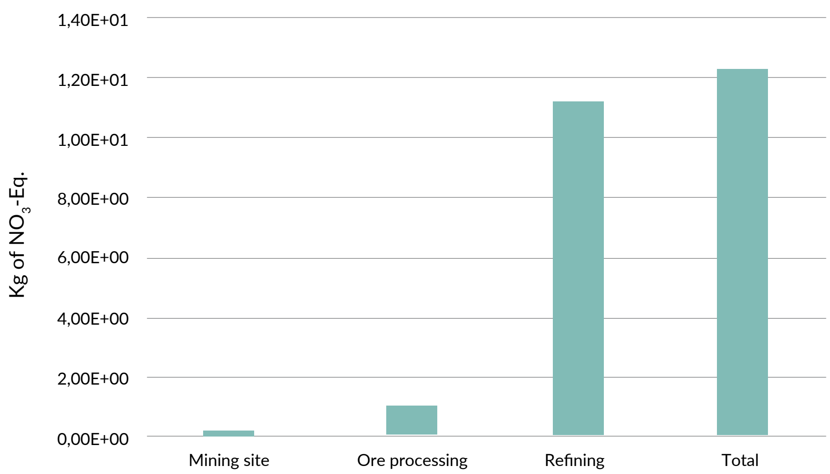

Figure 57. Eutrophication.

Source: elaborated in-house.

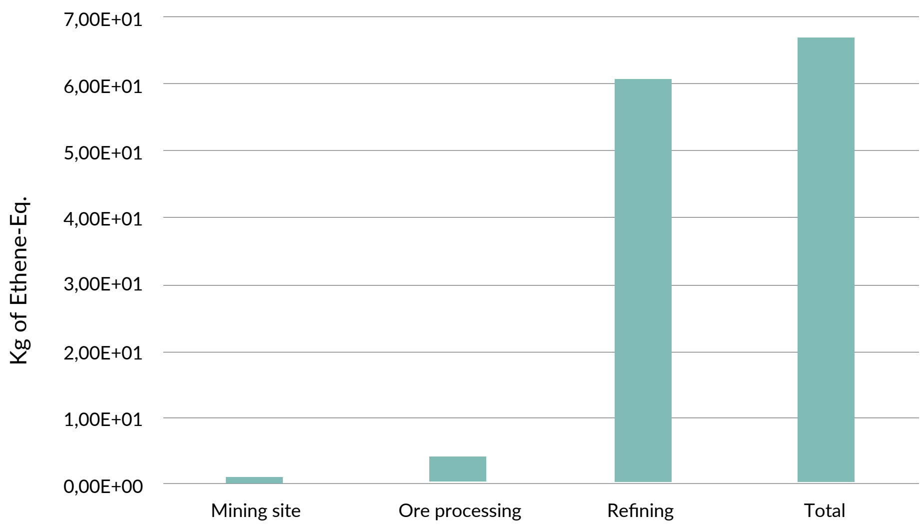

Figure 58. Photochemical ozone formation.

Source: elaborated in-house.

	Total	Unit
Climate change	5.32E+03	Kg of CO_2-Eq.
Ozone depletion	1.11E-07	Kg of CFC-11 eq
Human toxicity	3.21E-04	CTUh
Ecotoxicity (freshwater)	3.93E+03	CTUe
Acidification	3.22E+01	Kg of SO_2-Eq.
Nutrient enrichment	1.23E+01	Kg of NO_3-Eq.
Photochemical ozone formation	6.63E-01	Kg of Ethene-Eq.

Table 16. Calculated impacts.

Source: Elaborated in-house.

To detail the calculated impacts, we also analysed the data sources. Thus, Figure 59 shows the processes coming from primary (red) and secondary (blue) data.

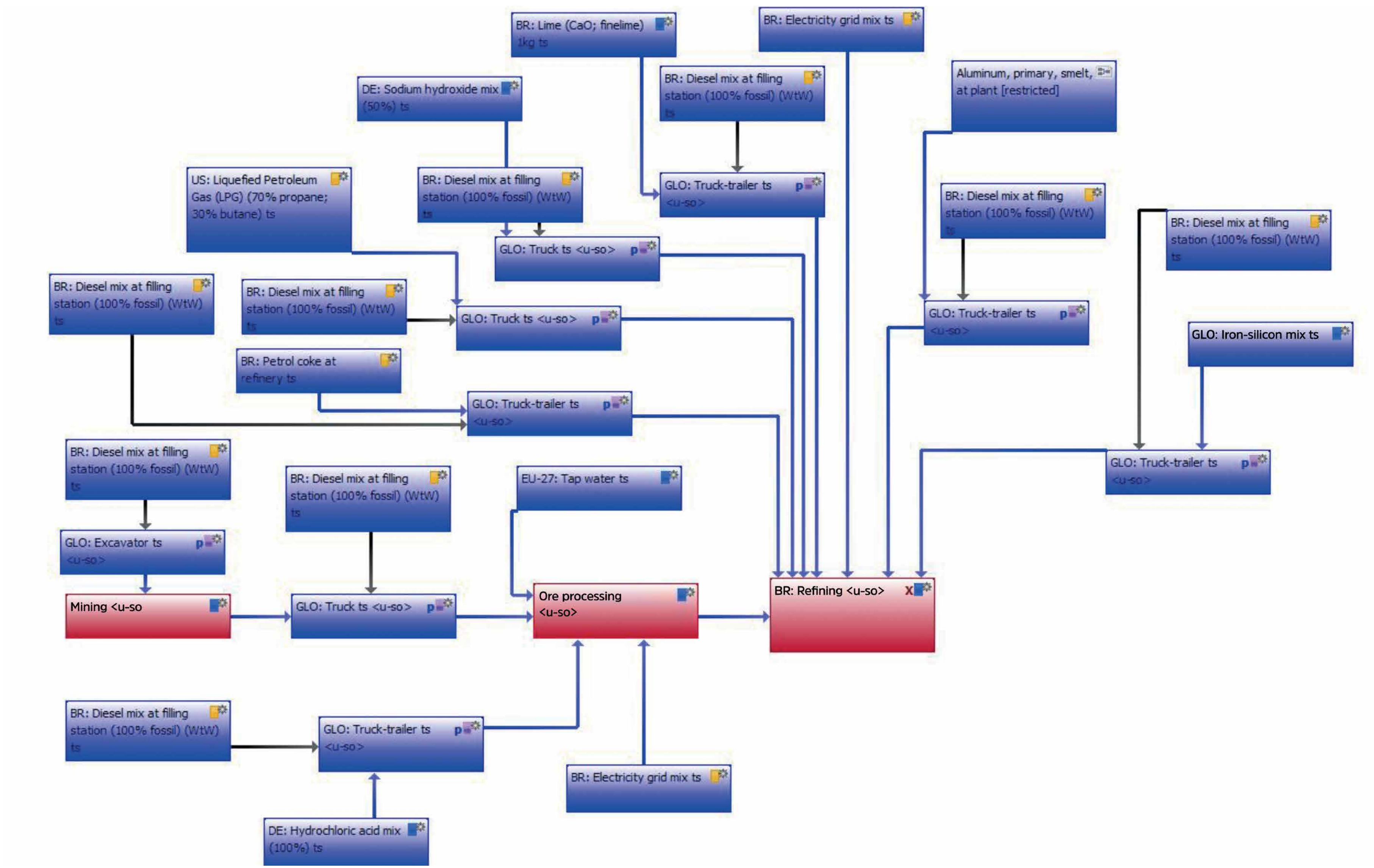

Figure 59. Data source.
Source: elaborated in-house

5.5.2. Details

Regarding input production processes, transportation, and production processes, the data can be seen in the following Figures and Table 17.

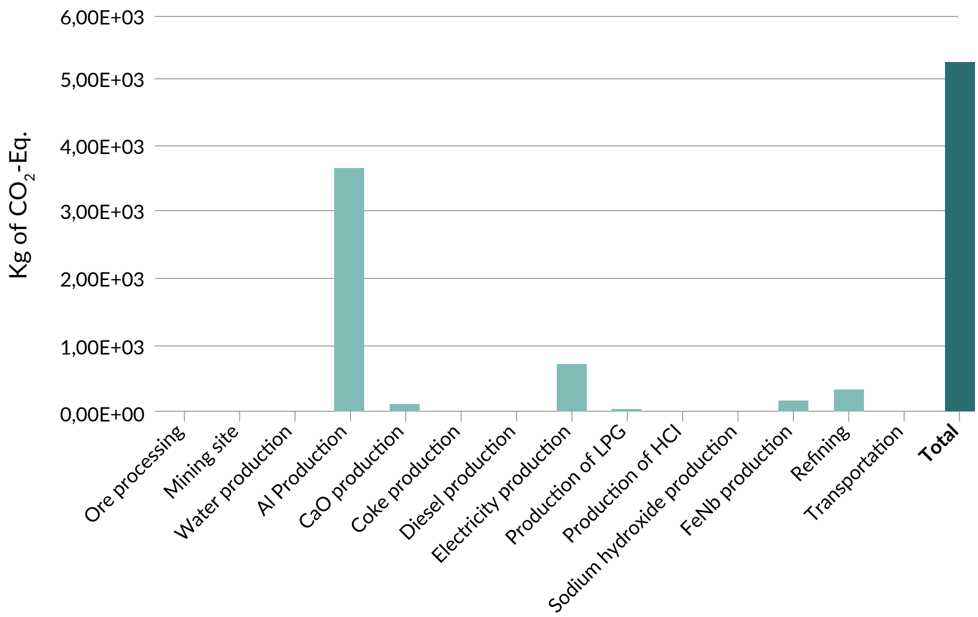

Figure 60. Climate change.

Source: elaborated in-house.

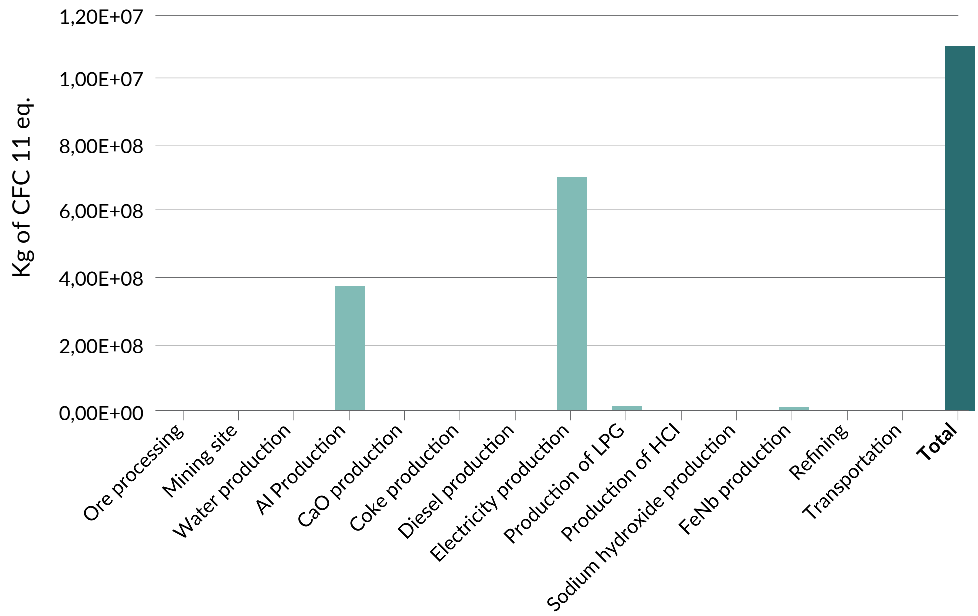

Figure 61. Ozone depletion.

Source: elaborated in-house.

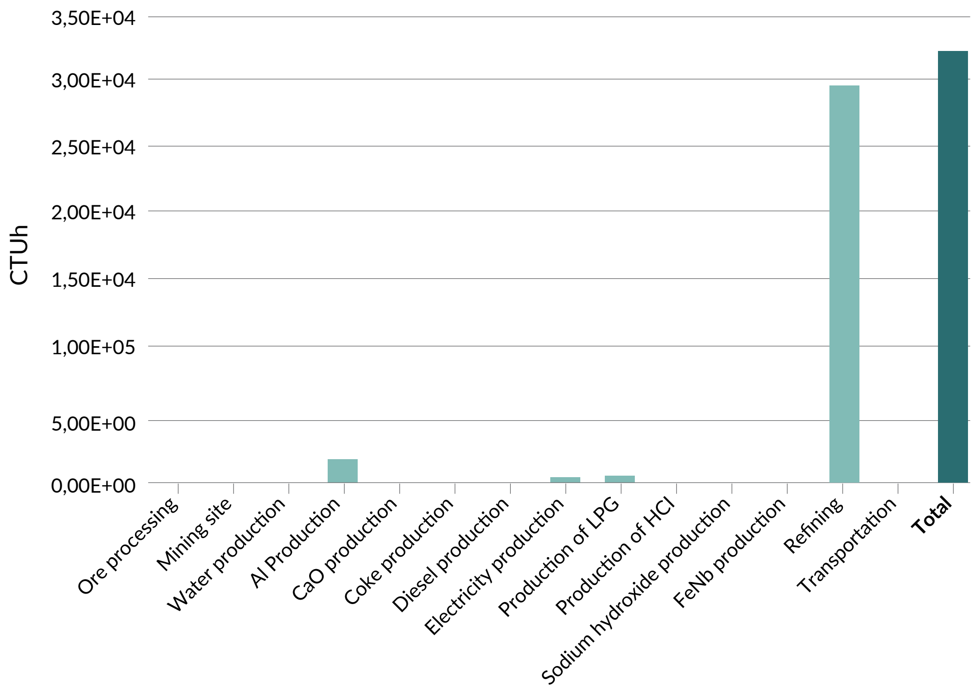

Figure 62. Human toxicity with carcinogenic effects.

Source: elaborated in-house.

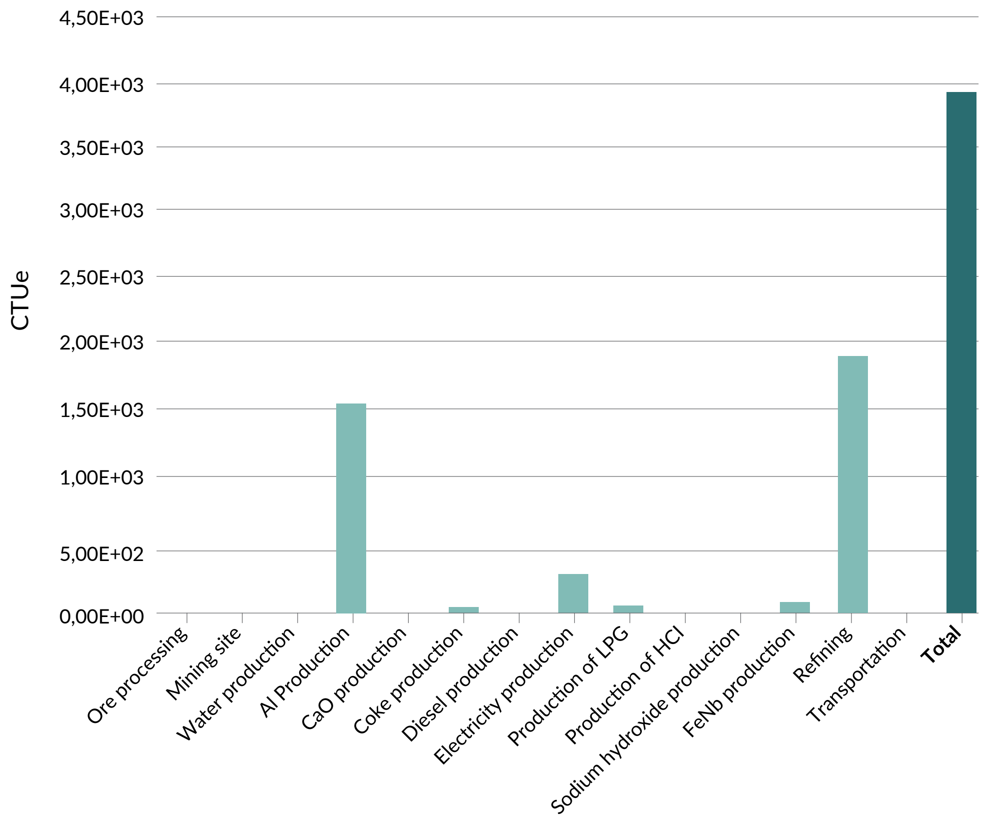

Figure 63. Ecotoxicity (freshwater).

Source: elaborated in-house.

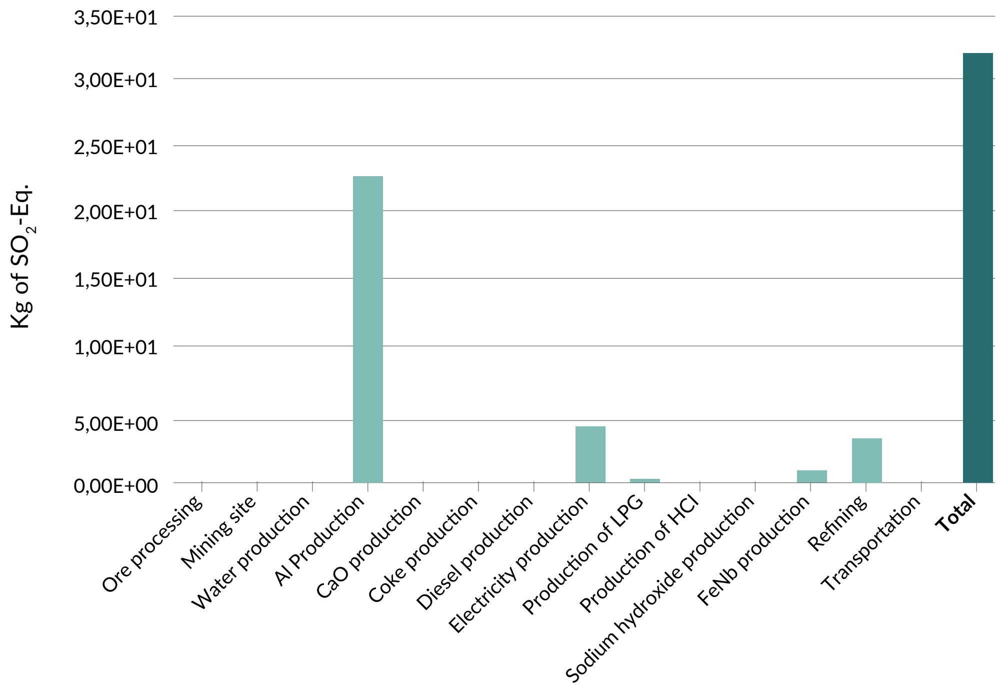

Figure 64. Acidification.

Source: elaborated in-house.

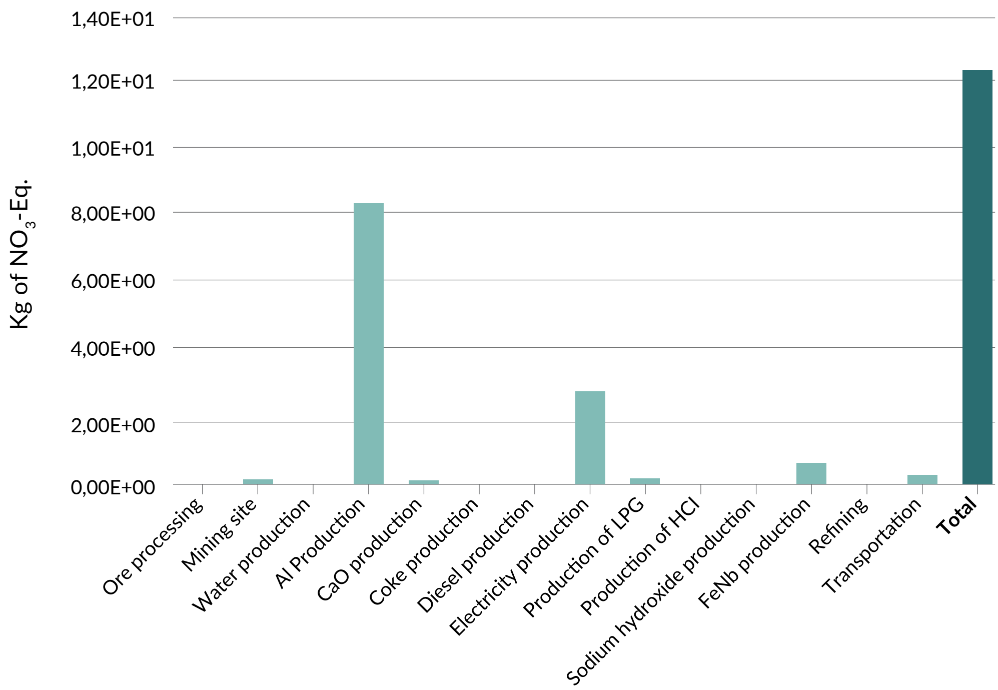

Figure 65. Eutrophication.

