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A CONTRADICTION IN SUSTAINABILITY: THE ENERGY TRANSITION AND RAPIDLY EXPANDING FRONTIERS OF EXTRACTION

AN EXAMINATION OF THE SOCIO-ENVIRONMENTAL IMPACTS OF GRAPHITE EXTRACTION IN CABO DELGADO, MOZAMBIQUE, THROUGH A LAND USE LAND COVER CHANGE ANALYSIS

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Abstract

The Global North finds itself heading full throttle into the energy transition, a transition from high to low carbon emission energy sources with the goal of fulfilling the vision of environmental, economic, and social sustainability. Alternative energy sources are being adopted to achieve carbon neutrality and to mitigate environmental deterioration. Shifting to alternative energy sources requires an increased amount of minerals, however, and this demand can only be met with increased extraction. The increased opening up of so called green mineral extraction projects calls for investigation of the sustainability of the energy transition in terms of its impact globally. Remote Sensing (RS) and Geographic Information System (GIS) techniques were used in combination with an interview analysis to determine the socio-environmental impacts of increased mining in the context of the energy transition. Specifically, two graphite mines in Cabo Delgado, Mozambique, are examined. This research applied a spatial focus by conducting a Land Use Land Cover (LULC) change analysis. The LULC change findings were further substantiated using community data. The LULC change analysis revealed the heterogeneous nature of change that comes paired with the early stages of mining operations. Overall, the analysis identifies the landscape changes noticeably because of the mines' presence, causing a reduction in vegetation. Moreover, farmland is stripped away where the mines emerge, which impacts the population's livelihood. The affected communities inside the concession zone are displaced and must navigate compensation and resettlement arrangements. Outside the concession zone, communities expand from migration and resettlement. Furthermore, the mines cause negative health and environmental impacts because of deforestation, graphite dust and water contamination. The results are discussed as they pertain to discourses of extractivism driven by the energy transition. Extraction driven by the energy transition is not inherently sustainable, and the findings indicate how energy transition-induced mining affects localities even in the early stages. The pursuit of sustainability through the energy transition exhibits internal contradictions as it drives processes which threaten sustainability in key places of green mineral extraction.

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List of abbreviations

BMA	Balama, Montepuez and Ancuabe
CRM	Critical Raw Material
EIA	Environmental Impact Assessment
GHGs	Greenhouse gases
GIS	Geographic Information System
LULC	Land Use Land Cover
MIREM	The Mozambique Ministry of Mineral Resources and Energy
RAP	Resettlement Action Plan
RS	Remote Sensing
SDGs	Sustainable Development Goals
SIA	Social Impact Assessment

1. Introduction

Currently our planet is faced with numerous challenges caused by climate change, and this is driven by high carbon emissions (Fahey et al., 2017; Hardy, 2003). Climate change has several problematic environmental consequences, such as declining biodiversity, rising sea levels and more extreme weather events. This causes increased vulnerability for people, and some are better able to cope with the risks and adverse effects than others (Kaijser & Kronsell, 2014). It is recognized internationally that there is a pressing need for action. Conventions such as the United Nations (UN) Climate Change Conference (COP26) are organized to collaborate globally in finding ways to mitigate and adapt to climate change and its impacts. It is stressed that carbon emissions must be reduced, as one of the Sustainable Development Goals (SDGs) is to shift towards carbon neutrality (UN, n.d.-a). Carbon neutrality refers to achieving net zero emissions of greenhouse gases (GHGs) by reducing emissions or GHG removal (Guterres, 2020).

The goal of carbon neutrality gives rise to alternative energy sources, to reduce negative environmental effects. Our current energy sources are the main component responsible for carbon emissions. Thus, there is a need for energy sources that are carbon neutral. The energy transition refers to transitioning from high to low-carbon energy sources, and this is a core part of fulfilling global ambitions for a more environmentally and socio-economically sustainable future. Possible alternatives include wind energy, solar energy, and geothermal energy (Hund et al., 2020). Shifting from energy sources that are responsible for high carbon emissions to low carbon emissions is not without its impacts. New technologies require increased an amount of materials.

The energy transition is highly mineral intensive and causes a rise in demand, because more minerals are required to create alternative energy sources (Hund et al., 2020). The minerals and metals needed for producing the technologies that enable a low-carbon economy are known as green minerals (Church & Crawford, 2018). Particularly wind, geothermal and solar technologies are more mineral intensive than fossil fuel technologies. Certain green minerals (e.g., copper, chromium, molybdenum) are more cross-cutting because they are used across a wide variety of clean energy generation and storage technologies, whereas others (e.g., lithium, graphite, cobalt) are more specific to certain technologies, for which no alternatives exist. Factors of availability and (ir)replaceability have given rise to the term critical minerals, which falls under the term critical raw materials (CRMs). Critical minerals or CRMs are substances for which there are no easy alternatives and supply risks exist (Critical

Materials Institute, n.d.). The cruciality of green minerals in the energy transition can consequently also turn them into critical minerals. This creates an urgency to secure the supply, which stimulates increased extraction.

The increased demand of minerals leads to opening of mineral extraction projects and this has an impact on the local environment. Sovacool et al. (2020) highlight the connection between the energy transition in the Global North and the negative consequences in the Global South. Within the energy transition much emphasis has been placed on diffusion or use of innovations that are low-carbon energy sources, but upstream and downstream processes have been overlooked (ibid.). This includes mining for required minerals, which is considered an upstream process. Most critical minerals are concentrated in a few countries, many of which are low- and middle-income nations (Institute of Development studies et al., 2022). In fact, of the 35 countries that are most dependent on mining, all but Australia and South Korea are developing countries. Such countries are typically more vulnerable to exploitation and exacerbation, because there tends to be weak environmental and labor regulations, and minimal government involvement (Institute of Development studies et al., 2022; Özkaynak et al., 2012). Therefore, changing to sustainable technologies in the Global North has negative human and environmental impacts for communities in the Global South where the needed minerals are extracted.

Mining operations can be very destructive to vegetation and livelihood. It affects land, water and air, and causes a loss of land for farming, thus depriving communities of their source of livelihood (Basommi et al., 2015, Werner, Bebbington, & Gregory, 2019). In areas where mining takes place there are visible land use and land cover (LULC) changes, often resulting in a decline of vegetation (Basommi, Guan & Cheng, 2015; Latifovic et al., 2005; Werner et al., 2019). This may contribute to a loss of biodiversity, desertification and thus damage ecosystems. Additionally, Sovacool et al. (2020, p.1) list impacts such as "toxic pollution, biodiversity loss, exacerbation of gender inequality, exploitation of child labor, and the subjugation of ethnic minorities". These negative effects are the opposite of the global ambition to "protect, restore and promote sustainable use of terrestrial ecosystems" (UN, n.d.-a). In the energy transition two SDGs are particularly relevant, which are the goals of combatting climate change and its impacts, and ensuring access to affordable, reliable, sustainable and modern energy for all. However, the energy transition should not come at the cost of the local population and environment, which is at stake particularly in increasing mining areas.

The province of Cabo Delgado, in northern Mozambique, finds itself experiencing the effects of increased mining stimulated by the energy transition. This region is host to graphite extraction frontiers among other minerals or substances, such as natural gas and ruby (Ministry of Mineral Resources and Energy & Trimble Land Administration, 2022). Graphite is considered a critical mineral in the clean energy transition, because it is used for batteries in electric vehicles. Its supply concentration is limited to a few locations, which makes this area one of the key places for extraction (Rui et al., 2021). The global graphite demand is expected to increase by nearly 500 percent by 2050 for its application in energy storage (World Bank, 2020). Tesla, the leading company in electric vehicles, and Syrah Resources, a graphite extraction company in Cabo Delgado, are securing a supply agreement which will mean that the graphite operation will only expand (Fastmarkets, 2022). Moreover, the United States' Department of Energy has also invested in the company, by making its first loan in more than a decade to fund the production of this key battery material (Shah, 2022; St. John, 2022).

It has become a pertinent issue to call attention to graphite extraction in the province of Cabo Delgado. As mentioned previously, the global graphite demand is expected to increase in the coming decades, and the supply is highly concentrated. Mining is increasing in this region and the socio-environmental impacts of energy transition-induced mining are currently insufficiently investigated (Agusdinata et al., 2018). It is important to gain understanding of how the energy transition is specifically affecting this area, both for stakeholders in Mozambique and beyond. Though socio-environmental impacts of mining may not be a new field of research, it is less known how the energy transition creates or enhances impacts of mining. In Cabo Delgado, graphite extraction is currently expanding and there is a need for spatial and temporal information on its impact as it relates to the energy transition. Scientific investigation can serve to provide such spatial and temporal information. This information is needed and helpful to government officials, local level planners and development practitioners who deal with these outcomes.

Though there are previous studies which identify LULC changes resulting from mining (e.g., Alvarez-Berríos & Aide, 2015; Areendran et al., 2013; Basommi et al., 2015; Latifovic et al., 2005; Werner et al., 2019), this has not yet been done for Cabo Delgado specifically, nor have such changes been put in relation to the energy transition. This study therefore seeks to gain insight into the LULC changes and socio-environmental impacts resulting from energy transition-induced graphite mining in the province of Cabo Delgado. This will contribute to knowledge on what impact mineral extraction has in the context of the energy transition from a spatial perspective. Therefore, the question this study seeks to answer is:

What is the socio-environmental impact of an expanding frontier of graphite mining stimulated by the energy transition in Cabo Delgado, Mozambique?

The aim is to contribute to academic debate on extractivism stimulated by the energy transition, by highlighting changes in LULC caused by the graphite mining activities and the consequential socio-environmental impacts of graphite extraction. Moreover, this study will contribute to policy debates of such projects in the field of international sustainable development. Two sub-questions are investigated to address the main research question. These are the following:

1. *What land use and land cover changes have occurred in Cabo Delgado over the last decade due to energy transition-induced mining?*
2. *What socio-environmental impacts have the land use land cover changes due to graphite mining had in Cabo Delgado?*

Before addressing the research questions, there are three chapters to further situate the study. Chapter 2 presents background information, which explores drivers of mineral extraction in a broader, global context. Then, a theoretical underpinning is presented (chapter 3). Next, chapter 4 describes the regional context and explains the selection of the study area. Following this, the methods are described (chapter 5), followed by the findings. The findings are presented in two chapters addressing both sub-questions successively. Chapter 6 addresses the changes that have occurred in Cabo Delgado over the past decade as a result of graphite extraction frontiers. In order to answer the first sub-question, the temporal LULC changes due to mining are examined. This is done by using Geographic Information Systems (GIS) and Remote Sensing (RS) techniques. Taking the results from the first question, the second sub question is addressed in chapter 7. Insights from the interview analysis about the socio-environmental impacts resulting from graphite mining activity are presented. Then, in the discussion (chapter 8) the results and broader implications of impacts of the energy transition are addressed. Furthermore, the contributions, limitations and recommendations of this research are described. Finally, chapter 9 closes by presenting the conclusion.

2. Study Background

2.1 Critical raw materials in the green transition

The first chapter already briefly alluded to the energy transition with its growing demand for minerals (Hund et al., 2020). Building on that, different countries or regions have compiled lists of CRMs. Once again, CRMs are substances that are considered difficult to substitute, and for which there may be supply risks (Critical Materials Institute, n.d.). These lists are relevant because they highlight an urgency to secure the materials in question. Examples of regions that have compiled such lists include the European Union (EU) and the United States (US). Not surprisingly, the materials they have included in their lists contain minerals that have a key role in technology for enabling the energy transition, such as cobalt, lithium and graphite (Hund et al., 2020). The US has listed 50 materials, and the EU's list contains 30 partially overlapping items (see Table 1) (European Commission, n.d.; Burton, 2022). The EU has grouped together rare earth elements and platinum group metals, whereas the US has listed these individually, meaning there is more overlap between the lists. Graphite is one of the CRMs and is mentioned (and highlighted) on both lists. To emphasize the importance of graphite even more, the US has targeted this mineral "for increased domestic production by the Biden administration as part of its push to reduce reliance on foreign supply of materials considered vital to meeting its clean energy and decarbonization goals" (St. John, 2022). In short, the inclusion of any material on this list points to the urgency of securing the supply, and thus indicates an increased interest in extraction frontiers of these materials.

Table 1. Critical Minerals according to the EU and US (European Commission, n.d.; Burton, 2022)

USA list of CRMs		**EU list of CRMs**	
Aluminum	Magnesium	Antimony	Strontium
Antimony	Manganese	Baryte	Tantalum
Arsenic	Neodymium	Bauxite	Titanium
Barite	Nickel	Beryllium	Tungsten
Beryllium	Niobium	Bismuth	Vanadium
Bismuth	Palladium	Borate	
Cerium	Platinum	Cobalt	
Cesium	Praseodymium	Coking coal	
Chromium	Rhodium	Fluorspar	
Cobalt	Rubidium	Gallium	
Dysprosium	Ruthenium	Germanium	
Erbium	Samarium	Hafnium	
Europium	Scandium	Heavy Rare Earth Elements	
Fluorspar	Tantalum	Indium	
Gadolinium	Tellurium	Light Rare Earth Elements	
Gallium	Terbium	Lithium	
Germanium	Thulium	Magnesium	
Graphite	Tin	Natural graphite	
Hafnium	Titanium	Natural rubber	
Holmium	Tungsten	Niobium	
Indium	Vanadium	Platinum Group Metals	
Iridium	Ytterbium	Phosphate rock	
Lanthanum	Yttrium	Phosphorus	
Lithium	Zinc	Scandium	
Lutetium	Zirconium	Silicon metal	

2.2 Globally critical raw materials and their local impacts

The lists of CRMs point to a global dynamic which impacts a locality such as Cabo Delgado, resulting in LULC change. According to Lambin et al. (2001, p.261-262) "peoples' responses to economic opportunities, as mediated by institutional factors, drive land-cover changes. Opportunities and constraints for new land uses are created by local as well as national markets and policies. Global forces become the main determinants of land-use change, as they amplify or attenuate local factors". Local opportunities and global dynamics interplay and affect land use and land cover outcomes. This notion corresponds with the translocal approach, which sheds light on investment flows, flows of people, and gives attention to complexity and the impacts on actors (Otsuki, Van Westen & Zoomers, 2021). The translocal approach acknowledges how localities are connected and influenced by one another, and participation in translocal and transnational networks shapes livelihood opportunities. In essence, developments or processes taking place in one area may have an impact on another spatially distant area, either directly or indirectly. In the case of Cabo Delgado, the presence of green minerals, including graphite, can be seen as an opportunity that consequentially creates new land uses and causes land cover changes (Lambin et al., 2001). Specifically, there is an increase in mineral extraction frontiers. Global forces that amplify this process are related to the energy transition. The nations of the Global North are making efforts to use alternative energy sources requiring these minerals, and therefore seek to secure the needed supply. Connecting to the translocal perspective, it highlights how investment flows are directed towards alternative energy sources to enable the transition, and therefore they are also directed towards areas that contain the required green minerals. This stimulates mining activity and employment, which affects the flows of people. Some may be drawn to mining areas for employment, whereas others may be displaced to make room for extraction frontiers. With these dynamics in mind, the central theories are first presented, and then a contextual framework of Cabo Delgado is explored, situating it geographically and historically.

3. Central theories and concepts

In this chapter the theoretical framework is explained as it is of interest for approaching the question of what impact the rapidly expanding frontier of extraction in Cabo Delgado has. Energy justice (3.1) and environmental justice (3.2) perspectives are briefly explained, because they are used as a lens for approaching the topic. Additionally, the use of GIS and RS techniques are discussed in 3.3 because they are relevant methodological concepts.

3.1 Energy justice

There are a range of energy justice frameworks that have emerged, as Jenkins et al. (2016) have summarized in their conceptual review of energy justice. Each of these frameworks have a different emphasis and purpose, along with strengths and weaknesses. There is energy security, which focuses on the security of the energy supply and production, and insecurities in the system. Secondly, fuel poverty is listed. This framework investigates distributional unfairness by scrutinizing energy vulnerabilities in communities, with the aim to reduce such inequity regarding a person's (in)ability to access and consume energy. Third, Jenkins et al. (2016) identify the energy justice framework. It is this framework, which is further applied for its relevance to this research.

