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# OekoRess II: Country Case Study VII: Brazil - Niobium (Barreiro complex)

by

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## Abstract

The project "Further development of policy options for an ecological raw materials policy" (OekoRess II) builds on the results of two preceding research projects, UmSoRess and OekoRess I. It links experiences gained in the analysis of environmental and social standards with the assessment of environmental risks in the mineral resources sector. The project team conducts 10 case studies to evaluate and refine the method to assess site-related environmental hazard potentials posed by mining operations, which was developed in the OekoRess I project. The focus is on improving the indicator for environmental sector governance, by comparing the assessed environmental hazard potentials, the observed environmental impacts and the governance analysis with existing governance indicators. The aim is to answer the questions whether existing governance indices and indicators are able to adequately reflect the capacity of governments, companies and civil society to manage potential environmental hazards and avoid or reduce environmental impacts of mining.

This study analyses the environmental hazard potentials and the environmental impacts of the niobium open pit mine at the Barreiro-complex in Araxá, Brazil. Although niobium does not represent a large share of Brazil's mineral exports in terms of quantity, the mine is of particular importance due to the fact that Brazil is the biggest exporter of niobium worldwide and the Barreiro-complex is the biggest niobium mine in Brazil. The mine covers a large area in the ecologically important and sensitive Cerrado region, affecting local biodiversity. Furthermore, elevated levels of radioactive components were found in surrounding waterbodies.

In general, Brazil's mining governance is characterized by sound environmental legislation, but often insufficient implementation. This is very well described by the Fraser Policy Perception Index (FPI). Brazil's generally average sector governance is also well reflected by the Worldwide Governance Indicators (WGI) and the Environmental Performance Indicator (EPI), but they do not seem to fully capture the lacking implementation.

## Kurzbeschreibung

Das Vorhaben „Weiterentwicklung von Handlungsoptionen einer ökologischen Rohstoffpolitik" (ÖkoRess II), welches auf den Ergebnissen zweier vorangegangener Forschungsprojekte (UmSoRess und ÖkoRess I) aufbaut, verbindet Erfahrungen aus der Analyse von Umwelt- und Sozialstandards mit der Bewertung von Umweltrisiken im Rohstoffsektor. Das Projektteam führt 10 Fallstudien durch, um die im Rahmen des ÖkoRess-I-Projekts entwickelte Methode zur Bewertung standortspezifischer Umweltgefährdungspotenziale im Bergbau zu evaluieren und weiterzuentwickeln. Der Fokus liegt auf der Verbesserung des Indikators für Umwelt-Governance, indem die bewerteten Umweltgefährdungspotenziale, die tatsächlichen Umweltauswirkungen und die Governance-Analyse mit vorhandenen Governance-Indikatoren verglichen werden. Ziel ist es, die Frage zu beantworten, ob die Governance-Indikatoren in der Lage sind widerzuspiegeln, inwiefern relevante Akteure (Regierungen, Unternehmen und Zivilgesellschaft) potentielle Umweltgefährdungen bewältigen und Umweltauswirkungen des Bergbaus vermeiden oder reduzieren können.

Diese Studie analysiert das Umweltgefährdungspotenzial und die tatsächlichen Umweltauswirkungen des Niob-Tagebaus im Barreiro-Komplex in Araxá, Brasilien. Obwohl Niob mengenmäßig keinen großen Anteil an den brasilianischen Mineralexporten ausmacht, ist die Mine von besonderer Bedeutung, da Brasilien der größte Exporteur von Niob weltweit ist und der Barreiro-Komplex die größte Niob-Mine Brasiliens ist. Die Mine erstreckt sich über ein großes Gebiet in der ökologisch bedeutsamen und sensiblen Cerrado-Region und beeinträchtigt die lokale Biodiversität. Darüber hinaus wurden erhöhte Konzentrationen radioaktiver Komponenten in den umliegenden Gewässern festgestellt.

Im Allgemeinen ist die brasilianische Bergbauverwaltung durch eine solide Umweltgesetzgebung gekennzeichnet, die jedoch oft nicht ausreichend umgesetzt wird. Dies wird durch den Fraser Policy Per-

ception Index (FPI) sehr gut wiedergespiegelt. Während Brasiliens generell durchschnittliche Bergbau-Governance gut in den Worldwide Governance Indicators (WGI) und dem Environmental Performance Indicator (EPI) erkennbar ist, scheinen sie die mangelnde Umsetzung nicht vollständig zu erfassen.

# Table of Contents

List of Figures .......... 6

List of Tables .......... 7

1 Focus of the study and relevance .......... 9

2 Structure and macroeconomic relevance of Brazil's mining sector .......... 11

3 Overview of mining operation and geology in Araxá .......... 14

  3.1 Geography .......... 14

  3.2 Geological context and ore deposit formation .......... 16

  3.3 Mining and Processing .......... 18

4 Overview of environmental hazard potentials and environmental impacts .......... 20

  4.1 Environmental hazard potentials .......... 20

    4.1.1 Geology .......... 21

    4.1.2 Technology .......... 22

    4.1.3 Site (surroundings) .......... 23

  4.2 Environmental impacts .......... 24

    4.2.1 Pressure .......... 24

    4.2.2 State and Impacts .......... 25

    4.2.3 Responses .......... 26

5 Governance .......... 27

  5.1 Sector governance, regulation and effectiveness of national institutions .......... 27

  5.2 Social context of mining and conflicts .......... 31

6 Conclusion and comparison of the analysis with existing governance indices .......... 32

7 References .......... 38

## List of Figures

Figure 2-1: Mineral Exports of Brazil ....................12
Figure 3-1: The location of the Araxá-Project in the state of Minas Gerais, Brazil ....................15
Figure 3-2: Schematic interpretation of the Araxá carbonatite geology ....................18
Figure 4-1: DPSIR Framework ....................24

# List of Tables

Table 2-1: Mineral Production in Brazil in 2014 ........ 13
Table 3-1: Average mineralogical composition of Araxá residual ore ........ 17
Table 4-1: Site-related OekoRess assessment ........ 21
Table 6-1: Overview of the governance indicators ........ 36

## List of Abbreviations

| | |
|---|---|
| **AMD** | Acid Mine Drainage |
| **ANM** | Agência Nacional de Mineração (National Mining Agency) |
| **AZE** | Alliance for Zero Extinction |
| **CBMM** | Companhia Brasileira de Metalurgia |
| **CFEM** | Compensação Financeira pela Exploração de Recursos Minerais (Financial Compensation on Mineral Exploration) |
| **CIMI** | Indigenous Missionary Council |
| **CODEMIG** | Companhia de Desenvolvimento Econômico de Minas Gerais |
| **CPI** | Corruption Perception Index |
| **DNPM** | Departamento Nacional de Produção Mineral (National Department of Mineral Production) |
| **DPSIR** | Driving forces, Pressures, States, Impacts and Responses |
| **EPI** | Environmental Performance Index |
| **FUNAI** | Fundação Nacional do Índio (National Indian Foundation) |
| **GDP** | Gross Domestic Product |
| **GSHAP** | Global Seismic Hazard Assessment Program |
| **IBAMA** | Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (Brazilian Institute of Environment and Renewable Natural Resources) |
| **ICMBio** | Instituto Chico Mendes de Conservação da Biodiversidade (Chico Mendes Institute for Biodiversity Conservation) |
| **MME** | Ministry of Mines and Energy |
| **NEP** | National Environmental Policy |
| **OekoRess** | Research Project 'Discussion of ecological limits of raw materials production and development of a method to evaluate the ecological availability of raw materials with the aim of further developing the criticality concept' |
| **PA** | Protected Area |
| **REE** | Rare Earth Element |
| **UmSoRess** | Research Project 'Approaches to reducing negative environmental and social impacts in the production of metal raw materials' |
| **USGS** | United States Geological Survey |
| **WGI** | Worldwide Governance Indicators |
| **WSI** | Water Stress Index |

# 1 Focus of the study and relevance

The following is the seventh of ten case studies that are being prepared as part of the project "Further development of policy options for an ecological raw materials policy" (OekoRess II), commissioned by the German Federal Environment Agency. The case studies build on the results of two previous research projects, the UmSoRess[1] project and the OekoRess I[2] project. In UmSoRess, the impacts of raw material production on the environment, society and the economy were analysed in 13 case studies.[3] The goal of the case studies was to gain a better understanding of the connections between the environmental and social impacts of mining in the context of various countries with different problems and governance contexts. In OekoRess, I a method to evaluate the ecological availability of raw materials and the site-related environmental hazard potentials posed by mining operations was developed, with the aim to further develop the criticality concept.

As part of the follow-up project OekoRess II, 10 additional case studies will be conducted, combining the analytical approaches of UmSoRess and OekoRess I in order to evaluate and further develop the method to assess the site-related environmental hazard potentials posed by mining operations, which was developed in the OekoRess I project. This effort will particularly focus on improving the indicator for environmental sector governance used in the methodology, by comparing the assessed environmental hazard potentials, the observed environmental impacts and the governance analysis with existing governance indicators. The aim is to answer the questions if existing governance indices and indicators are able to adequately reflect the capability of governments, companies and civil society to manage potential environmental hazards and avoid or reduce environmental impacts of mining. The results of the 10 case studies will be compared and a set of governance indicators will be identified that can be used to improve the raw-material-related assessment approach developed as part of the OekoRess I project.

This study analyses the environmental hazard potentials and the environmental impacts of the niobium open pit mine at the Barreiro-complex in Araxá, Brazil, and the countries´ mining governance. Even though the mining project is of minor importance for the Brazilian economy, the mine produces a significant amount of niobium for the global markets. Niobium is - due to its corrosion and heat resistance and its superconducting abilities - crucial for producing high-tech materials and is almost indispensable for certain industries such as the aerospace industry or automobile manufacturing (Alves and Coutinho 2015; Mineralienatlas 2017).