Source: elaborated in-house.

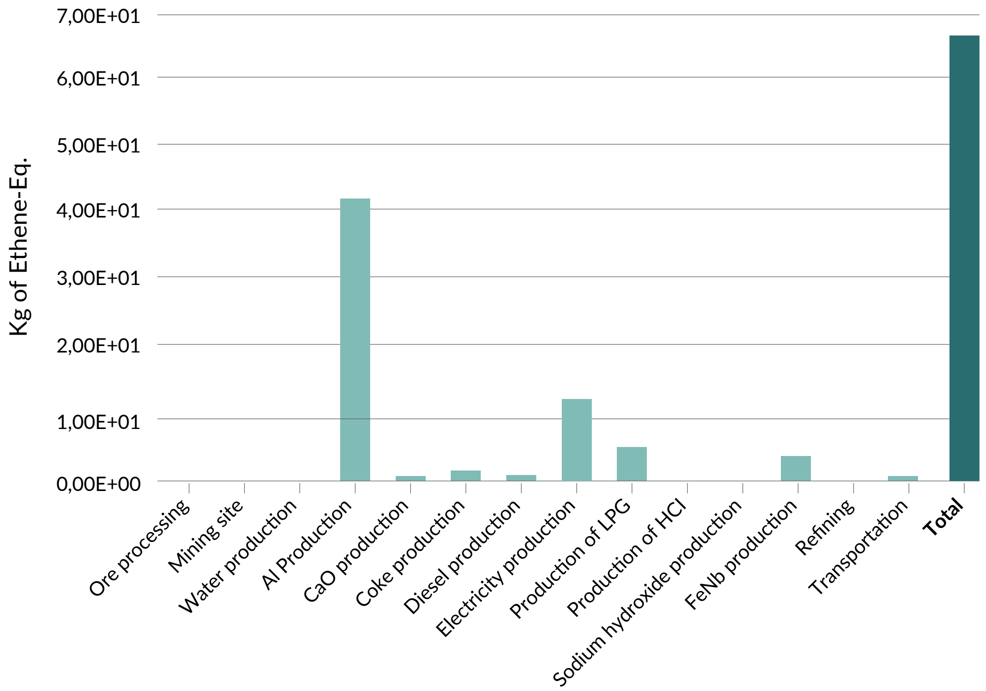

Figure 66. Photochemical ozone formation.

Source: elaborated in-house.

	Climate change	Ozone depletion	Human toxicity	Ecotoxicity (freshwater)	Acidification	Nutrient enrichment	Photochemical ozone formation
Beneficiation Unit	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Mining site	1,42E+01	0,00E+00	1,33E-12	7,44E-07	4,27E-02	8,05E-02	3,43E-03
Water production	6,31E+00	2,59E-10	3,42E-08	1,04E+00	1,21E-02	2,51E-02	7,68E-04
Production of AL	3,72E+03	3,75E-08	1,62E-05	1,57E+03	2,28E+01	8,33E+00	4,19E-01
CaO production	1,60E+02	1,46E-10	1,29E-07	1,63E+00	6,68E-02	8,75E-02	4,84E-03
Coke production	1,53E+01	4,41E-11	1,50E-06	2,99E+01	1,20E-01	3,83E-02	1,25E-02
Diesel production	6,62E+00	8,05E-11	8,44E-07	1,63E+01	5,11E-02	2,54E-02	7,63E-03
Electricity production	7,67E+02	7,09E-08	2,31E-06	2,73E+02	4,34E+00	2,72E+00	1,21E-01
Production of LPG	3,90E+01	1,16E-09	3,00E-06	4,98E+01	2,27E-01	1,40E-01	4,97E-02
Production of HCl	1,15E+01	2,72E-10	9,29E-08	1,20E+00	2,55E-02	2,88E-02	3,02E-03
Sodium hydroxide production	1,88E+00	9,18E-11	2,10E-09	6,43E-02	6,12E-03	5,98E-03	2,44E-04
FeSI production	1,92E+02	6,20E-10	9,23E-07	5,80E+01	9,36E-01	5,91E-01	3,68E-02
Refining	3,62E+02	0,00E+00	2,96E-04	1,92E+03	3,40E+00	0,00E+00	0,00E+00
Transportation	2,96E+01	0,00E+00	2,84E-11	6,11E-06	1,34E-01	2,61E-01	3,93E-03
Total	5,32E+03	1,11E-07	3,21E-04	3,93E+03	3,22E+01	1,23E+01	6,63E-01
Measurement unit	Kg of CO_2-Eq.	Kg of CFC-11 eq	CTUh	CTUe	Kg of SO_2-Eq.	Kg of NO_3-Eq.	Kg of Ethene-Eq.

Table 17. Detail of the calculated impacts.

Source: elaborated in-house.

Some data found in the literature can be compared to those found in this study (See Table 18).

Table 18. Comparison of results.

Category	Calculated data	Literature data	Source
Climate change (kg of $CO_{2\ eq}$/t FeNb)	5,322.53[10]	1,126,6	(CBMM, 2017)
Climate change (kg of $CO_{2\ eq}$/t of FeNb)	5,322.53[11]	12,500.00*	(NUSS; ECKELMAN, 2014)
Acidification (kg of $SO_{2\ eq}$/t of FeNb)	32.16	53.00	(NUSS; ECKELMAN, 2014)
Human toxicity (CTUh/t of FeNb)	0.00032	0.0064**	(NUSS; ECKELMAN, 2014)

** The authors consider the production of niobium*

*** The authors consider the toxicity of non-carcinogenic*

Source: elaborated in-house.

5.5.3. Hotspots

The Hotspots refer to the highlights in the life cycle studied, that is, the main environmental aspects[12] and impacts[13], and the most important elementary processes[14] in the study conducted (EUROPEAN COMMISSION, 2010). Table 19 illustrates the main hotspots of the study.

Table 19. List of environmental hotspots.

Impact category	Aspect	Elementary process
Human toxicity with car-cinogenic effects	Air pollutant emissions (volatilised lead)[15]	Refining
Climate change	Air pollutant emissions (carbon dioxide)	Input production (alumini-um) for refining
Acidification	Air pollutant emissions (sulphur dioxide)	Input production (alumini-um) for refining
Ecotoxicity (freshwater)	Air pollutant emissions (volatilised lead)	Refining[16]
Nutrient enrichment	Air pollutant emissions (nitrogen oxide)	Input production (alumini-um) for refining
Photochemical ozone for-mation	Air pollutant emissions (a group of Non-methane volatile organic com-pounds (NMVOCs))	Input production (alumini-um) for refining
Ozone depletion	Air pollutant emissions (Di-chlorotetrafluoroethane)	Electrical power genera-tion

Source: elaborated in-house.

10 It is worth adding that this figure was underestimated due to the limitations of this study, as mentioned earlier, namely: Lack of data on the transportation processes of some inputs, and the non-inclusion of their tailings dam's construction processes (high consumption of diesel was not computed).

11 Same as in note 6.

12 Aspect refers to "element of an organisation's activities, products or services, which may interact with the environment." (ABNT, 2009a)

13 Environmental impact refers to "any changes to the environment – adverse or beneficial – partly or totally resulting from the environmental aspects of the organization" (ABNT, 2009a).

14 Elementary process refers to "the smallest element considered in the assessment of the life cycle inventory for which input and output data are quantified" (ABNT, 2009a).

15 It is worth noting that the company runs mitigating measures to control these emissions.

16 Same as in note 12.

5.6. Interpretation

The objectives of this study were achieved i.e., quantifying the environmental impacts of the initial phases of the ferroniobium life cycle, indicating the hotspots, as follows: Human toxicity with carcinogenic effects in refining (emissions of volatilised lead into the air), and Climate change (Emissions of carbon dioxide into the air) for the production of input (aluminium) and refining. These results indicate the points of the processes that may require interventions to mitigate environmental impacts. It should be noted that CBMM has lead emissions capture systems in place that capable of reducing those emissions to much lower levels than those established by the current standards.

Besides, this phase permeated the entire study, which was essential, being characterized by the completeness, sensitivity and consistency checks. Together with the previous ones, it allowed the final considerations of the study, and the recommendations for future studies resulted consistently with the objectives proposed. According to ABNT (2009b), the completeness check "seeks to ensure that all relevant information and necessary data for interpretation are available and complete". Therefore, this information can be an empirical value to ensure that no important information has been forgotten. The standard suggests using checklists to assess whether all inventory parameters, such as emissions, energy, resources, waste, etc., have been met.

The sensitivity check seeks to "evaluate the reliability of the final results and conclusions, determined how they are affected by data uncertainties, allocation methods or calculation of the results of the category indicators" (ABNT, 2009b). Therefore, this analysis can be highly considered in the cut-off criterion used and could influence the adopted parameters. Consistency check seeks to "determine whether the assumptions, methods, and data are consistent with the purpose and scope."

Using the Recipe 2008 method (GOEDKOOP et al., 2009) to compare results, we developed the following analysis, as can be seen in Table 20, below. It is noted that the matching value was greater than 89%.

Table 20. Sensitivity analysis of the data found.

	Scenario I	Total value	Measurement unit	Correspondence
ILCD	Climate change	5.32E+03	Kg of CO_2-Eq.	97.26%
EDIP	Acidification	3.22E+01	Kg of SO_2-Eq.	89.44%
ILCD	Ozone depletion	1.11E-07	Kg of CFC-11 Eq	100.00%
	Scenario II.	**Total value**	**Measurement unit**	
RECIPE	Climate change	5.47E+03	Kg of CO_2-Eq.	
RECIPE	Acidification	2.88E+01	Kg of SO_2-Eq	
RECIPE	Ozone depletion	1.11E-07	Kg of CFC-11 Eq	

Source: elaboração própria.

In this study, the Completeness Check focused on verifying the compliance with all aspects of the inventory made available. It was not possible to run a Sensitivity Check, since there were no scenarios to compare against, but this could be run in future works, along with statistical analysis. The Consistency Check indicated that there were no impact data for 12 entries due to the lack of information in the software database information. For future studies, it is recommended to assess the scenarios in which ferroniobium is used in products, e.g., steels, as well as to investigate the possibilities for improvements to critical processes (refining).

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6.

Report on Social Life Cycle Assessment of Niobium

MARZIA TRAVERSO
LIGIA MARCELA ALVARADO

6.1. Introduction

The project started in January 2018 with the presentation of goal and scope from JRC and CETEM. The focus is one of the critical raw materials, Niobium, identified by the European Commission. To identify Raw Materials critical to the European Union, the EU published a methodology on defining critical raw materials in 2010 and identified 14 materials as critical. In 2014 the list of candidate materials was widened and let to 20 materials considered as critical. In a revised methodology of 2017, 27 out of 78 raw materials assessed were considered as critical. Influencing parameters in the definition of Critical Raw Materials are, for example:

- Herfindahl-Hirschmann Index (HHI)
- World Governance Index (WGI)
- Import Rate
- Substitutability
- Recycling

The main parameters used to determine the criticality of the material for the EU are:

- Economic importance - aims at providing insight into the importance of material for the EU economy in terms of end-use applications and the value-added (VA) of corresponding EU manufacturing sectors at the NACE Rev.2 (2-digit level). The economic importance is corrected by the substitution index (SIEI) related to technical and cost performance of the substitutes for individual applications.
- Supply risk - reflects the risk of a disruption in the EU supply of the material. It is based on the concentration of primary supply from raw materials producing countries, considering their governance performance and trade aspects.

Brazil produces more than 90 % of global Niobium. Seventy-one per cent (71%) of European Niobium imports are coming from Brazil. EU almost entirely relies on imports from one single country (Brazil). Substitution materials are not economically feasible yet. Consideration of Niobium's mining, production and recycling is of concern, especially in a circular economy context.

For all those reasons, a life cycle assessment and social life cycle assessment of Niobium have been funded by the EU - Brazil Sectoral Dialogues Program in this project.

Social Life cycle assessment is a relatively new methodology since the first guidelines were published in 2009 by the UNEP/SETAC Life cycle initiative and in 2013 the related Methodological Sheets were developed and implemented in several case studies in the last ten years. It is particularly important to assess the positive and negative impact of a product along its life cycle.

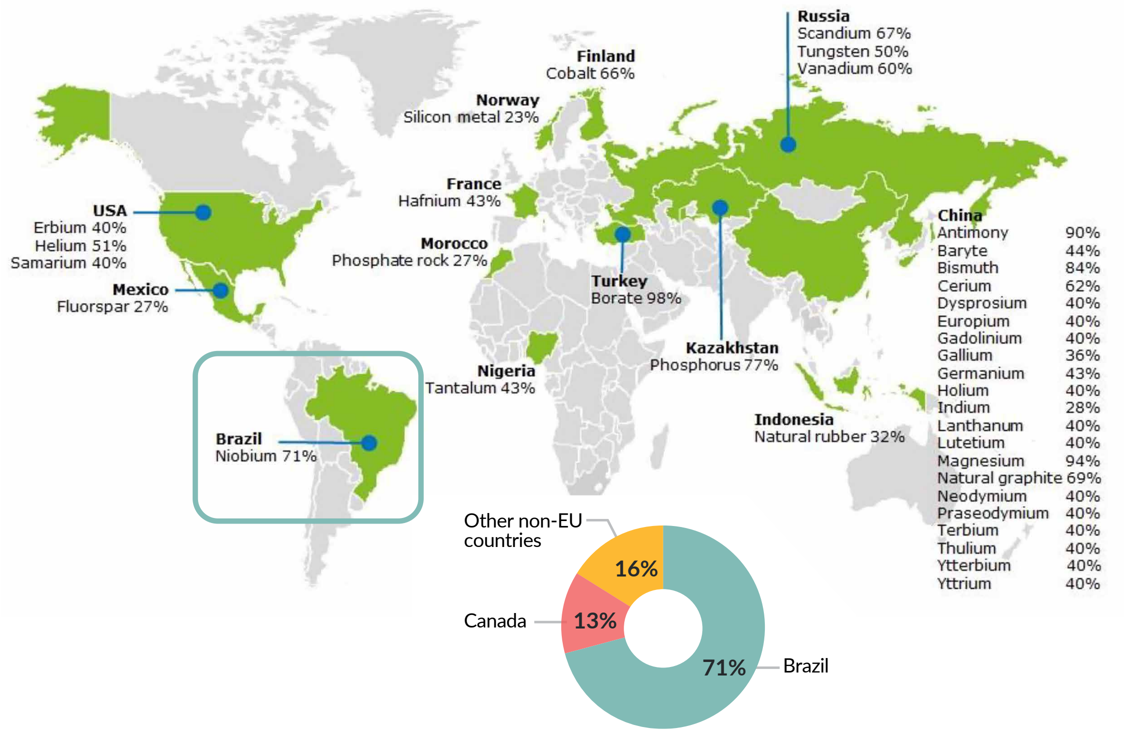

Figure 35. Critical raw material and their production sites.

Source: USGS (2018).

Niobium is mainly produced in Brazil (at least the European Niobium) and predominantly by one company CBMM. The company must be involved in collecting the inventory data to have primary data on the environmental and social impacts of the Niobium. The goal of the project is assessing the social and environmental impacts of this product in a circular economy perspective. A set of social and environmental indicators will be developed, and the relative inventory data collected. Limits and benefits of the methodology implementation will be identified and analysed.

The project started officially at the end of January 2018 and in June 2019 the second and main phase of the project was concluded with a final meeting in Rio de Janeiro at CETEM to present the LCA, and S-LCA resulted in June 2019. An overview of the S-LCA method will be given, and the Type 1 methodology used to assess the results will be shortly explained to help the reader to understand the obtained results better. The focus of this report is the case study and with the description of the data collection, assessment results and conclusion. With this report, activity 2 reported in the ToR of the External Senior Expert is presented.

6.1.1. Social Life cycle assessment methodology – an overview.

The social life cycle assessment (S-LCA) has been defined several years ago, and one of the first definition was given in 1996 from O'Brian M, Doig A, Clift R (1996) (KLÖPFFER, 2008). Other milestones to define S-LCA for a product and as the third pillar of life cycle sustainability assessment are the publications from Klöpffer and Finkbeiner et al. (FINKBEINER et al., 2010; KLÖPFFER, 2008). In those publications, the S-LCA is defined as a complementary approach of LCA and Life Cycle Costing to assess the social impacts of a product along its life cycle. It should be done by considering the same functional unit and an equivalent system boundary at it is also reported in the publication from UNEP (UNEP/SETAC Life Cycle Initiative, 2011).

The publication of the guideline for Social Life cycle assessment of products from UNEP in 2009 (UNEP/SETAC, 2009) represents the first handbook to introduce the methodology and its historical background to a broader audience. As we mentioned, the S-LCA has been developed as a complementary approach of the environmental Life cycle assessment (LCA). Because this has been already standardized since 2006 (ISO 14040: 2006), the same framework reported for the LCA has been used to define the S-LCA: goal and scope, life cycle inventory, life cycle impact assessment, interpretation. Even if the same framework was used to present the S-LCA, important differences could be identified between the two methodologies, such as:

- Definition of stakeholder categories, the results of S-LCA depend on the stakeholder category chosen.
- Assessment of positive and negative impacts
- Strongly dependency of the Impacts on the local conditions and company behaviour not on the production process.

According to the current literature two main references have been used to assess the social impacts of Niobium: the already mentioned guidelines for Social Life Cycle Assessment of a product (UNEP, 2009) and the Handbook of Product Social Impact Assessment (PSIA) (FONTES, 2016; FONTES et al., 2018). The two approaches described in the two references are quite similar and consistent with each other, and both consider among the stakeholder categories (or Groups): workers and local communities.

The Handbook of Product Social Impact Assessment (PSIA) was developed and published by the Roundtable of Product Social Metrics. This initiative had as main goal the development of a qualitative and quantitative methodology to assess the social impact of a product. They started from the scientific references already available and selected a certain number of topics. Then those topics have been matched against the company strategies and priorities. This approach led to the identification of a certain number of issues, called impact categories and related indicators. The Handbook of PSIA defines which indicators should be considered for each impact categories and in its Version 3 reports a quantitative and qualitative approach to assess the social impact of a product.

For the assessment, both guidelines were used UNEP 2009 and Handbook of PSIA (FONTES et al., 2018; TRAVERSO et al., 2018) and a life cycle inventory for both qualitative and quantitative assessment was collected. Because the UNEP guidelines were considered very theoretical a compendium document, called the Methodological Sheet, was necessary, and it was published in 2013 (BENOIT-NORRIS, 2013; BENOÎT-NORRIS et al., 2011). This is called Methodological Sheets and present and describe in details each impact subcategories giving: definition, political context and relation with sustainable development, and generic and specific data sources. A list of subcategories considered in the UNEP guidelines and the Methodological Sheets are reported in Table 21.

Table 21. Stakeholder categories and impact subcategories.

"Workers"	"Local community"	Value chain actors (not including consumers)
1. Freedom of Association and Collective Bargaining 2. Child Labour 3. Fair Salary 4. Working Hours 5. Forced Labour 6. Equal opportunities/ Discrimination 7. Health and Safety 8. Social Benefits/ Social Security	14. Access to material resources 15. Access to immaterial resources 16. Delocalization and Migration 17. Cultural Heritage 18. Safe & healthy living conditions 19. Respect of indigenous rights 20. Community engagement 21. Local employment 22. Secure living conditions	28. Fair competition 29. Promoting social responsibility 30. Supplier relationships 31. Respect of intellectual property rights
"Consumer"	**"Society"**	
9. Health & Safety 10. Feedback Mechanism 11. Consumer Privacy 12. Transparency 13. End of Life responsibility	23. Public commitments to sustainability issues 24. Contribution to economic development 25. Prevention & mitigation of armed conflicts 26. Technology development 27. Corruption	

Source: UNEP (2009).