The topic of mineral extraction can be analyzed with an energy justice framework, because this framework "evaluates where injustices emerge, which affected sections of society are ignored, and which processes exist for their remediation in order to reveal, and reduce such injustices" (Jenkins et al., 2016, p.175). It highlights and addresses issues such as spatial inequalities, displacement and livelihood impacts, and is therefore deemed appropriate as a framework for this topic (Sovacool et al., 2017). In short, Jenkins et al. (2016) highlight three main dimensions of energy justice, which are distributional, recognitional and procedural justice. These dimensions cover the issues on what is concerned (distributional), who is affected (recognitional) and possibilities for remediation (procedural). This study dwells especially on the first dimension. Distributional justice is linked to the concept of spatial inequality as it focuses on where energy injustices emerge in the world.

The dimension of distributional injustice emphasizes "physically unequal allocation of environmental benefits and ills, and the uneven distribution of their associated responsibilities" (Jenkins et al., 2016, p.176). In the case of Cabo Delgado, the increased mining, which contributes to alternative energy sources elsewhere, gives environmental burdens to the local community, whereas they do not necessarily reap any benefits in the energy system. This can be considered a distributional injustice.

This dimension thus has a spatial focus of making explicit where and in what way energy injustices occur. Likewise, Bouzarovski and Simcock (2017) spatialize the energy justice framework, emphasizing energy poverty and vulnerability are not dependent on individual choices but result from structural geographical inequities in the energy system, and these spatial inequalities are considered energy injustices. Typically, justice framing has focused on inequalities between social groups, but here the spatial inequalities are made explicit. That is also the aim of this study: to analyze spatially in what way impacts and injustices are caused in the mining regions as this is stimulated by the energy system. Therefore, the methodology also reflects the spatial focus specific to the mining regions to identify the impacts of this increased activity through LULC change.

Within the energy justice framework, a need has been identified for human-centered, social science explorations of energy developments (Jenkins et al., 2016). The reason for this is that distribution of benefits and burdens of energy systems must be recognized, which is a concern for any society that aspires to be fair. Thus, this framework leads to considerations of distribution of costs and benefits of energy production and consumption, and considerations of fairness towards future generations in terms of the state of the planet they are left with (ibid.). Sovacool et al. (2017) provide a complementary contribution as they have proposed a conceptual energy justice framework of ten principles: availability; affordability; due process; transparency and accountability; sustainability; intragenerational equity; intergenerational equity; responsibility; resistance; and intersectionality. The principles of due process, transparency and accountability, sustainability and responsibility are most relevant to this study. Due process is about countries respecting due process and human rights in their production and use of energy. Transparency and accountability cover access to information about energy and the environment along with fair, transparent, and accountable forms of energy decision-making, which this study aims to contribute to. The description of the principle of sustainability is that energy resources should be depleted with consideration for savings, community development, and precaution. Responsibility refers to the role *all* actors have in protecting the natural environment. (ibid.) Though this study does not deal with energy production and consumption directly, it ties into the energy system by focusing on the impacts of acquisition of materials needed for enabling sustainable energy production. As such, the highlighted principles from Sovacool et al. (2017) give rise to critical reflection on the impacts and implications of increased mining that is stimulated by the energy transition. This leads to consideration of the distribution of benefits and burdens in this process, which Jenkins et al. (2016) have proposed. Thereby, this study contributes to the identified gap of human-centered, social science explorations of energy developments.

3.2 Environmental justice

In addition to the energy justice framework, this study also borrows concepts from environmental justice. As summarized by White (2013, p.51) "It refers to the equitable distribution of environments among peoples in terms of access to and use of specific natural resources in defined geographical areas, and the impacts of particular social practices and environmental hazards on specific populations […]. It is especially concerned with the health and wellbeing of individuals, groups and communities in regards to toxic environments". This perspective emphasizes there are unequal environmental impacts that more negatively affect certain groups over others based on ethnicity, race or social class (Mohai, Pellow & Roberts, 2009). White (2013) illustrates the link between mining and the negative impacts on the environment and health and wellbeing of particular population groups. This link again demonstrates there are spatial inequalities in the distribution of environmental burdens, which corresponds with the distributional dimension of the energy justice framework. Thus, this research takes a spatial focus in exploring environmental and spatial inequality through the energy and environmental justice perspectives.

In environmental justice literature there are three key trends of analyses of mining activities from spatial and economic distribution perspectives, which Özkaynak et al. (2012) identified. The first is the trend is that there is universal displacement and redirection of investments from the global North towards the global South. Industries started moving to developing countries as reserves tend to be relatively unexploited, governmental intervention is generally minimal, and environmental and labor regulations are weak. The second trend they found is of investigations between increased mining and (economic) development. In general, mines are associated with unequal distribution of wealth, as well as unsustainable patterns of growth. Third, in literature it is widely acknowledged how mining has both negative environmental and social impacts, such as loss of biodiversity, LULC changes, high water consumption and contamination, and project-induced displacement of people. They attribute conflicts and discontent within communities to each of these trends. (ibid.) Project-induced displacement refers to any situation where people living on or using coveted land need to move to make way for extractive projects (Vanclay, 2017).

The topic of mining has been well-covered from spatial and economic distribution perspectives. The negative socio-environmental mining impacts are a known fact, as well as the other two common themes that Özkaynak et al. (2012) have pointed out. It must be mentioned that traditionally mining has always been hazardous in nature, and green mineral extraction is no exception to this (Khassab, 2021). Green mineral extraction refers to the acquisition of minerals that are needed for producing low-carbon energy technologies (Church & Crawford, 2018). As was mentioned previously, most mining takes place in low- and middle-income countries where the CRMs are concentrated, and these tend to be poorly regulated (Institute of Development studies et al., 2022; Özkaynak et al., 2012). According to the Institute of Development studies et al. (2022) this presents two main challenges for sustainable development. First, poorly managed mineral extraction could lead to worse global environmental impacts. Second, development tensions will increase in low- and middle-income countries that are rich in mineral resources. Khassab (2021) sharply articulates the contradictions of sustainability in the energy transition discourse. He points out that extraction projects are meant to contribute to the global sustainability ambition by providing green minerals to produce clean technologies, while also contributing to national and local development in the places of extraction. However, "extraction frontiers opened by the sustainability ambition have already proved to be unsuccessful in achieving the desired sustainable development" (Khassab, 2021, p.19). Considering these challenges, it is relevant to explore the discrepancies between sustainable development on the one hand and the extraction impacts on the other. Therefore, this study sheds light on the connection between increased extractivism and the energy transition.

3.3 Remote Sensing and Geographic Information Systems

This study applies a spatial perspective and methodology by conducting a LULC analysis through RS and GIS. For this reason, it is necessary to provide explanations of what RS and GIS methodologies are, their role in studying the socio-environmental impacts of mining, and debates in literature regarding the application of GIS and RS techniques. GIS is a computer-based system for managing, analyzing and manipulating geographical data, typically used to produce visualizations. RS refers to the use of satellite imagery to study features on the surface of the earth (Werner et al., 2019). Using RS and GIS techniques enables the identification of LULC change over time. The change in LULC can be analyzed in relation to mining activities by collecting data from before and after the activity began. The LULC serves as an indicator of the state of the environment and reveals how some elements (e.g., built area) may increase while others deteriorate (e.g., vegetation). In that way, RS and

GIS play a role in studying the socio-environmental impacts of mining. By looking into LULC changes, more can be said about how the extraction of graphite impacts the region of Cabo Delgado, and how it might contribute to local and global sustainability.

Werner et al. (2019) reviewed recent contributions of RS and GIS for assessing impacts of mining. They argued there are beneficial applications of these techniques at local, regional and global level. At the local level, RS and GIS applications could allow environmental and socioeconomic risk assessments, and disaster mitigation, among other things. Regionally, this kind of analysis can help with cumulative and strategic impact assessments. Finally, at a global level, industry-wide land use trends can be revealed, and this may provide key land use data for comparative analyses of mining impacts between commodities, locations, and mining configurations. The potential of these studies is to counter the mining industry's claims. Moreover, they can be helpful in mining-related conflicts. In the concluding remarks the importance of continuation in this field of research is mentioned as it offers additional insights which complement other research into mining and its impacts. Additionally, asymmetries between private, public and civil society sector research can be offset. It is suggested that future studies must be strategic as the possibilities and scope for research exceed current resources. Finally, Werner et al. (2019) list four challenges for GIS and RS analyses of the impacts of mining. These include data coordination and sharing, going beyond deforestation, and the analysis of synergistic or cumulative impacts.

Other important contributions in literature regarding the use of GIS and RS techniques are found in critical GIS scholarship. Critical GIS is an approach that evaluates GIS technology and principles by drawing on social theory, science and technology studies, and philosophy (Schuurmans, 2006). It draws attention to social implications of using GIS technology, demonstrating it could be political and power laden (Harvey, Kwan & Pavlovskaya, 2005). Critical GIS is concerned with power embedded in the production and use of technology, and the way this impacts people in various ways. Pavlovskaya (2018, p.42) argues that critical GIS can be used as a tool for social change and challenges the status quo in three ways: "by challenging the status quo of technology, by challenging the status quo of social power, and by creating spaces of possibility." Essentially, critical GIS gives cause to reflect on the impact of knowledge produced in this study. As such, the theoretical perspective has implications because it influences what aspects are perceived and given recognition.

Energy justice, environmental justice and RS and GIS tie together in this study through a spatial focus on inequalities of impacts resulting from mineral extraction due to the energy transition. Concepts from energy and environmental justice suggest that the distribution of environmental benefits and ills are unequal (distributional injustice). This study therefore applies the spatial RS and GIS methods (explained in chapter 5) to explore how LULC has changed as an indicator for socio-environmental impacts resulting from mining. It further grounds and identifies what impacts there are by drawing on community data, which will also be explained in more detail in chapter 5. Energy and environmental justice theories seek to identify how people are affected differently and draw attention to inequalities. This agenda resonates with the critical GIS ideas of using spatial data as a tool for social change and challenging the status quo. In sum, inequalities of the energy transition impacts are explored spatially with concepts from energy and environmental justice.

4. Regional context

In this chapter the geographical and historical context of Cabo Delgado are described (4.1). Then mining developments in Mozambique are explored in 4.2. Next, accessing land for mineral extraction is discussed in 4.3, which describes licensing and resettlement arrangements. Finally, the chapter narrows down to graphite extraction in Cabo Delgado and provides more specifics about the study area (4.4).

4.1 Geographical and historical context

Cabo Delgado province is located in northern Mozambique. It has an area of about 82,625 km², which lies around latitude 12°3 S, and longitude 39°3 E (Governo da Província de Cabo Delgado, 2017a). It borders the neighboring country of Tanzania, as well as the provinces of Nampula and Niassa, and the Indian ocean on the east (Figure 1). The capital of the province is Pemba, which is located on the coast. The province has a population of 1,287,814, of which the majority (83.2%) resides in rural areas (Governo da Província de Cabo Delgado, 2017b). The population mainly lives from subsistence agriculture (ibid.). The rural northern provinces of Mozambique are considered poverty-stricken (UN, n.d.-b).

The annual average temperature is 30 degrees, making it a very warm climate (World Data, n.d.). There is a wet and dry season, with the dry season being between May and November approximately. The seasonality causes fluctuation in vegetation and soil moisture level, which was important to keep in mind for conducting the analysis. The province of Cabo Delgado is divided into 17 districts (figure 2), including Balama, Montepuez and Ancuabe (BMA) (Governo da Província de Cabo Delgado, 2017a). The BMA districts are most relevant to this study, because this is where most graphite mining companies are active, which will be described later.

Figure 1. Map of Cabo Delgado province (ACI Africa, 2021)

Figure 2. Districts of Cabo Delgado (Club of Mozambique, 2018)

Over time, Mozambique has undergone a lot of changes. The nation as a whole, and the province of Cabo Delgado, have known much turmoil. Namaganda, Otsuki and Steel (2022) identify four stages in Cabo Delgado's history for contextualizing impacts of extractivism. Each of these epochs is riddled with displacement and resettlement. There was the time of slavery, the colonial period, the liberation struggle and the early post-independence period. Until the 1860s many were uprooted because of slave trade. The end of that period only marked the start of intensified colonialism under Portuguese rule, which was an oppressive regime. Then, in the 1960s Mozambicans fought for independence. This war took place mostly in the northern provinces of Cabo Delgado and Niassa. Finally, after becoming independent, a civil war broke out causing a million deaths and five million to be displaced across the nation. It ended in 1992, which is when the nation became democratic (Khassab, 2021; Namaganda et al., 2022).

Then, the question is where that leaves the province today. In Cabo Delgado, each of the historical stages that were described above have left destruction in their wake, hindering socioeconomic development. Namaganda et al. (2022) argue the province has not gained significantly from post-independence development, even though the liberation struggle was predominantly fought in and by peasants from Cabo Delgado. The capital is in the South of the country, therefore also concentrating the economy and resources in the south (ibid.). Nonetheless, an important economic turn, which concerns the province, came paired with the political shift in 1992. From when the nation became democratic, it has undergone an economic transition. It went from being dependent on official development aid to becoming an extraction-driven economy (Khassab 2021; Wiegink & García, 2022).

A few additional relevant factors include socioeconomic circumstances and environmental events. In short, the rural northern provinces of Mozambique are poverty-stricken, with adversities imposed by climate vulnerability and natural disasters, COVID-19, military conflicts and a debt crisis (Khassab, 2021; UN, n.d.-b). Since 2017 there has been an insurgence of armed conflict in the province of Cabo Delgado, instigated by Islamic militia. The instability and violence are attributed to high levels of poverty and contestation over access to land and jobs (Giles & Mwai, 2021). In 2020 there have been over 570 violent incidents, with an around 1700 deaths that year alone. Many people have left their homes in areas where conflict has erupted. The ongoing conflict has led to nearly 670 thousand people being displaced by the end of 2020. On top of that, Mozambique has had to cope with cyclones. The most recent one being in Nampula province last March, which is just south of Cabo Delgado (Reliefweb, 2022). The cyclones affect many people, causing death, injury and damage to property, crops or other forms of livelihood. In addition, COVID-19 has reached around the world in the course of 2020, leading to halts on travel and periods of quarantine and other health measures. All such events have had an impact on the situation in Cabo Delgado, as well as affecting the mining activity going on there.

4.2 The "extractive turn"

The presence of mineral resources (e.g., coal, heavy sands, graphite, rubies) has drawn multinational corporations and led to a sector boom in Mozambique (Wiegink & García, 2022). It is argued the government is not capable of dealing with this boom as a regulation system is absent (Khassab, 2021). Economic activity has been given priority over informal land rights, which has led to land transfers from traditional and informal land users to large multinational corporations (ibid.). Resettlement processes are considered involuntary, because the population cannot refuse to be resettled if the project is regarded to be of national interest. In this context, resettlement refers to a 'planned process of relocation' (Wiegink & García, 2022, p.3). Thus, this extractive boom has led nearly 20,000 families to be displaced through approximately 50 resettlement projects since 2010 (ibid.). People who are affected by this are entitled to compensation, but this requires the ability to negotiate with large corporations (Khassab, 2021). Here it is important to keep in mind that most of the population relies on subsistence agriculture, meaning that displacement can cost people their livelihood as they lose their agricultural land. Resettlement will be addressed further in the next subsection (4.3).

Linking back to the global demands discussed in 2.1, many companies are looking to extract CRMs, and Cabo Delgado has proven to be rich in natural resources including CRMs (Lehto & Gonçalves, 2008; Ministry of Mineral Resources and Energy & Trimble Land Administration, 2022). The Mozambique Ministry of Mineral Resources and Energy (MIREM) and Trimble Land Administration have developed a Mining Cadastre Portal which displays a map containing all application and active mining licenses (figure 3). It shows there are different types of licenses, which will be clarified in the next section. Additionally, this system provides information on what materials companies intend to extract. Essentially, the map demonstrates the extent to which extraction is occurring in the province, and of what materials. Almost the entire province has been designated as licensed areas (either in application or granted) apart from the nature reserve. Appendix 1 provides a list of some of the licensed companies that intend to explore or exploit CRMs in the province (MIREM & Trimble Land Administration, 2022). Materials listed on licenses in Cabo Delgado that coincide with the CRMs include graphite, vanadium, nickel, tin, aluminum, zinc, palladium, platinum group metals, rare earth elements and more (see appendix 1). Apart from the CRMs, Cabo Delgado is host to many gemstone-mining sites, but these have been excluded as the focus lies on energy transition-driven extraction. Nonetheless, this does speak of more extraction activities taking place in the province outside of just the CRMs.