Although the Araxá niobium mining project has been in operation for several decades, only limited information on the environmental impacts of the mine was publicly available. As the mining company does not provide any reports, there was only limited information available on topics such as the size of the mining operation, the use of water, the storage of tailings or the levels of pollution of soils and water bodies.

The deposits of the area naturally show elevated concentrations of radioactive minerals. The major environmental threats of Niobium mining operation in Araxá are the use of land, the emission of (radi-

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[1] Approaches to reducing negative environmental and social impacts in the production of metal raw materials. For more information see https://www.umweltbundesamt.de/umweltfragen-umsoress

[2] Discussion of ecological limits of raw materials production and development of a method to evaluate the ecological availability of raw materials with the aim of further developing the criticality concept. For more information see https://www.umweltbundesamt.de/umweltfragen-oekoress

[3] The case studies and fact sheets on the standards and approaches analysed can be accessed here: https://www.umweltbundesamt.de/umweltfragen-umsoress

oactive) dust and the contamination of waters due to mining. Furthermore, there may be negative impacts on workers' health and the dispersal of radioactive materials through processing.

The case study is divided into four parts: First, the structure of the mining sector of Brazil and its contribution to the national economy is analysed (chapter 2). Second, a brief overview of the Barreiro mining complex is given. The geographic and geologic context is analysed, followed by an overview of the applied mining and processing methods (chapter 3). Third, the environmental hazard potentials posed by the mining operation are discussed using the site-related OekoRess methodology, and selected environmental impacts and reactions to these are described using the DPSIR framework that was also used in the UmSoRess case studies (chapter 4).[4] Fourth, the governance of Brazil's mining sector is analysed (chapter 5). Lastly, the findings of the assessment of the environmental hazard potentials and environmental impacts and the governance analysis are compared to existing governance indicators and indices, and first conclusions for the methodology development are drawn (chapter 6).

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[4] The DPSIR framework comprehensively accounts and visualizes the causal connection between environmental issues, their origin, their impacts and the responses taken. The model consists of driving forces, pressures, state, impacts and responses. For further information see e.g. Kristensen (2004).

## 2 Structure and macroeconomic relevance of Brazil's mining sector

Brazil is the geographically largest Latin American country and the fifth largest country globally (DERA 2014). With around 205 million inhabitants and a nominal gross domestic product (GDP) of 1.796 trillion € in 2016 (World Bank 2017a), the country is the seventh-largest national economy in the world and the leading nation in Latin America. Brazil is one of the world's most important raw material producers, in particular for niobium, tantalum, iron ore, bauxite and increasingly also for oil (DERA 2014). The value of minerals produced in Brazil in 2012 was 51 billion USD (DERA 2014).

Compared to other mining countries, the GDP contribution of the extractive industry is small, as non-fuel resources constitute only a low percentage of total GDP (between 1 and 4 per cent, depending on the source and the year; see: ICMM 2013; Soto-Viruet 2013; World Bank 2017a). The service sector is the most important sector for the national economy, generating 73 per cent of GDP and providing 77 per cent of all jobs in Brazil (Statista 2017). The industrial sector accounts for around 22 per cent of employment (Statista 2017).

Nonetheless, mining has considerable effects on the local economic and social structure of some of the country's regions. Especially in rural areas, where the population density is rather low, the mining sector is an important employer and triggers further investments, for instance in infrastructure (ICMM 2013). In 2011, the year of peak production, 175,000 people were directly employed in the mining sector.[5] Furthermore, the sector is assumed to have a multiplier effect of 1:13 in Brazil, which leads to the creation of 2.2 million additional, indirect jobs (IBRAM 2012). In addition, it is estimated that about 300,000 to 500,000 artisanal miners are not covered in the statistics. Artisanal miners mostly engage in the mining of minerals such as gold or diamonds, whereas niobium and iron ore are mostly industrially mined (IBRAM 2012).

Exports contribute a share of 12.9 per cent to the Brazilian GDP, which is below the average of all Latin American countries (20.6 per cent) and less than half the global average (29.4 per cent) (World Bank 2017a). In Brazil, exports are mainly driven by various raw materials and non- or semi-processed products, especially soy products, meat, sugar and iron ore. The biggest export market is China, followed by the EU and the USA (ResourceTrade.Earth 2017). According to the Brazilian government, mining contributed approximately 20 per cent of total export value in 2016[6] (BrazilGovNews 2017). Iron ore is the most important mineral product contributing 80 per cent of all mineral exports, followed by gold, niobium and copper (Figure 2-1; IBRAM 2012; see also Brazil's mineral production in Table 2-1). In 2012, niobium contributed only 4.68 per cent to Brazil's non-fuel mineral exports, but at the same time Brazil was the most important producer of niobium and niobium products globally. Approximatly 95 per cent of all niobium deposits worldwide are in the national territory of Brazil and the country accounts for 80 to 90 per cent of the global niobium production. Therefore, the country has a strategic position in the global markets (DERA 2014; USGS 1996 - 2017).

Niobium is of particular importance for many industries in the European Union and especially for those industries that have a high demand for steel materials as niobium is commonly used in alloys. The annual consumption of niobium in the European Union ranges between 10,000 and 30,000 tons and exceeded 40,000 tons in 2014. There is no active niobium production within the European Union and all niobium is imported. Because of this dependency and a limited number of niobium suppliers on the global markets, niobium is considered as a critical resource (ITZ and adelphi 2011; MSP Refram

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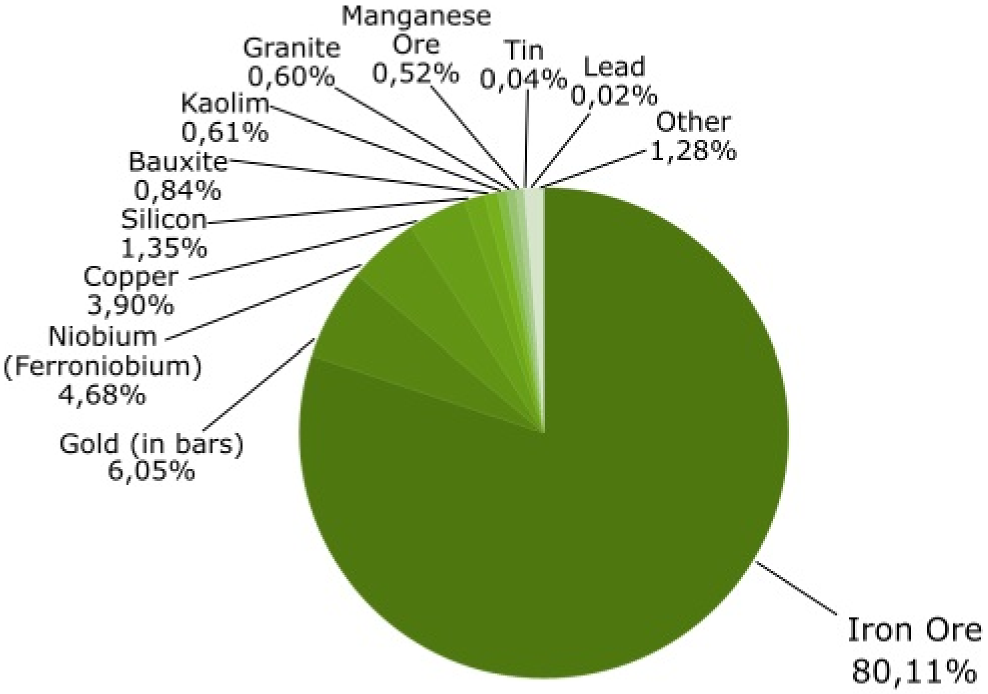
[5] In comparison, the tourism sector directly employed 2.53 million people in 2014 (WTTC, 2017).

[6] Total export of the mining sector accounted for 36.6 billion US$ (compared to 185.2 billion US$ of total exports; BrazilGovNews, 2017).

2017). Nevertheless, steel manufacturers rarely substitute niobium with other materials (ITZ and adelphi 2011) and due to the low niobium content in steel alloys; niobium recycling is not economical in the current market situation (Angerer et al. 2013).

Figure 2-1: Mineral Exports of Brazil



Source: IBRAM (2012).

The role of Brazil as the biggest player in niobium markets grew over the years: The USGS (1996-2017) estimates a development of the global niobium production from approximately 16,000 t in the mid-1990s to around 92.000 t in 2014. In Brazil, 58,000 t were reached in the period from 2007 to 2011, followed by an intermediate drop due to the global economic crises in the early 2010s and has recovered since 2014 (reaching 73.700 t, see Table 2-1) (USGS 2017). There are only three active niobium mining projects in Brazil: Pitinga in the Amazon state, Catalão de Goiás in Goiás and the Barreiro complex in Araxá (state of Minas Gerais) (DERA 2014). The latter is by far the most important of these mines (see chapter 3; Soto-Viruet 2013; DERA 2014). While the mines in Pitinga and Catalão are operated by foreign firms, a Brazilian company is the main stakeholder in the Barreiro project[7] (see section below).

The Brazilian mining sector is predomninantly characterised by private companies. For instance, the largest mining company in Brazil is Vale S.A., which used to be state-owned company but was privatized in 1997 (Vale 2012). Today, the company is mainly privately owned by both national and international shareholders. The Brazilian government holds 12 'golden shares' which gives it privileges such as a veto-right over a wide range of buisness operations (Vale 2017).