In the Handbook of PSIA, three of the five stakeholder categories (called the group in the Handbook) have been considered: workers, local communities, users and in the small--scale entrepreneurs that have been added in the Version 2018 of the Handbook. In Table 22 are reported the relative impact categories as well.

Table 22. Stakeholders categories from the Handbook of PSIA.

1 - Workers	3 - Local communities
1. Health and Safety 2. Remuneration 3. Child Labour 4. Forced Labour 5. Discrimination 6. Freedom of Association and Coll. Bargaining 7. Work-life balance	1. Health and Safety 2. Access to tangible resources 3. Community engagement 4. Employment
2 - Users	**4 - Small-scale entrepreneurs**
1. Health 2. Product safety 3. Responsible communication Privacy 4. Inclusiveness 5. Effectiveness and comfort	1. Meeting basic needs 2. Access to services and inputs 3. Women's empowerment 4. Child Labour 5. Health and Safety 6. Land rights 7. Trading relationships

Source: UNEP (2009).

As we can see, by comparing Table 21 and 22 for workers and the local community, several topics in the two documents are the same or at least equivalent. Those similar are reported in bold in Figure 68.

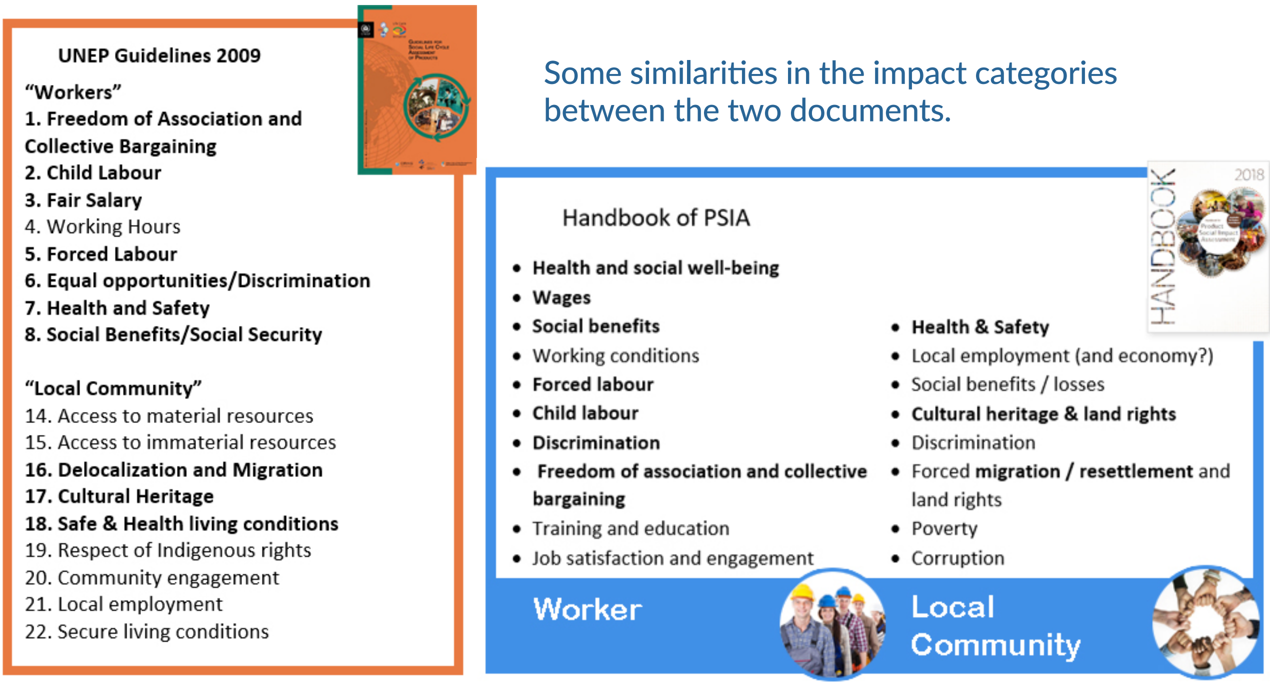

Figure 68. A comparison between the impact categories considered in the UNEP guidelines and the handbook of PSIA.

Source: UNEP (2009).

To develop a Social Life Cycle Impact Assessment and the interpretation of its results two main methodologies will be used which are both defined as type 1 approach according to the UNEP Guidelines: Subcategory Assessment Method (SAM) (KARINA et al., 2014) and the Product Social Impact Assessment (FONTES et al., 2018). For both methodologies evaluating the results according to type 1 means that the impacts are reported in terms of performance points. Performance points are defined according to reference values.

In our assessment, both guidelines and approaches have been implemented to assess Niobium production in the CBMM Company in Brazil.

The focus in our implementation was to assess the impact of workers and local communities, which are considered the most relevant stakeholder categories in this case study.

The assessment allows the identification of the main positive and negative impacts produced by the product and the company to the workers and the local community. It is the first implementation to a critical raw material and one of the first implementations in general with primary data. The audience is mainly the CBMM company and the project partners with the possibility to develop a publication for an external audience.

The case study showed that the implementation is possible and that often the data are already collected by the company at the corporate level for developing the sustainability report and as well as monitoring the satisfaction and workers conditions. Those data are usually managed by the Human resources department and not from the department for developing a new product or for environmental protection. Furthermore, the agent responsible for those data in the resources department often is not an LCA practitioner, and it makes the collection of the data more complex pushing towards further guidelines to clarify each step.

6.2. CBMM and Minas Gerais

A privately-held Brazilian company, CBMM (Companhia Brasileira de Metalurgia e Mineração) was founded in 1955 in Araxá, Minas Gerais, Brazil, site of a large ferroniobium ore deposit. Decades of investment in Niobium technology, Niobium applications and customer service have earned CBMM the position of the world's leading Niobium producer and the sole company present in all Niobium market segments.

CBMM counts on a team of over 1,971 trained (year 2018), dedicated professionals who are committed to providing cutting-edge Niobium products and technology to over 300 customers in 50 countries around the globe. CBMM is the main supplier of European and world niobium.

A commitment to the environment, employees and the community that dates to the Company's earliest days has solidified CBMM's reputation as a sustainable enterprise. In addition to numerous certifications and honours, including the first mining and metallurgy company in the world to earn ISO 14001 certification, CBMM's mission is sustainable: expand the use of Niobium technology, transforming a natural resource into solutions to build a better world.

The Moreira Salles Group has been the majority shareholder of CBMM since 1965. Between 2002 and 2006 the Group increased its ownership from 55% to 100% through successive purchases of minority shareholder Molycorp's stake in the Company. In 2011 a 15% share of CBMM was sold to a Japanese-South Korean consortium, and a group of Chinese companies acquired another 15% stake.

An agreement signed in 1972 between CBMM and Minas Gerais state-owned COMIG (now Codemig) disciplines the best use of Araxá's Niobium deposit. It ensures to Codemig a 25% participation of the adjusted net profit of the entire Niobium operation.

Figure 69. Mining site of CBMM Plant.

Source: CBMM (2018).

When it was founded in the 1950s, the Niobium market was not relevant, and the know-how to produce it was very low. Today, CBMM reached a very high technological and know-how level and is the only company present in all market segments, supplying 100% of Brazil's needs and nearly 75% of the global demand for Niobium products in 2017. Moreover, CBMM developed the uses of Niobium and created the market through the implementation of a Niobium technology development program that promotes Niobium's efficiencies, demonstrating the advantages that make Niobium a unique addition in its main applications. Today, the company's main product – ferroniobium – is used primarily to manufacture high strength micro-alloyed steels, stainless steels and heat resistant steels. Among the final products using Niobium steels are in pipelines, automobile bodies and structural components. Currently, Niobium, in the form of ferroniobium, is used in approximately 10% of steels produced worldwide.

Figure 70. Use of Niobium Steel in Automotive Industry.

Source: CBMM (2018).

The economy of Minas Gerais is mainly based on the production and export of Non-agglomerate Iron Minerals, Ferroniobium and agricultural products such as coffee and cane sugars.

Table 23. Minas Gerais Main Export Products – 2017.

Minas Gerais Main Export Products – 2017 (US$ millions)			
RANK	Export Products	TOTAL	Percentage
1st	Non-agglomerated Iron Minerals and their concentrates	8,281	32.67
2nd	Coffee, Not Roasted, Not Decaffeinated, In Grain	3,438	13.56
3rd	Ferroniobium	1,342	5.29
4th	Other Cane Sugars	1,198	4.73
5th	Soybeans, Whether or not Grounded, Except for sowing	990	3.91
6th	Gold in bars, Solid Section Wires and Profiles	820	3.23
7th	Chemical Pulp of Wood, not coniferous, Soda or Sulphate, Bleached or Semi Bleached	630	2.49
8th	Frozen Boneless Cattle Meat	498	1.96
9th	Raw Cast Iron Not Alloyed, Weight <=0.5% of Phosphorus	471	1.86
10th	Agglomerated Iron Ore for Pelletizing Process	399	1.57
	Other products	**7,283**	**28.73**
	Minas Gerais Total	**25,350**	**100.00**

Source: MDIC.

The unemployment rate is still high (12,6%) but lower than the Brazilian average 13.1%.

Table 24. Minas Gerais economy – some figures (2017).

Minas Gerais Economy	
Nominal GDP (2017)	US$ 179.3 billion (8,7% of Brazil's GDP)
GDP Per Capita (2017)	US$ 8,488
Formal Employment (2016)	4.6 million
Monthly Average Salary (2018)	US$ 598 (Brazil: US$ 678)
Economically Active Population (2018)	11.2 million people
Unemployment rate (2018)	12,6% (Brazil: 13,1%)

Source: IBGE (PNAD) / João Pinheiro Foundation (FJP).

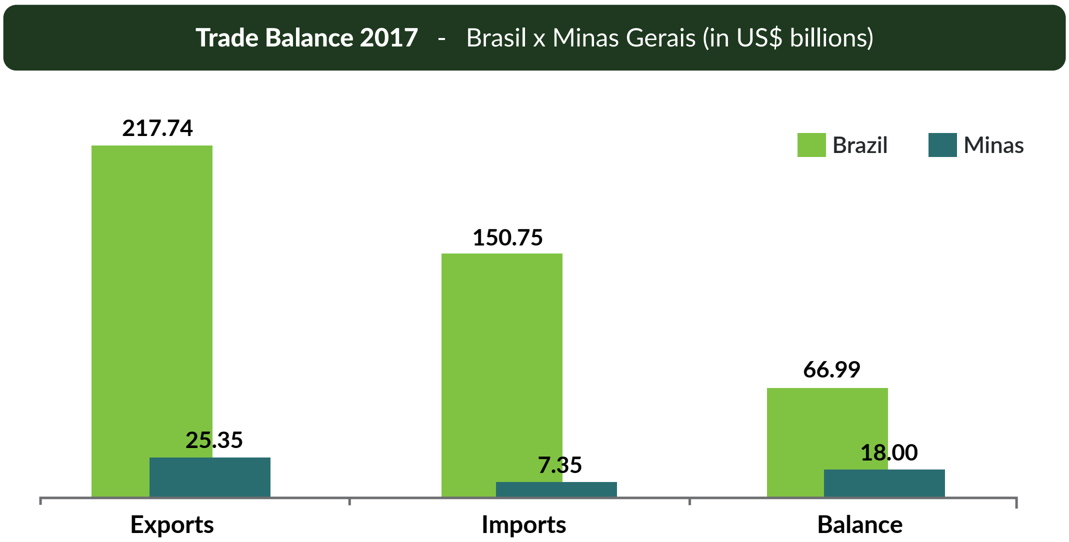

Figure 39. Minas Gerais Economy – Trade Balance (2017).

Source: MDIC.

How it can be seen from those data, the economy of Minas Gerais can represent the average Brazil conditions and the production of Niobium, as well as other Minerals, represent an important economic sector.

6.3. Social Life Cycle Assessment: step-by-step

6.3.1. Goal, scope and system boundary

As it was mentioned before, the main goal of this project is an assessment of positive and negative social impacts of Niobium from the extraction of raw material to manufacture to present the results to the company managers and eventually identify further potential improvements. The approach is a cradle to gate with some consideration on the production of steel alloys and the relative end of life/ recycling phase. The methodology used is the Social LCA Type 1, where the life cycle inventory is based on quantitative and semi-quantitative data, and the social life cycle impact assessment results are reported performance reference points. Because the S-LCA is for the first time applied to a critical raw material and for the first time to CBMM product, it is important to understand not only the current positive and negative impacts but also those topics which could be further improved and those where the company has already the best performance.

Generally, the S-LCA, as well as environmental LCA, aims to support decision-making process towards more sustainable production, that is the reason why it is particularly important to identify those aspects which have not met the best performance yet, considering that the data reported refer to 2017 inventory.

As shown in the first chapter, Niobium has been listed as one of the European critical raw material, because its production, 71% of it, is produced in Brazil. The main producer company is Companhia Brasileira de Metalurgia e Mineração (CBMM). The company, as we described in the first activity project report, has been involved in the project and accept to deliver our data to assess the environmental and social performance of their niobium production. The focus of this part of the report is on social impacts. Still, because it must be integrated into the environmental Life Cycle Assessment, the same or equivalent system boundary has to be considered as well as the same functional unit.

Because the main steps of production from the extraction of raw material to the FeNb are entirely owned by CBMM and located all in Araxá, it was easier to collect the data and referring to Araxá for defining the local conditions.

The main unit process included in the system boundary is reported in Figure 72.

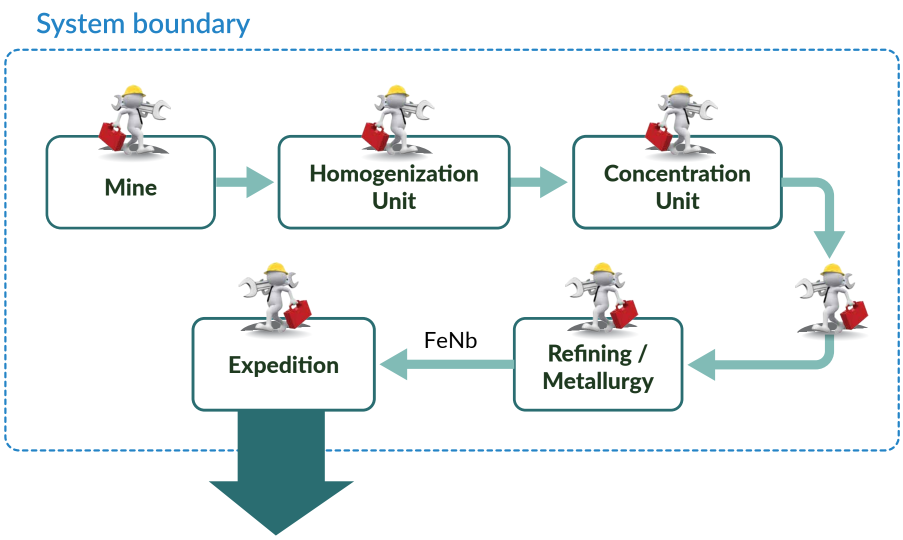

Figure 72. System boundary considered in the social life cycle assessment.

The main operations involved in the FeNb production process are the extraction and transportation of the ore from the mine; ore concentration by operations such as grinding, magnetic separation, flotation, and desliming.

Then, the pyrochlore concentrate is processed by filtration, pelletizing and sent to a steel belt sintering furnace for desulphurisation. Next, there is the dephosphorylation, lead removal in an electric arc furnace and aluminothermic production of the FeNb. Figure 40 shows the main stages of the FeNb production process (CBMM, 2014).

FeNb is produced in an electric arc furnace by melting a mixture containing a previously desulphurised and dephosphorylated refined Niobium concentrate feed, iron, granulated lime, and fluorite. Besides, aluminium powder and electricity are used as an energy source. The concentrated raw material is sent for the preparation of final products in a metallurgical unit, which involves the aluminothermic reduction in an electric furnace, a chemical unit to produce Nb_2O_5, a vacuum processing unit for the production of special metal alloys, and packaging and expedition.

All the unit processes have been analysed to collect data for social and environmental assessment. The main functional unit considered is 1 ton of FeNb produced. The functional unit did not affect the S-LCA results because the evaluation was done qualitatively but based on quantitative data. The functional unit was anyway relevant for the environmental one.

Before the collection of primary data, it was important to carry out a social hotspot assessment to identify important country and sector issue. For doing it, the social Hotspot Database (SHDB) was used. The SHDB is one of the two S-LCA available in the literature to identify my social issue at country and sector level. No precise S-LCA can be implemented with them. Still, they allow identifying the social Hotspot and the main stakeholder categories to be considered in the collection of the data, assessment and interpretation of the final results.

6.3.2. Hotspot analysis of Niobium production

Niobium and European Niobium is mainly produced in Brazil and Canada. That is the reason why those two countries have been analysed with SHDB. The social Hotspot Analysis allows identifying which are the main issues in that region where the product is produced and identify the potential positive contribution that the company can do to improve the local social conditions.

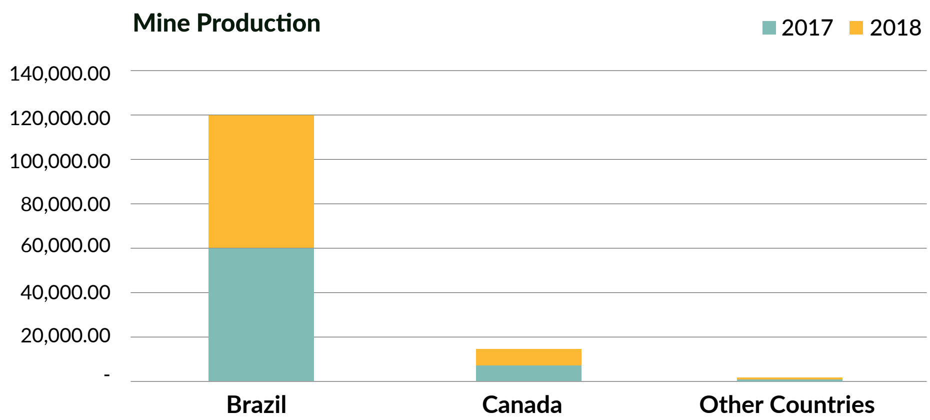

Figure 73. Niobium production in Brazil and Canada 2017-2018.

Source: USGS (2019).

The main hotspots, according to the Social Hotspot database related to the sector minerals for both countries are reported in a few figures. Brazil presents some social issues, such as:

- Child labour
- Risk Sector Average Wage being lower than Country´s non-Poverty guidelines
- Risk of Forced labour by sector
- Risk of Country not enforcing Freedom of Association rights

For Canada we have the following risk:

- Characterization of population that are immigrants
- Risk of country has not ratified ILO conventions

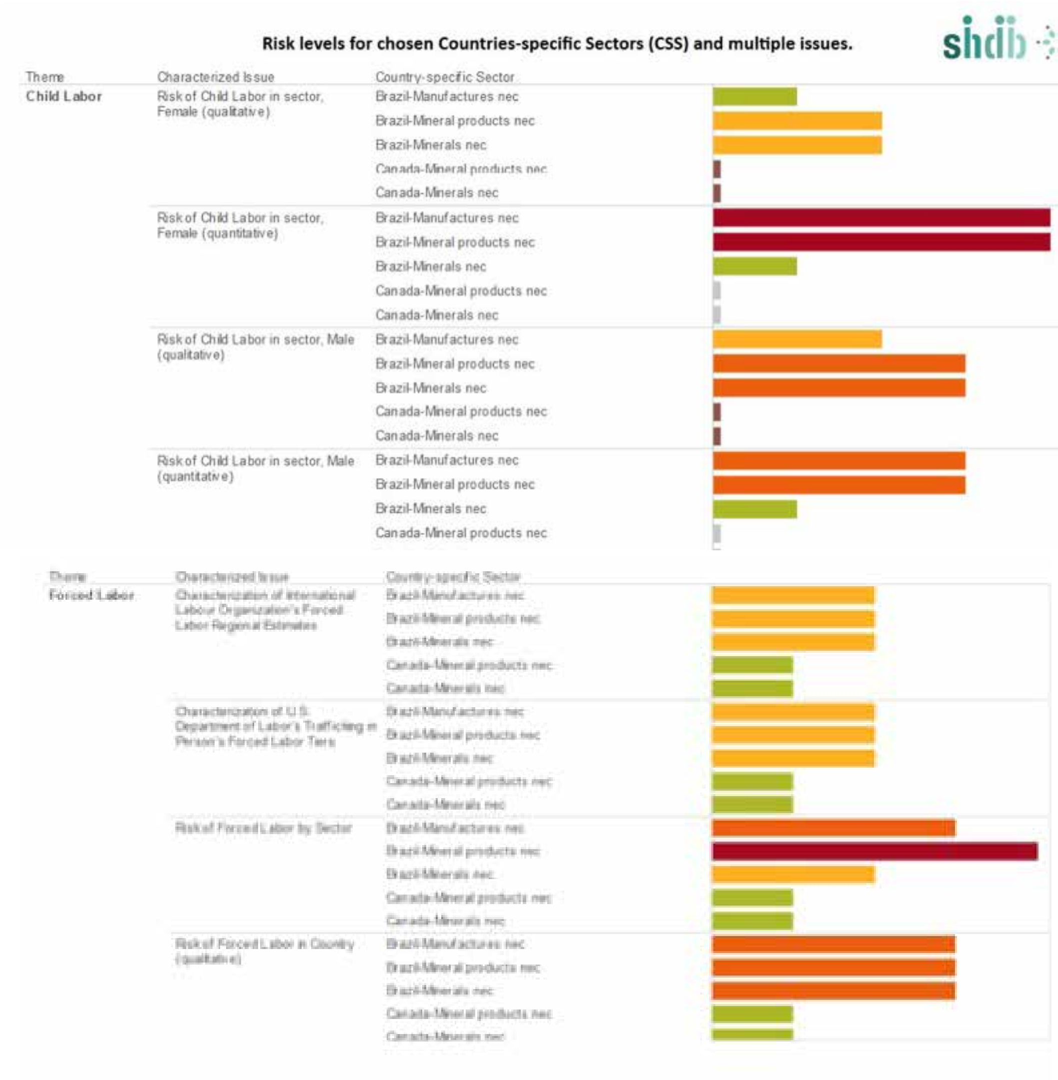

Figure 74. Social Hotspot Database results for Brazil and Canada.