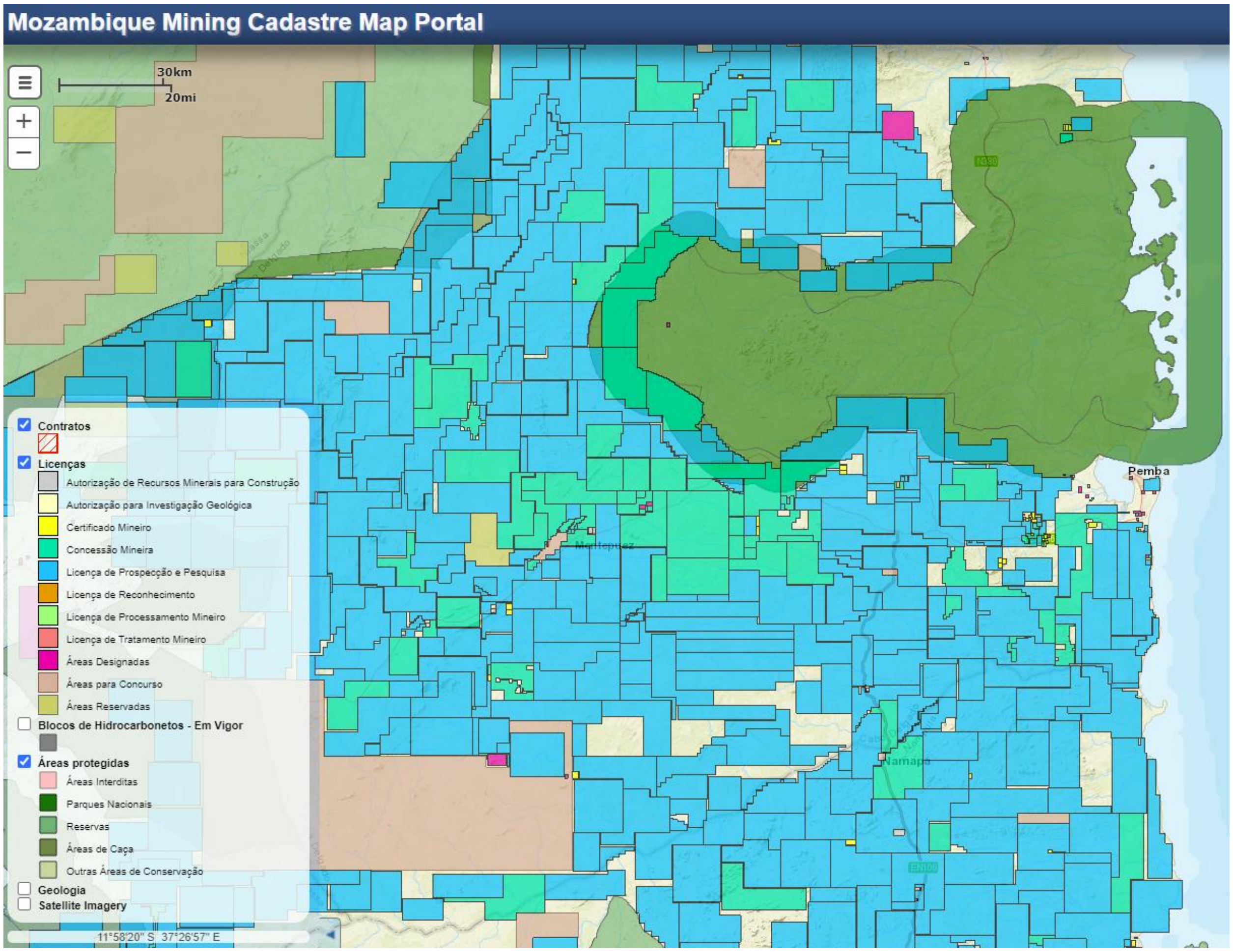

Figure 3. Application and active mining licenses in Cabo Delgado displayed in the Mozambique Mining Cadastre Map Portal (MIREM & Trimble Land Administration, 2022)

4.3 Access to land for mineral extraction in Mozambique

There are seven different mining related licenses in Mozambique (De Amaral & Mussagy, 2020). First, there is an exploration license which grants the rights to undertake exploration and prospecting with the purpose of assessing whether there are mineral resources. This license is valid for up to eight years, though typically it is 5 years (De Amaral & Mussagy, 2020; MIREM & Trimble Land Administration, 2022). Second, De Amaral and Mussagy (2020) mention the mining concession license which grants concessionaires the exclusive right to undertake mining exploration, production and mineral disposal for a period of 25 years, which is renewable at the government's discretion. Third and fourth are the mining certificate and mining pass, which are relevant to small-scale artisanal mining activities. Finally, there are licenses for mineral treatment, mineral processing and mineral products trade. These licenses do not relate to impacts of extraction as much as the exploration licenses and mining concessions and are therefore not further considered in this study.

Concession and exploration licensed areas are considered most relevant to this study, as these areas will experience mineral extraction and consequently socio-environmental impacts. From the moment an exploration license is obtained, impacts may start to become visible as companies may already have some extraction activities for the purpose of charting whether to pursue further extraction of minerals in that particular area. However, the exploration license is valid for a shorter period of time, and there is no guarantee whether mining in this area will be pursued beyond the exploration phase. Thus, the chief focus is on mining concession areas. These areas indicate the presence of extraction activities for a longer period, which is also likely to be more intensive as they will have commercial purposes. The mining concession licensing typically is acquired after first having had the exploration license. This means initial extraction activities may have started before the date on which the mining concession was granted.

One may ask how a company comes to acquire the land for mining when it was previously occupied. To answer that question, it is necessary to turn to the Mozambican resettlement and land legislation, which also has important implications for compensation. Wiegink and García (2022) summarize that according to the Mozambican constitution land belongs to the state and cannot be sold. The land law may not recognize ownership, but instead acknowledges land use rights known as DUATS (Direito de Uso e Aproveitamento da Terra). Mozambicans do not need to register, because they automatically have a permanent DUAT for land they already occupy. On the other hand, companies are required to apply for a registered DUAT, by which they acquire state permission to use the land. The land acquisition process includes community consultations, which are separate from, but often parallel with, the resettlement process. Considering there is no recognition of land ownership, there cannot be compensation for this either. Rather, the use of land or what is on the land can be compensated for, and the lost farmland is to be replaced with new land for cultivation. Resettlement regulations are guided by national and, in some cases, international social performance standards. The stages of the resettlement process include (1) formulation of a Resettlement Action Plan (RAP), which is incorporated in the Environmental Impact Assessment (EIA) process and (2) compensation and assistance for restoring the livelihood of those who are affected. The standard of living and livelihood of the affected is to be maintained at a minimum, and preferably improved in the process of resettlement. Companies are to take responsibility for the resettlement process (that is, preparing the

RAP, financing and relocation implementation) and the government is to facilitate by appointing replacement land and approving the plans. (ibid.)

4.4 Graphite extraction in Cabo Delgado

In this study, the focus is on graphite extraction and the resulting socio-environmental impacts. Though other CRMs are also relevant, a narrower focus is adopted by highlighting one specific green mineral. Graphite is of particular interest for two reasons. First, the graphite demand is expected to increase dramatically over the next 30 years, as Hund et al. (2020) suggest. That is driven by energy transition related technologies. As has been highlighted, graphite has an essential role in clean energy technologies, because it is needed in the production of energy storage systems and batteries for electric vehicles. The second reason for studying graphite is the current state of graphite extraction within Cabo Delgado. The level of graphite extraction is further advanced than other CRMs in Cabo Delgado. It was found many critical minerals are listed among exploration licenses (see appendix 1); however, few are currently found under mining concessions, apart from graphite (MIREM & Trimble Land Administration, 2022). There are already multiple sites where companies have active mining concessions for graphite extraction (MIREM & Trimble Land Administration, 2022; EOH CES, 2014a; Triton Minerals, 2015). That being the case, this means the impact can also be investigated specific to the places where the extraction activity is found.

The graphite mining activities in Cabo Delgado, Mozambique, are mostly found in the BMA districts, as has been mentioned briefly in the geographical context (4.1). The locations of graphite mining concessions were determined based on the Mining Cadastre Map (MIREM & Trimble Land Administration, 2022). Companies that have been granted a concession license are listed in Table 2. When a license was granted, this implies that the concession holding company is free to start activities whenever it pleases. Therefore, the licensing information is an indicator for the areas where graphite mining activities take place. Companies with mining concessions may begin activities immediately to make the most of their concession period, however there could be reasons for postponing commencement. Thus, the licensing information may not perfectly reflect the presence or level of mining activity, but it serves as a perimeter for the timeframe the analysis covers. In sum, Table 1 provides an overview of the mining companies; their locations; dates of the license application, acquisition, and expiration; and size. These listed companies in the table are accordingly presented in the map of figure 4.

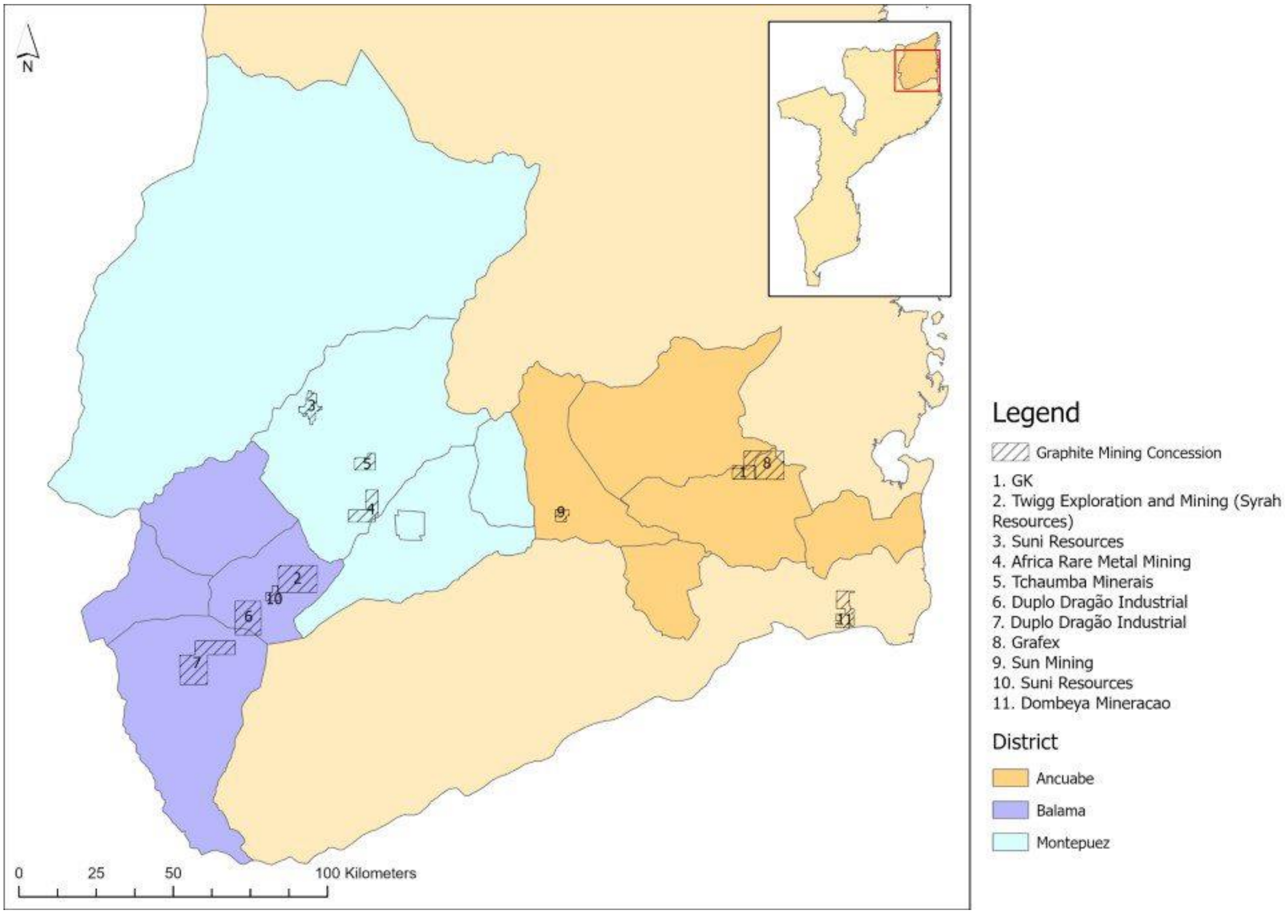

Figure 4. A map of the graphite mining locations in Cabo Delgado, Mozambique

Table 2. Graphite mining companies in Cabo Delgado that are in possession of a mining concession license

Leading Company	(Subsidiary) Local company	Locality and District	Mineral	Date License application	Date License Acquired	Date License Expiration	Area (km²)
AMG Graphite	GK Ancuabe Graphite Mine	Metoro & Ancuabe, Ancuabe	Graphite	15-07-93	05-08-93	05-08-28	33.3
Syrah Resources	Twigg Exploration e Mining	Balama, Balama	Graphite, Vanadium	08-07-13	06-12-13	06-12-38	110.6
Battery Minerals	Suni Resources (Montepuez)	Mirate, Montepuez	Graphite, Vanadium	09-05-17	22-02-18	22-02-43	36.7
	Africa Rare Metal Mining Development Company	Mirate, Montepuez	Graphite, Gold	17-05-18	11-03-19	11-03-44	61.8
	Tchaumba Minerais	Mirate, Montepuez	Graphite	24-05-18	26-03-19	26-03-44	30.2
	Duplo Dragão Industrial	Balama & Kwekwe, Balama	Graphite	13-04-18	08-05-19	08-05-44	93.1
	Duplo Dragão Industrial	Kwekwe, Balama	Graphite	13-04-18	18-06-19	18-06-44	145.4
Triton Minerals	Grafex	Metoro & Ancuabe, Ancuabe	Graphite	17-11-17	07-08-19	07-08-44	102.7
	Sun Mining	Meza, Ancuabe	Iron, Graphite, Gold, Ruby	06-03-19	09-09-20	09-09-45	15.0
Battery Minerals	Suni Resources (Balama)	Balama, Balama	Graphite, Associated Minerals	28-06-19	23-07-21	23-07-46	15.4
	Dombeya Mineracao	Mazeze, Chiure	Graphite, Base Metals	07-08-20	24-11-2021	24-11-2046	543.5

In this study, I focus on two areas which are the Syrah mine in Balama, and the GK mine in the Ancuabe district. Of the ten listed graphite mines in Cabo Delgado, the Syrah and GK mines have been most active and therefore are the most insightful for analyzing. Moreover, Syrah sits on one of the world's largest single graphite deposits, and GK is the oldest graphite mine in Cabo Delgado (MIREM & Trimble Land Administration, 2022; Pistilli, 2022; Syrah Resources, n.d.-a). Figure 5 shows a close-up of the Balama study area, including the locations of the Project Affected Communities (PACs) which are the villages of Nquide, Ntete, Maputo and Pirira (EOH CES, 2014a). PACs refer to the villages which are anticipated to be significantly impacted by the presence of graphite extraction projects. The PACs are faced with economical displacement as the mine acquired 667 machambas, which is the in vivo term for cultivated farmland, and temporary structures on this land (EOH CES, 2014a; EOH CES, 2014b; Khassab, 2021). In addition to the most directly affected communities, five other communities are likely to face notable impacts, which are Balama Sede, Marica, Muape, Nacole and 7 de Setembro (Syrah Resources, 2018). The Ancuabe study area is found in figure 6 showing both GK and Grafex. In the remainder of the study only GK is highlighted, because Grafex has not demonstrated much activity yet. In Ancuabe, it was reported there were 60 people who were to lose machambas (interviewee 1, Nankhumi). This mine was originally established in the 1990s and then stopped their activities until recently. In that time people had begun making use of the land since the abandonment of the project and they now face economic displacement with the reactivation. The PACs around the GK mine include Muaguide, Nacussa, Nankhumi and Nathokua.