Regarding the Barreiro complex in Araxá, mining concessions are conceded to two companies: The first, Companhia Brasileira de Metalurgia e Mineração (CBMM), is a private company. 70 per cent of it are held by the Moreira-Salles Group. The remaining 30 per cent belong to Japanese and Chinese shareholders who each own a stake of 15 per cent (CBMM 2017a). The second company, Companhia

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[7] The Boa Vista mine in Catalao that previously belonged to Anglo American is now owned by China Molybdenum Co., Ltd. (CMOC2020); the Pitinga mine in the Amazon state belongs to the Peruvian mining company Minsur (MiningAtlas.com 2018)

de Desenvolvimento Econômico de Minas Gerais (CODEMIG), is owned by the federal state of Minas Gerais. However, it is not directly involved in niobium production itself. To manage the ore extraction, these two companies founded Cosimir as a subcontractor to exploit the niobium deposit. CODEMIG receives 25 per cent of the net profit achieved by CBMM's niobium operations (CBMM 2017a).

Table 2-1: Mineral Production in Brazil in 2014

| **Mineral** [*= critical according to EC 2014] | **Production 2014** | | |
|---|---|---|---|
| | **Volume [t]** | **% of ∑ World** | **Rank** |
| Asbestos *(fiber)* | 311,230 | 14% | 3 |
| Bauxite *(dry basis, gross weight)* | 35,000,000 | 14% | 3 |
| Crude Steel *(excluding castings)* | 33,900,000 | 2% | 9 |
| Graphite *(concentrate)* | 80,000 | 7% | 3 |
| Iron ore *(gross weight)* | 411,183,000 | 12% | 3 |
| Manganese *(gross weight)* | 2,498,000 | 6% | 5 |
| Niobium *(Pyrochlore concentrate, $Nb_2O_5$ content)*∗ | 73,700 | 89% | 1 |
| Tantalum *($Ta_2O_5$ content)* | 190 | 12% | 3 |
| Vermiculite *(concentrate)* | 68,000 | 18% | 3 |

Source: USGS (2017).

# 3 Overview of mining operation and geology in Araxá

Niobium is a lithophilic element often referred to as the ‘geochemical twin’ of tantalum. Its primary deposits are all associated with igneous rocks. Niobium and tantalum usually occur jointly in different weightings. Economically viable deposits of niobium occur most commonly in carbonatites but also in alkaline to peralkaline granites and syenites as well as peraluminous pegmatites. In the carbonatitic deposits, niobium is often associated with uranium, thorium and Rare Earth Elements (REEs), while peraluminous pegmatites are more prone to an association with caesium (Vaupel and Maassen 2011, Linnen et al. 2014). Both niobium and tantalum are resistant to weathering and comprise high specific gravities, which favours their accumulation in alluvial deposits. Such deposits play an important role for the world production during periods of tight supplies (Linnen et al. 2014). The minerals of the pyrochlore group are by far the most important ore minerals for niobium, but niobium also occurs in columbite -and here in paragenesis with cassiterite and other pegmatite minerals (Linnen et al. 2014).

As stated before, 80-90 per cent of the world’s niobium is produced in Brazil, with three mines being in operation (USGS 2017). The world’s largest niobium deposit is the Barreiro carbonatite complex belonging to the Araxá Group, a geological formation containing exceptionally large reserves of more than 820 Mt of niobium-rich pyrochlore ore. It is located in the Araxá district of Minas Gerais. The mine is managed by CBMM, the world’s largest niobium producer and supplier and the sole company present in all niobium market segments (Patel 2014; CBMM 2017a).

The pyrochlore deposit near Araxá was discovered in 1953. The mining and production operations began in 1961 (CBMM 2017b).

## 3.1 Geography

The niobium open-pit mine of CBMM is located 5 km south of the municipality Araxá and approximately 350 km west of the state’s capital Belo Horizonte (see Figure 3-1). Headquarters, manufacturing facilities and a technology centre are located in the immediate vicinity of the mine (CBMM 2017c).

Figure 3-1: The location of the Araxá-Project in the state of Minas Gerais, Brazil

Source: Open Street Map (n.d.)

The niobium mine of CBMM is located adjacent to the Vale Fertilizantes S.A.'s phosphate mine as well as to the Araxá Project of MBAC Fertilizer Corp. (now Itafos), an exploration project with mineral resources of rare earths, niobium and phosphate (Clay and Ackroyd 2013).

The Araxá region lies within a geological old area called Brazilian Highlands. Rising to an average elevation of 1,000 ma.s.l., the highlands are characterized by a hilly relief and tabular plateau formations (Brawer 1991).

The mine is connected to the city of Araxá by a tarred road (BR 146) and has good infrastructural links to the major cities of Brazil. The city is served by the Araxá Airport and the cargo transports of the Centro Atlântica Railway pass the city.

The climate in Araxá is warm and temperate, with summers being much rainier than the winters. In the Köppen-Geiger system, the climate is classified as Cwa-climate – a Monsoon-influenced humid subtropical climate. The average annual temperature is 20.2 °C and the rainfall averages 1,626 mm. The driest month with also lowest average temperatures in the year is June, with 17 mm of rainfall and around 17.3 °C. The highest amount of precipitation occurs in January, with an average of 297 mm. The warmest month of the year is January, with an average temperature of 22.2 °C (Climate-Data.org 2017).

In the area of the Barreiro Complex some smaller rivers have their source. These are part of the Paranaiba River Basin which is one of the main rivers of the, Paraná Great Basin. Mining takes place in a microbasin called Córrego do Sal (Clay and Ackroyd 2013).

The Araxá mine is located in a vast tropical savannah ecoregion – the Cerrado. It is the largest savannah region in South America and biologically the world's richest savannah. The biodiversity of Cerrado is extraordinary with at least 10,400 species of vascular plants, 780 of fishes, 180 of reptiles, 113 of amphibians, 837 of birds and 195 of mammals. During the last decades, the Cerrado landscape has been strongly impacted and modified. Nature reserves or national parks cover only 1% of the total area of the Cerrado (WWF 2017a). The major threat to the Cerrado's biodiversity comes from unsustainable agricultural activities, as soy production, livestock farming and deforestation (WWF 2017b).

## 3.2 Geological context and ore deposit formation

The Barreiro Carbonatite complex belongs to the alkaline ultramafic carbonatite complexes of the Alto Paranaíba igneous province (Linnen et al. 2014; Nasraoui and Warenborgh 2001). The complex lies within the Araxá Group, a pelitic metasedimentary formation deposited by erosion processes. (CBMM 2017d). The Araxá Group comprises mica schists, which are associated with quartzite (CBMM 2017d; Issa Filho et al. 2001).

The Barreiro Carbonatite complex is situated 5 km south of the city of Araxá. The circular structure with a surface diameter of approximately 5 km intruded roughly 90 million years ago, in the Late Cretaceous, into the Araxá schists. .. Dolomite is the predominant mineral of the Barreiro Carbonatite complex with subordinate calcite and ankerite, surrounded by glimmerite and phoscorite (Issa Filho, et al.2001; Linnen et al. 2014; Nasraoui and Warenborgh 2001; Traversa 2001).

At the contact zone between the Barreiro Carbonatite complex and the surrounding proterozoic quarzites of the Araxá Group, alterations occur up to a distance of 2.5 km from the intrusive contact (Linnen et al. 2014). Additionally, weathering and erosion has created a lateritic cover of 1,800 m in diameter and up to 230 m thickness in the central part of the dome structure (Nasraoui and Warenborgh 2001).

In the unweathered primary ore, Niobium occurs as oxide in the mineral pyrochlore. The above mentioned phoscorite – a magnetite-apatite-phologpite-carbonate rock– shows the highest concentration of pyrochlore[8] in the unweathered rock (Nasraoui and Warenborgh 2001). The primary ore of the Araxá deposit has a mean grade of 1.5% $Nb_2O_5$ (niobium oxide), and a maximum grade of 8% $Nb_2O_5$.

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[8] A mineral group (Pyrochlore Group) of Niobium containing minerals.

Table 3-1: Average mineralogical composition of Araxá residual ore

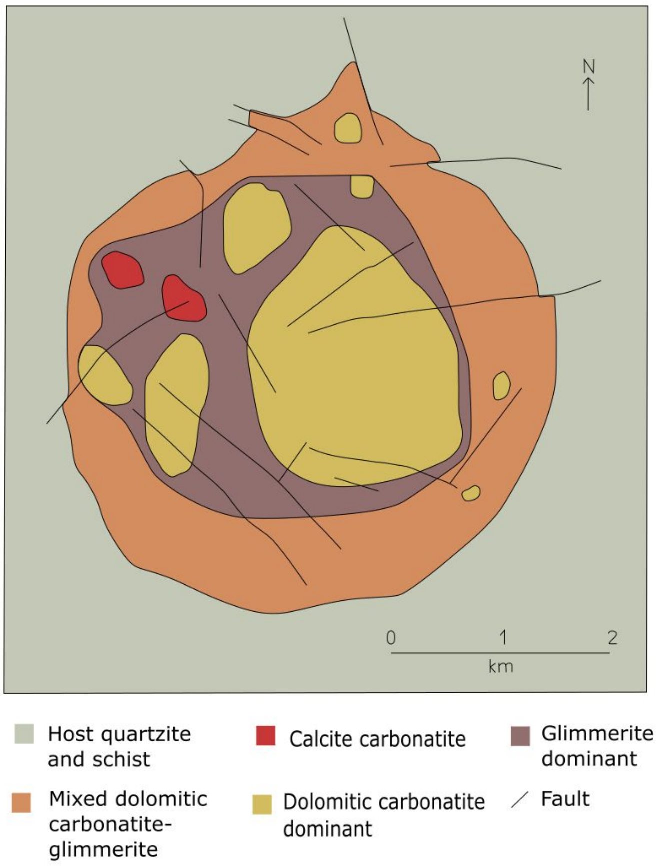
| Mineral | % |
|---|---|
| Bariopyrochlore | 4 |
| Limonite, goethite (includes silica in the plasma) | 36 |
| Barite | 20 |
| Magnetite | 16 |
| Gorceixite | 6 |
| Monazite | 4 |
| Ilmenite | 5 |
| Quartz | 4 |
| Others | 5 |
| Total | 100 |

Source of information: Issa Filho, Riffel and de Faria Sousa (2001).