Source: Social Hotspot Database (2019).

6.4. Social life cycle inventory

To collect data for the life cycle inventory, we started from the indicators suggested in the Handbook of PSIA, and we integrated with the aspect included in the guidelines. A further questionnaire was elaborated.

According to the main references considered, there are 56 indicators, qualitative and quantitative, for the worker stakeholder category and 37 indicators for the local community. Those are the indicators at inventory data to obtain a complete picture on the social impact of a product. Among them, we can find positive, negative and neutral indicators. Moreover, according to the SHDB child labour, forced labour and wages are the possible risks, that is the reason why data must be collected on those aspects.

The questionnaire was adjusted and differentiated to obtain quantitative and qualitative data from different sources and to be able to triangulate and verify the data.

The following questionnaire was developed to get information from different stakeholders:

- Responsible and managers of the unit process and plant
- Workers indifferent process units
- Human resources department
- Responsible for the Occupational Medicine
- Local community
- The worker trade representatives

Specific Quizzes have been developed for collecting primary data on two stakeholder categories: workers and local communities.

The indicators and the questionnaire were explained to the expert in Brazil who works in CETEM and is responsible for collecting the primary data on it. The inventory data of those indicators were collected for each unit process and each step of the product life cycle from cradle-to-gate. The recycling phases of Niobium are still in its early steps. According to the best currently available technologies, it is not yet economically affordable. End of Life and recycling are phases not under CBMM control, and no social data are currently available. That is why the study system boundary is cradle-to-gate.

It was underlined to the working group responsible for collecting the data to make a triangulation for ensuring that the data are correct. The triangulation was done by interviewing more stakeholders in the unit process, e.g. manager, workers and the local community, NGOs sited there. It will allow a better understanding of the quality and validity of the data collected.

In the questionnaire, we have underlined if an indicator is used to measure a positive, negative or neutral impact respectively to make easier for the operator who has to collect the data, the necessity to collect data on both positive and negative impacts.

The original Quizzes in English were translated into Portuguese and make in a more discursive form to be able to collect more information from the respondents. The translation was also important to allow the respondents to understand the question better and answer thoroughly. It was done from the colleagues of CETEM (see Appendices II and III).

Other important sources for data and to verify the data received are the sustainability report published from the CBMM Company in 2017 and 2018. Using the results reported in the sustainability report is important to show that to implement the S-LCA not so many further data are necessary, and it can be used as a further approach to assess criticalities and opportunities. Often the data in sustainability report are not able to show if there is an improvement, and they do not give any information on the quality of the social performance. The analysis of an improvement can only be done by comparing two reports from two different years, but this is not always possible because there is not a standardized way to present the results neither a norm that makes mandatory which indicators and quantitative data should be published.

However, the S-LCA allows the comparison of the social data with the local conditions and with the interpretation phase to measure the social performance of the product and a company.

The collection of the data was successful counting on the objective collaboration of CBMM staff and from other stakeholders, such as the Araxá municipality offices for education, health, social assistance and economy, tourism and innovation, as well as the two workers unions (mining and metallurgical workers).

Data on the following aspects have been collected for:

- Workers stakeholder category: injuries, health and safety training and equipment, health check-up, number of working hours per week, time flexibility, overtime management, benefits for education training and family education support, economic support for a flat, satisfaction level, wages, gender equality in terms of wages and roles.
- Local community category: improvement of infrastructure, level of engagement, access to material and immaterial resources, job creation, environmental protection and environmental disasters, support of the local people and their employment, support to cultural heritage.

Table 25 reports an example of the type of data collected for measuring the impact subcategories according to UNEP 2009.

The data collected were both qualitative and quantitative, and with them, it was possible to implement an accurate quantitative evaluation with referencing approach in both methodologies: Social Assessment Method (SAM) (PETTI et al., 2018) and PSIA (FONTES et al., 2018).

Table 25. Impact subcategories for workers and data type collected to measure them.

Impact categories	Life cycle Inventory	
	Level	Assessment
Freedom of Association and Collective Bargaining	Collected	Qualitative & Quantitative
Child Labour	No evidence	-
Fair Salary	Collected	Qualitative & Quantitative
Working Hours	Collected	Qualitative & Quantitative
Forced Labour	No evidence	-
Equal opportunities/Discrimination	Collected	Qualitative & Quantitative
Health and Safety	Collected	Qualitative & Quantitative
Social Benefits/Social Security	Collected	Qualitative & Quantitative

Source: UNEP (2009).

Some data have been collected throughout interviews and other from the Sustainability report 2018. In figure 42 are shown the data at process level: injuries, number of workers involved, working hours for duty training hours differentiate for Health & Safety training and operation training.

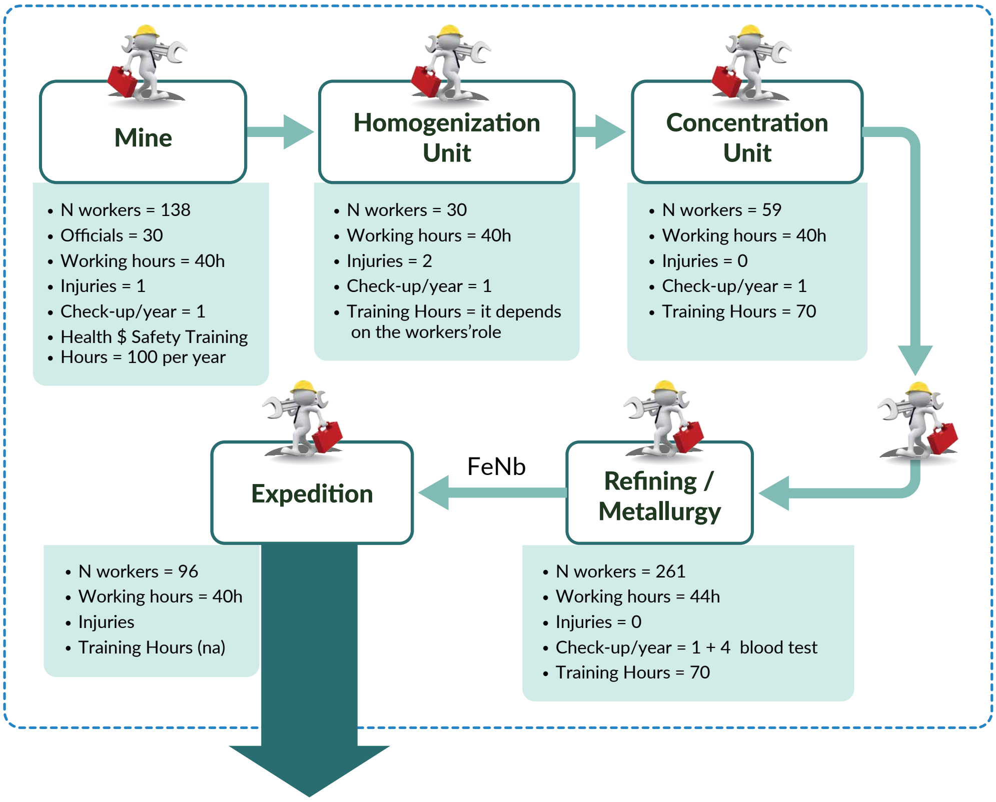

Figure 75. Life cycle inventory data at the process level

All data were primary data collected with the questionnaire during the project. In particular, the data on the working hours have been collected from the human resources department. Other quantitative data includes the salary received per gender and per role played in the company, as shown in Figure 76.

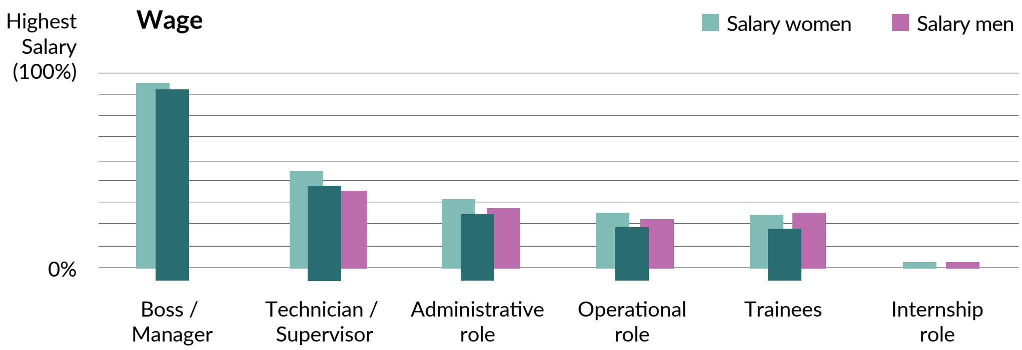

Figure 76. Wage per role played in the company (in Brazilian reais).

The data reported in figure 43 can already show that no discrimination occurs at the gender level in terms of salary.

At the local community, a long list of activities carried out by CBMM aims to improve the quality of life of the local community and to engage them in different activities. CBMM actively participates in the cultural, educational, environmental, urbanization and health initiatives of the community of Araxá, where it has invested since 1982 in actions that have sought to meet the demands of the population and increase their well-being. It is also a major employer and in 2016 accounted for approximately 69% of what the municipality produced.

The CBMM's relevance to the local economy goes beyond its participation in the collection of the municipality, thanks to its capacity to generate employment and income. Based on the Employment and Income Generation Model, produced by the National Economic and Social Development Bank (BNDES), the Company found that during 2017, 685 indirect jobs and 4,096 jobs were generated based on the income effect. The income effect is understood as the transformation of the income of direct and indirect workers into consumption, stimulating other sectors and stimulating the economy and the process of job creation.

The Company also participates in several infrastructure projects, such as the construction and expansion of the Industrial District. Among the works financed by CBMM are the paving of streets and public roads and the construction of daycare centres, sports gyms and a multi-sport centre.

The expected benefits from the investments made by the Company in the community are not directly measured. Still, the general idea is to provide the population of Araxá and region with a better quality of life, either by improving basic services such as health and education, or by offering attractions cultural or sporting activities, or by assisting those most in need. The monitoring of the indirect economic impact in the community is established specifically for each support. It can be accomplished by receiving reports, visits, participation in events and social media announcements. The Executive Committee evaluates the demands and, after their pre-approval, are analysed by the Compliance Department. The criteria for donations and sponsorships follow the rules established by the Donations and Sponsorship Policy, in line with the Compliance Program and the Code of Ethics and Conduct.

Examples of those activities and its expenses are reported in the sustainability report, see table 26.

Table 10. Investment for local communities.

Project activity	Current or expected impacts on local community and economies	Amounted invested 2018 (R$)
Social Assistance	Improve the quality of life of served communities	723,089
Sports	Stimulate involvement in athletic activities in the community	20,000
Health	Encourage providers to continue their best for the health of the served communities	2,478,304
Education	Promote high quality education for the residents of Araxá	151,984
Culture	Stimulate public interest in and knowledge of culture in general	1,390,000

Source: CBMM Sustainability Report (2018).

6.5. Social Life Cycle impact assessment and interpretation

To evaluate the results, we use both methodology Subcategory Assessment Method (SAM) (Karina et al., 2014) and the Product Social Impact Assessment (Fontes et al., 2018).

The SAM methodology referred in terms of indicators and subcategories to the UNEP guidelines and the methodological sheets. According to the SAM, it was possible to compare the data of LCI with an established requirement for each impact categories according to the International Labour Organization conventions or other international and national agreements. SAM defines four levels: A, B, C, D and each of them as a score from 4 to 1. Considering the SAM methodology, if the company owner of the life cycle step considered in the assessment is compliant with the minimum requirements and have met a good average level of corporate social responsibility, then its score will be B (this represents the standard good practice towards which a responsible company should aim). If a company is proactive in some or in several topics, with the ambition to improve their social performance at that level, it can be considered a best practice. Then, the score is A (this represents excellence, well beyond the standard practice). The scores C and D mean both non-compliant, but they also depend on the local conditions. If the local conditions are critical for that specific aspect than the non-compliant is also critical, and it means D, otherwise C.

Even if we cannot show the results in detail, due to confidentiality issues, we can generally say that in our assessment, we have not found any non-compliance. For this reason, all the indicators are B (good practice) or above, with several A (best practice). In other words, in most of the cases, the company behaviour can be considered as a best practice. Particular attention is given to the workers' benefits as well as to infrastructure, educational and engagement of the local community.

The same positive assessment was found implementing the PSIA approach. PSIA evaluation is based in 5 categories, see Table 19, and also, in this case, we have a reference level which is an indicator as 0. It is obtained when the data show compliance with local laws or with international standards. International standards are preferred if there are some conflicts between the two national and international norms. According to the PSIA, we have two levels of positive impact and two levels of negative impacts, differentiate according to the definition shown in table 27.

Table 27. Evaluation criteria, according to PSIA.

+2	Ideal performance: a positive output achieved and reported
+1	Progress beyond compliance is made and monitored
0	Compliance with local laws and aligned with international standards
-1	The non-compliant situation, but actions to improve have been taken
-2	No data, or Non-compliant situation; no action is taken

Source: Fontes (2018; 2016).

For a few indicators such as living wage, health and safety, and gender discrimination, we had quantitative data according to the PSIA quantitative methodology. In terms of the living wage, it was also possible to compare it with the regional living wage and the average gained, and we can confirm that the CBMM's workers wage is higher of both and allow them and their family to have a decent life.

6.6. Results

The results obtained according to SAM for workers and the local community are reported in Table 19.

In the final evaluation, according to the S-LCA methodology, we considered the local conditions. It means, in one hand, that if a topic is a local/national social hotspot and the company reaches a good performance in that topic, in the final evaluation will be considered A (ideal performance). On the other hand, if the company is in a region with no social hotspots, it will be evaluated with B (good average performance). The A grade is because the company behaves proactively in a critical aspect for that region, and it deserves to be awarded and considered a front runner; it is a standardized method to evaluate a positive impact. This is the approach used for the evaluation of the Niobium production at CBMM company in Araxá. Most of the aspects often reached a standard good performance (B score) but, because the company is located in a region where those topics are social hotspot (see the results in the previous section given by SHDB), the evaluation given was excellent or A score. This is the case for child labour and forced labour, as well as for fair salary, social benefits and equal opportunities/discriminations. In other aspects which are not hotspots in that area, a standard social responsibility performance is evaluated with B. This is important to be underlined to interpret the results correctly. A company with the same measured performance of CBMM, but located in Europe, would have been assessed with a standard B score in most of the topics. The same discussion should be considered for the PSIA methodology, which evaluates an average corporate social quality with +1, instead of B and ideal performance (excellent) with +2 instead of A. Of course, the PSIA with its five levels evaluating score can better underline the difference between compliance with minimum requirements (level 0), a proactive behaviour (+1) and the excellent performance (+2).

Table 28. Results according to SAM for workers.

Impact categories	SAM evaluation	
	Level	Assessment
Freedom of Association and Collective Bargaining	B	3
Child Labour	A	4
Fair Salary	A	4
Working Hours	B	3
Forced labour	A	4
Equal opportunities / Discrimination	A	4
Health and Safety	B	3
Social benefits / Social security	A	4

Level	A	B	C	D
Assessment	4	3	2	1

For the workers' stakeholder category, CBMM performance represents a best practice (A) in most of the aspects. No critical aspects scoring C or D were identified, the difference is only between B and A, which shows anyway that the company meets a very good level in terms of corporate social responsibility. Example of best practice are related to the most of ILO convention; in fact, the CBMM contract clearly states that no child labour or forced labour will be tolerated and each employee signing the contract is in charge to avoid any type of involvement of children in the production process.

It must be outlined that a new Labour Law was approved by the Brazilian Congress in 2017 (Law N° 13.467, 13th June 2017) causing modifications such as:

- The end of the yearly worker syndicates compulsory contribution (one day salary per year) encouraging de-affiliation of workers from their unions.
- Direct agreements and contracts between employers and employees prevail over most labour obligations, except the one month vacation a year and the extra annual salary (the thirteenth salary).
- Workday periods can now be intermittently scheduled.
- Continuous workday hours shift from 12 to 36 hours of rest, limited to 44 hours per week.
- Pregnant employees can be licensed, upon medical evaluation, to work at low and medium healthy risk workplaces.

The new law was intended to increase employment, but it weakened some traditional workers' rights, as well as the financial support of syndicates to represent their affiliates. Those changes in the national norm create a bad trend in the Brazilian business model, decreasing the local conditions if compared to international updated labor regulations and agreements. In spite of that, CBMM is still a best practice in several social aspects, as it was shown in most indicators. Some improvement could be done anyway related to two aspects: freedom of association and working hours.

Health and Safety is an important issue, and there the company has a rate of injuries quite low compared with similar working realities. CBMM has shown its health and safety programs data, as well as yearly statistics on workers training following methods that comply with good practices. But if compared at the international level, CBMM still need some improvements in order to reach the A score.

About working hours, in mining and homogenization phases, the employees are working in shifts, and it is not always working at the same time, they have a loop changing the working time. They have three different hours (7h to 16h, 16h to midnight and midnight to 7h) with one hour stop for lunch, dinner or later dinner. Besides, the number of free days between shifts vary according to the shift. That is why the average is 42 hours, to comply with the Brazilian legislation and allowing the 24h/7 days per week operation of the plants. Also, in this case, the company is compliant with national law but a more proactive behaviour could be performed since Brazil is among the highest working hours countries list.

For the local community, excellent social conditions were measured in all subcategories except delocalization and migration, but it is not a hotspot topic for Brazil. Particular attention must be paid on the Health and Safety conditions. Two big disasters occurred in other mining plants 350 km away from Araxá. It is not related to CBMM but, because it is a hot topic at the national level, we must consider it anyway. Moreover, other dams are located nearby, and they need lots of management to avoid bad conditions.

This mentioned disaster that has not involved CBMM occurred at 12:28 PM on a Friday, January 25, 2019, when the tailings dam no. 1 of Córrego do Feijão from iron ore mine near Brumadinho, metropolitan area de Belo Horizonte, Minas Gerais, Brazil, suddenly failed, releasing almost its complete holdings of 12 million cubic meters of tailings in a big burst. Travelling at up to 120 km/h, the tailings wave first touched the foot of adjacent Dam no. 6, then hit the mine's loading station, its administrative area (including a cafeteria where many workers had lunch at the time), and two smaller sediment retention basins (B4 and B4A).

The slurry wave then travelled approximately 7 km downhill until reaching Paraopeba River, thereby destroying a bridge of the mine's railway branch, and spreading to parts of the local community Vila Ferteco, near the town of Brumadinho. The slurry wave killed 246 people, and 24 are reported missing.