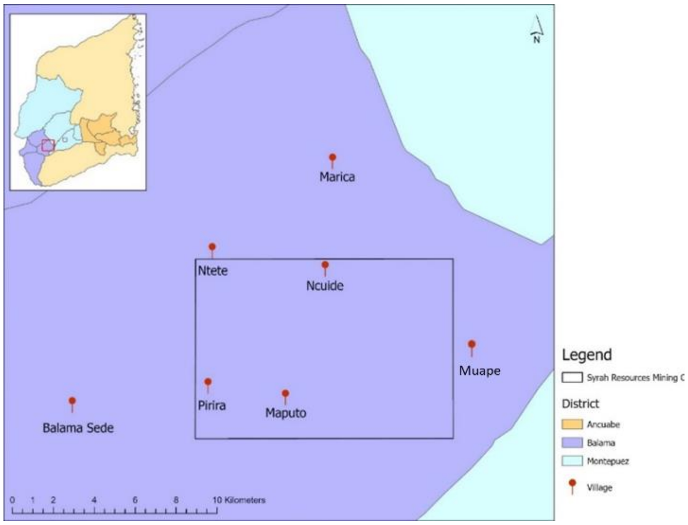

Figure 5. Map of Balama study area

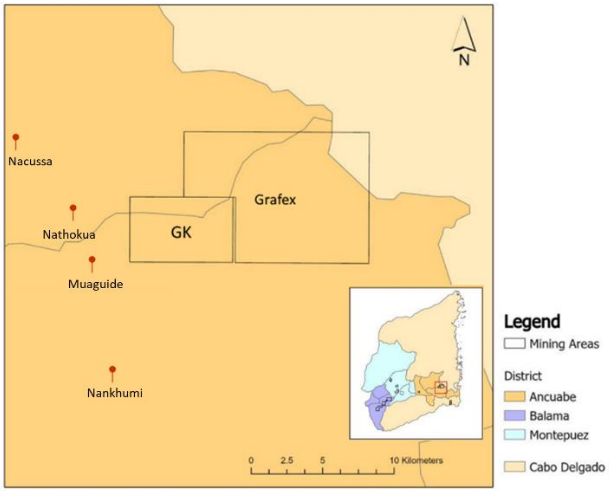

Figure 6. Map of Ancuabe study area

5. Methodology

This chapter provides an overview of the applied research methods and techniques for data collection and analysis (5.1). The rationale is explained along with a systematic account of the analysis steps. In addition, there is a reflection on positionality as a researcher and the potential biases that may be involved in the process (5.2).

5.1 Research design

There are two main ways in which data was collected and analyzed. This study was designed to be conducted remotely, as the circumstances around COVID-19 and violent conflicts restricted possibilities for site visits to Mozambique. In part, this study includes an analysis of LULC change by using RS and GIS techniques, which is to address the first sub-question. The specific RS and GIS methods will be discussed in more detail (5.1.1). Second, this research consists of analyzing interviews and secondary data, which contribute by building on the RS and GIS analysis results. The second sub-question is addressed by drawing on interviews conducted with affected communities as well as key stakeholders. Secondary data collection refers to any insightful material that was not produced specifically for the purpose of this research (Bryman, 2016). This included environmental impact assessment reports and other company reports. The research covers the early stages of graphite extraction projects, with the advantage of identifying the initial changes. These would be more difficult to trace at a later stage. The timing of interviews is particularly advantageous, because people shared their experiences as changes were happening, rather than recollecting them years after a mine is already well established as is typical in several impact studies (e.g., Kangongo, 2008; Moeng, 2019; Morrison-Saunders et al., 2016; Shi & He, 2012).

Based on the theoretical framework, environmental and energy justice issues are viewed from a spatial perspective for addressing the research questions. As this study emphasizes the spatial and environmental aspects of the mining impacts with the perspectives of energy and environmental justice, using RS and GIS techniques are deemed appropriate. The following section will explain and further justify the RS and GIS methodological decisions.

5.1.1 Remote Sensing and Geographic Information Systems analysis

There are a number of important factors that affect the final result of image classification. These factors include the classification algorithm, the image data available, pre-processing of the data, classification scheme, training sample selection, post processing techniques, and validation methods

(Li et al., 2014). The overall process of the analysis is presented in figure 7 based on the Balama analysis. The procedure for Ancuabe is largely the same, except that only two images were included. These are of different dates (2013 and 2020), resulting in two classifications and one change detection performance.

Classification algorithm

In order to determine the change in LULC over time, this study has adopted the post-classification comparison technique, applying a supervised maximum likelihood classification (MLC). It is the most commonly used change detection technique and is considered the most accurate procedure. In short, post-classification comparison means that satellite images are taken from different dates and are classified independently and then compared. The classification is done pixel by pixel. In essence, several areas are selected and identified for an image as belonging to different classes, which serve as training sample data. The computer then uses these samples and identifies the characteristics of the data for each type of phenomenon and uses this information to classify the most similar remaining pixels. Classification is conducted separately for each image from the different dates, which minimizes atmospheric and sensor differences between the images. Post-classification comparison has the advantage of indicating the nature of changes. (Alqurashi & Kumar, 2013)

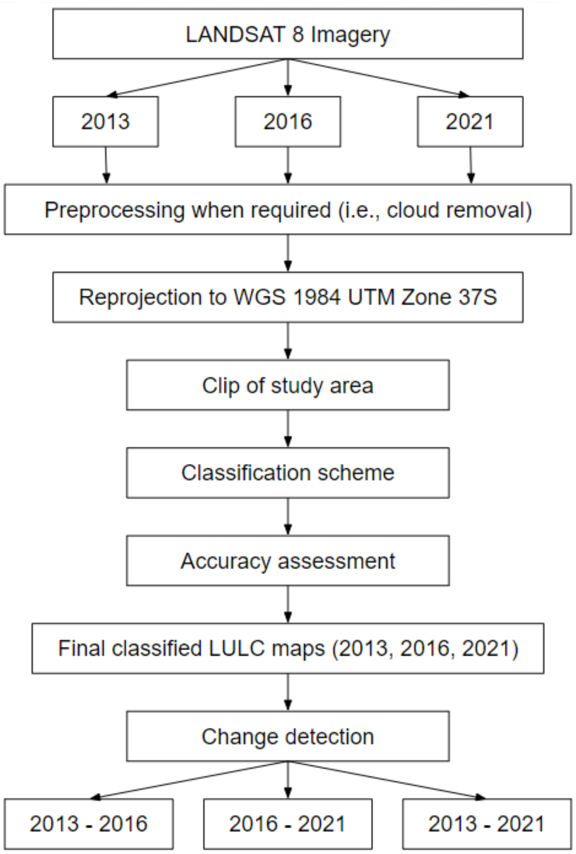

Figure 7. Diagram of the RS and GIS analysis workflow

Data Acquisition

The first step for conducting the post-classification comparison is to collect the satellite data from which classifications are made. This study aims to demonstrate what change has occurred as a consequence of increased graphite extraction. The temporal LULC change is demonstrated by selecting images from different points in time, namely images from before the mining increased to the present. In selecting the data, the availability of comparable images without cloud obstruction is a key factor. The data was chosen from available images of the same satellite and processing level: Landsat 8, Collection 2, level 2 (C2L2). The advantage of C2L2 is that USGS has preprocessed this data so that it contains less errors (USGS, n.d.-a).

Images were taken from the same time in the year approximately, by selecting images taken in or around the month of June. This is to ensure comparability and to prevent change being attributed to seasonal fluctuations such as changing vegetation density and soil moisture content. In June, the level of cloud cover was most favorable across the years, while also being relatively green.

Images of the scene of Path 165, Row 69, cover the Balama study area (USGS, n.d.-b). A scene refers to "the extent, or footprint, that exists on the ground" and the image refers to "the collection of spatially arranged measurements (i.e., bands) captured in the scene at a single time" (Young et al., 2017, p922). Syrah Resources first received its concession license in 2013 (table 2), but began its activity around 2017 (MIREM & Trimble Land Administration, 2022; Syrah Resources, n.d.-a). The dates the images were taken are June 3rd, 2013; May 10th, 2016; and June 9th, 2021. The earliest year shows no activity, then 2016 reveals the initial changes, and finally 2021 is the most recent comparable image from June that was available. In 2016 the best available image happened to be from May, which slightly affects the results because it is a wetter and greener time in the year. For this reason, it shows more vegetation in the classification. Nonetheless, this image was selected for its place in the mining activity timeline as it demonstrated the initial appearance of the mine.

The Ancuabe mines are covered best by the scene of Path 164, Row 69 (USGS, n.d.-b). The activity of this mine had originally started in 1993, however these activities were paused for a time and only restarted around 2017 (Mumba, 2017). The changes since the reboot can be related to the energy transition process. Therefore, for the GK mine images from May 27th, 2013, and June 15th, 2020, are deemed most appropriate for the analysis. These two years were selected for being before and after the reactivation of the mine, as well as being the best available image within a comparable date range. For the purpose of this study, the focus is on the impact from the recently resumed activities. The earlier mining activities are not related to the energy transition, nor is there Landsat 8 data available from that timeframe, which reduces comparability. Therefore, the changes around 1993 are left out. Because this mine was already present, only two years were included for the analysis to find what changes occurred since the resumption.

Pre-processing

According to Young et al. (2017) certain preprocessing steps may be required when working with satellite data to account for sensor, solar, atmospheric and topographic effects. The Landsat Collection 2 Level 2 data has already been geometrically and atmospherically corrected (USGS, n.d.-a). Apart from removing cloud cover, no further preprocessing steps will be taken for the purpose of this analysis. As a guiding principle Young et al. (2017) propose minimizing preprocessing steps only to the necessary steps for a given analysis. They suggest this because each preparation step alters the data further from the original values and could therefore potentially introduce more errors.

Additional preprocessing steps are not necessary, because change in the cover classes is detected from each classified map, not the spectral values. Though the analysis involves the use of different satellite images over time and from two different scenes, they are only compared after classification and the two scenes are analyzed separately. The spectral values are analyzed within a single scene and single time, meaning they are analyzed independently to create classified maps. As was mentioned before, post-classification change detection involves classifying images from multiple dates and subsequently comparing the categorical maps to identify changes. It is the land cover classes that are analyzed and compared, and not necessarily the spectral values of the satellite images. Because spectral values from different images are not compared directly, correctional preprocessing steps to make them comparable are not required. Furthermore, topographic correction is not needed. (ibid.)

Classification scheme and classification process

The classification scheme consists of four classes: (1) developed/bare soil, (2) water, (3) dense vegetation and (4) sparse vegetation. In the remainder of this report, light vegetation is used synonymously with sparse vegetation. The four classes were selected for representing the main LULC classes present in Cabo Delgado. Though in the first place more classes were adopted, the distinction between some of these classes was problematic and resulted in a lower accuracy. Therefore, the classes with similar spectral signatures were merged, leaving these four distinct classes. The process of MLC involved selecting training samples to classify the image. Li et al (2014) found that the MLC algorithm performs well with around 60 training samples per class. Increasing this number does not necessarily improve the results for MLC. Therefore, in each classification 60 training samples were selected per class to create the classified maps. There was one exception where it was not possible to select 60 samples, namely the water class in the Ancuabe study area. This was because there is very little open water within this study area.

Accuracy assessment

The validation of the produced classified maps is an important step for determining the reliability of the results. When it comes to the post-classification comparison technique, the quality of each classification affects the final accuracy (Alqurashi and Kumar, 2013). Therefore, the accuracy of each individual classification was assessed. This was done by creating accuracy assessment points for which the classified and ground truth values were registered. Hay (1979) suggests a minimum of 50 sample points per class are needed to determine true error rates. As 60 training samples were adopted in the classification process, so too 60 sample points per class were taken for the accuracy assessment. In sum, for each accuracy assessment 240 sample points were generated using an equalized stratified random sampling strategy. The ground truth data of these points was determined using the same image from which the classification was made as well as Google Earth Pro satellite data. Taking this information, a confusion matrix table was generated, which reflects the accuracy per class and overall accuracy. The classification process was repeated until the accuracy level was deemed sufficient. The targeted accuracy was 80% per class, and minimum overall accuracy was 85%. These accuracies are typically adhered to within the research community (Foody, 2002; Lechner et al., 2019).

Change detection

The change detection was conducted using the final classified maps. Throughout the classification procedure (up to the accuracy assessment) the administrative boundaries of the localities were used as the extent of the analysis. The final maps were produced by extracting a more relevant, smaller study area within these extents. A buffer area of approximately 460 km^2 was taken in both Ancuabe and Balama, within which some of the district or locality borders are still present. In Balama the final study area was made to include the reservoir from which the mine draws water for their processes. Therefore, the mine is not perfectly centered in the final maps. Additionally, the Balama study area covers all the affected surrounding communities. For Ancuabe, the mine is also slightly off-center in the final maps, due to restrictions from the scenes covered by the satellite. The LULC change analysis was conducted with these extracted, final maps. The area of each class was calculated in the given years per study area. Then the change in percentage was calculated of each class's area between years. Additionally, in ArcGIS pro, change detection maps were generated which visualize where change in LULC has taken place. The change detection maps also provide information between which classes change took place (e.g., from sparse vegetation to developed/bare soil) and the area could be determined.

5.1.2 Interview and secondary data analysis

Following the RS and GIS analysis, the findings are contextualized by drawing on interviews. In-depth interviews are able to provide insight into personal experiences of certain topics and issues (Hennink Hutter & Bailey, 2020). Therefore, they are suitable for grounding the findings from the RS and GIS analysis. The interviews that were included had been conducted previously with members from local communities as part of a PhD project. The translated verbatim transcripts were made accessible. They were conducted during the time the mines were beginning, and therefore their reports are more reliable in terms of what changes they experienced during this stage. The purpose of analyzing the interviews was to provide richer data on the changes taking place in Cabo Delgado because of increased mining activity. The interview data has a supplementary role in the analysis, so it was not necessary to reach a point of saturation. This refers to a point where new information no longer comes up (Hennink et al., 2020). The data was used to better understand the impacts of LULC changes on the environment and inhabitants.

Given the time constraint and purpose of the data from interviews, a subsample was selected from the total number of available transcripts. This was considered sufficient to inform a general view of key issues from the perspective of both the community members and stakeholders. There were interviews with community members near the GK and Grafex mines as well as the Syrah mine. Additionally, stakeholders were interviewed, and these interviews are in reference to all mining in Cabo Delgado in general. All GK community interviews were included. In the case of Syrah, two interviews were randomly selected per community. The communities that were included are the four PACs (Nquide, Ntete, Maputo and Pirira) as well as Balama Sede and 7 de Septembro. Furthermore, six stakeholder interviews were selected based on relevance, as specific roles provide different insights and perspectives. Table 3 summarizes details of the interviews included for the analysis. The interviews were first anonymized and assigned labels using the community names (e.g., Interviewee 1, Maputo). Then they were coded using NVivo, which is a computer-assisted qualitative data analysis software. The software is used as a facilitating tool to analyze the data (Hennink et al., 2020). After coding, the data was analyzed by code and category. The list of codes is provided in appendix 2. The codes were developed both deductively deriving from the conceptual framework, and inductively from the data, and during the process of coding memos were added (ibid.).

Table 3. Overview of interviews

Type of interview	**Community or organization**	**Interviewees and gender**
Community interviews near GK	Muaguide	1 (M)
	Nacussa	3 (M)
	Nankhumi	3 (1F, 2M)
	Nathokua	1 (M)
Community interviews near Syrah	Nquide	2 (M)
	Ntete	2 (F)
	Maputo	2 (1F, 1M)
	Pirira	2 (1F, 1M)
	Balama Sede	2 (1F, 1M)
	7 de Septembro	2 (M)
Stakeholder interviews	Mineral resources department	1 (M)
	Provincial department of Mineral Resources	1 (unknown)
	Provincial department of Land and Agriculture	1 (unknown)
	ARA-Norte (department in charge of water quantity and quality monitoring for Northern Mozambique)	1 (unknown)
	Servico Ambiental (state department of Environment)	2 (unknown)
	Ambiente (provincial department of environment)	2 (unknown)

Table 4 shows an overview of the data collected for the analysis in terms of documents, reports and policies. These were used with the purpose to understand the companies' decisions and activities taking place in Cabo Delgado. They provided information on the ways the companies (planned to) deal with the anticipated socio-environmental impacts.