Niobium moreover occurs in the lateritic cover in residual ore. Due to weathering processes, pyrochlore was altered to secondary niobium-rich barium-pyrochlore (Pell 1996 as cited in Linnen et al. 2014; Mariano et al. 1997). Only the residual ore that forms the largest known niobium reserves in the world is mined (Nasraoui and Warenborgh 2001; Clay and Ackroyd 2013). It comprises 457 million tons of ore reserve containing 11.4 million tons niobium. The mined residual ore has a mean concentration of 2.5% $Nb_2O_5$ (Issa Filho et al.2001; Germany Trade and Invest 2015) but drilling performed in 2001 revealed zones with 4.6 to 7% $Nb_2O_5$ (CBMM 2017d; Issa Filho et al.2001). Table 3-1 (above) shows the mineralogical composition of the Araxá residual niobium oreTable 3-1.

The complex has magnetic and radioactive anomalies, particularly at the centre (CBMM 2017d; Issa Filho et al.2001). The radioactive anomalies can be explained by the presence of typically radioactive minerals (e.g. pyrochlore or monazite with varying uranium-/thorium-contents (Hochleitner et al. 1996)); the magnetic anomalies are caused by the presence of magnetite in the phoscorite.

Figure 3-2: Schematic interpretation of the Araxá carbonatite geology



Source: Own Graphic based on information from Linne et al. (2014).

## 3.3 Mining and Processing

Due to the friable residual ore, there is no need for explosives or drilling. The residual ore can be exploited with an open-pit. When the residual ore reserves will be exhausted, the unweathered primary ore will be dismantled. The pit walls have an inclination of 32 degrees with 10 m high strata sets. The friable residual ore is easily uncovered by bulldozers. After uncovering, the loosened ore is loaded with front loaders on dump trucks and is transported to a 3.2 km long conveyor belt, which transports the ore from mine to mill (Issa Filho et al.2001).

CBMM's mining complex in Araxá comprises a concentration plant, refining and metallurgical facilities for niobium oxide, special oxides, special alloys and niobium metal as well as transport infrastructure. CBMM sells only processed and finished niobium products. Niobium ore does not leave Araxá without being transformed into higher value-added, finished niobium products. CBMM's production capacity amounts to 90,000 t of ferroniobium equivalent per year (CBMM 2017e).

The conveyor belt transports the ore from the mine to an ore blending station, where the material gets homogenized. Thereafter the pyrochlore ore is transported from the ore blending yard to the concentration plant via another conveyor belt (CBMM 2017e). The processes in the concentration plant are described in detail below:

**Crushing and grinding:** The ore does not require heavy crushing because it is usually completely disaggregated and decomposed. Crushing is conducted with the help of an apron feeder and a roll crusher. Afterwards, the crushed material is stored in two 4,500t capacity silos with two separate grinding circuits. After grinding, the bariopyrochlore crystals of the Araxá ore are smaller than 104 microns.

The material is then transported to a specific magnetic separation section (Issa Filho et al. 2001).

**Magnetic Separation:** Low intensity (800 – 900 Gauss) double-drum magnetic separators are used to remove the magnetite from the ore. The share of magnetite in the ore is around 15-30%. The magnetic concentrate is deposited in a tailings pond while non-magnetic slurry is treated in 508 mm (20”) hydro-cyclones (Issa Filho et al.2001).

**Desliming:** Lateritic ores are known to be associated with slimes. Since the following process of flotation of ore is very sensitive to larger amounts of slimes, desliming is mandatory. For this reason, a three-stage desliming is used at 50 mm (2”), 120 mm (4”) and 381 mm (15”) (Issa Filho et al.2001).

**Flotation Circuit and Filtering:** The process of selective froth floatation is used to concentrate the bariopyrochlore crystals. An amine type cationic collector is used for the conditioning of the deslimed slurry. Hydrocholoric acid is used to acidify the flotation circuit and pH is controlled at 2.5-3.5. The flotation circuit includes the rougher flotation with eleven floatation cells and the cleaner floatation with four cleaning stages. The four cleaning stages of the cleaner flotation comprise a total of 25 flotation cells with different sizes. Following the flotation circuit the floated concentrates are thickened and filtered. Floated concentrates containing 11% moisture are ready for refining by using leaching or a pyrometallurgical process (Issa Filho et al.2001).

In the refining plants the pyrochlore concentrate, is refined by a pyrometallurgical process to remove unsolicited by-products such as sulfur, phosphorus and lead. Depending on the intended product (ferroniobium, niobium oxide, vacuum grade niobium alloys, niobium metal) the refined pyrochlore concentrate is then processed in different plants. For instance in the metallurgical plant it is converted to ferroniobium, CBMM's principal product, by way of aluminothermic reduction in electric arc furnaces. The finished niobium products are sent to customers around the world from CBMM’s central shipping facility (CBMM 2017e).

# 4 Overview of environmental hazard potentials and environmental impacts

## 4.1 Environmental hazard potentials

As part of the OekoRess I research project an evaluation scheme for assessing the environmental hazard potentials (EHPs) of the extraction of primary abiotic raw materials was developed. This evaluation scheme is based on indicators, which are assigned to three levels of consideration. These levels are geology, technology and site surroundings. The level “Geology” comprises five indicators, which include environmental factors inherent to the geology on site. These key influencing factors are “precondition for acid mine drainage (AMD)”, “paragenesis with heavy metals”, “paragenesis with radioactive components”, “deposit size” and “specific ore grade”. The second level is “Technology” and includes the indicators “mine type”, “use of auxiliary substances”, “mine waste management” and “remediation measures”. The third level “Site (surroundings)” comprises the indicators “natural accident hazard due to floods, earthquakes, storms, landslides”, “water Stress Index (WSI) and desert areas”, and “protected areas and Alliance for Zero Extinction (AZE) sites”. Furthermore, the indicator “conflict potential with local population” focusses on the social context. The latter indicator is further developed by analysing ten case studies of which the present case study is one.

The environmental hazard potential for each indicator can be rated as low (green), medium (yellow) or high (red) (for detailed information on the method see Dehoust et al. 2017b). Table 4 1 shows the evaluation of the EHPs of the Barreiro complex, which are described in detail below.

The assessment of the EHPs of the Barreiro complex is followed by an analysis of the actual situation and impacts of the mining activities on the environment as well as the responses from the mine site operator, the responsible authorities as well as the local communities, using the DPSIR framework (Chapter 4.2).

The assessment of environmental hazard potentials for the Barreiro complex is followed by an analysis of the actual situation and impacts of the mining activities on the environment as well as the responses from the mine site operator, the responsible authorities as well as the local communities, using the DPSIR framework (Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**).

Table 4-1: Site-related OekoRess assessment

| Level of consideration | Indicator | Environmental hazard potential | | |
|---|---|---|---|---|
| | | low | medium | high |
| Geology | Preconditions for acid mine drainage (AMD) | X | | |
| | Paragenesis with heavy metals | | X | |
| | Paragenesis with radioactive components | | | X |
| | Deposit size | | | X |
| | Specific ore grade | X | | |
| Technology | Mine type | | | X |
| | Use of auxiliary substances | | | X |
| | Mining waste management | | | X |
| | Remediation measures | X | | |
| Site (surroundings) | Natural accident hazard due to floods, earthquakes, storms, landslides | X | | |
| | Water Stress Index (WSI) and desert areas | X | | |
| | Protected areas and AZE sites | X | | |
| | Conflict potential with local population | X | | |

### 4.1.1 Geology

*Preconditions for acid mine drainage (AMD)*

According to the Goldschmidt classification, niobium is a lithophile element. Lithophile elements are extracted from oxidic deposits and do not provide an elevated risk for AMD. The literature review indicates that no sulfidic minerals are present at the Araxá mine. Thus, the potential for acid mine drainage is assessed as low (*low environmental hazard potential*).

*Paragenesis with heavy metals*

Niobium is mostly excluded from the group of heavy metals[9]. No specific data on the paragenesis with heavy metals was obtained for the Barreiro complex. Nonetheless, metal mining usually goes hand in

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[9] However, there is no explicit scientific definition of heavy metals and some classifications define heavy metals as those metals with a density of more than 5 g/cm³. In this sense, Niobium, with a density of 8.57 g/cm³ would be classified as heavy metal (Ignatowitz, 2011). The site-related OekoRess, however, uses the Reuter Wheel as a classification approach.

hand with slightly elevated heavy metal concentrations.t The measuring instructions, hence, recommend a blanket evaluation with a medium environmental hazard potential in case no more specific data is at hand (*medium environmental hazard potential*).

*Paragenesis with radioactive components*

The niobium's host mineral pyrochlore is, among others, generally associated with the radioactive elements thorium and/or uranium (Ronald 2016). The Araxá area has magnetic and radioactive anomalies, especially at the centre of the Barreiro-complex with high radioactivity. Analysed rocks from Araxá show uranium concentrations of 150 ± 18 ppm (Motta Ferreira 2016). According to the site-related OekoRessassessment, such concentrations pose a high environmental hazard potential due to radioactivity (*high environmental hazard potential*).

*Deposit size*

The Araxá mine is the largest mine for niobium worldwide. It contains reserves of more than 820 Mt of niobium rich pyrochlore ore (cf. introduction to Chapter 3). Jointly with the Brasilian Catalão mine, Araxá covers around 90% of world production (Linnen et al. 2014). There is no classification for the size of niobium mines at hand but the measuring instructions evaluate the size of a deposit in relation to other mines of the same raw material. Araxá, as the world´s largest niobium mine that has such few competitors in size, can therefore be regarded as large and consequently be assessed with a high environmental hazard potential. (*high environmental hazard potential*).