The accident did not involve CBMM extraction areas, and it happens far away from its plant. The dams of the company were built with safer construction technology, the "downstream method", its dams site embankments are under permanent surveillance monitoring, also considering that the industrial facilities are out of a hypothetical dam break area. CBMM has always been sensitive regarding that safety and emergency procedures since its foundation and were recently improved under a new revised governance and policy initiative.

The project team visited the mine site in May 2019, when CBMM staff guided the team to the new dams control room, continuously operated 24h a day, fed by automatic piezometers and other data sensors, as well as satellite imaging of the six existing dams. Sirens and other emergency warning equipment were to be tested as required by the Dams Emergency Plan approved by the Brazilian Mining Agency. CBMM works proactively to ensure that its dam and their plants are perfectly saved and well managed to avoid any possible disaster. It is testified for example by the document "Política de Governança de Barragens".

Furthermore, CBMM built Casa do Caminho (Wayside Home). The Casa do Caminho began operations in 1980 to provide medical services to the under-served population in the region. Over the ensuing almost 30 years, CBMM has contributed to the construction of a 10,000 square meter day hospital that has made it possible to treat psychiatric patients.

About Cultural Heritage, lots of projects have been organized and funded by the company to support the local community in this regard. A list of these 2017 projects is reported in Appendix IV (Appendix IV) of this report.

Table 29. Results according to SAM for the local community.

Impact categories according to the UNEP guidelines	SAM evaluation	
	Level	Assessment
Access to material resources	A	4
Access to immaterial resources	A	4
Delocalization and migration	B	3
Cultural Heritage	A	4
Safe & healthy living conditions	A	4
Respect of indigenous rights	n.a.	n.a.
Community engagement	A	4
Local employment	A	4
Secure living conditions	n.a.	n.a.

Level	**A**	**B**	**C**	**D**
Assessment	4	3	2	1

The social impact assessment has also been calculated using the PSIA methodology. With this methodology, more detailed analysis at life cycle step was possible for the workers' stakeholder category to see Table 30.

Table 30. Social Life impact assessment according to PSIA for workers.

	Health and safety	Wages	Social benefits	Working hours	Child labour	Forced labour	Discrimination	Freedom of association and collective bargaining	Employment relationship	Training education	Work-life balance	Job satisfaction and engagement
Average according to the Social Metrics	1	2	2	1	1	2	2	1	2	1	1	No data
Mining	0	2	2	1	1	2	2	1	2	1	1	No data
Homogenization	0	2	2	1	1	2	2	1	2	1	1	No data
Concentration	1	2	2	1	1	2	2	1	2	1	1	No data
Refining	1	2	2	1	1	2	2	1	2	1	1	No data
Expedition	1	2	2	2	1	2	2	1	2	1	1	No data

Also, according to PSIA for worker stakeholder category, we could not find any critical aspect. The working hours in mining and Homogenization are changing in a turn of three weeks on average we have for Mining 42.6 hours per week and in Homogenization 40 per week. No data could be collected on the work-life balance monitoring tool no data is available on this topic and not a regular survey is developed from the company to understand the work-life balance as well as not compensation measures to overtime seems to be applied to CBMM. However, some initiatives have been developed to help the employees to relax and to increase their work-life-balance, examples of activities are sport, and anti-stress exercises regularly offer given for free to all employees. In this sense, a proactive attitude related to this issue is organized.

Table 31. Social Life impact assessment according to PSIA for the local community.

		Health and safety	Access to tangible resources	Local capacity building	Community engagement	Employment
Entire FeNb production	Average according to the Social Metrics	0	1	2	1	2

Also, with the PSIA methodology, the only critical point for the local community except for Health and Safety that considers is the dam disaster that occurred at VALE iron ore mine in Brumadinho, Minas Gerais state this year. Of course, the disaster happened quite far from the CBMM plant (about 350 km), and it did not affect the plant there. A more standard approach and control from the government to encourage the best practice is desirable.

Then analysing a few quantitative indicators according to PSIA, we can say that Niobium guarantees a decent life to its workers and family, the wages paid are substantially higher than the living wage, see table 32. It can be until seven times the living wage in Araxá area.

Table 32. Comparison between salary and living wage.

Role	Percentage compared to living wage
	%
Boss / Manager	680 (7x)
Technician/supervisor	284
Administrative role	230
Operational role (operator)	180
Trainees	200

** All values according to the Living Wage (2014)*

Further Benefits are guaranteed for all workers: support for education, medical and dental assistance, medicines, private insurance, food voucher, canteen, transport, funeral assistance, uniform, housing assistance and life insurance.

The frequency rate of injuries 2,02 per million hours worked (2018) is very low if compared with other raw material extraction. We can also measure an absolute reduction of last years compared to 2017, as shown in figure 45.

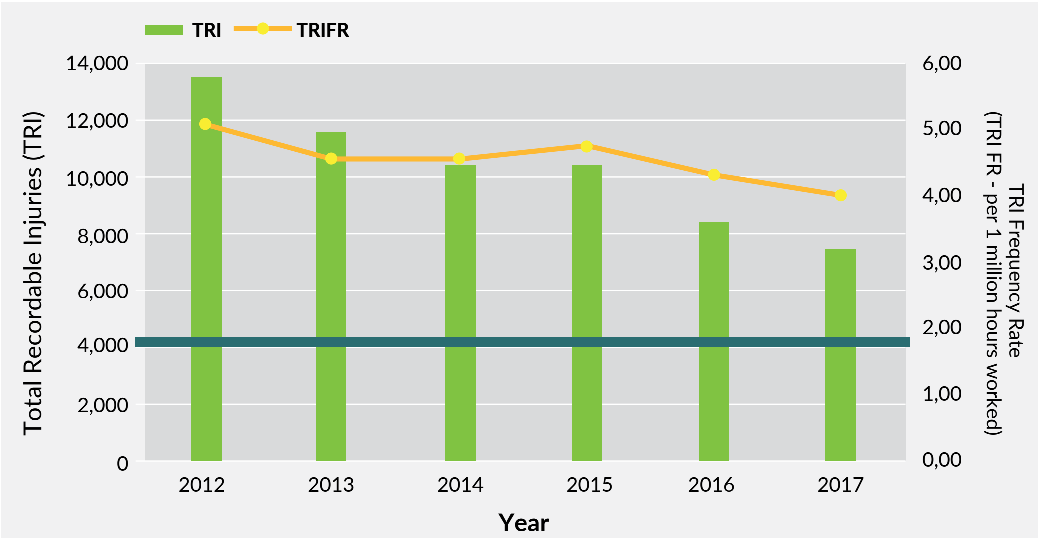

Figure 77. The comparison of Frequency rate of injuries per 1 million hours with an average in the mining sector.

Source: ICMM (2017).

Finally, we can conclude that Niobium and CBMM have a good or even excellent social performance associated with Niobium as a product and its supply chain and from CBMM as a company.

Summarizing, thanks to this project it was possible to measure with quantitative and qualitative data and the PSIA and SAM type 1 impact methodologies, the social impact of Ferroniobium on two important stakeholder categories, workers and local communities. This project allows the company to understand better which improvements can be done and the important role played by this product and production site in the region. Even if this mineral is listed in European Commission as a critical raw material for its potential risks in the supply chain, regarding the social aspects, it represents an important source for the region Araxá. It plays an important role for the local economy with its positive impact. Moreover, it is the first critical raw material assessed with social LCA and thanks to it. It was possible to identify the challenges and benefits of this methodology.

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7.

Conclusions

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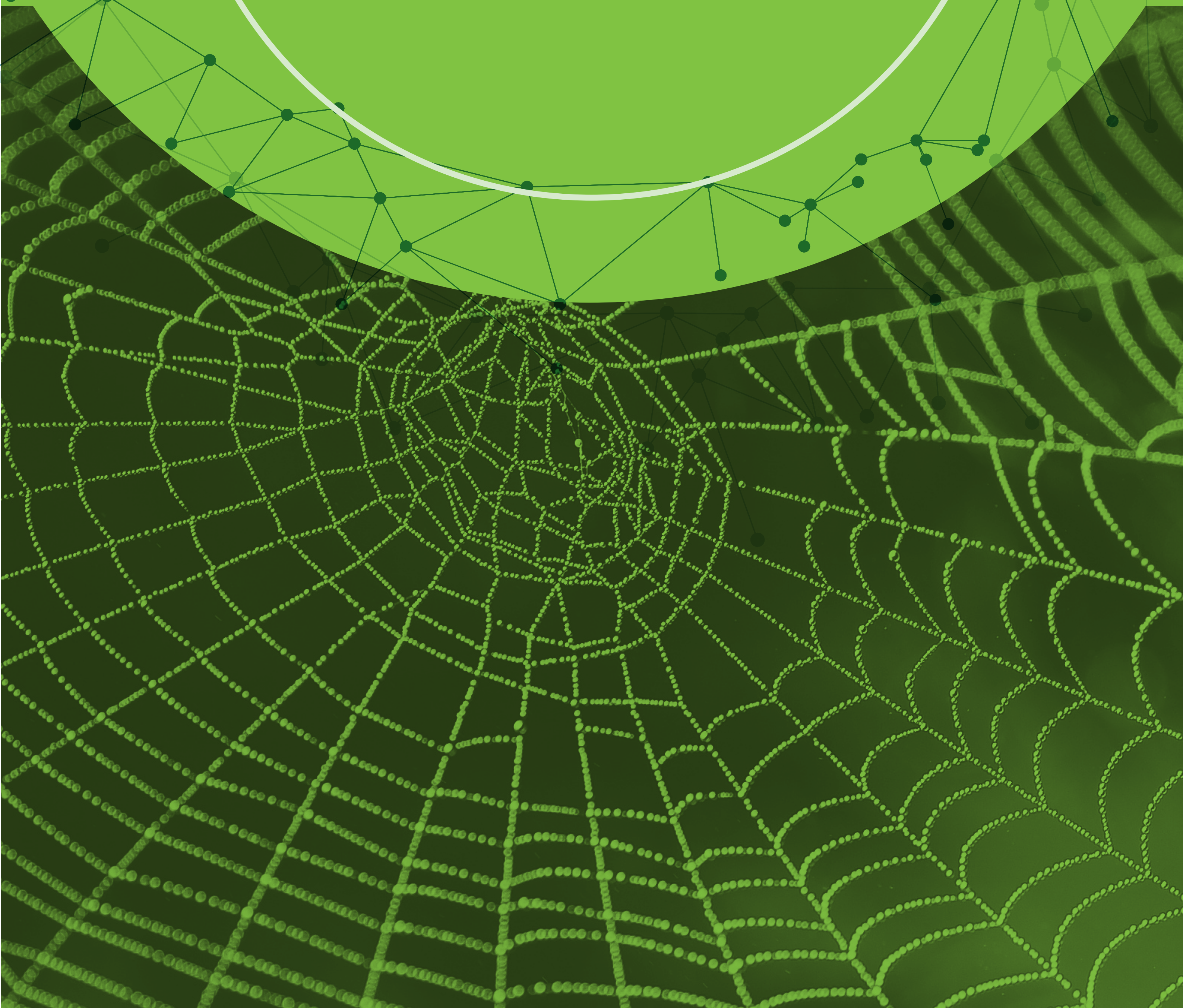

The proposal of Project n. 128 A, entitled "Study of critical materials' production chains: opportunities and threats of the circular economy", was to meet the general objective of studying the production and consumption chains of the Brazilian niobium or one of the rare-earth, based on the concepts of the Circular Economy, while evaluating the implications under the Brazilian and European perspectives.

The specific objectives of the project were as follows:

A) Surveying impacts and changes in the production chains of mineral raw materials as per the Circular Economy perspective, using one or two case studies. The first case study, on the niobium production chain could reach end products using European data from steel production for the automotive industry or, alternatively, the other one would be regarding magnets containing rare-earth elements intended for the energy industry;

B) Presenting a framework of opportunities and threats to strategic or critical raw materials in a circular economy scenario, based on the assessment of foreseen changes versus the technology or knowledge available to materialize them for the actual case studies;

C) Comparing the results achieved with the study, which was produced with estimates obtained, taking into account possible changes in the production chains, as promoted by the adoption of the Circular Economy.

Niobium was chosen for this study, as it is one of the critical raw materials from the EU Critical Raw materials list and the preliminary list of U.S. *Critical Minerals*, and also because niobium's minerals are also considered strategic in the current Brazilian mining, science, technology, and innovation policies. This dual aspect of the niobium – being critical versus strategic, was explored in Section 1, where the methodologies to assess EU and US raw materials criticality are presented, as well as the Brazilian policies and initiatives.

For all the above, we may conclude that:

- Nowadays, the geopolitics of raw materials is being rescued and renewed by new policies and actions arising in response to trade conflicts scenarios. Such conflicts are inherent to present global market and international political relations, currently under major stress among its main players. It is worth emphasizing the emerging new technologies and the growth of markets demanding raw materials with supply at some sort of risk.
- Countries producing these raw materials, which are very well-identified, should also be considered as protagonists in this process and should establish their plans to deal with a new geopolitical reality.
- The case of niobium has specificities that highlights it as critical raw material due to its uses in materials essential to important economic sectors, as well as for the concentration of primary production in a couple of countries (Brazil and Canada), what raises risk level. On the other hand, this situation is offset because these

countries are knowingly open to world trade. This is the case of Brazil, which is willing to establish international partnerships to foster the use of niobium with a high level of shared investment in R&D&I.

- If, on the one hand, the production is concentrated across few countries, this does not apply as to the number of niobium minerals known deposits and other occurrences of niobium containing ores, i.e., there are over forty already known occurrences some with positive prospects for new mining projects.

- We can also conclude that the current market for niobium – which production is estimated on 140 thousand tons/year (2019) of its main product, the ferroniobium – is limited, as compared to the market for other metals used as elements for metallurgical alloys, such as high-consumption chromium and nickel, and closer to consumption for vanadium and molybdenum.

To meet the specific objective described in item A, regarding the Circular Economy, we performed an exploratory assessment on the niobium production chain. We adopted two approaches for this project: the Material Flow Analysis (MFA), which departed from the mineral production figures to final use in the automotive transport sector, and the determination of the Material Circularity Indicator (MCI), to assess the consumption of niobium in the European scenario.

We could identify a high level of recycling of steel, but a low level of niobium circularity, as present in ferroniobium for the automotive segment steels, verified through the MFA and the MCI. On the other hand, the uses in civil construction steel structures – a market in full expansion – and gas and oil pipelines favour the long-life aspect that, in turn, contributes much to the circular economy. Nevertheless, there is still no data on the reuse, remanufacture or recycling of these materials due to the long durability of the works.

Other studies (MSP REFRAM, 2016) also conclude on the low recovery of niobium, from its main consumer segment, i.e., that of microalloyed and stainless steels, even if both materials have a high level of recycling, consolidated in the most developed countries. Vehicle scraps are systematically collected, although they are randomly mixed, without any separation by the type of composition. It is implied that selecting the scraps per type of steel could enable the expansion of the recovery of niobium and other alloying elements. Nevertheless, there are technical and economic difficulties, especially as a result from the low content of niobium (400 ppm, on average), and the contamination of scrap by other deleterious elements in the manufacture of steel, such as the zinc present in the bodies that are galvanized.

These difficulties do motivate or could motivate new attitudes and policies on critical raw materials, such as:

- The use of substitute metal elements in steels.

- Search for other substitutes, both for structural applications and to produce alternative materials with similar properties across other applications.

- Advance practices specific to the Circular Economy, such as reuse, remanufacture or even seeking new technologies that allow the recycling of niobium, even if they come from low-content sources.

Although it still seems a distant reality, some practices of Circular Economics can be observed from the emergence of new businesses, such as those of car sharing, which compete to decrease the acquisition of new vehicles, especially by individual owners, favouring a more optimized use per vehicle. These practices can influence the profile of materials market while providing opportunities for new businesses.

The specific objective of the project (item B) was met through the overview of technological innovations in five years time, which included the information disclosed, both by the main patent databases and by the collection of scientific papers. The current higher intellectual property interests, where incremental innovations improve products and processes, focus on metallurgy (steel industry in the first place).

Searching for disruptive innovations, aimed at other segments of products, identify patents applications at a lower number. Among such, the majority focuses on energy applications, e.g., high storage capacity batteries, and special devices such as capacitors, which are likely to grow given the interest in clean energies and the high R&D investments[17]. There are tangible expectations that these applications could significantly increase the size of the niobium market, especially due to the emergence of the electric transport vehicle market. CBMM, for example, is investing in cooperation with the Japanese company Toshiba, to realize the first application of niobium in lithium-ion battery anodes.

With the predominance in the number of patent applications, through companies and research institutions, China is increasingly expanding its relevance in several key markets for raw materials essential to the industrialized economies.

The use of niobium is promising, seen through the perspectives of scientific and technological research observed from the articles published in the main international journals. Our survey indicates that materials and products that depend on or may need niobium are mentioned and studied in a scale of hundreds of times a year. In a desirable next step, the systematic reading and assessment of the articles raised could contribute to identify trends, based on the results and perspectives of application, the work quality of the organizations, and the number of researchers involved.

We must emphasize the commitment of the companies in the segment to promote research and development. CBMM, for instance, has a historical and successful contribution. CMOC also stands out in this field, as it has been hiring mineral technological research in Brazil. Part of the history of the niobium and its evolution across the applications had the participation or partnership of Brazilian companies and research institutions. This is a unique case in the country, and it confirms that the combination of R&D and management expertises are essential foundations of good business, even in the

17 The Brazilian company CBMM has maintained important investment in this area, as well as in R&D, in addition to fostering other technologies that need niobium, with an estimated subsidy of USD 40 million per year.

mining sector, which often limits its scope to mineral exploration and production, rarely seeking downstream partnerships like other segments across the production chains.

Aimed at maintaining its leadership and high market profitability involving raw materials, the formula of CBMM's success, in particular, has been to persist in fostering and forming partnerships for innovation that secure the maintenance or growth of the niobium consumption. An opportunity of interest to primary producers and immediate impact is the reduction of niobium losses in the ore processing phases, and the metallurgical or chemical processing of concentrates. It was observed that Brazilian companies have invested in this direction, using technologies to increase the recovery of niobium minerals in the finer fractions of the ores – as performed by CBMM, as well as in the optimization of the recovery of the niobium minerals associated to phosphates in ore processing, in the case of Niobras/CMOC.

Currently, the novelty lies in the emergence of opportunities created within the logic of Circular Economics involving niobium and its materials. New businesses created by the adoption of the Circular Economy will require other connections and expertise profiles that can drive opportunities for new investments. That is, companies in the supply chains and applications of niobium could benefit from this new environment that is under development, as they have the previous knowledge leverage over new competitors.

In this sense, adopting new design techniques and products manufacturing may give rise to challenges. For instance, in the case of vehicles, companies that anticipate the disassembly and selective collection of vehicles steel body parts, which are then submitted to new remanufacturing and recycling processes, would reduce their losses in terms of alloy elements. The processes developed could also be used for steels used in durable installations, such as gas/oil pipelines, and constructions that are ending their life cycle of use and operation, or being decommissioned, thus enabling the reuse of retained niobium content.

Therefore, we may conclude that this is a unique moment and requires the attention of producers and governments alike. At the same time, we can observe international policies for mineral resources being recaptured. In this scenario, geopolitics will become more influential due to the emergence of new market segments with potential interest for niobium. On the other hand, there is the identification of low niobium circularity, at the same time when Circular Economy-based sustainability policies emerge.

From the diplomatic standpoint regarding raw materials, to have the supply risk derived from a concentrated production to be offset, it is understood that mineral producers should maintain their balanced and cooperative trade behaviour led by companies operating in Brazil, collaborating with government agencies and bodies to increase the international confidence in the supply of niobium. It would be additionally desirable, to expand other public actions and policies, such as the existing national Science & Technology support policies. This, in turn, could be better arranged, while counting on more resources insofar as there are much less activities in progress in Brazil, as compared to what happens abroad. Policies to encourage internal consumption of niobium are also timely, especially in steels intended for construction and installations since this demand is well-established for the oil and gas piping sector.

As a support to specific national policies our suggestion is to identify in further detail which minerals are critical for Brazil, among those considered as strategic, broadening criteria to allow guiding public policies and actions. As to raw materials supply risk issue, this should be studied in-depth, not limited to the dependence on importations, but also with a strategic reach, along with the geopolitical relevance of exporting mineral goods produced by companies operating in Brazil.