Table 4. Overview of secondary data documents

Name	Document type	Purpose	Reference
Social Impact Assessment (SIA)	Assessment Report	Assessment of all socio-economic impacts as a result of the mine construction	(EOH CES, 2014a)

Resettlement Action Plan (RAP)	Assessment Report	Mitigation actions for project induced impacts	(EOH CES, 2014b)
Health and Safety Policy	Company policy statement	Presentation of health and safety standards the company applies	(Syrah resources, n.d.-b)
Environment Policy	Company policy statement	Presentation of environmental standards the company applies	(Syrah resources, n.d.-c)
Non-technical summary of the socio-economic impact assessment report post implementation of the resettlement for economic displacement	Assessment Report	Assessment of all socio-economic impacts as a result of the mine construction	(Syrah Resources, 2018)
Q1 2022 Quarterly Sustainability Update	Sustainability report	Informational purpose, update of how sustainability is implemented	(Syrah Resources, 2022)
Quarterly activities report	Activity update report	Activity report for the period ending 31 March 2015	(Triton Minerals, 2015)
Enabling the circular economy: Annual report 2019	Annual AMG company report	Company-wide activity report	(AMG, 2019)
Environmental, social, & governance report executive summary 2020	Sustainability report	Informational purpose, update of how sustainability is implemented	(AMG, 2020)

5.2 Reflection on positionality as a researcher

According to Takacs (2003) positionality shapes the way things are perceived, because people make assumptions based on their own positionality which influences how they view the world. The researcher's personal background, values and biases may have implications for the research outcomes (Bryman, 2016). Moreover, according to Hennink et al. (2020, p.485) positionality refers to “the way researchers portray themselves during data collection, which can influence data generated”. To put it briefly, positionality can influence both the data collection and analysis process. For this reason, it is important to recognize and acknowledge potential influences that might affect the research. In my case, I am a 24-year-old female Caucasian of Dutch and American nationality, with no experience of visiting Mozambique. This means both the study context and cultural context are distant to me. My (lack of) cultural understanding may impact my interpretations in the analysis. On the other hand, it may have the added advantage that I can take a fresh view on the data as I am further removed from it. In that sense, the data can truly speak for itself. In any case, I aim to prevent my views from influencing the analysis as much as possible by staying close to the data itself as well as the theoretical lenses through which I analyze the data. Addressing any influence on the data collection, the entire study was conducted remotely and digitally. No field visits were included, nor did I personally interact with any participants. The community data by means of interviews was collected by other researchers, so my positionality did not influence that aspect of data collection. In terms of the RS and GIS portion of the study, my positionality may have influenced the study because I was swayed towards the program and methods I had most experience with. Nevertheless, this is preferable because the classifications were made with more skill (in contrast to learning and applying a new method or program). For any program or GIS decision it can be argued this influences the results, outcomes and conclusions in some way. Therefore, the whole procedure has been described above with each step conducted systematically and accounted for. The decisions are justified and grounded in other research and literature. Moreover, secondary materials were used to validate the findings. The combination of two study areas and two methods strengthens the reliability of the results. The methods reinforced one another, which reduces personal influence on the findings, as the different methods and sources are in agreement.

6. Land use land cover change in Cabo Delgado — insights from Remote Sensing and Geographic Information Systems analysis

In this chapter, the LULC change analysis results are presented. The observed changes are described and the sub-question is addressed of what LULC changes have occurred due to energy transition-induced mining in Cabo Delgado over the last decade.

6.1 Findings in Balama

The results of the LULC analysis reveal notable changes occurring as a result of graphite mining activities in Balama. Three satellite images were used to classify the locality of Balama, from which the smaller study area was later extracted. The LULC change detection analysis was conducted for the whole of the (extracted) study area, rather than the concession area alone. This way the changes in the surrounding areas could also be detected and measured. The classified maps are presented in figures 8, 9, and 10. These maps reveal what the land cover was for each given year. The accuracy of these classifications is presented in tables 5, 6 and 7. The accuracy is expressed in the confusion matrix with the producer accuracy, user accuracy, overall accuracy in bold, and kappa.

Looking more closely at the changes that have occurred in Balama, the maps reveal where the mining site has emerged within the concession area (see figures 8-10). An entirely new, solid colored develop/bare soil area emerges and by 2021 water retention areas have also appeared. This shows up in figures 11 through 13 as the largest homogenous changed areas. To clarify, the maps of figures 11, 12, and 13 reveal where LULC change has occurred between years, by showing what class the pixels have changed into. When there was no change, the area is grey, but when there was change these maps show what type of land cover now occupies the area. Aside from the changes in the appearance of the mine, there are a few noteworthy changes that have become evident, and these changes, though less homogeneous, will be explored further. The maps, tables and figures indicate that the largest land cover classes are developed/bare soil and sparse vegetation, and these are investigated more closely.

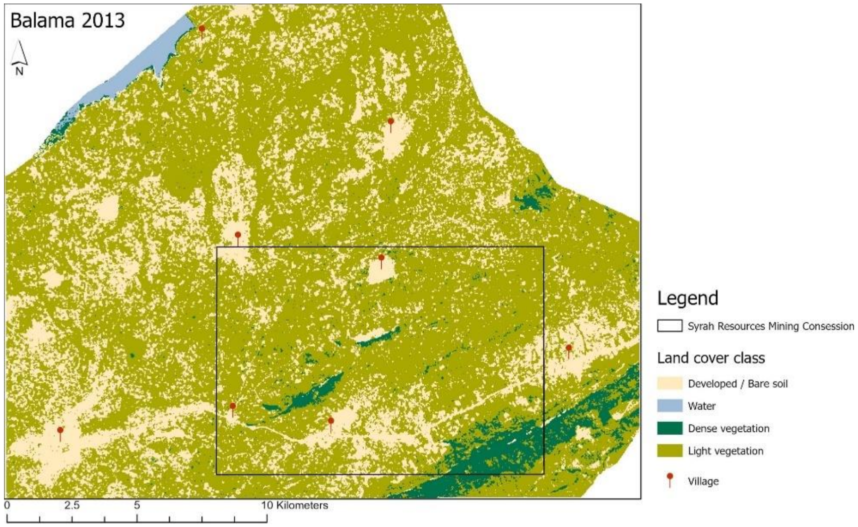

Figure 8. Classified map of Balama study area 2013

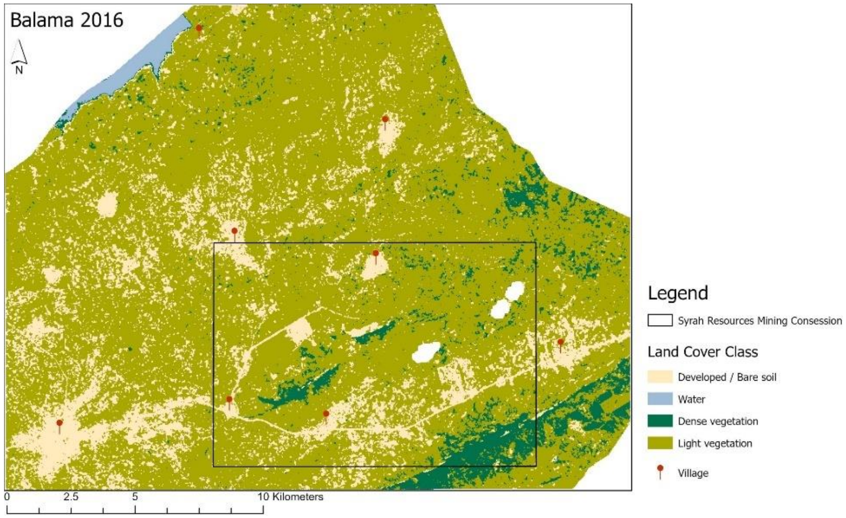

Figure 9. Classified map of Balama study area 2016

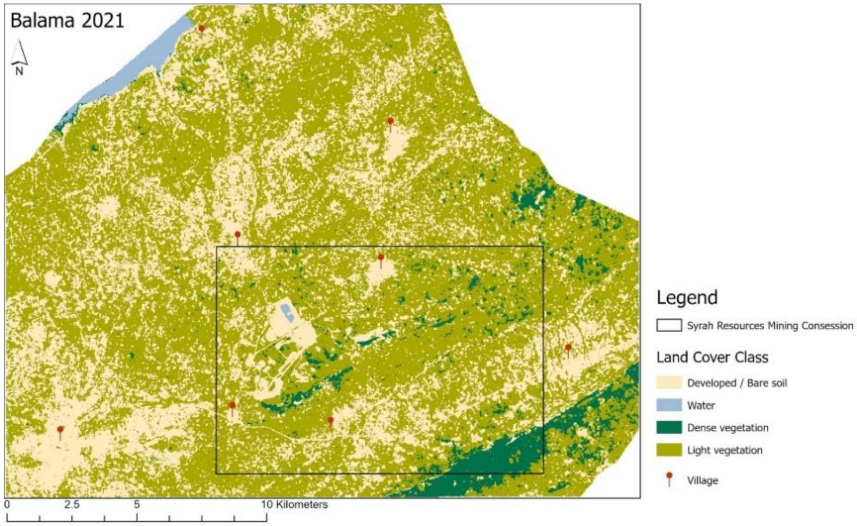

Figure 10. Classified map of Balama study area 2021

Table 5. Confusion Matrix of Balama 2013 classification

Class Value	Developed / Bare soil	Water	Dense Vegetation	Light vegetation	Total	User Accuracy
Developed / Bare soil	51	1	0	8	60	85.00%
Water	0	60	0	0	60	100.00%
Dense Vegetation	0	0	60	0	60	100.00%
Light vegetation	2	0	5	53	60	88.33%
Total	53	61	65	61	240	
Producer Accuracy	96.23%	98.36%	92.31%	86.89%		**93.33%**
Kappa	91.11%					

Table 6. Confusion Matrix of Balama 2016 classification

Class Value	Developed / Bare soil	Water	Dense Vegetation	Light vegetation	Total	User Accuracy
Developed / Bare soil	51	0	1	8	60	85.00%
Water	0	60	0	0	60	100.00%
Dense Vegetation	0	0	55	5	60	91.67%
Light vegetation	2	0	2	56	60	93.33%
Total	53	60	58	69	240	
Producer Accuracy	96.23%	100.00%	94.83%	81.16%		**92.50%**
Kappa	90.00%					

Table 7. Confusion Matrix of Balama 2021 classification

Class Value	Developed / Bare soil	Water	Dense Vegetation	Light vegetation	Total	User Accuracy
Developed / Bare soil	48	0	1	11	60	80.00%
Water	0	60	0	0	60	100.00%
Dense Vegetation	0	0	60	0	60	100.00%
Light vegetation	3	0	7	50	60	83.33%
Total	51	60	68	61	240	
Producer Accuracy	94.12%	100.00%	88.24%	81.97%		**90.83%**
Kappa	87.78%					

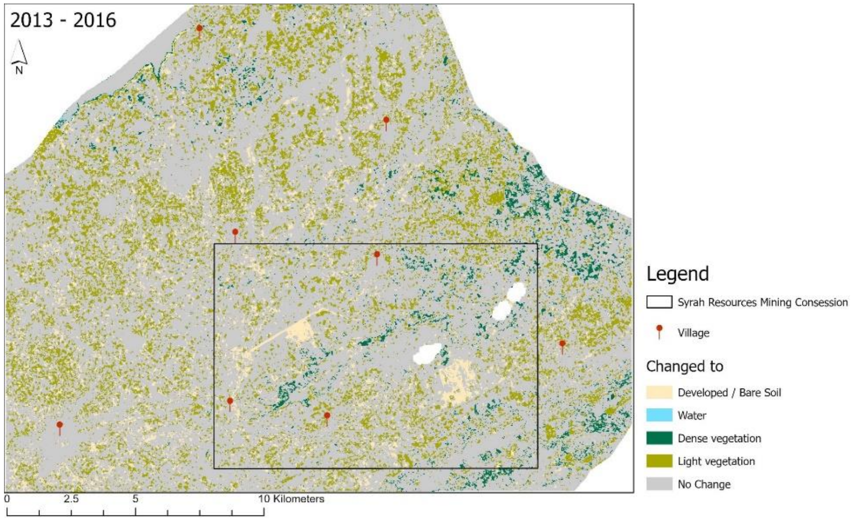

Figure 11. Map of the changed areas in Balama from 2013 to 2016

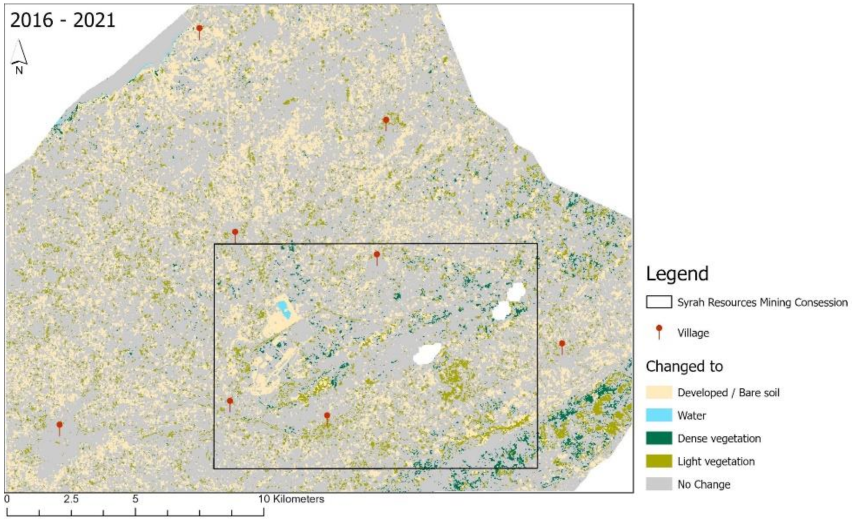

Figure 12. Map of the changed areas in Balama from 2016 to 2021

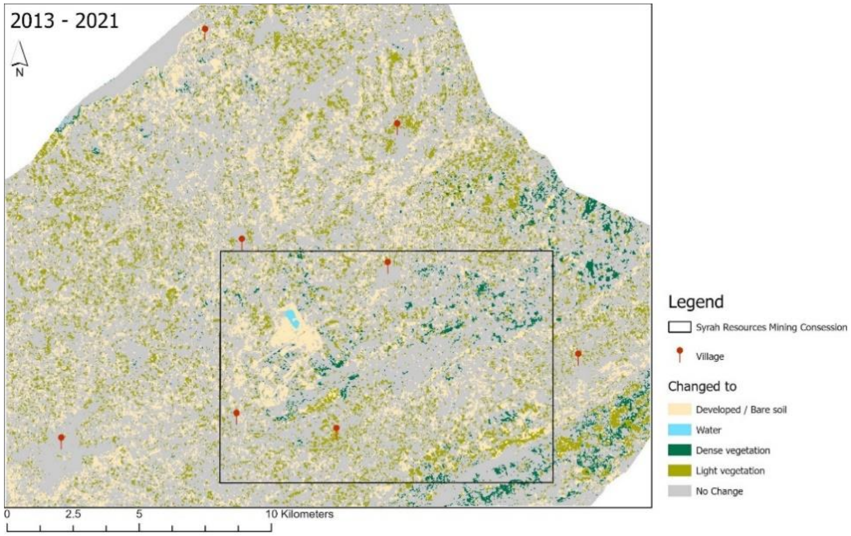

Figure 13. Map of the changed areas in Balama from 2013 to 2021

The changed areas (figure 13) were investigated more closely in ArcGIS to determine what these areas were formerly. There unchanged areas cover about 272.6 km^2 in total. As for substituted areas, changes happened in both directions between each of the classes (e.g., developed/bare soil areas became sparse vegetation and vice versa). When these areas were cancelled out against each other, it revealed between which classes most change took place in terms of absolute area. The main directions of change were from sparse vegetation to developed/bare soil (approx. 22.3 km^2), from sparse vegetation to dense vegetation (approx. 3.9 km^2), and from dense vegetation to developed/bare soil (approx. 1.6 km^2).

The total area of each land cover class can be found in table 8, along with figure 14 which demonstrates the change in area over the years. The total area in km^2 (y-axis) is plotted against the years (x-axis), so that the lines reveal whether the area of each land cover class increases or decreases over time. Additionally, table 9 contains the percentage of change of the area between the years. When this percentage is positive it represents an increase in area, whereas a negative number indicates a decrease in area. In figure 15 this table is also visualized as a graph. The percentage, whether increase (positive) or decrease (negative), is shown on the y-axis, and again the years are on the x-axis. The graph shows for each class whether it has increased in size or decreased between the depicted years.

Table 8. Area in km^2 of the study area in Balama per class per year.

	AREA IN KM^2 PER YEAR		
CLASS	2013	2016	2021
Developed / Bare soil	104,5	65,5	128,5
Water	3,6	3,4	3,6
Dense vegetation	15,7	22,1	18,2
Light vegetation	270,1	301,6	234,7

Table 9. Change in percentage per class between years for Balama.