*Specific grade*

In Araxá, only the residual ore is currently mined, which has a mean concentration of 2.5% $Nb_2O_5$ (Issa Filho et al.2001). Due to these values, the Araxá mine is classified as a high-grade ore mine compared to, for instance, Canada with an ore grade of approximately 0.6% (Papp 2012). Ore grades of this type indicate a low environmental hazard potential (*low environmental hazard potential*).

### 4.1.2 Technology

*Mine type*

Weathering led to a formation of residual ore that is exploited mechanically by open-pit mining (Issa Filho, Riffel and de Faria Sousa 2001). Mining in deeply weathered formations is regarded as mining in unconsolidated materials as the weathering process significantly softens the rock formation. Thus, the mining method is evaluated with a high environmental hazard potential (*high environmental hazard potential*).

*Use of auxiliary substances*

The ore is extracted mechanically without using explosives or any toxic additives. Mining without explosives has a low environmental hazard potential. However, the subsequent processing steps include crushing and grinding, magnetic separation, desliming and floatation. For the floatation process organic flotation reagents are used which leads to a high environmental hazard potential for this indicator (*high environmental hazard potential*).

*Mining waste management*

In 2014, the company recycled, reused or reprocessed about 50,000 tons of 30 types of waste (CBMM 2017f). A permeable tailing dam with an average length of 900 m and a structural height of approximately 28 m (own estimation based on Google Earth images) was built to retain residues of the metallurgical slag (Mineralienatlas 2017). This management of waste material can pose a significant potential for environmental hazards (*high environmental hazard potential*).

*Remediation measures*

Since there are enough deposits for the Araxá mine to be operated for at least another 200 years at current extraction levels, no closure plan is in place so far. Nonetheless, CBMM established an Environmental Management System that consists of multiple measures to mitigate their mining induced environmental impact (CBMM 2017f). CBMM created a plant program to stop the loss of biodiversity. The program mainly grows native species of the originally riparian vegetation. Furthermore, the Environmental Development Center trains local teachers about biodiversity and its threats to provide knowledge of the Cerrado Fauna and to improve environmental protection (CBMM 2017f) (*low environmental hazard potential*).

### 4.1.3 Site (surroundings)

*Natural accident hazard due to floods, earthquakes, storms, landslides*

The total natural disaster risk is assessed by analyzing four individual sub-indicators. All sub-indicators (earthquakes, floods, tropical storms, landslides) show a low environmental hazard potential. The evaluation is carried out in accordance with the measurement instructions which suggest to use georeferenced data from publicly available risk maps. The results are taken directly from the given risk assessment. The indicator total is derived by the highest hazard potential of the sub-indicators.. The risk for earthquakes is low since Minas Gerais is not located in an active seismic area (GSHAP world MAP) and also no other indications for increased hazard potential of natural disasters are known for the area (*low environmental hazard potential*).

*Water Stress Index (WSI) and desert areas*

The WSI by Pfister et al. (2009) provides characterization factors on the relative water availability at watershed level. The indicator combines this information with an evaluation whether the site is located in a desert area. Mining operations often need large amounts of water for the operation. Depending on the hydrological situation, a competition for water between the different users can occur. The evaluation was carried out in accordance with the procedure described in the measurement instructions (Dehoust et al. 2017a). For the investigated area, the water stress poses a low environmental hazard potential (*low environmental hazard potential*).

*Protected areas and AZE (Alliance for zero extinction) sites*

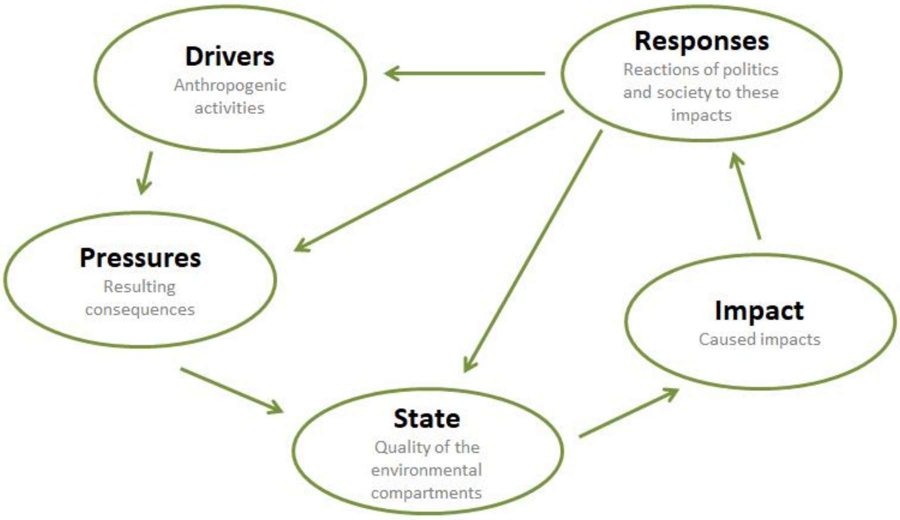
Georeferenced data for designated protected areas are used to assess hazards posed by mining extraction. The metric to evaluate EHPs corresponds to the method first described in the draft standard of the Initiative for Responsible Mining Assurance (IRMA 2014). The Araxá mine lies within the Cerrado shrubland which is the largest savannah in South America and is referred to as being the biologically richest savannah worldwide (WWF 2017a). Nevertheless, only a few protected areas exist in the entire region. There is no protected area as defined in the measuring instructions close to the mining operation which leads to a low environmental hazard potential (*low environmental hazard potential*).

*Conflict potential with local population*

The governance indicators “Control of Corruption” and “Voice and Accountability” indicate a percentile rank of 41.35% and 60.10%, respectively (World Bank 2017b). Consequently, the environmental hazard potential related to governance is classified as medium (*medium environmental hazard potential*).

## 4.2 Environmental impacts

Figure 4-1: DPSIR Framework



Source: Own preparation, based on Kristensen (2004).

The DPSIR framework is a systemic analytical approach to better understand the interaction of humans and their environment in order to derive adequate policy measures. It comprehensively accounts for and visualizes the causal connections between human activities, the resulting consequences for the environment and the responses of humans. The model consists of driving forces, pressures, state, impacts and responses.[10]

This chapter focuses on the mine's land use and the mining operation's impact on biodiversity and water quality. Furthermore, it covers the impacts of dust generated by the mine operation and the worker's health, and assesses the occurrence of radioactivity. The chapter further points out responses of the mining company.

In view of the results, it is crucial to mention that there was only limited information available on the environmental impacts of Niobium mining in the Araxá area. As the mining company does not provide any reports, there is nearly no information on the size of the mining operation, the use of water, the storage of tailings or of the levels of pollution of soils and water bodies. The next passages are therefore mainly based on some rather general scientific analyses of worker's health and the pollution of ground and surface waters and information from the website of CBMM and should be interpreted with caution.

### 4.2.1 Pressure

The deposits of the Niobium mine site in Araxá naturally show elevated concentrations of radioactive minerals. The major environmental pressures of Niobium mining operation in Araxá are the use of

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[10] For further information on the DPSIR framework and its elements see Kristensen (2004).

land, the emission of (radioactive) dust and the contamination of waters due to mining. The major environmental impacts of the operation and responses will be outlined in the following paragraphs.

### 4.2.2 State and Impacts

**Land use and Biodiversity**

In general, mining activity in the state Minas Gerais and particular in the area of Araxá is high. Besides the niobium mine of CBMM, there is a phosphorus mine and a fertilizer factory of Vale S.A. in the vicinity of Araxá (Clay and Ackroyd 2012).

Open pit mining generally is a major intervention in the natural environment, and leads to the destruction of ecosystems, which is also the case for the Niobium open pit mine in Araxá. The mine site is located in the Brazilian Cerrado, an open savannah mosaic with patches of bushes and forest. The entire ecological zone is considered being a precious ecosystem rich in species. However, no protected areas exist in the vicinity of the mining project. There was no information available on the current size of the mining operation.

**Water and soil quality**

The substrates of the Barreiro complex are weathered and have no or very little potential for acid generation (Issa Filho et al. 2001; Dias da Cunha 2010; see also Chapter 4.1).

The surface waters of the area show slightly increased conductivity and are enriched with minerals which are abundant in the parent material, like barium; the waters show also elevated levels of chloride and sodium, which are related to urban waste waters (Mancini and Bonotto 2014). In addition, the water shows elevated levels of phosphorus due to mining and fertilizer production of Vale S.A. (Mancini and Bonotto 2014). However, the topography, which leads to a ground water flow that is directed to the surface, helps to avoid further concentration of minerals and a contamination of the environment.

The surface water bodies in Araxá have pH-values of 7 and slightly above, but also increased conductivity values related to mining and other human activities (Clay and Ackroyd 2012; Mancini and Bonotto 2014).

No data is available on the current status of heavy metal pollution in soils and water.

**Radioactivity**

Radioactive nucleoids occur naturally in geological formations of the Berreiro complex with uranium and thorium showing elevated concentrations ($U_3O_8$ Concentration ranges between 150 – 200 ppm) (Issa Filho et al. 2001; Dias da Cunha et al. 2010; Clay and Ackroyd 2012; Mancini and Bonotto 2014). Especially the upwelling water from the underground – such as the water from Fonte Dona Beja in the direct proximity to the niobium mine – shows increased radioactivity (Clay and Ackroyd 2012; Mancini and Bonotto 2014). This increased radioactivity is also documented for bottled mineral water from several sources in Minas Gerais state. However, in most of the cases radioactivity is below the national drinking water limits and those of the WHO (Oliveira et al. 2001).