The partnership with the European Union in recent times has been particularly positive because it has allowed the exchange of high-level information between the areas of geology and mining across government, academy, and research staffs. The methodology used to assess raw materials criticality could be adjusted to the Brazilian conditions, in order to complement the definition of the strategic minerals. Moreover, bilateral agreements could collaborate to build a research network comprising Brazilian and European groups within a set of priorities jointly established.

The EU-Brazil Sector Dialogues Program has been a very useful source towards the compliance with demands and interests in common, thanks to which, together with the MCTIC support, we could carry out this project and others of major relevance. The technical-scientific partnership established between the JRC and the Aachen University, on one side, and CETEM, IBICT and USP, on the other, proved to be very efficient and productive, also highlighting the collaboration of CBMM.

7.1. Conclusions for the Studies on Social-environmental Life Cycle Assessment

It is worth to comment on the works we conducted with CBMM concerning social-environmental life cycle assessments, where various aspects of their objectives were met. Emphasis should be given to the preparatory study phase since, overall, it is extremely difficult to obtain data on life-cycle inventories, based on information from companies. This is probably due to the level of detail such inventories need, which often unveil industrial and technological information that companies usually consider as confidential information, or which are not consistent with companies' disclosure policy. Therefore, being able to present and approve the project before the CBMM Board of Directors, was a remarkable achievement, i.e., a proposal for, collaborative work on the LCAs. The cooperation consent was sealed through a Partnership Agreement executed with the Centro de Tecnologia Mineral – CETEM / MCTIC, governed by a separate Confidentiality Agreement.

The following step was to establish and implement a work plan to organize the collection of information for both production and social-environmental inventories, which should be provided by the management of the company and some other stakeholders.

The Questionnaires sent to CBMM regarding the environmental inventory were objectively answered, making their use in the LCA softwares platform (Gabi) fast, while generating more realistic and reliable results. Analysis of the indicators will favour the ratification or improvement to internal policies of the company, since from 2017 CBMM elaborate and release to public its Sustainability Report, type GRI (Global Reporting Initiative).

We also found the same cooperative atmosphere while running the inventory portion of the social life cycle assessment, which required us to visit and interview other stakeholders, such as employees and colaborators, unions and community organizations in the region, representing the social segments, as well as the secretariats and branches of the local administration of Araxá municipality.

Getting all the information, with the full support and agreement from the company's superior management, was only possible because of the effort and attention various of their professionals and contributors dedicated to CETEM and USP's teams. We would like to thank each and all of them for a substantial part of this extensive research, for all the planning and participation in dozens of interviews and consultations.

Moreover, we may conclude that it will be most useful for future case studies on the niobium-rich product, and other raw materials, to carry out life cycle assessments that will benefit databases of Brazilian inventories IBICT is in charge for, and European inventory databases, under JRC's responsibility.

7.2. Evaluation of the results and perspectives for the future

The environmental LCA enabled highlighting the hotspots that need greater attention and monitoring from the company, which have been seeking to demonstrate transparency and improvement to its environmental and social indicators, as demonstrated in its sustainability reports in 2017 and 2018. On the other hand, the ferroniobium production process has variations, like those used by Niobras/CMOC, and by Niobec/Canada, whose LCAs, if available, could allow for interesting comparisons. Comparison with other LCAs for different ferroalloys is also desirable, a goal to be pursued in future studies.

It is worth to outline the results from the Social-LCA. This assessment ratified the relevance of CBMM for Araxá municipality and the surrounding region, with actions and programs arranged with the local administration leading to the excellency across various social indicators. The company's relationship with employees and benefits for their families is also differentiated, thus resulting in a very positive assessment in this topic.

Finally, we must mention that JRC was responsible for proposing the inclusion of Life Cycle Assessments as a component of raw materials criticality assessment, being niobium the first case study conduct for that matter. It is, therefore, expected testing this same approach to other raw materials in the next versions of the Euopean Comission Critical Raw Materials (CRMs) lists.

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Appendices

APPENDIX I – Inventory Questionnaire on Mineral Production Life Cycle.

INDUSTRY DATA	
Respondent Name:	
Job Title:	Dept.: Refining Unit
Date:	
Base year: 2017	
Quiz	
Daily production capacity (tons of ferroniobium)	
Ore density (kg/m³)	
Waste rock material and ore density (kg/m³)	
Hourly production of FeNb	
Employment Contract Type (h)	
Production process flow chart (inputs and outputs)	
Mining site	
1. Mining site production capacity (ore t/day)	
2. Extraction method	
Does it require explosives? Y ( ) N ( )	
Extraction equipment:	
Name/Brand/Model	
Type (B – Bulldozer or BH = Backhoe)	
Diesel consumption (L/h)	
What type of diesel is used? ( ) S1800 ( ) S500 ( ) S50 ( ) S10	
Capacity (m³/h)	
Performance (ore kg/h)	
Soil transformation	
Open-pit mining per ore mass (m²/t of ferroniobium)	
The volume of water used in water tankers for dust suppression (L/t of ferroniobium)	
Is it necessary to add any substances to the water used in the water tankers? If yes, what are they, and what is the volume used (kg/t of ferroniobium)?	
Transportation from the mining site to the homogenization yard	
Are trucks used? Y ( ) N( )	
If not: How is transportation made to the homogenization yard?	
If conveyor belts are used	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m³/h)	
Power consumption (kWh/t of ferroniobium)	

Conveyor belt travelling distance (m)	
If trucks are used:	
Type (drive shafts/wheel-drive)	
Model	
Horsepower (HP)	
Year	
Capacity (m^3)	
What is the distance between the mining site and the homogenization yard? (km)	
Fuel consumption (diesel L/km)	
What type of diesel is used? ( ) S1800 ( ) S500 ( ) S50 ( ) S10	
Homogenization yard	
Name of the equipment	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Are there any other raw materials/inputs? Which are they? (kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What is the capacity of the trucks that carry the raw materials/ inputs?(t)	
The volume of mining wastewater generated (L/t of ferroniobium)	
Amount of waste generated (kg/t of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2)(kg/t of ferroniobium)	
Transportation from the homogenization yard to the beneficiation unit	
How is the material taken to the beneficiation unit?	
If conveyor belts are used	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Power consumption (kWh/t of ferroniobium)	
Distance travelled (m)	
ORE PROCESSING UNIT	
Comminution	
Is crushing or grinding necessary at this step? Y ( ) N( )	
If yes:	
Name of the equipment	

Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Are there any other raw materials/inputs? What are they? (kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What are the capacities of the trucks carrying the inputs? (t)	
Amount of waste generated (kg/t of ferroniobium)	
The volume of mining wastewater generated (L/t of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2) (kg/t of ferroniobium)	
Magnetic separation	
Name of the equipment	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Are there any other raw materials/inputs? What are they? (Kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What are the capacities of the trucks carrying the inputs? (t)	
Waste generated:	
Amount of magnetite (kg/t of ferroniobium)	
Amount of aluminium (kg/t of ferroniobium)	
Amount of silicon (kg/t of ferroniobium)	
Amount of phosphorus (kg/t of ferroniobium)	
Amount of sulphur (kg/t of ferroniobium)	
Amount of titanium (kg/t of ferroniobium)	
Amount of barium (kg/t of ferroniobium)	
Amount of manganese (kg/t of ferroniobium)	
Amount of iron (kg/t of ferroniobium)	
Amount of the radionuclides 238U, 226Ra, 210Pb, 232Th, and 228Ra (kg/t of ferroniobium)	
Are there any other wastes? Y( ) N( ) – If yes, how much? (kg/t of ferroniobium)	

The total amount of wastewater generated (L/t of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2) (kg/t of ferroniobium)	
Desliming	
Name of the equipment	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Are there any other raw materials/inputs? What are they? (Kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What are the capacities of the trucks carrying the inputs? (t)	
Waste generated:	
Amount of barite (kg/t of ferroniobium)	
Amount of calcium (kg/t of ferroniobium)	
Amount of sodium (kg/t of ferroniobium)	
Are there any other wastes? Y( ) N( ) – If yes, how much? (kg/t of ferroniobium)	
The total amount of wastewater generated (L/t of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2) (kg/t of ferroniobium)	
Flotation	
Name of the equipment	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Consumption of HCl (Chloridric acid) (L/t of ferroniobium)	
Consumption of fluosilicic acid (L/t of ferroniobium)	
Consumption of amine (cationic collector) (L/t of ferroniobium)	
Are there any other raw materials/inputs? Which are they? (kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What are the capacities of the trucks carrying the inputs? (t)	

Waste generated:	
Amount of amine (kg/t of ferroniobium)	
Amount of wetting agent (kg/t of ferroniobium)	
Amount of sodium fluorosilicate (kg/t of ferroniobium)	
Are there any other wastes? Y( ) N( ) – If yes, how much? (kg/t of ferroniobium)	
The total amount of wastewater generated (L/t of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2) (kg/t of ferroniobium)	
Thickening and filtration	
Name of the equipment	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Are there any other raw materials/inputs? What are they? (Kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What are the capacities of the trucks carrying the inputs? (t)	
For the entire ore processing Unit:	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Amount of waste generated (kg/t of ferroniobium)	
The volume of mining wastewater generated (L/t of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2) (kg/t of ferroniobium)	
For the entire ore processing Unit:	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Amount of waste generated (kg/t of ferroniobium)	
The volume of mining wastewater generated (L/t of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2) (kg/t of ferroniobium)	
Transport from the ore processing unit to the refining unit	
How is the material taken to the refining unit?	
If conveyor belts are used	

Name of the equipment	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Distance travelled (m)	

Source: elaborated in-house.

APPENDIX II – Quizzes on Refining Life Cycle Inventory.

INDUSTRY DATA	
Respondent Name:	
Job Title:	Dept.: Refining Unit
Date:	
Base year: 2017	
QUIZ	
Desulphurisation	
Unit 1	
Name of the equipment	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Consumption of flotation concentrates (kg/t of ferroniobium)	
Consumption of bentonite (kg/t of ferroniobium)	
Consumption of petroleum coke (kg/t of ferroniobium)	
Consumption of LPG (m^3/t of ferroniobium)	
Are there any other raw materials/inputs? Which are they? (kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What are the capacities of the trucks carrying the inputs? (t)	
Amount of particulate matter generated (kg/t of ferroniobium)	
Amount of sulphur removed (kg/t of ferroniobium)	
Amount of water removed (L/t of ferroniobium)	
Amount of acidic wastewater (L/t of ferroniobium)	
Amount of basic wastewater used upon acidic wastewater neutralisation pro-cess (L/t of ferroniobium) and its composition	
Is there precipitate formation during the neutralisation process?	
Is there a radionuclide output? If yes, in what amount (kg/t of ferroniobium)?	
Are there any other wastes? Y( ) N( ) – If yes, how much? (kg/t of ferroniobium)	
The total amount of wastewater generated (L/t of ferroniobium)	
Emissions generated (please, describe the gases,) (kg/t of ferroniobium)	

List of Important consumables (Please, list the consumption per ton of ferroniobium)	
Unit 2	
Name of the equipment	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Consumption of flotation concentrates (kg/t of ferroniobium)	
Consumption of bentonite (kg/t of ferroniobium)	
Consumption of charcoal (kg/t of ferroniobium)	
Consumption of LPG (m^3/t of ferroniobium)	
Are there any other raw materials/inputs? Which are they? (kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What is the capacity of the trucks that carry the raw materials/ inputs?(t)	
Amount of particulate matter generated (kg/t of ferroniobium)	
Amount of sulphur removed (kg/t of ferroniobium)	
Amount of water removed (L/t of ferroniobium)	
Is there a radionuclide output? If yes, in what amount (kg/t of ferroniobium)?	
Are there any other wastes? Y( ) N( ) – If yes, how much? (kg/t of ferroniobium)	
The total amount of wastewater generated (L/t of ferroniobium)	
List of Important consumables (Please, list the consumption per ton of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2) (kg/t of ferroniobium)	
Transport from the desulphurisation unit to the dephosphorization unit	
How is the material taken to the dephosphorylation unit?	
If conveyor belts are used	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Power consumption (kWh/t of ferroniobium)	
Distance travelled (m)	
Dephosphorization unit	
Name of the equipment	

Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption(L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Consumption of synthesized concentrate (kg/t of ferroniobium)	
Consumption of charcoal (kg/t of ferroniobium)	
Consumption of graphite electrodes (kg/t of ferroniobium)	
Consumption of LPG (m^3/t of ferroniobium)	
Are there any other raw materials/inputs? What are they? (kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What are the capacities of the trucks carrying the inputs? (t)	
Amount of volatilised lead (kg/t of ferroniobium)	
Amount of ferrophosphorus generated (t/ t of ferroniobium)	
Are there any other wastes? Y( ) N( ) – If yes, how much? (kg/t of ferroniobium)	
Amount of waste generated (kg/t of ferroniobium)	
The total volume of wastewater generated (L/t of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2) (kg/t of ferroniobium)	
List of Important consumables (Please, list the consumption per ton of ferroniobium)	
Transport from the refining unit to the metallurgical unit	
How is the material taken to the metallurgical unit?	
If conveyor belts are used	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Power consumption (kWh/t of ferroniobium)	
Distance travelled (m)	
Metallurgical Unit	
Name of the equipment	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Consumption of refined concentrates (kg/t of ferroniobium)	

Consumption of aluminium powder (kg/t of ferroniobium)	
Consumption of iron powder (kg/t of ferroniobium)	
Consumption of lime (kg/t of ferroniobium)	
Consumption of electrodes (kg/t of ferroniobium)	
Are there any other raw materials/inputs? What are they? (Kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What are the capacities of the trucks carrying the inputs? (t)	
Waste generated:	
The total amount of slag (t/t of ferroniobium)	
Amount of alumina (kg/t of ferroniobium)	
Amount of barium oxide (kg/t of ferroniobium)	
Amount of calcium oxide (kg/t of ferroniobium)	
Amount of particulate matter (kg/t of ferroniobium)	
Are there any other wastes? Y( ) N( ) – If yes, how much? kg/t of ferroniobium)	
The total amount of wastewater generated (L/t of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2) (kg/t of ferroniobium)	
List of Important consumables (Please, list the consumption per ton of ferroniobium)	
In terms of percentage, what is the product mass-produced at the metallurgy that is sent out to crushing and shipping, and what is sent for special metal production?	
Transport from metallurgical plant to crushing and shipping	
Are trucks used? Y ( ) N( )	
If not: How is the material taken to crushing and shipping?	
If conveyor belts are used	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Distance travelled (m)	
No caso de caminhões:	
Type (drive shafts/wheel-drive)	
Model	
Horsepower (HP)	
Year	
Capacity (m^3)	

What is the distance between the metallurgical plant and the crushing and shipping areas? (km)	
Fuel consumption (diesel L/km)	
What type of diesel is used? ( ) S1800 ( ) S500 ( ) S50 ( ) S10	
Crushing and shipping	
Name of the equipment	
Code/Model/Brand	
Employment Contract Type (h)	
Capacity (m^3/h)	
Water consumption (L/t of ferroniobium)	
Power consumption (kWh/t of ferroniobium)	
Diesel consumption (L/t of ferroniobium)	
Are there any other raw materials/inputs? Which are they? (kg/t of ferroniobium)	
How are these raw materials/inputs transported? What is its origin? (km)	
What are the capacities of the trucks carrying the inputs? (t)	
Waste generated	
Amount of waste generated (kg/t of ferroniobium)	
Emissions generated (please, describe the gases, e.g., SO_2, CO_2) (kg/t of ferroniobium)	
How are the products stored? (Please, specify the types of packaging and respective capacities, and the material of the packaging used)	
Additional questions	
Are there any forms of recycling processes in place? (Niobium recycling, as well as other materials used throughout the production chain)	
Do they use reclaimed water throughout any of the processes?	

Source: elaborated in-house.

APPENDIX III – Quiz on Social Life Cycle Inventory.

SOCIAL LIFE CYCLE ASSESSMENT (S-LCA) FORM – AS

INDUSTRY DATA				
Respondent Name:				
Job Title:	Dept.: Social assistance			
Date:				
Base year: 2017				
QUIZ				
1. Does the company offer day-care or day-nursery for their employees' kids at the company?				
Yes		No		
Number of vacancies:				
2. Does the company abide by human rights regulations?				
Yes		No		
3. Are there any claims or labour laws violation suits filed against the company?				
Yes		No		
	Number of cases per group of employees			
Board				
Management				
Leadership / coordi-nation				
Techni-cians/ Supervisors				
Clerical jobs				
Operational				
Trainees				
Outsourced				
Apprentices				
Trainees				
Other				
4. What are the measures in place to increase diversity, while encouraging equal opportunities per gender or special needs among personnel?				
5. How many claims per year have been filed in connection with discrimination?				
	Volume			
Board				
Management				

Techni-cians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
Other remarks or comments:	

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Human Resources Manager

SOCIAL LIFE CYCLE ASSESSMENT (S-LCA) FORM - LEGAL

INDUSTRY DATA	
Respondent name:	
Job Title:	Dept.: Legal
Date:	
Base year: 2017	

QUIZ	
CBMM total number of employees:	
The total number of employees in Araxá	
The total number of outsourced labour (Please, describe per type of services hired from third parties, e.g., Various services or technical services; maintenance services, among others:	
Other remarks on the hiring categories at CBMM:	

6. What is the average salary paid per group of employees? (R$/month)

	Average salary
Board	
Management	
Leadership / coordi-nation	
Techni-cians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

7. Do employees get paid for overtime work?

Yes		No		

8. In percentage terms, how many employees get a salary above the minimum wage?

Other comments:

9. Does any employee get a salary below the minimum wage?

Yes		No		

Outras observações:

10. Qual é a relação entre o maior e menor salário? (relação/ano)	

11. How many women are there per group of employees, and what are their salaries like?		
	Number	Salary
Board		
Management		
Leadership / coordination		
Technicians/ Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		
12. How many men are there per group of employees and what is their salaries like?		
	Number	Salary
Board		
Management		
Technicians/ Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		

13. Does the company offer any social services or benefits for their employees? (If yes, please, describe the percentage and type of benefit per group of employees)				
Yes		No		
Increment percentage on base salary:				
Benefits for all employees:				

	Type of differential benefit	
Board		
Management		
Leadership / coordination		
Technicians/ Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		

14. Do employees get any type of support for physical activities or affiliation-based spaces? E.g., Academy, living space.				
Yes		No		
15. Do employees get any type of support to purchase their own homes? If yes, please, detail the percentage and type of benefit per group of employees				
Yes		No		

	Percentage	Tipo de beneficio
Board		
Management		
Leadership / coordination		
Technicians/ Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		

16. Do employees get any family-based benefit for themselves or their family members, such as self-development programs? E.g., education, post-graduation support, technical training.				
Yes		No		
If yes, please, detail the benefits or programs:				

17. On average, how many work hours are there per week?		
	Hours	
Board		
Management		
Technicians/ Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		

18. What is the average (wage) value for work hours hired by week?	
	Salary
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

19. Is the main work time (hours) pre-defined? E.g., 8h a day, from 7h00 to 18h00				
Yes		No		

	Hours
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	

Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
20. How many employees, in percentage terms, work on a flexitime basis?	
	Flex-time
Board	
Management	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
21. How many employees, in percentage terms, work under a formal contract? (Employment contracts)	
	Percentage
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
22. How many employees, in percentage terms, work under a temporary employment contract?	
	Percentage
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	

Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
23. What the average retention time of employees with the company? (Employment stability)	
	Media
Board	
Management	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
24. What is the average number of regular vacation days?	
	Average number
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

25. How many pregnant women can rely on proper protection?	
26. How many male employees, in percentage terms, are on paternity-leave?	
27. Does the company offer day-care or day-nursery for their employees' kids?	

Yes		No		

The total number of vacancies:					
28. How many times a year, an external audit is carried out:					
29. Does the company notify the employees about all work conditions to which they will be exposed? (Wages/salaries, work schedules, work location etc.)					
Yes		No			
30. How many employees are from Araxá City or nearby cities?					
Total					
Please, specify the number per group of employees:					

	Number
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

31. Are employees required to leave their documents at the company? (ID, driver's license, passport)				
Yes		No		
If yes, please, inform the number per group of employees.				