	PERCENTAGE CHANGE BETWEEN YEARS		
CLASS	2013 - 2016	2016 - 2021	2013 - 2021
Developed / Bare soil	-37,31%	96,19%	22,99%
Water	-6,46%	5,59%	-1,24%
Dense vegetation	40,42%	-17,74%	15,51%
Light vegetation	11,64%	-22,17%	-13,12%

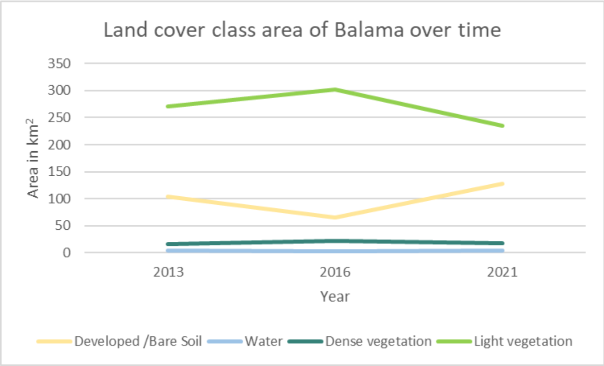

Figure 14. Graph of land cover class area in Balama

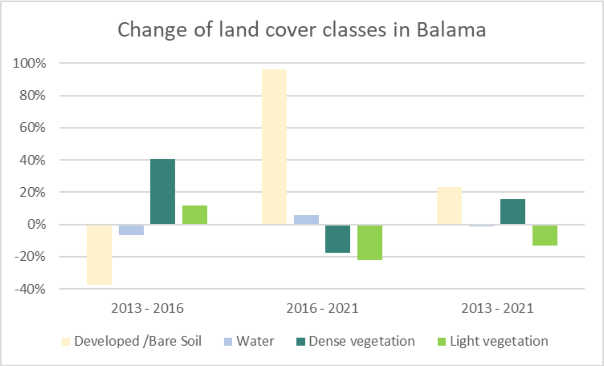

Figure 15. Graph of land cover class change percentage between years in

The general expectation was to see a decrease in vegetation and increase in the developed/bare soil area. The results in land cover change from 2013 to 2021 and from 2016 to 2021 clearly indicate that the area of sparse vegetation has indeed decreased, and the developed/bare soil area has increased (tables 8 & 9). This is most clearly seen in figure 15 for those years. However, the changes from 2013 to 2016 demonstrate the opposite. Figure 14 shows the vegetation line rises between 2013 to 2016, and the developed/bare soil line declines. Here it is important to note again that the satellite image in 2016 was taken in May instead of June, which would account for why it appears greener and explains the outcome. In the end the line for sparse vegetation drops again as figure 14 shows. It declines to be lower than it originally was in 2013. And the opposite occurs for the developed/bare soil class.

To highlight the direction of change from both vegetation classes to developed/bare soil, changes can be attributed to mining activity as well as indirect outcomes. It is interesting to observe more specifically where there were changes in LULC, especially paying attention to the villages. This analysis demonstrates the heterogeneity of change in the beginning stages of the mine's activity. Upon closer examination of the change detection maps (figures 11, 12 & 13), it shows the sparsely vegetated areas increased in and around the four PACs inside the mining concession, whereas outside the mining concession, particularly around Balama Sede and Muape, there is an increase in developed/bare soil areas. Inside the concession area, it is probable there was regrowth of sparse vegetation following the displacement process. The increase in the developed/bare soil class is likely due to increased built area outside of the concession zone due to in-migration from neighboring communities and districts, and secondly from project-induced resettlement. Syrah's SIA report predicted people from surrounding areas are drawn to the settlements near the mine in search of job opportunities, be it directly for the mine or alternatively for starting up small-scale businesses (EOH CES, 2014a). Businesses start popping up as there is increased economic activity. Additionally, Balama Sede hosts many of the workers of the company (ibid.). As for resettlement, some of those displaced have moved to Balama Sede or Muape, which are the nearest towns. The farming practices of the displaced are moved outside of the concession area, and nearer to these towns. This also appears on the classified maps as more developed/bare soil at the borders of these towns, because the harvested fields resemble bare soil.

Next, elaborating on the area that became dense vegetation, table 9 and figure 15 show dense vegetation has increased by approximately 16% overall (2013-2021). The increase in dense vegetation was mostly east of the mine (see figure 11 & 13) in areas that were already more vegetated (see figures 8 & 9). Therefore, the areas that became densely vegetated were previously sparsely vegetated. On the whole, vegetation has still declined in the study area though. The decrease in sparse vegetation may be a lower percentage of about 13%, however the absolute change in dense vegetation covers about 2.5 km^2, whereas the sparse vegetation concerns an area of 35.4 km^2. Thus, it is still appropriate to speak of an overall decrease in vegetation and increase in developed/bare soil areas.

Additionally, an interesting observation is that the largest densely vegetated area, a forest in the southeast corner, has declined on the northern hillside, and expanded southwards. It may be that the agricultural land has expanded up the hillside as a result of the loss of farmland in the mining area, causing the forest to retreat. Another cause may be that the inhabitants were forced to look elsewhere for natural resources from the forest, after they lost access to the forested areas near the mine. Thus, this southern forest is exploited more, which causes decline in dense vegetation. On the other hand, this has increased in other areas, as was addressed previously.

Finally, to mention observations in the water class, there are not very big changes from a land cover perspective, apart from the added water retention areas within the mining concession zone. It may be that the water level depth in the reservoir has changed or water quality is affected, but based on the LULC change analysis alone little can be said about it. Therefore, the environmental changes are further substantiated in the next chapter by drawing on the community and stakeholder interviews. But first, the findings of the second study area, Ancuabe, are highlighted.

6.2 Findings in Ancuabe

Two satellite images were included in the analysis for Ancuabe from which the classified maps were produced, presented in figures 16 and 17. The changed areas are presented in figure 18. For this region, the changed areas were again investigated in ArcGIS to see which classes became which classes, as the map only shows the new land cover area and not what they were formerly. The total unchanged area is approximately 264,8 km^2. For the changed areas, there is again a lot of heterogeneity in the nature of changes happening. The trends of the main directions of change between classes in terms of absolute area were similar to Balama, apart from one. In Ancuabe too, changes happened in both directions between each of the classes, and these were again subtracted to see in which direction most change occurred. So, it was found that nearly 40.8 km^2 went from sparse vegetation to developed/bare soil. Secondly, and here the direction of change differs from Balama, dense vegetation changed to sparse vegetation (approx. 11.9 km^2). Finally, dense vegetation also changed into developed/bare soil (approx. 3.7 km ^{2}). This means that there was an overall decrease of vegetation in this area, including a reduction in dense vegetation. Those are the main changes that can be attributed to the rebooted mining activities of the GK mine based on the LULC change analysis.

The maps (figures 16, 17 & 18) help reveal the change from both vegetation classes to developed/bare soil. Comparing images 17 and 18 shows the mine has expanded inside the concession area as the portion of developed/bare soil has increased. Additionally, water retention areas for wastewater have visibly expanded near the mine. These water retention areas form a part of the mining process. Outside of the concession area the increase in developed/bare soil area is related to two things. First, the villages appear larger, which may be due to an influx of people coming for employment and business development opportunities, just as with Balama. Secondly, surrounding the villages, scattered areas that were already developed or bare only seem to have grown. Though the concession area of GK does not contain villages as in Balama, the mine still affects nearby communities. Because they lose access to the land within the mining concession area, they will need to turn elsewhere. Land uses are likely to have intensified following the displacement out of the concession zone, because the demand of the land's resources has become more concentrated to remaining available and accessible areas. This leads to growing developed and bare areas and declining sparse and dense vegetation.

The aforementioned land use intensification may also account for the change from dense vegetation changed to sparse vegetation. Increased exploitation of such areas causes the density of vegetation to be reduced. Many locals previously used the concession area for farming or accessed certain resources in that area, as will be further explored in the following chapter. Because they have lost access to this land along with its resources, the demand on surrounding land grows. Thus, this may cause the dense vegetation to decline, see for example the areas to the north and south of the mine in figures 16, 17 and 18. Those are the largest new sparsely vegetated areas, which were formerly densely vegetated.

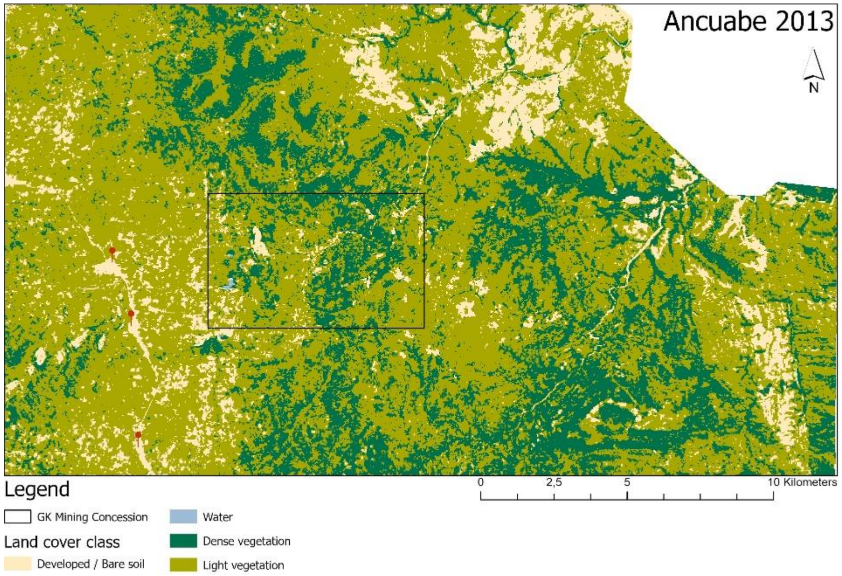

Figure 16. Classified map of Ancuabe study area 2013

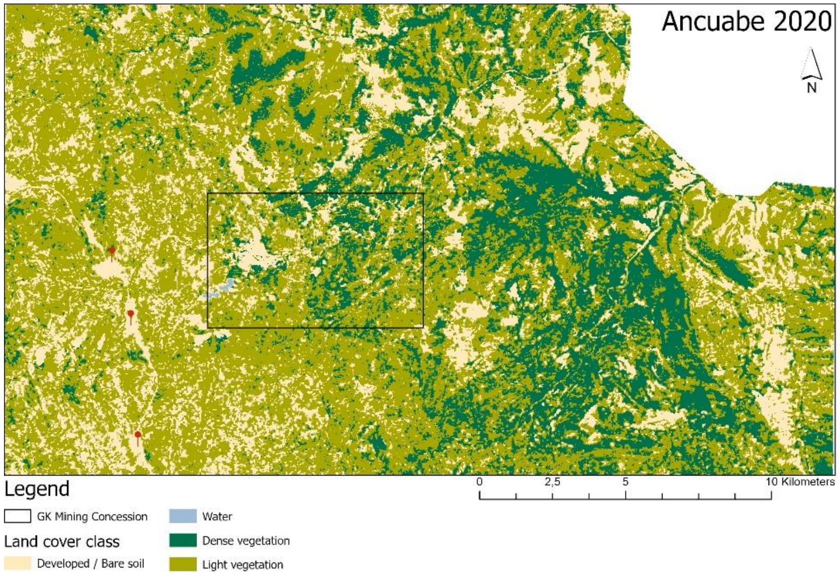

Figure 17. Classified map of Ancuabe study area 2020

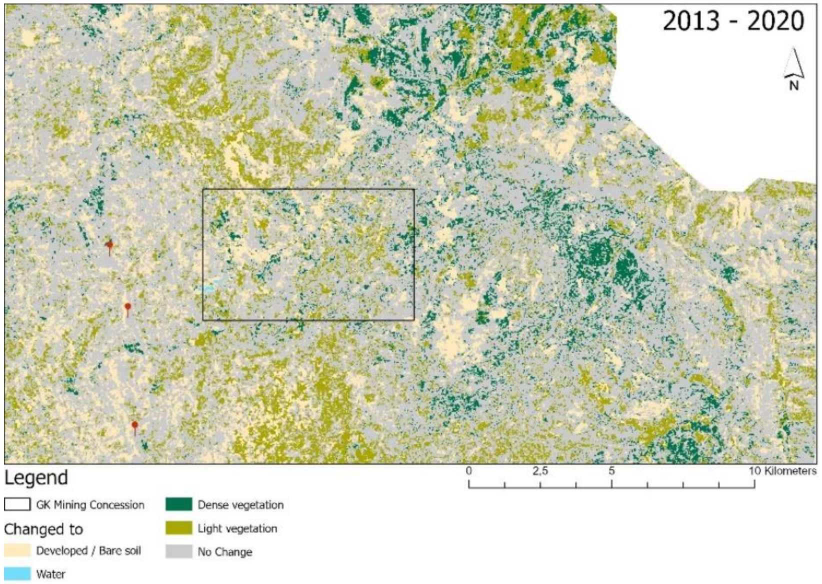

Figure 18. Map of the changed areas in Ancuabe from 2013 to 2020

The accuracy of the classified maps (figures 16 & 17) is presented in the confusion matrix tables below (table 10 and 11). Upon reviewing these tables, it becomes clear that the water class is rather low in accuracy. This class is very small, as there is very little open water in the area. Moreover, during the classification process there were a few overshadowed hillsides which were frequently mistaken for water as they resembled that spectral signature most. As such, these areas were overrepresented in the accuracy assessment, which led the table to reflect an extremely low user accuracy of water. When the misclassified shadow areas were ignored (I.e., generating a confusion matrix table where these areas were deemed as water), the accuracy was far higher for this class. Therefore, knowing that this was the cause of the low accuracy, the classifications were considered satisfactory for continuing the analysis.

Table 10. Confusion Matrix of Ancuabe 2013 classification.

Class Value	Developed / Bare soil	Water	Dense Vegetation	Light vegetation	Total	User Accuracy
Developed / Bare soil	52	0	0	8	60	86,67%
Water	2	13	45	0	60	21,67%
Dense Vegetation	0	0	58	2	60	96,67%
Light vegetation	5	0	6	49	60	81,67%
Total	59	13	109	59	240	
Producer Accuracy	88,14%	100,00%	53,21%	83,05%		**71,67%**
Kappa	62,22%					

Table 11. Confusion Matrix of Ancuabe 2020 classification.

Class Value	Developed / Bare soil	Water	Dense Vegetation	Light vegetation	Total	User Accuracy
Developed / Bare soil	54	0	1	5	60	90.00%
Water	4	21	35	0	60	35.00%
Dense Vegetation	0	0	59	1	60	98.33%
Light vegetation	3	0	5	52	60	86.67%
Total	61	21	100	58	240	
Producer Accuracy	88.52%	100.00%	59.00%	89.66%		**77.50%**
Kappa	70.00%					

The results of the LULC classifications are quantified in table 12, which shows the total area of each land cover class and the percentage of change of the area between the years. This table is visualized in the graphs of figures 19 and 20. Just as with figure 14, figure 19 shows the change in area over the years. On the y-axis the total area in km^2 cand be read, and the years are on the x-axis. The lines represent each land cover class, which shows whether the area of each land cover class increases or decreases over time. As for figure 20, the percentage is shown on the y-axis, and the years are on the x-axis. Each bar represents one of the land cover classes and how their size has changed between 2013 and 2021. Again, when the percentage is positive it represents an increase in area, whereas a negative number indicates a decrease in area.

Table 12. Area in km^2 of the study area in Ancuabe per class per year and change in percentage per class between years for Ancuabe

	AREA IN KM^2 PER YEAR		PERCENTAGE CHANGE BETWEEN YEARS
CLASS	2013	2020	2013 - 2020
Developed / Bare soil	43,3	87,8	102,9%
Water	0,1	0,1	55,3%
Dense vegetation	104,3	88,7	-15,0%
Light vegetation	268,8	239,9	-10,8%

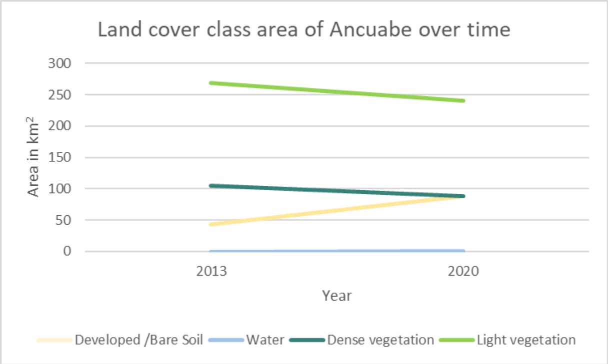

Figure 19. Graph of land cover class area in Ancuabe

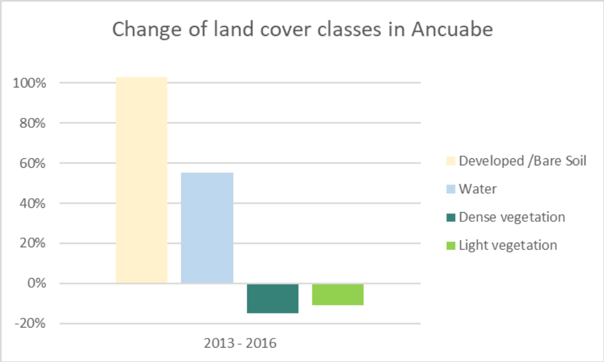

Figure 20. Graph of land cover class change percentage between years in

Once more, just as Balama, the results of the LULC analysis in Ancuabe show a decline in vegetation in combination with an increase in developed/bare soil area (table 12 and figures 19 & 20). In this case however, dense vegetation also declines overall, because it has become sparser in certain areas.