There are no reports pointing at mining in Araxá being an increasing factor for the dispersal of radioactive elements in the environment. However, the mining and processing cause dust, which can contain radioactive elements, that certainly spreads in the surrounding area (see following section).

**Dust and Noise**

The nuisance of dust and noise due to the mining activity in Araxá is – compared to other mining sites – relatively low. The ground is thoroughly weathered and hence no drilling or blasting is necessary for ore extraction. Ore and overburden material can easily be moved by excavators. Also due to its weathered state, the material itself contains only low levels of silica or asbestos, which are usually the main causes for respiratory diseases of mine workers (Borges et al. 2016). Overall, CBMM states, that the load of airborne particles around the mine and in Araxá is "eight times lower than regulatory limits" (CBMM 2017f).

However, as already pointed out above, there are elevated concentrations of radioactivity in the geologic formations. More than mining, the crushing and processing of the minerals can result in radioactive dust. The respirable particles can affect the health of the workers. An investigation of respiratory symptoms of mine workers shows that health problems were found in 33 out of 147 cases. However, there is only a weak correlation between the exposure to dust and the occurrence of respiratory symptoms (Borges et al. 2016).

Moreover, besides the investigation on worker's health, no reports on the potentially negative health effects on the population around Araxá were available.

### 4.2.3 Responses

#### Commitment to international standards

The mine operator does not publicly provide detailed or regular reports. On their website, CBMM claims "strict adherence to environmental legislation" (CBMM 2017f). Furthermore, the mine was the first being certified according to ISO 14001 standards, which specifies requirements for environmental management systems.

According to their website, CBMM also provides a health and safety management system to prevent diseases and accidents. The Company's Worker Health and Safety Management System gained OHSAS 18001 certification (CBMM 2017g).

#### Rehabilitation

There are no closure and rehabilitation plans in place.

#### Water and tailings management

Water management is an important factor for every mine operation. At the Araxá mining site, 95 per cent of the water used is recycled, which reduces both, fresh water use and energy demand. Furthermore, as the operator purports, an extensive monitoring programme for water quality exists; however, CBMM does not publish any results (CBMM 2017f). CBMM has installed a sealed tailing facility to deposit the minerals sorted out by magnetic separation.

#### Community development

CBMM claims to be one of the most important development actors in the region. Beyond its network of local suppliers, it is the largest taxpayer and employer in the region and claims to promote infrastructure and communal development (CBMM 2017h).

# 5 Governance

## 5.1 Sector governance, regulation and effectiveness of national institutions

### Institutional and administrative framework

In Brazil, the regulation of mining is executed by the Ministry of Mines and Energy (MME) as the highest authority through its Secretariat of Geology, Mining and Mineral Processing and through the federal National Mining Agency (ANM) (Visconti and Fransani 2017). While the MME coordinates and develops general mining policies and grants mining concessions, the performance management and monitoring is the task of the ANM, e.g. through inspections, managing claims and compensational credits and imposing of sanctions (Visconti and Fransani 2017; Presidency of the Republic of Brazil 2017a). The ANM was created in December 2017, following almost a decade of plans to revise the mining law (Visconti and Frasani 2017; Beyersdorf and Krautter Romeiro 2013). The creation of ANM followed a larger trend of restructuring the Brazilian state by establishing more public regulatory agencies to decrease the role of the state in the economy and reduce its interferences to a facilitating and regulating function (ANA 2013). The ANM was conceived to speed up the permitting process in mining and improve efficiency by increasing transparency and reducing bureaucracy. The idea was to offset some of the additional costs of higher royalties that were concurrently enacted (BMI Research 2018). However, critics argue that the new agency "lacks the teeth and personnel to do the job" (Sullivan 2017). Furthermore, a new tax on mining projects, planned as funding for the ANM, was not approved (BMI Research 2018).

### Legal and regulatory framework

Due to its importance for Brazil and the Brazilian economy, the regulation of mining is partly enshrined in the constitution (Freire 2016). Despite Brazil being a federal country, the power over mining resides exclusively with the federal state ("the union"). Environmental regulation and enforcement, however, is a shared competence with larger powers residing on the state and municipal level (Freire 2016).

Key legal sources that constitute the governance of mineral resources in Brazil are the respective parts of the federal constitution, the 1967 Mining Code[11] and its amendments, some specific mining laws, as well as the regulations issued by the MME (Freire 2016). For niobium, no specific laws or regulations could be found.

Based on these laws and regulations, the mining regime is governed by a set of principles, including the following:

- The sovereign right over mineral resources and deposits and their exploration is held by the union (Freire 2016);
- Mining titles are granted by the union, the mining must be carried out in the national interest and it can only be done by Brazilians or Brazil-based companies (Freire 2016);
- Land ownership and the mineral wealth in the subsoil are legally separated entities that can have different ownerships (a principle introduced by Portuguese colonial rulers) (Triner 2015);
- The exploration of the subsoil takes precedence over the surface land use (which in theory even permits expropriation of the landowner in case of dissent, however, in practice rarely happens) (Visconti and Fransani 2017);

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[11] Basically consisting of Decree-Law No. 227/1967.

- Landowners must be compensated for any damages (Visonti and Fransani 2017) and receive a share of the profits of the mining (Freire 2016);
- Mining concessions do not expire until the very depletion of the deposit (Freire 2016); and
- Mining companies shall adhere to environmental sustainability, which means that “mineral resources must be extracted with technical, economic and environmental feasibility” (Freire 2016).

Pre-requisites for the granting of a mining concession by the MME are the accomplishment of exploration works, the submission of a Final Exploration Report and the Plan for Economic Use as well as the environmental licenses issued by the respective state (Visconti and Fransani 2017). In addition, necessary on the local level are a local authorisation to work (“operating license”) and a permit for adequate occupancy (“certificate of occupancy”) (Visconti and Fransani 2017).

In general, the economic climate is relatively favourable for mining companies, aided by a loose regulation of the financial sector and therefore easy access to credit. However, barriers to trade and investment and a complicated tax regime weigh on Brazil’s economic openness. In addition, the mining code has been considered by some as too complicated and inefficient (BMI Research 2018).

In July 2017, in response to calls for a more streamlined mining code, President Temer issued a temporal decree with wide-ranging changes, allegedly aiming at improving the competitiveness of the Brazilian mining industry (Jamasmie 2017). There has been much polemic around it (as will be further discussed below) and the decree was not extended by the Senate after its expiry six months later. Some segments of Temer’s reforms, however, were approved by Congress, such as the founding of the ANM (see above) and a change to mining royalties, also known as CFEM (Financial Compensation on Mineral Exploration) (Jamasmie 2017).

With the new CFEM, the calculation, rates and distribution of mining revenues changed. Whereas in 2016 the Brazilian government earned about 510 million USD, the new mining royalty rates are expected to increase by 80 per cent (Sullivan 2017). Tax rates still vary according to the extracted resource. For niobium, the tax rate was in 2017 at 3 per cent (up from 2 per cent in 2017) (BMI Research 2017). As for the distribution of revenues, in 2017, the cities directly affected by the mining companies receive 15 per cent of the royalties. Another 15 per cent goes to the states and 60 per cent to the municipalities in which the mining occurs. Only 0.2 per cent is directed towards the federal environmental agency IBAMA for environmental protection in mining affected areas (Presidency of the Republic of Brazil 2017b), which is assessed by several sources as being too low (see the following section).

### Environmental legislation in the mining sector

The Brazilian environmental regime is constituted by a range of legal sources, of which the most important are the federal constitution, where environmental protection has its own chapter, and the state constitutions. Furthermore the federal law no. 6938/1981 that established the National Environmental Policy (NEP) and the law no. 9605/1998 with the decree 6514/2008, which address criminal and administrative breaches and penalties have to be named (Damião Gonçalves et al. 2012). In addition, there are also several state-specific local laws and regulations such as the Deliberative Resolution no.116/2008 of Minas Gerais (central mining region, also comprising the niobium mines discussed in this report) on soil protection and management of contaminated areas (Damião Gonçalves et al. 2012). Besides the general environmental laws (e.g. the NEP law, the Forest Code or the National Water Resources Policy) there are also mining-specific environmental laws, covering e.g. mining activities in special protected areas. Furthermore, there are mining-specific rules governing e.g. health and safety in the Mining Regulation Rules (Freire 2016). The major agencies that support the executives of the individual states and of the union with regard to the environment are the IBAMA and the ICMBio. Public participation also plays an important role. NGOs participate in multi-stakeholder decisionmaking bodies and public consultation is mandatory prior to the concession of environmental licenses (OECD 2015).

Brazil's environmental legislation is overall referred to as being stringent and received much praise; its implementation and enforcement, however, is lacking (EEAS 2007; OECD 2015; Neves 2016). Therefore, mining has many first and secondary impacts on the environment and continues to present a large threat.

One example is mining in protected areas. In Brazil, protected areas (PAs) are sub-divided into strict PAs and sustainable-use PAs. In strict PAs and on indigenous lands, mining is not permitted. However, in sustainable-use PAs (called APAs and ARIEs) 1,195 mining projects were established over an area of 160,000 ha by 2016 (Villén-Pérez et al. 2017). In addition, 367 projects covering 420,000 ha were established in restricted PAs, where mining was permitted before the PAs were established or where concessions were made improperly because of legal misinterprations (Villén-Pérez et al. 2017). If all projects currently planned through to 2026 will be implemented, the territory occupied by mining is estimated to increase 23-fold (Villén-Pérez et al. 2017).

Furthermore, financing of environmental rehabilitation is a challenge. Indeed, in order to start any mining project, a mining closure plan must be submitted and three separate environmental licenses obtained: a preliminary license, an installation license and an operating license (Freire 2016; Visconti and Fransani 2017). It is, however, still not obligatory for the mining company to make provisions for the costs incurred by the mining closure or by potential environmental damages, for example through an environmental insurance (Freire 2016).