	Number
Board	
Management	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

32. Does the company have policies against child labour? (If no, how many employees are under-aged? How many hours do they work per week?				
Yes		No		

	Number
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

33. How many trainees or apprentices does the company have every year? Please, inform the type per workgroup.

	Percentage	Type
Board		
Management		
Leadership / coordination		
Technicians/ Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		

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Human Resources Manager

SOCIAL LIFE CYCLE ASSESSMENT FORM – DESULPHURISATION UNIT

INDUSTRY DATA	
Respondent Name:	
Job Title:	Dept.: Dephosphorylation Unit
Date:	
Base year: 2017	

QUIZ	
1. Working hours at the mining site 8h()12h()24H(X)	
2. What is the range of time for a full cycle (clock-in/clock-out)?	
3. What is the output of FeNb production in tons per hour?	
4. Total number of employees in the operation	
5. Total number of teams	4
6. How many employees are there in each team per shift?	
7. Number of teams per shift of operation	3
8. Resting time per team	6 days
Other comments:	Shift 1: 6 days for the daytime shift, 1 day off. Shift 2: 6 days for the afternoon shift, 2 days off. Shift 3: 6 days for the overnight shift, 3 days off.
9. Operation's flow chart detail (e.g.: ((4) backhoe operators, (1) management supporter, (1) team leader, (1) operations manager etc.)	

Volume	Role or position
	Manager
	Department leader
	Management supporter
	Maintenance supervisor
	Production head
	Filtration lead-operator
	Electric Oven Operator
	Oven lead-operator
	Control Room Operator II
	General Services Operator
	Forklift operator
	Dephosphorylation operator I

10. The number of unskilled workers (e.g., oven operator, digger, machine feeding operator, etc.):	
11. Within this area, how many employees are directly involved in the FeNb production?	Total:
Please, detail per group of employees with their respective educational background.	

	Volume	Educational background (schooling)

Manager		
Department leader		
Management supporter		
Maintenance supervisor		
Production head		
Filtration lead-operator		
Electric Oven Operator		
Oven lead-operator		
Control Room Operator II		
General Services Operator		
Forklift operator		
Dephosphorylation operator I		

12. At this stage, what is the operating time required to produce 1 ton of FeNb?		
13. How much of this time consists of manual labour, and how much consists of machine handling?	Manual labour:	Machine handling:

14. Do you get training on health care and the prevention of work-related accidents?

Yes		No		

If you answered Yes, please, list the training you attended each year.	
15. What is the average number of cases of occupational diseases per year? Please, specify.	
16. What is the average number of deaths due to the activities in this unit per year? Please, specify the reasons.	
17. What is the average rate of injuries in this unit per year? Please, specify the types of injuries.	

18. Do employees undergo health check-ups? How often per year?

Yes		No		

If the answer is Yes, please, indicate the number per group of employees:	
Manager	
Department leader	
Management supporter	
Maintenance supervisor	
Production head	
Filtration lead-operator	
Electric Oven Operator	
Oven lead-operator	
Control Room Operator II	

General Services Operator				
Forklift operator				
Dephosphorylation operator I				
19. On average, how many work hours are there per week?				
Yes		No		
If the answer is Yes, please, indicate the number per group of employees:				
	Volume			
Manager				
Department leader				
Management supporter				
Maintenance supervisor				
Production head				
Filtration lead-operator				
Electric Oven Operator				
Oven lead-operator				
Control Room Operator II				
General Services Operator				
Forklift operator				
Dephosphorylation operator I				
20. Are there any emergency plans in place? E.g., in case of fire. Please, specify the plans.				
Yes		No		
Which are they?				
21. Does this Unit have a Health and Safety Committee with the participation of employees?				
Yes		No		
22. Are employees equipped with personal protective equipment (PPE)? E.g., Safety goggles, earplugs etc				
Yes		No		
	Type of equipment			
Manager				
Department leader				
Management supporter				
Maintenance supervisor				
Production head				

Filtration lead-operator	
Electric Oven Operator	
Oven lead-operator	
Control Room Operator II	
General Services Operator	
Forklift operator	
Dephosphorylation operator I	
23. Is the main work time (hours) pre-defined? E.g., 8h a day, from 7h00 to 18h00	
Please, detail the information per group of employees.	
	Hours
Manager	
Department leader	
Management supporter	
Maintenance supervisor	
Production head	
Filtration lead-operator	
Electric Oven Operator	
Oven lead-operator	
Control Room Operator II	
General Services Operator	
Forklift operator	
Dephosphorylation operator I	
24. How many employees, in percentage terms, work under a temporary work contract?	
Please, detail the information per group of employees.	
	Hours
Manager	
Department leader	
Management supporter	
Maintenance supervisor	
Production head	
Filtration lead-operator	
Electric Oven Operator	

Oven lead-operator	
Control Room Operator II	
General Services Operator	
Forklift operator	
Dephosphorylation operator I	
25. How many employees, in percentage terms, work on a flexitime basis?	
Please, detail the information per group of employees.	
	Flex-time
Manager	
Department leader	
Management supporter	
Maintenance supervisor	
Production head	
Filtration lead-operator	
Electric Oven Operator	
Oven lead-operator	
Control Room Operator II	
General Services Operator	
Forklift operator	
Dephosphorylation operator I	
26. The number of hours in unskilled work (manual labour)?	
Please, detail the information per group of employees.	
	Hours of manual labour per day
Manager	
Department leader	
Management supporter	
Maintenance supervisor	
Production head	
Filtration lead-operator	
Electric Oven Operator	
Oven lead-operator	
Control Room Operator II	

General Services Operator	
Forklift operator	
Dephosphorylation operator I	

27. How many trainees or apprentices does the company have every year? Please, inform the type per workgroup.

Please, detail the information per group of employees.

	Volume
Manager	
Department leader	
Management supporter	
Maintenance supervisor	
Production head	
Filtration lead-operator	
Electric Oven Operator	
Oven lead-operator	
Control Room Operator II	
General Services Operator	
Forklift operator	
Dephosphorylation operator I	

28. On average, how many hours of training to employees get per year? Please, specify the type of training (technical training).

Please, detail the information per group of employees

	Horas de treinamento
Manager	
Department leader	
Management supporter	
Maintenance supervisor	
Production head	
Filtration lead-operator	
Electric Oven Operator	
Oven lead-operator	
Control Room Operator II	
General Services Operator	
Forklift operator	
Dephosphorylation operator I	

29. Other notes or additional comments:	

Dephosphorylation Unit Manager

SOCIAL LIFE CYCLE ASSESSMENT (S-LCA) FORM – MO

INDUSTRY DATA				
Respondent Name:				
Job Title:			Dept.: Occupational Medicine	
Date:				
Base year: 2017				
Quiz				
1. What is the average number of cases of work-related chronic diseases per year?				
Please, specify the conditions:				
2. What is the average rate of injuries occurring at work per year?				
Please, specify the types of injuries.				
3. What is the average number of work-related mental health conditions per year?				
Please, specify the reasons::				
4. Do employees undergo health check-ups?				
Yes		No		
Number of check-ups per year, per group of employees				
	Volume			
Board				
Management				
Leadership / coordination				
Technicians/ Supervisors				
Clerical jobs				
Operational				
Trainees				
Outsourced				
Apprentices				
Trainees				
Other				
5. What are the negative impacts on health from the harmful substances at the work environment? Please, specify the number of conditions per year for each group of employees:				
	Volume			
Board				
Management				
Leadership / coordination				

Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
6. Other notes or general comments	

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Human Resources Manager

SOCIAL LIFE CYCLE ASSESSMENT (S-LCA) FORM – MINE

INDUSTRY DATA	
Respondent Name:	
Job Title:	Dept.: MINE
Date:	
Base year: 2017	
QUIZ	
30. Working hours at the mining site 8h()12h()24H(X)	
31. Total number of employees in the operation	
32. Total number of teams	
33. How many employees are there in each team per shift?	
34. Number of teams per shift of operation	
35. Resting time per team	
Other comments:	
36. Operation's flow chart detail (e.g.: ((4) backhoe operators, (1) management supporter, (1) team leader, (1) operations manager etc.)	

Volume	Role or position

37. The number of unskilled workers (e.g., oven operator, digger, machine feeding operator, etc.):	
38. Within this area, how many employees are directly involved in the FeNb production?	Total:
Please, detail per group of employees with their respective educational background	

Role or position	Volume	Educational background (schooling)

39. At this stage, what is the operating time required to produce 1 ton of FeNb?					
40. How much of this time consists of manual labour, and how much consists of machine handling?				Manual labour:	Machine handling:
41. Do you get training on health care and the prevention of work-related accidents?					
Yes		No			
If you answered Yes, please, list the training you attended each year.					
42. What is the average number of cases of occupational diseases per year? Please, specify.					
43. What is the average rate of injuries in this unit per year? Please, specify the types of injuries.					
44. On average, how many work hours are there per week?					
Yes		No			
If the answer is Yes, please, indicate the number per group of employees:					
Role or position					Volume
45. Are there any emergency plans in place? E.g., in case of fire. Please, specify the plans.					
Yes		No			
Which are they?					
46. Does this Unit have a Health and Safety Committee with the participation of employees?					
Yes		No			
47. Are employees equipped with personal protective equipment (PPE)? E.g., Safety goggles, earplugs etc.					
Yes		No			
48. Is the main work time (hours) pre-defined? E.g., 8h a day, from 7h00 to 18h00					
Please, detail the information per group of employees.					
Role or position					Hours

49. How many employees, in percentage terms, work under a temporary work contract?	
Please, detail the information per group of employees.	
Role or position	Hours
50. How many employees, in percentage terms, work on a flexitime basis?	
Please, detail the information per group of employees.	
Role or position	Flex-time
51. The number of hours in unskilled work (manual labour)?	
Please, detail the information per group of employees.	
Role or position	Hours of manual labour per day

52. How many trainees or apprentices does the company have every year? Please, inform the type per workgroup.

Please, detail the information per group of employees.

Role or position	Volume

53. On average, how many hours of training to employees get per year? Please, specify the type of training (technical training).

Please, detail the information per group of employees.

Role or position	Hours of training

54. Other notes or additional comments:	

Gerente de Mina

SOCIAL LIFE CYCLE ASSESSMENT FORM – HOMOGENIZATION YARD

INDUSTRY DATA	
Respondent Name:	
Job Title:	Dept.: Homogenization yard
Date:	
Base year: 2017	
QUIZ	
55. Working hours at the mining site 8h()12h()24H(X)	
56. Total number of employees in the operation	
57. Total number of teams	
58. How many employees are there in each team per shift?	
59. Number of teams per shift of operation	
60. Resting time per team	
Other comments:	
61. Operation's flow chart detail (e.g.: ((4) backhoe operators, (1) management supporter, (1) team leader, (1) operations manager etc.)	

Volume	Role or position
	Mining analyst
	Management supporter
	Mining Site Planning Assistant
	Department Leader
	Production Head
	Mining Site Planning Engineer
	Geologist
	Hydrogeologist
	Support operator
	Crusher operator
	Reclaimer Operator
	Control Room Operator
	Stacker Operator
	Supervisor
	Mining Technician

62. The number of unskilled workers (e.g., oven operator, digger, machine feeding operator, etc.):	
63. Within this area, how many employees are directly involved in the FeNb production?	Total:
Please, detail per group of employees with their respective educational background	

	Volume	Educational background (schooling)
Mining analyst		

Management supporter				
Mining Site Planning Assistant				
Department Leader				
Production Head				
Mining Site Planning Engineer				
Geologist				
Hydrogeologist				
Support operator				
Crusher operator				
Reclaimer Operator				
Control Room Operator				
Stacker Operator				
Supervisor				
Mining Technician				
64. At this stage, what is the operating time required to produce 1 ton of FeNb?				
65. How much of this time consists of manual labour, and how much consists of machine handling?			Manual labour:	Machine handling:
66. Do you get training on health care and the prevention of work-related accidents?				
Yes		No		
If you answered Yes, please, list the training you attended each year.				
67. What is the average number of cases of occupational diseases per year? Please, specify.				
68. What is the average number of deaths due to the activities in this unit per year? Please, specify the reasons.				
69. What is the average rate of injuries in this unit per year? Please, specify the types of injuries.				
70. Do employees undergo health check-ups? How often per year?				
Yes		No		
If the answer is Yes, please, indicate the number per group of employees:				
Mining analyst				
Management supporter				
Mining Site Planning Assistant				
Department Leader				
Production Head				
Mining Site Planning Engineer				
Geologist				
Hydrogeologist				
Support operator				
Crusher operator				

Reclaimer Operator	
Control Room Operator	
Stacker Operator	
Supervisor	
Mining Technician	

71. On average, how many work hours are there per week?

Yes		No		

If the answer is Yes, please, indicate the number per group of employees:

	Volume
Mining analyst	
Management supporter	
Mining Site Planning Assistant	
Department Leader	
Production Head	
Mining Site Planning Engineer	
Geologist	
Hydrogeologist	
Support operator	
Crusher operator	
Reclaimer Operator	
Control Room Operator	
Stacker Operator	
Supervisor	
Mining Technician	

72. Are there any emergency plans in place? E.g., in case of fire. Please, specify the plans.

Yes		No		

Which are they?

73. Does this Unit have a Health and Safety Committee with the participation of employees?

Yes		No		

74. Are employees equipped with personal protective equipment (PPE)? E.g., Safety goggles, earplugs etc.

Yes		No		

	Type of equipment
Mining analyst	
Management supporter	
Mining Site Planning Assistant	
Department Leader	

Production Head	
Mining Site Planning Engineer	
Geologist	
Hydrogeologist	
Support operator	
Crusher operator	
Reclaimer Operator	
Control Room Operator	
Stacker Operator	
Supervisor	
Mining Technician	
75. Is the main work time (hours) pre-defined? E.g., 8h a day, from 7h00 to 18h00	
Please, detail the information per group of employees.	
	Horas
Mining analyst	
Management supporter	
Mining Site Planning Assistant	
Department Leader	
Production Head	
Mining Site Planning Engineer	
Geologist	
Hydrogeologist	
Support operator	
Crusher operator	
Reclaimer Operator	
Control Room Operator	
Stacker Operator	
Supervisor	
Mining Technician	
76. How many employees, in percentage terms, work under a temporary work contract?	
Please, detail the information per group of employees.	
	Hours

Mining analyst	
Management supporter	
Mining Site Planning Assistant	
Department Leader	
Production Head	
Mining Site Planning Engineer	
Geologist	
Hydrogeologist	
Support operator	
Crusher operator	
Reclaimer Operator	
Control Room Operator	
Stacker Operator	
Supervisor	
Mining Technician	
77. How many employees, in percentage terms, work on a flexitime basis?	
Please, detail the information per group of employees.	
	Flex-time
Mining analyst	
Management supporter	
Mining Site Planning Assistant	
Department Leader	
Production Head	
Mining Site Planning Engineer	
Geologist	
Hydrogeologist	
Support operator	
Crusher operator	
Reclaimer Operator	
Control Room Operator	
Stacker Operator	
Supervisor	
Mining Technician	
78. The number of hours in unskilled work (manual labour)?	

Please, detail the information per group of employees.	
	Hours of manual labour per day
Mining analyst	
Management supporter	
Mining Site Planning Assistant	
Department Leader	
Production Head	
Mining Site Planning Engineer	
Geologist	
Hydrogeologist	
Support operator	
Crusher operator	
Reclaimer Operator	
Control Room Operator	
Stacker Operator	
Supervisor	
Mining Technician	
79. How many trainees or apprentices does the company have every year? Please, inform the type per workgroup.	
Please, detail the information per group of employees.	
	Volume
Mining analyst	
Management supporter	
Mining Site Planning Assistant	
Department Leader	
Production Head	
Mining Site Planning Engineer	
Geologist	
Hydrogeologist	
Support operator	
Crusher operator	
Reclaimer Operator	
Control Room Operator	
Stacker Operator	
Supervisor	

Mining Technician	
80. On average, how many hours of training to employees get per year? Please, specify the type of training (technical training).	
Please, detail the information per group of employees.	
	Hours of training
Mining analyst	
Management supporter	
Mining Site Planning Assistant	
Department Leader	
Production Head	
Mining Site Planning Engineer	
Geologist	
Hydrogeologist	
Support operator	
Crusher operator	
Reclaimer Operator	
Control Room Operator	
Stacker Operator	
Supervisor	
Mining Technician	
81. Other notes or additional comments:	

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Homogenization yard Manager

SOCIAL LIFE CYCLE ASSESSMENT (S-LCA) FORM - Grievances

INDUSTRY DATA				
Respondent Name:				
Job Title:			Dept.: Compliance	
Date:				
Base year: 2017				
QUIZ				
34. Are there any discrimination-related grievances reported?				
Yes		No		
		Number of cases per employee group		
Board				
Management				
Leadership / coordination				
Technicians/ Supervisors				
Clerical jobs				
Operational				
Trainees				
Outsourced				
Apprentices				
Trainees				
Other				
35. Do employees understand how to report a grievance, or raise concerns regarding any administrative actions, working conditions, labour issues, motivations or discrimination?				
Yes		No		
Please, describe the channels they can use to report grievances.				
Other remarks or comments:				

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Human Resources Manager

SOCIAL LIFE CYCLE ASSESSMENT (S-LCA) FORM – HR

INDUSTRY DATA	
Respondent Name:	
Job Title:	Dept.:
Date:	
Base year: 2017	

QUIZ	
CBMM total number of employees:	
The total number of employees in Araxá:	
The total number of outsourced labour (Please, describe per type of services hired from third parties, e.g., Various services or technical services; maintenance services, among others:	
Other remarks on the hiring categories at CBMM:	

36. What is the average salary paid per group of employees? (R$/month)

	Average salary
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

37. Do employees get paid for overtime work?

Yes		No		

38. In percentage terms, how many employees get a salary above the minimum wage?	
Other comments:	

39. Does any employee get a salary below the minimum wage?

Yes		No		

Other comments:

40. What is the ratio between the highest and the lowest salary? (ratio/ year)		
41. How many women are there per group of employees, and what are their salaries like?		
	Number	Salary
Board		
Management		
Leadership / coordination		
Technicians/Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		
42. How many men are there per group of employees and what is their salaries like?		
	Number	Salary
Board		
Management		
Technicians/ Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		

43. Does the company offer any social services or benefits for their employees? (If yes, please, describe the percentage and type of benefit per group of employees)				
Yes		No		
Increment percentage on base salary:				
Benefits for all employees:				

	Type of differential benefit
Board	
Management	
Leadership / coordination	

Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

44. Do employees get any type of support for physical activities or affiliation-based spaces? E.g., Academy, living space.

Yes		No		

45. Do employees get any type of support to purchase their own homes? If yes, please, detail the percentage and type of benefits per group of employees.

Yes		No		

	Percentage	Type of benefit
Board		
Management		
Leadership / coordination		
Technicians/Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		

46. Do employees get any family-based benefit for themselves or their family members, such as self-development programs? E.g., education, post-graduation support, technical training.

Yes		No		

If yes, please, detail the benefits or programs:

47. On average, how many work hours are there per week?

	Horas
Board	
Management	
Technicians/Supervisors	

Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
48. What is the average (wage) value for work hours hired by week?	
	Salary
Board	
Management	
Leadership / coordination	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

49. Is the main work time (hours) pre-defined? E.g., 8h a day, from 7h00 to 18h00				
Yes		No		

	Hours
Board	
Management	
Leadership / coordination	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
50. How many employees, in percentage terms, work on a flexitime basis?	

	Flex-time
Board	
Management	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
51. How many employees, in percentage terms, work under a formal contract? (Employment contracts)	
	Percentage
Board	
Management	
Leadership / coordination	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
52. How many employees, in percentage terms, work under a temporary employment contract?	
	Percentage
Board	
Management	
Leadership / coordination	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	

Trainees	
Other	
53. What the average retention time of employees with the company? (Employment stability)	
	Media
Board	
Management	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
54. What is the average number of regular vacation days?	
	Average number
Board	
Management	
Leadership / coordination	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

55. How many pregnant women can rely on proper protection?				
56. How many male employees, in percentage terms, are on paternity-leave?				
57. Does the company offer day-care or day-nursery for their employees' kids?				
Yes		No		
The total number of vacancies:				
58. How many times a year, an external audit is carried out::				
59. Does the company notify the employees about all work conditions to which they will be exposed? (Wages/salaries, work schedules, work location etc.)				
Yes		No		

60. How many employees are from Araxá City or nearby cities?			
Total			
Please, specify the number per group of employees:			

	Number
Board	
Management	
Leadership / coordination	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

61. Are employees required to leave their documents at the company? (ID, driver's license, passport)				
Yes		No		
If yes, please, inform the number per group of employees.				