6.3 Land use land cover change in Cabo Delgado

After having analyzed the two study areas of Balama and Ancuabe, it is now possible to return to the sub-question this chapter aimed to address. This question is what land use and land cover changes have occurred in Cabo Delgado over the last decade due to energy transition-induced mining. The previous sections have zoomed in to two active mines to determine the nature of changes occurring by applying a RS and GIS analysis. Each mine operated within its own timeline. Relevant years were selected for the analysis spanning over the last 9 years.

The RS and GIS analysis presents a clear picture of the occurring energy transition-induced mining impacts. The results from both study areas reveal similar trends. In this way, these results reinforce one another. First, the study areas both clearly demonstrate change has occurred where the mining activities take place inside the concession zones. The increased mining activity has brought on visible spatial expansion of developed and bare areas, as well as the addition or expansion of water retention areas needed for extraction processes. Second, it has become apparent that developed/bare soil class increased not only where the mines themselves are, but also in the surrounding villages outside of the concession area. This is related to the indirect consequences of migration, and displacement and resettlement dynamics. The study has shown how the changes surrounding the early stages of mining activity are heterogenous in nature. Inside the mining concessions and outside the occurring changes differ and are caused by different dynamics. The dynamics inside the concession are shaped by the development and activity of the mine, whereas the outside changes are shaped by the aforementioned dynamics of migration, displacement and resettlement. Finally, there was an overall increase in the developed/bare soil class and a decline in vegetation in both cases, which is consistent with academic literature (Basommi, Guan & Cheng, 2015; Latifovic et al., 2005; Werner, Bebbington, & Gregory, 2019). The similarity in both study areas reinforces the argument of the trends in LULC change as a result of mining. Energy transition-induced mining is not exempt from creating socio-environmental impacts, as these mines in Cabo Delgado exemplify.

7. Socio-environmental impacts of graphite extraction in Cabo Delgado — insights from interview analysis

This chapter addresses what socio-environmental impacts the LULC changes had in Cabo Delgado due to graphite mining. First, the results of the interview analysis are presented. The impacts from mining operations are addressed through the experiences of affected communities. Several themes are identified and addressed individually in subchapters 7.1 to 7.4. Then, from the two methodologies, the links are briefly explored between the observed LULC changes and the experience of community members in the affected villages (7.5). The two cases of Balama and Ancuabe are highlighted side by side.

The appearance of the mines has brought on LULC change while also displacing previous land users. The previous chapter has demonstrated how the LULC has changed over time. Regardless of what the land cover was previously, the selected areas have been replaced by the newly implemented land uses. Figure 21 shows what the Syrah mine looks like, and in figure 22 the newly recovered and expanded facilities of GK are shown. The mining facilities and their areas of operation have completely displaced any previous activity taking place on that same land. In the words of someone from the village of Maputo: "*First we heard that a graphite company was coming and after that we saw them building and when they finished, they came to our area and said that they needed the new machambas* [cultivated farmland] *because there was graphite and that we had to leave so that they could extract the ore*" (interviewee 1, Maputo). The impacts from operational mines extend beyond merely LULC changes on the mine's territory and are therefore highlighted.

Figure 21. Aerial photo of the Syrah mine facilities (Syrah Resources, n.d.-a)

Figure 22. Aerial photo of the GK mine facilities (Mumba, 2017)

The most important topics that emerged from community interviews included the compensation arrangements or commitments made to communities, followed by resettlement and (economic) displacement, which are all related topics. Other important topics include employment opportunities, conflict or competing interests and a variety of environmental impacts. To any community member, the impacts he or she experiences are those which affect him or her personally and directly. It is therefore these experiences and perceptions which are articulated most and reveal what the key themes are from the communities' point of view. Therefore, the next sections dive further into the themes of displacement, compensation and resettlement (7.1), employment (7.2), environmental impacts (7.3) and finally, monitoring and regulation of environmental impacts (7.4).

7.1 Displacement, compensation and resettlement

The mines' social impacts through displacement, compensation and resettlement are best understood through the perspective of PACs. As mentioned in chapter 3, in Balama, the mining company settled on farmland of 667 machambas with a variety of structures on there to be compensated, such as storehouses, resting huts, temporary kitchen huts and sheds (EOH CES, 2014b; Khassab, 2021). In Ancuabe, an interviewee reported there were 60 people who were to lose machambas (interviewee 1, Nankhumi). Displacement is experienced in most PACs, in Balama even as far as 7 de Setembro, which is outside the concession area. This village is near the reservoir from which the mine draws water for their activities (EOH CES, 2014a). Water pipes were installed which pass through people's machambas for which they received payment, but cultivation was banned to prevent drilling the pipes (Interviewee 1, 7 de Setembro). The participant expressed: "*I'm sad because my 5-hectare machamba was affected by this plumbing process and I didn't receive full compensation, today the machamba is full of stones and even if the project ends, I won't be able to weed*" (ibid.). Such developments help to explain the increase in developed/bare soil, as people are forced to use alternative land. This means the demand on remaining land grows and in the end relocation of land uses takes away from the natural landscape.

In some cases, the companies have not appropriated all the land they acquired licensing for yet, which also indicates that more LULC can be anticipated. An interviewee from Nankhumi expressed that the machamba had not been taken yet and they were informed they could still use their cultivated farmland for the time being, but they needed to be aware that at any time they could be asked to leave and look for alternative machambas (Interviewee 1, Nankhumi). This leaves the concerned community members in uncertainty. On the other hand, others have already lost their farmland and experience this quite negatively: "*Yes, we all lost [our machamba] and up until then we are suffering from hunger because it is* *in those fields that we were producing food, since they took it away, we are suffering.*" (Interviewee 1, Pirira). This sentiment is echoed by an interviewee from Muaguide. He mentioned that their land was good for producing crops such as corn, cassava and other crops to pay for their children's school. But they can no longer use this suitable land (interviewee 1, Muaguide). Though regulations are in place to ensure compensation, these statements indicate there can be issues with compensation and replacement or resettlement arrangements.

When there are issues in the compensation process, these tend to fall within three categories. The main reasons which have caused dissatisfaction are related to differing compensation rates, unfulfilled pledges and unsatisfactory resettlement arrangements. First, the received or pledged compensation can differ per area and company. Initially, people may be satisfied until they learn what others have received elsewhere. The interviewee from the Provincial Department of Land and Agriculture explained that in Palma people received 168 meticais (Mozambican currency) per square meter, whereas in Balama it was 25, and he goes on to list some more rates per company or area. In the first place, this was all fine and there was no disagreement. But then the problem arises when, for example, someone from Balama has a cousin in Palma who comes to visit. They exchange their experiences, asking one another whether they were given money for their land and how much. Upon learning that people in Palma received nearly seven times more, they may begin to feel ripped off (interviewee Provincial Department of Land and Agriculture). The second reason for dissatisfaction is that there are delays in fulfilling the pledged compensations. Different participants indicate that there has been no compensation yet, or only partial compensation. As someone from Nquide put it: "*they were lying to us saying they're going to bring school, hospital, energy but we haven't seen anything so far, they just took the machambas, and so far, we said that this company brought us problems let's not say we're living well this way, and so far, we cry that at least they gave us our machambas*" (Interviewee 1, Nquide). This experience is not unique to Balama, as someone in Ancuabe has also expressed that the mining company promised people they would receive homes and new agricultural fields in addition to compensation money, but the community has not seen this fulfilled yet (Interviewee 1, Nacussa). That is not to say nothing is being done at all. In fact, this dissatisfaction can go paired with the knowledge that in other villages things *are* happening. An interviewee from Maputo village observed they were to have a road built in their village, which has not happened yet. On the other hand, they have seen a school that is being built in Nacole (interviewee 1, Maputo). The third frequent issue is related to resettlement, because finding suitable replacement land is a challenge.

To elaborate more on resettlement, it is officially the government who is responsible for finding land, and the company is to pay for any preparatory expenses (EOH CES, 2014b; Interviewee State department of Environment). The village head of Nathokua explained how the district resettlement committee and the government are responsible for indicating a resettlement area with the approval of some influential community members. The community does not get to choose the alternative area. The conditions for the resettlement area include soil fertility, presence of water, trees for construction, and there are to be no stones which hinder agricultural production (interviewee 1, Nathokua). It appears the population has little say in the resettlement process. Someone from the provincial department of land and agriculture framed it as a matter of creating the conditions of energy and water in a proposed resettlement area, and that's it. Then the population will go (interviewee Provincial department of Land and Agriculture). The government grants the company land access through licensing procedures and reappoints the original occupants to other land by creating conditions for them to go there. The community members have little control over the process, which can lead them to feel powerless: "*we are not happy, we will only regret the loss and we cannot challenge the government. The company promised to open new agricultural fields and offer bean, corn and sesame seeds for production in the new machambas*" (interviewee 2, Nankhumi).

In practice, there can be issues in finding a suitable resettlement area because of availability, accessibility (e.g., distance) and fertility. On occasion the newly appointed areas were in fact already occupied. An interviewee from Nquide experienced that the newly arranged machambas were on the same land as that of other owners, who in turn expelled them from this land, and nothing was done about this (interviewee 1, Nquide). According to one interviewee "*poverty is evident, because people used to go to that area and after the [graphite] plantations occupied it, most people have lost their fields and others are forced to travel long distances to farm*" (Interviewee 1, Balama Sede). Long distances are problematic for people who do not have the means to arrange good transportation. Similarly, suitable land for cultivation was mentioned to be a problem. Someone from Nquide talked about how they were provided with alternative land for cultivation, but they ended up turning it down because the place was too watery, and they were not able to use it for production (interviewee 2, Nquide). If the resettlement arrangements come with obstacles, the outcome is that the community members can experience it the same as having no arrangements at all.

7.2 Employment

It must be said that there is a certain appeal to having companies come to Mozambique. As a member of the provincial department of environment expressed: "*the positives are obvious that of income, some social projects, some companies give a lot of support to the communities in the creation of income for some groups of people, there are improvements in the dynamics of the district itself*" (interviewee 1 Provincial Department of Environment). The introduction of mining companies is expected to boost the economy as well as provide employment locally. Moreover, communities are promised different improvements as they are even given opportunities to make requests during the consultation process. Even though some may need to relocate, compensation and resettlement arrangements are to be made so that everyone is taken care of. Overall, this creates high expectations. According to the interviewee of the Provincial Department of Environment, some go as far as to stop their cultivation practices and wait at the door of the mining companies thinking everyone will be given a job. A member of the mineral resources department keenly observed: "*as [mining] is a recent fact for all these communities, when a company of this kind appears, the communities only pay attention to the positive impacts it brings without taking into account the negative ones, because the company brings money, jobs and good offers. However, after the operation of the project begins, its negative effects begin to be perceived*". Disappointment is bound to set in when the communities do not reap the benefits and instead begin to experience negative (environmental) impacts. As it turns out, there are only a few locals who are hired to work in the companies, and even fewer who have stayed on through the pandemic. The communities who have been displaced by the mine need alternative livelihood sources, however, these populations are not necessarily hired by the companies. "*Now we see that the company has arrived, but it is difficult for us natives to get jobs there, only outsiders work there, not foreigners, but Mozambicans from Maputo, Beira, Zambezia, Nampula and some from here in Cabo Delgado, but we from our district get in very few, and our salary is lower than those from outside*" (interviewee 2, Maputo).

7.3 Environmental impacts

This section explores what environmental impacts are experienced following the mines installation and operations. The communities are not able to assess environmental changes or provide quantified data from the mining activities. Nonetheless, they can make claims about the environmental changes they have experienced since the mine appeared. In short, the main environmental impacts that can be identified are the consequences of deforestation and graphite dust, increased waste, floods and water pollution.

To start with the first point, the wind has become stronger because trees have been cut down by the company. Furthermore, displacement drives deforestation further as new space is made to replace agricultural fields. Dust is a byproduct of mining activities, which is generated in the process of extraction. Combining these factors, the increased wind spreads the graphite dust so that it affects local communities. An interviewee from Ntete expressed her distress at the situation, saying: "*Here the situation is terrible, there is a lot of wind, they produce a lot of dust that when we put our products to dry in the courtyard, everything gets dirty from dust, but all this is because there are no more trees to defend us*" (Interviewee 1, Ntete). The dust is harmful to the production of crops, but also to the population's health through consumption and direct inhalation. Additionally, it is important to note that deforestation in itself can also be considered an environmental change, which causes loss of biodiversity. On the whole, these observations serve as confirmation to the trend of decreasing vegetation in accordance with the RS and GIS analysis results.

Another interesting point that was raised by a member of the provincial department of environment, is that solid waste management is becoming a problem in almost all places near large companies (interviewee provincial department of environment). The interviewee described that there is an increase of consumption which comes paired with an increase of income in nearby communities, and therefore also naturally an increase of solid waste generation. Such developments too are an indirect consequence following the presence of mines, which cannot be overlooked as these developments also have an environmental impact.

Moving to the water impacts, both flooding and water pollution have occurred since the appearance of the mine. LULC change analysis alone is unable to provide insight on water impacts, because only the area and location of each class is measured at single points in time. The community data provided more information on how water impacts are experienced. Basically, flooding occurs when there is rainfall, because the company releases excess water from their dams. This is reflected by a quote from a Piriran: "*Before there was no water, we used to cultivate everything, but now with the arrival of the company they have turned into swamps*" (Interviewee 2, Pirira). Floods are damaging to crops, roads and homes. Furthermore, the flood water mixes into communities' water supplies, such as wells, which also causes contamination. Additionally, water pollution is caused by the windblown dust which ends up in water supplies that are used for consumption.

7.4 Monitoring and regulation of environmental impacts

Monitoring and regulation are very important elements in ensuring environmental and health safety standards are maintained. They enable the government to determine both the state of the situation and what kind of interventions or mitigation measures may be necessary to protect their population and environment. At present, the provincial department of environment is unable to quantify the environmental impact of mining, and lacks historical, base data. "W*e have national agency for the control of environmental quality and we have other smaller entities that work on standardizations, but it is a challenge, now we are not doing at least at the provincial level, we are not doing quantifications* […] [*the companies*] *by themselves are already very concerned with these issues and even in the audits there are companies that make very good measurements, they themselves have very fantastic kits, very modern, to make these evaluations in a very permanent way, we believe that one day we can also compare this data with our own, but for the moment we are not doing quantitative analysis, only qualitative*" (interviewee provincial department of environment). In essence, the government's limited ability to monitor and regulate the mine's impacts leaves the population at the mercy of the company's actions and intentions. As the quote shows, some companies have internal environmental specialists to ensure monitoring, safety and mitigation when necessary. Syrah has documents on their sustainability strategy, environmental policy, as well as health and safety policy that state the standards they personally pursue (Syrah Resources, n.d.-b; Syrah Resources, n.d.-c; Syrah Resources, 2022), but others may only seek to fulfil the minimum requirements imposed by the government. Should these requirements be insufficient, then the population and environment will suffer the effects. Moreover, not all companies are equally as transparent in their activities. For GK, companywide reports exist which cover topics of sustainability and their activities, however, there is very little specific information reported about their mining operations in Mozambique (AMG, 2019; AMG, 2020). The government is put in a challenging position as they must weigh the benefits of attracting companies against the impacts of extraction. "*As time goes by the companies depending on the impacts that are going to be monitored, if it is found that the impacts are not balanced with the financial side, then maybe we propose the closing of the activity, but we never had this case but it is the extreme*" (interviewee provincial department of environment). This framing reflects the government faces a dilemma, as they weigh economic development through such projects against the (potential) socio-environmental consequences.