Furthermore, there is no explicitly mining-related legal policy for environmental compensation. General legislation nonetheless states that it is a requirement for all projects having "the potential to cause significant environmental impact" (Freire 2016). For example, permission for deforestation in the Atlantic Forest, a large biome stretching along Brazil's Atlantic coast (Araxá is just outside this forest and not included), is only granted in exchange for a compensation in form of allocating an equivalent area to the environmental agency or through replanting (Freire 2016). Some states have their own requirements, such as Minas Gerais, where it is possible to compensate deforestation with money (Freire 2016).

Penalties for environmental crimes are relative to the damage caused and can include a fine and imprisonment (Damião Gonçalves et al. 2012). However, the laws are weakly enforced, which is mainly due to a marginalisation of the responsible public authorities within the executive branches and a resulting lack of human and financial resources (Neves 2016). Furthermore, the varying environmental requirements across jurisdictions also provide for a "risk of environmental dumping" (OECD 2015). The new ANM, for example, is also said to be lacking quality and quantity in terms of personnel, and in the case of the state of Minas Gerais, there was not enough staff to supervise all mining-related dams which in 2015 contributed to a dam collapse that killed 19 people and dumped 50 million tonnes of toxic waste into the drinking water supply of 1.6 million people (Sullivan 2017).

Moreover, the absence of effective coordination and cooperation within and between the three different levels of government (union, federal states, municipalities), and the fact that legislative and executive powers are shared amongst those levels, contribute to the weak implementation of Brazil's environmental legislation (OECD 2015; Neves 2016). Bogus logging permits, public sector corruption and bureaucratic inefficiency only add to the enforcement problems (Climate Home News 2017; BMI Research 2018). In addition, several Brazilian politicians (the so-called "ruralista bloc" or "rural caucus") are said to have close ties with mining companies who fund their campaigns and thus push for legislation that neuters environmental regulation (El Bizri et al. 2016; Sullivan 2017). Almeida et al. (2016), for example, state that this is visible in the constitutional amendment PEC65/2012, which, according to them, "effectively abolishes Brazil's environmental licensing process" by eliminating environmental agencies' power to suspend projects because of negative Environmental Impact Assessments and instead is reducing the latter to "a tick-box requirement for the mining industry" (El Bizri et al. 2016).

Enforcement of environmental protection is further hampered by the recent reform attempts by President Temer. His decree, issued on 23 August 2017, brought about an array of changes to the mining and environmental framework and, although not all changes have been reaffirmed by the congress, it indicates the current political trend. Large national reserves were opened up to mining, industry environmental monitoring was quasi nullified by the new mining "revitalization plan" and the monitoring of environmental standards was shifted from the government towards the mining companies themselves (Sullivan 2017). The planned measures led to strong concerns among scientists and activists (Tollefson 2016; Ramon 2017), as well as with the environment minister himself (Phillips 2016). Concurringly, the agencies' funding was cut significantly, thereby further precluding an effective oversight of environmental policy implementation (Tollefson 2016); the budget of the environment ministry was curtailed by over 40 per cent (Arsenault 2017).

### Indigenous rights

Brazil is home to about 240 tribes comprising 900,000 people. 690 of their territories, equalling 13% of the entire country's land, have been recognised by the Brazilian government. Though only 1.3% of those territories lie outside the Amazon region, they host about half of the Brazilian indigenous population (Survival 2018).

The status and rights of Indians are protected by Article 231 of the 1988 federal constitution, which states that "Indians […] shall be entitled to the exclusive usufruct of the riches of the soil" and explicitly delineates that "prospecting and mining of mineral wealth on indigenous lands may only be done with the authorization of the National Congress, after hearing from the communities involved, which shall be assured of participation in the results of the mining […] except in the case of important public interest of the Union" (constituteproject.org 2014). Due to the hitherto non-existence of a special law or authorisation regarding mining on indigenous lands, there is currently no organised and regular mining taking place on those territories in Brazil; however, illegal mining activities are common (Freire 2016).

Discussions about changing the legislation and opening up protected indigenous areas to mining have been ongoing since at least 1996, when Senator Jucá, a leading member of the "rural caucus" introduced the bill PL 160/1996 to legalise mining on indigenous lands (Branford 2017). A commission of the lower chamber has been debating the bill ever since. Under the Temer government, the bill's goal was seemingly reached for the time being: Per above-mentioned presidential decree, Temer introduced a so-called "marco temporal", recognising only indigenous land claims on the basis of a legal title proving that the respective indigenous community occupied its land in October 1988, the date of ratification of the federal constitution (Millikan and Poirier 2017). However, this cut-off date was widely criticised because it deliberately ignores that many indigenous communities were brutally driven off their ancestral lands, particularly during the military dictatorship preceding the new constitution. This is why the Brazilian Supreme Court has ruled against it and undid the bill's mining permission (Millikan and Poirier 2017).

The degree to which indigenous rights are enforced and protected is akin to the enforcement of environmental policies. Significant cuts of over 40 per cent to the budget of the responsible government body, the National Indian Foundation (FUNAI), weaken official oversight. Indigenous lands, normally representing "one of the most effective barriers against deforestation" (El Bizri 2016) therefore had more difficulties to control deforestation. In 2016, deforestation increased by 29 per cent, despite previous decreases (Arsenault 2017). It is dangerous for indigenous people to resist against illegal activities; in 2015 alone, the Indigenous Missionary Council (CIMI) reported 137 killings in the context of land conflicts and several communities have asked the police for protection from threats and violence by illegal miners and loggers (Sullivan 2016).

With regard to the niobium mine in Araxá, no specific conflict with an indigenous community could be found. Throughout Brazil, however, there are numerous incidents of open conflicts between the interests of miners and indigenous communities.

## 5.2 Social context of mining and conflicts

Conflicts around mining are a common result of the poor enforcement of environmental and indigenous rights, particularly in areas dominated by mining, logging or cattle ranching. Brazil is said to be the most dangerous country worldwide for environmental activists: Since the 1990s, more than 1,500 environmental activists have been killed and over 2,000 have received death threats (Miller 2015). Often, local politicians are involved in the criminal activities. A founder of Greenpeace Brazil has compared the country to the “wild west”, as offices and staff of public environmental agencies have been subject to physical threats to their buildings and lives (Climate Home News 2017). The policies of President Temer are believed to have only worsened matters, e.g. by legitimising land grabs or allowing squatters to acquire land for prices lower than the actual market value (Climate Home News 2017). Furthermore, particularly environmental crimes committed by big companies often remain unpunished (Nogueira and Lopes 2016). However, laws and regulations favouring big companies already existed before Temer taking of office. Nevertheless, it seems to be especially under the new government that large companies are benefitting from the new mining regulations (Sullivan 2017).

While – as already stated – no conflicts could be found in relation to the niobium mines in Araxá, there are accounts of disputes over officially undeveloped niobium deposits in the biological reserve Morro dos Seis Lagos. The reserve is located near the Colombian/Venezuelan border in the state of Amazonas and hosts with 2,897 million tonnes niobium the largest single niobium deposit in the world (Pollard 1995) – enough to cover the current global demand for 400 years (Cruz 2015). Due to the deposit’s location both in a protected area and an indigenous reserve, mineral extraction in the Seis Lagos area is not allowed; This prohibition became even more obvious since the local indigenous community voiced its opposition to mining activities when it came to privatisation efforts, which were stopped by the environmental agency IBAMA (Farias 2013; Figueiredo 1997). However, some report that minerals are being illegally extracted by hand and smuggled out of the reserves (Cruz 2015). Moreover, Jair Bolsonaro, at the time of the study pre-candidate for the 2018 presidential elections, has demanded to lift the ban and to exploit the niobium wealth (Vettorazzo, 2017).

Regarding the mine in Araxá, the wealth generated by the niobium production triggered popular demands for a larger public participation in the profits. Rumours arose that the government sells niobium under value and thus that the Brazilian population loses money. While there is no proof, the Araxá mine is by far the largest niobium mine worldwide and responsible for about 80-90 per cent of the global niobium production. It has helped the Moreira Salles family (which mainly owns the mine) to become one of the richest in Brazil. Yet, there are also other niobium deposits elsewhere and it is questionable whether a higher niobium price would not rather lead to a decreased global demand of Brazilian niobium than to more revenues for the local population.

# 6 Conclusion and comparison of the analysis with existing governance indices

In this final chapter, the findings of chapter 4 (environmental hazard potentials and environmental impacts) and chapter 5 (governance analysis) are analysed to answer the following research questions:

- Does the assessment of the environmental hazard potentials adequately point to the actual environmental impacts?
- Are existing governance indices and indicators able to adequately reflect the governance capability to cope with the challenges arising around the environmental hazard potentials and environmental impacts of mining? In other words, are the identified governance gaps reflected in existing governance indices and indicators?

In order to answer the second question, a number of indices and indicators (see Table 6-1) were chosen based on a screening of a wide range of existing governance, environmental governance, and peace and conflict indices.

The results of this case study will be compared with the results of nine additional case studies that are conducted as part of this project as well as the case studies conducted in UmSoRess and OekoRess I. By comparing the findings of the case studies, a set of governance indicators will be identified that can be used to improve the assessment approach to analyse the environmental hazard potentials of the OekoRess I project.

**Does the assessment of the environmental hazard potentials adequately point to the actual environmental impacts?**

The main environmental impacts outlined in this study were use of land, the emission of (radioactive) dust and the contamination of waters due to mining. Furthermore, the potentially negative impacts on worker’s health and the dispersal of radioactive materials through processing were highlighted.

The site-related OekoRess methodology includes several indicators that reflect potentials for these environmental hazards. The indicators “deposit size” points out the high use of land outlined as one major environmental impact. The Araxá Niobium mine is an open pit mine and therefore affects large areas of surface, and leads to a destruction of ecosystems and a loss of biodiversity.