	Number
Board	
Management	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

62. Does the company have policies against child labour? (If no, how many employees are under-aged? How many hours do they work per week?				
Sim		No		

	Number
Board	
Management	
Leadership / coordination	

Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

63. How many trainees or apprentices does the company have every year? Please, inform the type per workgroup.

	Percentage	Type
Board		
Management		
Leadership / coordination		
Technicians/Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		

Human Resources Manager

SOCIAL LIFE CYCLE ASSESSMENT (S-LCA) FORM – HR

INDUSTRY DATA				
Respondent Name:				
Job Title:			Dept.:	
Date:				
Base year: 2017				
QUIZ				
CBMM total number of employees:				
The total number of employees in Araxá:				
The total number of outsourced labour (Please, describe per type of services hired from third parties, e.g., Various services or technical services; maintenance services, among others:				
Other remarks on the hiring categories at CBMM:				
64. What is the average salary paid per group of employees? (R$/month)				
	Average salary			
Board				
Management				
Leadership / coordination				
Technicians/ Supervisors				
Clerical jobs				
Operational				
Trainees				
Outsourced				
Apprentices				
Trainees				
Other				
65. Do employees get paid for overtime work?				
Yes		No		
66. In percentage terms, how many employees get a salary above the minimum wage?				
Other comments:				
67. Does any employee get a salary below the minimum wage?				

Yes		No		
Other comments:				
68. What is the ratio between the highest and the lowest salary? (ratio/ year)				
69. How many women are there per group of employees, and what are their salaries like?				

	Number	Salary
Board		
Management		
Leadership / coordination		
Technicians/ Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		
70. How many men are there per group of employees and what is their salaries like?		
	Number	Salary
Board		
Management		
Technicians/ Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		

71. Does the company offer any social services or benefits for their employees? (If yes, please, describe the percentage and type of benefit per group of employees)				
Yes		No		
Increment percentage on base salary:				
Benefits for all employees:				

	Type of differential benefit				
Board					
Management					
Leadership / coordination					
Technicians/ Supervisors					
Clerical jobs					
Operational					
Trainees					
Outsourced					
Apprentices					
Trainees					
Other					
72. Do employees get any type of support for physical activities or affiliation-based spaces? E.g., Academy, living space.					
Yes		No			
73. Do employees get any type of support to purchase their own homes? If yes, please, detail the percentage and type of benefits per group of employees.					
Yes		No			
	Percentage		Type of benefit		
Board					
Management					
Leadership / coordination					
Technicians/ Supervisors					
Clerical jobs					
Operational					
Trainees					
Outsourced					
Apprentices					
Trainees					
Other					
74. 74. Do employees get any family-based benefit for themselves or their family members, such as self-development programs? E.g., education, post-graduation support, technical training.					
Yes		No			
If yes, please, detail the benefits or programs:					

75. On average, how many work hours are there per week?	
	Hours
Board	
Management	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
76. What is the average (wage) value for work hours hired by week?	
	Salary
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
77. Is the main work time (hours) pre-defined? E.g., 8h a day, from 7h00 to 18h00	
	No
	Hours
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	

Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
78. How many employees, in percentage terms, work on a flexitime basis?	
	Flex-time
Board	
Management	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
79. How many employees, in percentage terms, work under a formal contract? (Employment contracts)	
	Percentage
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
80. How many employees, in percentage terms, work under a temporary employment contract?	
	Percentage

Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

81. What the average retention time of employees with the company? (Employment stability)	
	Media
Board	
Management	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

82. What is the average number of regular vacation days?	
	Average number
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	

Other				
83. How many pregnant women can rely on proper protection?				
84. How many male employees, in percentage terms, are on paternity-leave?				
85. Does the company offer day-care or day-nursery for their employees' kids?				
Yes		No		
The total number of vacancies:				
86. How many times a year, an external audit is carried out:				
87. Does the company notify the employees about all work conditions to which they will be exposed? (Wages/salaries, work schedules, work location etc.)				
Yes		No		
88. How many employees are from Araxá City or nearby cities?				
Total				
Please, specify the number per group of employees:				

	Number
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

89. Are employees required to leave their documents at the company? (ID, driver's license, passport)				
Yes		No		
If yes, please, inform the number per group of employees.				

	Number
Board	
Management	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	

Apprentices	
Trainees	
Other	

90. Does the company have policies against child labour? (If no, how many employees are under-aged? How many hours do they work per week?				
Yes		No		

	Number
Board	
Management	
Leadership / coordination	
Technicians/ Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

91. How many trainees or apprentices does the company have every year? Please, inform the type per workgroup.

	Percentage	Type
Board		
Management		
Leadership / coordination		
Technicians/ Supervisors		
Clerical jobs		
Operational		
Trainees		
Outsourced		
Apprentices		
Trainees		
Other		

____

Human Resources Manager

SOCIAL LIFE CYCLE ASSESSMENT (S-LCA) FORM – SSO

INDUSTRY DATA	
Respondent Name:	
Position: Safety and Occupational Health Manager	Dept.: Safety and Occupational Health
Date: January 2019	
Base year: 2017	

QUIZ				
92. Do you get training on health care and the prevention of work-related accidents?				
Yes		No		
Please, list the training attended per year: DOS (Daily Safety Dialogues), OJT: Workplace training, legal requirements of approximately: 80h/year				
What is the average number of cases of work-related chronic diseases per year?				
Yes		No		
93. What is the average rate of injuries occurring at work per year? Please, specify the types of injuries.				
94. What is the average number of deaths due to the mining activities per year? Please, specify the causes				
95. Do employees undergo health check-ups? How often per year?				
96. Do employees get free-of-charge meals?				
97. Does the company provide adequate sanitation facilities for employees?				
98. Are there any emergency plans in place? E.g., in case of fire, specify the plans.				
99. Is there a Health and Safety Committee with the participation of the employees?				
100. Are employees equipped with personal protective equipment (PPE)? E.g., Safety goggles, earplugs etc.				

	Type of differential benefit
Board	
Management	
Leadership / coordination	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

101. How many negative impacts on health and safety are there, as derived from the harmful substances at the work environment? Please, specify the number of impacts per year for each group of employees.	
Board	
Management	
Leadership / coordination	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	

102. Do the company's facilities comply with local employee health and safety regulations?				
Yes		No		

103. The number of hours in unskilled work (manual labour)?	
	Hours
Board	
Management	
Technicians/Supervisors	
Clerical jobs	
Operational	
Trainees	
Outsourced	
Apprentices	
Trainees	
Other	
Other comments:	

Human Resources Manager

SOCIAL LIFE CYCLE ASSESSMENT FORM – Ore processing Beneficiation unit

INDUSTRY DATA	
Respondent Name:	
Job Title:	Dept.: Beneficiation Unit 1
Date:	
Base year: 2017	

QUIZ	
82. Working hours at the mining site 8h()12h()24H()	
83. Total number of employees in the operation	
84. Total number of teams	
85. How many employees are there in each team per shift?	
86. Number of teams per shift of operation	
87. Resting time per team	
Other comments:	
88. Operation's flow chart detail (e.g.: ((4) backhoe operators, (1) management supporter, (1) team leader, (1) operations manager etc.)	

Volume	Role or position
	Manager
	Department leader
	Production Head
	Occupational Health and Safety (OHS) Facilitator
	Panel Operator 2
	Production operator 1
	Production operator 2

89. The number of unskilled workers (e.g., oven operator, digger, machine feeding operator, etc.):	
90. Within this area, how many employees are directly involved in the FeNb production?	Total:

Please, detail per group of employees with their respective educational background.

	Volume	Educational background (schooling)
Manager		
Department leader		
Production Head		
Occupational Health and Safety (OHS) Facilitator		
Panel Operator 2		
Production operator 1		
Production operator 2		

91. At this stage, what is the operating time required to produce 1 ton of FeNb?	Manual labour:	Machine handling:

92. How much of this time consists of manual labour, and how much consists of machine handling?				
Yes		No		

If you answered Yes, please, list the training you attended each year.	
93. Do you get training on health care and the prevention of work-related accidents?	
94. What is the average number of cases of occupational diseases per year? Please, specify.	
95. What is the average number of deaths due to the activities in this unit per year? Please, specify the reasons.	

96. What is the average rate of injuries in this unit per Year? Please, specify the injuries.				
97. Do employees undergo health check-ups? How often per year?.				
Yes		No		

If the answer is Yes, please, indicate the number per group of employees:	
Manager	
Department leader	
Production Head	
Occupational Health and Safety (OHS) Facilitator	
Panel Operator 2	
Production operator 1	
Production operator 2	

98. On average, how many work hours are there per week?				
Yes		No		

If the answer is Yes, please, indicate the number per group of employees:	
	Volume
Manager	
Department leader	
Production Head	
Occupational Health and Safety (OHS) Facilitator	
Panel Operator 2	
Production operator 1	
Production operator 2	

99. Are there any emergency plans in place? E.g., in case of fire. Please, specify the plans.				
Yes		No		

Which are they?				
100. Does this Unit have a Health and Safety Committee with the participation of employees?				
Yes		No		
101. Are employees equipped with personal protective equipment (PPE)? E.g., Safety goggles, earplugs etc.				
Yes		No		

	Type of equipment
Manager	
Department leader	
Production Head	
Occupational Health and Safety (OHS) Facilitator	
Panel Operator 2	
Production operator 1	
Production operator 2	

102. Is the main work time (hours) pre-defined? E.g., 8h a day, from 7h00 to 18h00
Please, detail the information per group of employees.

	Horas
Manager	
Department leader	
Production Head	
Occupational Health and Safety (OHS) Facilitator	
Panel Operator 2	
Production operator 1	
Production operator 2	
Manager	
Department leader	
Production Head	

103. How many employees, in percentage terms, work under a temporary work contract?
Please, detail the information per group of employees.

	Hours
Manager	
Department leader	
Production Head	
Occupational Health and Safety (OHS) Facilitator	
Panel Operator 2	

Production operator 1	
Production operator 2	
104. How many employees, in percentage terms, work on a flexitime basis?	
Please, detail the information per group of employees.	
	Flex-time
Manager	
Department leader	
Production Head	
Occupational Health and Safety (OHS) Facilitator	
Panel Operator 2	
Production operator 1	
Production operator 2	
105. The number of hours in unskilled work (manual labour)?	
Please, detail the information per group of employees.	
	Hours of manual labour per day
Manager	
Department leader	
Production Head	
Occupational Health and Safety (OHS) Facilitator	
Panel Operator 2	
Production operator 1	
Production operator 2	
106. How many trainees or apprentices does the company have every year? Please, inform the type per workgroup.	
Please, detail the information per group of employees.	
	Volume
Manager	
Department leader	
Production Head	
Occupational Health and Safety (OHS) Facilitator	
Panel Operator 2	
Production operator 1	

Production operator 2	
107. On average, how many hours of training to employees get per year? Please, specify the type of training (technical training).	
Please, detail the information per group of employees.	
	Hours of training
Manager	
Department leader	
Production Head	
Occupational Health and Safety (OHS) Facilitator	
Panel Operator 2	
Production operator 1	
Production operator 2	
108. Other notes or additional comments:	

Beneficiation Unit Manager

SOCIAL LIFE CYCLE ASSESSMENT FORM – Ore processing unit

INDUSTRY DATA	
Respondent Name:	
Job Title:	Dept.: Beneficiation Unit 2
Date:	
Base year: 2017	

QUIZ	
109. Working hours at the mining site 8h()12h()24h(X	
110. Total number of employees in the operation	
111. Total number of teams	
112. How many employees are there in each team per shift?	
113. Number of teams per shift of operation	
114. Resting time per team	
Other comments:	
115. Operation's flow chart detail (e.g.: ((4) backhoe operators, (1) management supporter, (1) team leader, (1) operations manager etc.)	

Volume	Role or position
	Manager
	Department leader
	Management supporter
	Online Analyst assistant
	Production Assistant
	Production head
	Maintenance Facilitator
	Panel Operator 1
	Panel Operator 2
	Production operator 1
	Production operator 2
	Production operator 3

116. The number of unskilled workers (e.g., oven operator, digger, machine feeding operator, etc.):	
117. Within this area, how many employees are directly involved in the FeNb production?	Total:
Please, detail per group of employees with their respective educational background.	

	Volume	Educational background (schooling)
Manager		
Department leader		

Management supporter		
Online Analyst assistant		
Production Assistant		
Production head		
Maintenance Facilitator		
Panel Operator 1		
Panel Operator 2		
Production operator 1		
Production operator 2		
Production operator 3		

118. At this stage, what is the operating time required to produce 1 ton of FeNb?		
119. How much of this time consists of manual labour, and how much consists of machine handling?	Manual labour:	Machine handling:

120. Do you get training on health care and the prevention of work-related accidents?				
Yes		No		

If you answered Yes, please, list the training you attended each year.	
121. What is the average number of cases of occupational diseases per year? Please, specify.	
122. What is the average number of deaths due to the activities in this unit per year? Please, specify the reasons.	
123. What is the average rate of injuries in this unit per year? Please, specify the types of injuries.	

124. Do employees undergo health check-ups? How often per year?				
Yes		No		

If the answer is Yes, please, indicate the number per group of employees:	
Manager	
Department leader	
Management supporter	
Online Analyst assistant	
Production Assistant	
Production head	
Maintenance Facilitator	
Panel Operator 1	
Panel Operator 2	
Production operator 1	
Production operator 2	
Production operator 3	

125. On average, how many work hours are there per week?				
Yes		No		
If the answer is Yes, please, indicate the number per group of employees: :				

	Volume
Manager	
Department leader	
Management supporter	
Online Analyst assistant	
Production Assistant	
Production head	
Maintenance Facilitator	
Panel Operator 1	
Panel Operator 2	
Production operator 1	
Production operator 2	
Production operator 3	

126. Are there any emergency plans in place? E.g., in case of fire. Please, specify the plans.				
Yes		No		
Which are they?				
127. Does this Unit have a Health and Safety Committee with the participation of employees?				
Yes		No		
128. Are employees equipped with personal protective equipment (PPE)? E.g., Safety goggles, earplugs, etc.				
Yes		No		

	Type of equipment
Manager	
Department leader	
Management supporter	
Online Analyst assistant	
Production Assistant	
Production head	
Maintenance Facilitator	
Panel Operator 1	
Panel Operator 2	
Production operator 1	
Production operator 2	
Production operator 3	

129. Is the main work time (hours) pre-defined? E.g., 8h a day, from 7h00 to 18h00	
Please, detail the information per group of employees.	
	Horas
Manager	
Department leader	
Management supporter	
Online Analyst assistant	
Production Assistant	
Production head	
Maintenance Facilitator	
Panel Operator 1	
Panel Operator 2	
Production operator 1	
Production operator 2	
Production operator 3	
130. How many employees, in percentage terms, work under a temporary work contract?	
Please, detail the information per group of employees.	
	Hours
Manager	
Department leader	
Management supporter	
Online Analyst assistant	
Production Assistant	
Production head	
Maintenance Facilitator	
Panel Operator 1	
Panel Operator 2	
Production operator 1	
Production operator 2	
Production operator 3	
131. How many employees, in percentage terms, work on a flexitime basis?	
Please, detail the information per group of employees.	
	Flex-time

Manager	
Department leader	
Management supporter	
Online Analyst assistant	
Production Assistant	
Production head	
Maintenance Facilitator	
Panel Operator 1	
Panel Operator 2	
Production operator 1	
Production operator 2	
Production operator 3	
132. The number of hours in unskilled work (manual labour)?	
Please, detail the information per group of employees.	
	Hours of manual labour per day
Manager	
Department leader	
Management supporter	
Online Analyst assistant	
Production Assistant	
Production head	
Maintenance Facilitator	
Panel Operator 1	
Panel Operator 2	
Production operator 1	
Production operator 2	
Production operator 3	
133. How many trainees or apprentices does the company have every year? Please, inform the type per workgroup.	
Please, detail the information per group of employees.	
	Volume
Manager	
Department leader	
Management supporter	
Online Analyst assistant	

Production Assistant	
Production head	
Maintenance Facilitator	
Panel Operator 1	
Panel Operator 2	
Production operator 1	
Production operator 2	
Production operator 3	
134. On average, how many hours of training to employees get per year? Please, specify the type of training (technical training).	
Please, detail the information per group of employees.	
	Hours of training
Manager	
Department leader	
Management supporter	
Online Analyst assistant	
Production Assistant	
Production head	
Maintenance Facilitator	
Panel Operator 1	
Panel Operator 2	
Production operator 1	
Production operator 2	
Production operator 3	
135. Other notes or additional comments:	

Unit Manager

APÊNDICE IV – Projects funded by CBMM through the incentive law for cultural heritage (2017).

Project name	Observation	PRONAC Code	Investment amount (R$)
Urban Culture - Art and Culture across the Communities	Dance festival for the Araxá population (including groups at social risk)	162,070	R$ 380,000.00
33Th Drivers Party: Tradition and culture in one place	Popular traditional festival for truck drivers.	160,690	R$ 120,000.00
Lit-up Araxá Theatre	Cultural activity in Araxá	160,960	R$ 400,000.00
FLIARAXá – LiteraryFestival – 6th Edition	Literary Festival of Araxá	164,897	R$ 1,810,000.00
Revelry of the three Kings 27Meeting - The faith and bravery of Filomena, the martyr.	Popular culture and religious ceremony	160,666	R$ 60,000.00
Celb: Overcoming barriers	Project using Art as a therapy to support visually impaired groups	160,387	R$ 100,000.00
Earth's heritage: The Canastra's Mountain Chain and the Paraná River	Book with geological information, natural aspects and the population of the Canastra Mountain Chain, a State park nearby Araxá.	151,960	R$ 900,000.00
Artistic Program of the II Festival of Araxá's Wisdom and Flavours	Music and arts festival with tickets at popular prices	170,771	R$ 329,000.00
Annual Activity and Maintenance Plan 2017 - Inhotim Institute	The purpose of the project is to maintain such a special open-air museum in operation. The institute is far from Araxá, but close to the Brumadinho dam disaster area.	170771	R$ 329.000,00
This is one of the most important Modern and Contemporary Art open-air museums in the world.	163,824	R$ 16,441,868.69	R$ 16.441.868,69
17th Dançaraxá Festival	Dance festival	170,261	R$ 135,000.00
ECOAR - Ecology with Art (Children's shows)	Children theatre plays featured in different cities, including Araxá.	160,377	R$ 500,000.00
1/3 Christmas Festival - Year IX.	Christmas city activities and music festival	171,602	R$ 1,028,000.00

Project name	Observation	PRONAC Code	Investment amount (R$)
History Album - The families from Araxá.	History book about traditional families in the Araxá area.	171,080	R$ 100,000.00
Featuring the Maestro Elias Porfírio Orchestra	Presentation of the orchestra as a homage to Maestro Elias Porfírio, in Araxá.	171,686	R$ 50,000.00
2/3 Christmas Festival with art activities	Christmas Festival	171,602	R$ 1,000,000.00
3/3 Christmas Festival with arts activities	Christmas Festival	171,602	R$ 1,000,000.00
2nd Araxá Music Festival	Music festival for new musicians	170,347	R$ 55,000.00
Say Yes	Project focused on recruiting young people to learn Acting and Music for a play.	165,050	R$ 150,000.00
27th SESI Meeting of Performing Arts	Theatre plays' festival held in different places around the city of Araxá.	171,094	R$ 560,000.00
Roaming Exhibit: Brazilian Indigenous Stools	Exhibition on Brazilian indigenous people's culture (as part of an international tour).	163,248	R$ 752,000.00
Lit-up Easter	Cultural activities during Easter	176,996	R$ 215,000.00
First meeting	Brazilian literature event in many cities (including Araxá)	154,042	R$ 120,000.00
Always a chat	Project activities intended to foster the taste for literature and to read across some cities (Araxá included).	178,738	R$ 780,000.00
Book "Liporema Meropil: Na Floresta de Alfabeto e o Sumiço das Vogais." [Liporema Meropil: the alphabet forest and the vowels disappearance]	Literary activities to encourage children to read.	178,379	R$ 60,000.00
FLIARAXÁ - Literary Festival of Araxá – 7th Edition	Literary Festival of Araxá	178,998	R$ 2,200,000.00

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