Furthermore, the indicator “ paragenesis with radioactive components” showed a high environmental hazard potential and therefore adequately reflects the actual environmental impacts of radioactive dusts and enhanced levels of radioactivity for example of the water. In addition, the indicators “use of auxiliary substances” and “mining waste management” were categorised as having a high environmental hazard potential. Also in the assessment of environmental impacts, the indicator “use of auxiliary substances” was identified as having a negative environmental impact; however, this was not due to flotation reagents (there was no information provided on potential environmental impacts), but due to the distribution of potentially radioactive dust. Concerning the indicator “mining waste management”, there was no information publicly available to assess actual environmental impacts in that regard.

The indicators for “ paragenesis with heavy metals” and the “mine type” shows medium environmental hazard potentials. The assessment of environmental impacts could not confirm the occurrence of heavy metals, because data for heavy metals in soil and water was not available. The indicator “Water Stress Index (WSI) and desert areas” only indicates a low environmental hazard potential. However, the actual environmental impacts concern contamination, not the general lack of water or the competition between mining and other sectors or local communities over the resource itself. This might be the case due to water recycling measures of the mining company.

The indicator "remediation measures" shows a low environmental hazard potential even though the mining company has no mine closure plan in place. This is the case because the mine could operate for at least another 200 year at the current extraction levels. However, mine closure seems to be a general problem in Brazil, as legislation does not account for a proper financial plan. Therefore, the non-existence of a mine closure plans could be an environmental risk.

The indicator "Conflict potential with local population" has a low environmental hazard potential. The governance analysis showed that - particular when focusing on environment - Brazil's legal system is referred to as being "stringent". Nevertheless, there is a lack of implementation and enforcement, with corruption and non-compliance being a problem. With this in mind, a medium risk for environmental hazards concerning governance would be more accurate.

### Main findings of the governance analysis

The governance analysis showed that, overall, Brazil's governance is characterised by sound regulations and strategies, but also by problems concerning implementation and enforcement due to a lack of human and financial resources. Furthermore, the absence of effective coordination and cooperation within and between the union, federal states and municipalities and the fact that that legislative and executive powers are shared amongst those levels, contribute to a weak implementation of Brazil's legislation (OECD 2015; Neves 2016). Environmental requirements also vary across jurisdictions and non-compliance is sometimes not sanctioned. There is a trend to improve the competitiveness of the Brazilian mining industry, which went in line with the opening of national reserves to mining. In addition, the economic climate is relatively favourable for mining companies and several Brazilian politicians are said to have close ties with mining companies.

Conflicts around mining are a common result of the poor enforcement of environmental and indigenous rights, and of local politicians being involved in criminal activities. Nevertheless, no conflicts were found in relation to the niobium mines in Araxá. However, there are accounts of disputes over officially undeveloped niobium deposits and of illegal mining in the biological reserve Morro dos Seis Lagos.

### Do existing governance indicators reflect Brazil's governance gaps and challenges?

Brazil's overall average sector governance is reflected well in the set of Worldwide Governance Indicators (WGI), however, the rank varies between the different underlying indicators.

Brazil has by far the highest value for WGI Voice and Accountability in comparison to its other WGI values, with a percentile rank[12] of 60.1. This reflects the overall situation in Brazil well as the governance analysis also pointed out that for example prior to the concession of environmental licenses, public consultation is mandatory. However, the indicator is not able to reflect the sometimes lacking implementation.

All of the other WGI indicators also reflect the situation in Brazil well and range in average percentiles between 34.3 and 50.0: Brazil's lowest value is the WGI Political Stability and Absence of Violence, with a value of -0.40, and a percentile rank of only 34.3. This indicator describes the "perceptions of

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the likelihood of political instability and/or politically motivated violence, including terrorism". As the governance analysis shows, particularly conflicts around the use of land are common. Furthermore, environmentalists live in danger of death threats and politicians are involved in criminal activities. Thus, the indicator reflects the situation in Brazil well.

The medium-rated WGIs are the indicators on Government Effectiveness, on Regulatory Quality and on Control of Corruption, which range around the 50th percentile with values between -0.19 and -0.21 making it an average result. This reflects the actual situation pointed out in the governance analysis well, as Brazil shows a medium performance for these categories.

An index that aims specifically at capturing Brazil's performance of the protection of human health and of ecosystems is the Environment Performance Index (EPI). Brazil ranks 46 out of 178, scoring 78.90 out of 100. The index measures a countries' performance in several areas such as health impacts, air quality, water and sanitation, agriculture and forest. Unlike the WGI, the EPI uses scientific data in order to analyse a countries' performance, not existing indicators, which are then combined to a new index. Furthermore, it does not measure for example legislations in place to protect the human health and ecosystems, but a countries performance regarding the success or the failure to achieve specific thresholds. The index reflects Brazil's overall average to good performance with stringent environmental legislation but also with some problems concerning implementation and financing well.

Brazil's sector governance and its associated problems are very well reflected in the Fraser Policy Perception Index surveyed yearly by the Fraser Institute. Brazil ranks only 66th of 91 countries in the world in terms of attractiveness of its policy environments (55.66 /100 points). Interviewees highlighted uncertainties concerning environmental regulation and the duplication or inconsistency of regulations. Furthermore, the unclear taxation system was highlighted (Fraser Institute 2017). On the other hand, the topic of socioeconomic agreements and the conditions for community development were rated quite positively. With these results, the assessment particularly points towards strengths and weaknesses identified in the governance analysis in terms of a high level of participation of stakeholders, but on the other hand the lack of implementation and enforcement and the absence of effective coordination and cooperation within and between the union, federal states and municipalities. Again, this higher granularity in reflecting the actual situation in Brazil seems to be a result of the type of data the Fraser Index uses. The expert assessment of professionals actually working in the mining sector on 15 policy factors via questionnaires seems to reflect the actual sector-governance situation in Brazil accurately. With this, the Fraser Index combines qualitative with quantitative approaches. The Corruption Perception Index (CPI) rates countries on how corrupt their public sector is seen by experts (Transparency International 2016). Brazil ranks 96 out of 180 countries assessed, which reflects the results of the governance analysis well. In Brazil, corruption is common and the economic climate is favourable for mining companies – which is also because of the close relationship between some politicians and the private sector.

### Conclusion

Brazil's overall average governance is well reflected in key governance indices of the WGI. However, the existing indices and indicators show only in some cases a good ability to also reflect the specific and nuanced governance challenges in the mining sector of Brazil, particularly the lack of implementation of legislation.

The good ability to reflect the actual situation was particularly provided by the Fraser Policy Perception Index that reflected the specific challenges of Brazil's sector governance best, which might be explained by it being a perception index based on an expert survey. This will have to be tested as part of the following case studies; however, the results of the previous case studies already underline this finding.

The data available for the assessment of environmental impacts was weak. Based on the available data, the challenges around poor enforcement of environmental legislation and conflicts around mining could only in some parts be identified for the Araxá mining site. However, examples from other mining projects around Brazil show that shortcomings still exist in the mining sector.

Table 6-1: Overview of the governance indicators

| Indicator | Brazil | Year | Indicator measures… | Applicability |
|---|---|---|---|---|
| Voice and Accountability (WGI) | 0.38 (estimate between -2.5 and 2.5)<br>60.1 (percentile rank terms from 0 to 100, with higher values corresponding to better outcomes) | 2015 | Voice and Accountability captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media. | Reflects well the relatively good governance performance in the area of participation. |
| Political Stability and Absence of Violence (WGI) | -0.4 (estimate between -2.5 and 2.5)<br>34.3 (percentile rank terms from 0 to 100, with higher values corresponding to better outcomes) | 2015 | Political Stability and Absence of Violence/Terrorism measures perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism. | Reflects well the overall average to weak governance in this area |
| Government Effectiveness (WGI) | -0.19 (estimate between -2.5 and 2.5)<br>47.6 (percentile rank terms from 0 to 100, with higher values corresponding to better outcomes) | 2015 | Government Effectiveness captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. | Reflects well the overall average governance in this area. |
| Regulatory Quality (WGI) | -0.21 (estimate between -2.5 and 2.5)<br>46.6 (percentile rank terms from 0 to 100, with higher values corresponding to better outcomes) | 2015 | Regulatory Quality captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. | Reflects well the overall average governance in this area. |
| Rule of Law (WGI) | -0.19 (estimate between -2.5 and 2.5)<br>50.0 (percentile rank terms from 0 to 100, with higher values corresponding to better | 2015 | Rule of Law captures perceptions of the extent to which agents have confidence in and abide by the rules of | Reflects well the overall average governance in this area. |

| Indicator | Brazil | Year | Indicator measures… | Applicability |
|---|---|---|---|---|
| | outcomes) | | society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence. | |
| Control of Corruption (WGI) | -0.43 (estimate between -2.5 and 2.5); 41.3 (percentile rank terms from 0 to 100, with higher values corresponding to better outcomes) | 2015 | Control of Corruption captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests. | Reflects well the overall average to weak governance in this area |
| Corruption Perception Index (CPI) | 113 out of 176 | 2016 | The CPI scores countries on how corrupt their public sectors are seen to be. It captures the informed views of analysts, businesspeople and experts. | Reflects well the overall average to weak governance in this area |
| Environmental Performance Index (EPI) | Rank 46 of 178, Score 78.90 (out of 100) | 2016 | The protection of human health and protection of ecosystems. | Reflects well the overall average governance in this area |
| Fraser Policy Perception Index | Policy perception Index:<br>Score 55.66 (out of 100)<br>Rank 66 (out of 91) | 2017 | The index measures the overall policy attractiveness and the country's government policy on attitudes towards exploration investment | Reflects well the overall average governance particularly for the mining sector. |

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