7.5 Links between Remote Sensing, Geographic Information Systems, and community data

Reflecting on both methodologies combined, these findings have contributions which reinforce each other, as well as individual contributions which add to a more comprehensive understanding of the situation. The community data has shed more light on the displacement and resettlement dynamics which drive land cover changes that were identified in the RS and GIS analysis. The mining activities cause people to have to farm elsewhere, so that dense vegetation is removed in such appointed resettlement areas. The mine itself is also responsible for removing vegetation. Additionally, the community data provided more information on the air and water impacts, which the LULC change analysis fails to measure. Floodings are a single time event, and the dust and water contamination issues are not observable through satellite data. Thus, the qualitative data added valuable information to make the picture more complete. The only topic the community data is relatively silent about is migration. This may be due to the fact that it is a more subtle and gradual process, and people are able to negotiate with individuals who come to start up businesses in the area. As such, this is not experienced as a drastic change that is experienced very directly and personally, in contrast with displacement for example. The arrival of 'the company' is a far bigger event to the small surrounding communities than the changes migration brings with it. Nonetheless, the in-migration dynamics play an important role in the contribution to expanding developed and built-up areas in the communities near the concession zone (EOH CES, 2014a; Syrah Resources, 2018).

8. Discussion

This chapter is composed of four main sections that provide reflection on the research, both in terms of findings and contributions. First, in 8.1 the results are further discussed in terms of their meaning, importance and relevance. The implications of the findings are also considered and related to a broader perspective of the impact of the energy transition. Next, the contributions of this study are explored in 8.2. Then, the limitations of this research are considered (8.3), also in relation to the potential impact of this study. Finally, the chapter closes by presenting recommendations which follow from both the research implications and its limitations.

8.1 Socio-environmental implications of the energy transition

This research has sought to address the socio-environmental impacts of increased energy transition-induced graphite mining in Cabo Delgado. The energy transition leads to a heightened mineral demand, which stimulates (re-)opening of new extraction frontiers, such as the graphite mines highlighted in this study. Mining projects are known to be destructive to local environments because it negatively affects vegetation and livelihood sources (Basommi et al., 2015, Werner, Bebbington, & Gregory, 2019). With these issues in mind, the socio-environmental impacts of an expanding frontier of graphite mining were investigated through both a LULC change analysis, and an interview and secondary data analysis. The findings indicate that several shifts have taken place in the landscape following the opening of new mines. Both the LULC analysis and interview and secondary data point to LULC changes following the appearance of mines. Mines require space for operation and waste water retention areas, and the former land occupants are required to relocate. All vegetation and previous constructions are removed and in their place the mines emerge. Deforestation and displacement will only increase as the mines advance and utilize the full concession area. Moreover, they cause displacement and resettlement, as well as growth of nearby villages from in-migration. Environmental pressure increases around the mines as land uses are relocated and demands on the natural landscape intensify correspondingly.

In terms of environmental impacts, the results have unveiled several effects, including decreasing vegetation (i.e., deforestation), air and water impacts. The findings from this research are consistent with Khassab (2021), who studied the same area, as well as other mining impact studies elsewhere (e.g., Basommi et al., 2015; Latifovic et al., 2005; Werner et al., 2019). However, this study uniquely identifies and highlights changes in the early stages of mining. It has revealed there are different changes taking place inside and outside of the mining concession areas. As shifts become more or less solidified, initial movements of people (e.g., from resettlement) will cease. For this reason, such initial changes might be less visible at a later stage as the mine is further established. It is interesting to add that though only the early mining stages are investigated, already environmental changes have become apparent as affecting the area and population notably. Then, giving consideration to the future, the extractive activities of these mines are only expected to expand as they may utilize the entire concession area. Thus, the environmental impacts will also continue to manifest consequentially. Linking to a broader context, the increase in extraction will not be unique to graphite frontiers in Cabo Delgado. Increased extraction can also be anticipated for other CRMs in key places of extraction, along with all its impacts.

Expanding on the social impact following the emergence of the graphite mines, matters of displacement, compensation and resettlement affect the population considerably. It became apparent that, apart from voicing themselves in community consultations, the population has little control in the process even though it concerns them more than anyone. It was found resettlement was framed as an improvement opportunity for the population because they were stimulated to move by creating conditions of water and energy. This finding is in line with the findings of Wiegink and García (2022) who suggested that practitioners and policy makers tend to depict extractive projects as opportunities for national economic development, and resettlement can be considered a sacrifice for this. But then resettlement itself could also be depicted as an opportunity for development as it could lead to improved housing, access to electricity, water, employment, education, health centers, etc. Following those lines, resettlement could be considered a potential improvement to people's lives (ibid.). However, the results also pointed out that the displaced population experienced numerous issues in the resettlement process, meaning the process failed to improve their situation. Thus, these findings point to the need for further considerations of the resettlement process and its framing. When the resettlement process does not turn out as ideal as depicted in the 'development' scenario, in the end this leaves the population in a worse position than before.

Without proper or suitable resettlement arrangements, people risk losing their livelihood, because they rely on (subsistence) agriculture. Consequently, this puts the displaced population in a vulnerable position, because it creates a state of dependency on the companies and government. The findings also indicated that the affected population is not incorporated into the labor market necessarily either, as the mine allocates jobs to people from outside the district. This finding is very much in line with

Wiegink and García's (2022) findings, who argue that the displaced local populations are not incorporated in the labor markets or business opportunities that are created by extraction projects, thus making them surplus population. By 'surplus population' they refer to a situation in which the local resources are useful, but the population is not, so that they are not included in the labor market. In the end, this whole process leaves people unable to sustain their own lives through either production or access to a living wage. Therefore, it can be argued displaced people do not benefit from the emergence of the mines, nor its linked developments and economic progress. This is consistent with findings from other studies, which have also argued that developments and economic progress from mining tends to be unequally distributed (Özkaynak et al., 2012; Wiegink & García, 2022). The community data from this research have similarly demonstrated this tendency, which shows that energy transition-induced mining exhibits unequal tendencies just as well.

Overall, these results build on existing evidence of the negative consequences of mineral extraction. This is just as much the case in energy transition-driven extraction of CRMs. Energy transition-induced mining has been shown to create socio-environmental impacts, as these mines in Cabo Delgado exemplify. The negative impacts are exacerbated in contexts of the Global South where environmental regulations are weak, as previous research has also established (Institute of Development studies et al., 2022; Khassab, 2021; Özkaynak et al., 2012). This study illustrated how governments find it appealing to draw large corporations that bring economic development. From their point of view, it is about finding balance between impacts and financial gain. However, the benefits of mining related development are poorly distributed, which is in accordance with earlier studies (Jenkins et al., 2016; Özkaynak et al., 2012; White, 2013; Wiegink & García, 2022). As was argued, the displaced people are left in vulnerable positions, and can be excluded from benefits, which ultimately leaves some in worse situations than before, while others profit. Thus, the study reaffirms the disposition towards unequal development and impacts, which is equally the case with energy transition-driven extraction.

Moving on to the implications of this research, some final comments can be made about the global extraction demands driven by the energy transition. The need for extraction remains due to the heightened mineral demand, which can only be met with increased extraction. Key debates suggest increasing extraction is unavoidable with the current envisionment of how to achieve carbon neutrality. In fact, academics are calling for investment in and (policy) support of the production industry, which includes graphite extraction projects (Institute of Development studies et al., 2022;

The Hague Centre for Strategic Studies, 2022). This study has demonstrated that in Cabo Delgado there are many upcoming mines, which bring about different changes and inherent socio-environmental impacts. It was found the expanding extraction frontiers are legitimized for their national economic interest, development opportunities and contribution to sustainability, which is in line with observations from Wiegink and García (2022). The findings of this study may be specific to the graphite mines in Cabo Delgado, but it serves to exemplify how energy transition-driven mining might impact localities. It has proven to be consistent with other studies on mining impacts. Considering the fact that mining is expected to increase beyond just the Mozambican graphite extraction frontiers, this research points to the need of sustainability considerations of the energy transition in a broader context. Most nations that are rich in resources are developing nations, which are also known to have poor regulation of the mining sector (Institute of Development studies et al., 2022). As such, there is a need for better environmental regulation of the mining sector. Though this study has focused on graphite, it also pertains to extraction of other CRMs in any other low- and middle-income countries that are rich in natural resources. The findings discussed here should be taken into consideration not only to the Mozambican context of graphite extraction, but also to other key points of extraction.

8.2 Research contribution

There are several ways in which this thesis adds to current academic literature. In this research, the socio-environmental impacts of graphite mining in Cabo Delgado, Mozambique, were investigated in relation to the energy transition. Essentially, this research addresses mining impacts in local communities in the context of sustainability transitions, which Agusdinata et al. (2018) identified was urgently needed. The spatial insights of the mining impacts are brought into relation with discourses of the energy transition, which is a unique contribution. Typically, RS and GIS techniques are used only for the purpose of identifying LULC changes (e.g., Alvarez-Berríos & Aide, 2015; Areendran et al., 2013; Basommi et al., 2015; Latifovic et al., 2005). Therefore, within energy transition-discourses, the spatial analysis in combination with qualitative community data complements literature. There are previous studies on extraction of CRMs, including lithium, cobalt and copper (e.g., Agusdinata et al., 201; Rachidi et al., 2021; Tabelin et al., 2021). Such articles have pointed out the importance of addressing impacts along life cycle stages of the energy transition, including extraction, to be fully sustainable. Few, however, have used spatial methods to identify impacts of the energy transition.

Several environmental and social impacts were identified and discussed in the previous section (8.1). It was briefly mentioned how the findings from this research are consistent with Khassab (2021). He has also investigated what environmental impacts local inhabitants near Syrah report having experienced. While his study focuses on the Syrah mine in Balama using interviews, this study provides additional insights by analyzing two study areas and using RS and GIS techniques too. The results demonstrated not only what changes occurred, but also *where*. The produced maps give insight into the locations of change around the mines by means of mapping the LULC at different points in time. The spatial analysis also is a contribution in terms of providing spatial and temporal information for monitoring change in the graphite extraction areas, because no LULC analysis had been conducted for these areas before. Such insights are needed to understand the complexities, risks and opportunities of mining both now and in the future (Lechner et al., 2019).

8.3 Limitations

This study could potentially be used to estimate the environmental impact of graphite mining activities on communities in Cabo Delgado. In turn, this could be used to inform decisions. This can be problematic if there is any type of misreporting of the mining impacts. As has been argued, RS and GIS tools produce knowledge and as such are part of social processes that define and shape social realities (Pavlovskaya, 2018). This section therefore addresses limitations along with their influence on the research process and results. The potential limitations of this study are discussed by reviewing both methodologies separately.

First, it should be mentioned that the study included four LULC classes, and this is a simplified representation of the landscape. Though it is possible to distinguish more classes, further separation lowered the accuracy of the classified maps. Agricultural fields, for example, were no longer distinguished, because these areas sometimes resembled bare soil (when harvested) and other times appeared more vegetated. If this class distinction had been made, it would be more informative on previous and new land uses resulting from mining and all its surrounding changes. Nevertheless, a decision had to be made on how to conduct the study, and in this case fewer classes were adopted to be able to present more consistent classifications with higher accuracies. This means the results are more simplified, but also more reliable.

Second, a more specific issue that could influence RS and GIS methods is the variation in vegetation depending on rainfall and seasonality. This influence was minimized by selecting data that falls within the same time of the year, and from the same source and satellite to ensure comparability of base data. There was one exception, because the Balama 2016 image was from May instead of June, and as the results have shown, this did in fact lead the classification to reflect a higher portion of vegetation. Nevertheless, it was the most appropriate image for that year, because it revealed how the mining activity began unfolding. Thus, this exception is accounted for, and the differences could be explained with this knowledge in mind.

Finally, reflecting on the accuracy assessment procedure, this was validated with the original satellite image in combination with Google Earth satellite. The accuracy assessment is an important procedure as it is telling of the reliability of the results, and therefore this procedure must also be conducted well. The challenge was that the Google Earth satellite data did not always align with the dates of the Landsat 8 data, thus making it less reliable as ground truth data. Nonetheless, this was resolved by falling back on the original satellite data. Google Earth satellite data had a higher spatial resolution, which gave insight of what the landscape truly looked like. Landsat 8 data was higher in terms of spectral resolution, so that the level of vegetation could be determined using different band combinations, when the season shown in Google Earth did not match. In this way, the accuracy assessment procedure was made possible. The outcome from this procedure determined whether the produced classified maps were adequate. When classification accuracies were insufficient, the classification procedure was conducted again selecting new samples for the class that was not accurate enough. The resampling and accuracy assessment processes may have involved some bias. However, all the procedures were conducted systematically and transparently described with the goal of minimizing bias (see chapter 4).

The interview data may reflect influences on the part of interviewees, because those who benefit from the mining industry are likely to downplay negative impacts, whereas those who don't may overemphasize these (Khassab, 2021). Thus, this could explain the discrepancies between the reports from the local population and government officials, who had the tendency to stress the positives it brought. However, considering the reports were used to inform the experiences of the local population, this is not an issue. The purpose of the interviews was not to gather data of socio-environmental impacts with the highest possible accuracy, but rather to identify what impacts the population experiences and in what ways.

Another factor is that the interviews were only in the form of transcripts as they had been conducted by other researchers previously. As a result, contextual information such as nuances, intonation and body language cues are missing. Additionally, in the process of translation some meanings may be lost, because Portuguese is foreign to the researcher and a software was used to produce English transcripts. In the end this does not hinder the research aim, however, because interviewees' accounts of mining impacts can still be determined. The analysis was made possible because of having transcripts as well as translation, and the gist of what interviewees express still comes across.

8.4 Recommendations

Based on the discussion of the results and in light of the expected increase in mineral extraction, a key question is how extraction might be led in the most beneficial way? The first, perhaps obvious suggestion is to anticipate the potential socio-environmental impacts, and then to focus on minimizing these where possible. One avenue of anticipation is through longitudinal and future oriented analyses of LULC changes using RS and GIS technology, as Werner et al. (2019) have already suggested. Rather than having a passive stance towards mining-induced impacts, there should be a proactive approach to strategically deal with these by means of prevention and mitigation. Second, the environmental and energy justice frameworks also help to inform what aspects must be considered to ensure extraction is well-guided (e.g., unequal distribution of benefits and ills, issue of overlooked population) (Jenkins et al., 2016; White, 2013). The distributional, recognitional and procedural dimensions help to uncover and address energy injustices. Furthermore, the principles suggested by Sovacool et al. (2017) can be implemented to address the uncovered issues.

A key issue to draw attention to is the matter of who is responsible for guiding the mining activity in a just and sustainable way. For the local context, the government and companies themselves have the most (direct) influence over such processes and therefore should assume responsibility. It is possible to mitigate environmental impacts. Companies like Syrah will comply with the legislation that is in place where they operate, thus the government is responsible to ensure that it adequately protects its people and environment. Therefore, the role of the government is especially important, as they have the authority to oversee and regulate all mining activity. It can be argued that at present the government in Mozambique implements inadequate legislation (Khassab, 2021). The Mozambican government faces many issues and challenges on different fronts (lack of resources, natural disasters, violence, etc.) as was briefly addressed in the background chapter. Khassab (2021) argues the lack of both resources and qualified people leads to inadequate processes such as the environmental licensing process. There is a need to implement regulation which better protects and supports the population, while still making extraction possible. Any issues (e.g., around compensation, resettlement, etc.) must be acknowledged and sought to be addressed, rather than dismissing difficult questions. It is unlikely we can move away from the need for CRMs and extraction altogether, therefore efforts must be directed towards ensuring sustainable practices both for the local livelihood and the environment. This process should be guided by principles from the energy and environmental justice frameworks.

This research has also identified there is an urgent need for standardized, objective, quantitative monitoring of (socio-)environmental changes from mining in order to be able to regulate and mitigate environmental deterioration. At present, the government has no standardized nor quantitative forms of environmental monitoring of the mining sector in Cabo Delgado. This is problematic, because it means they lack an overview of environmental data in the province that might be needed for informing decisions. Moreover, they rely on other parties, including the mining companies themselves to supply data. Monitoring should be conducted by an objective party, and mining companies themselves should not be the primary provider of such data. Following the findings of this study, it is suggested efforts are directed towards creating standardized, objective, quantitative environmental monitoring in mining affected areas.

Another area of improvement this research identified is the transparency of active mining companies. Some companies are more transparent in their activities and intentions than others. Moreover, it was very difficult to trace and establish the link between local subsidiary companies and the leading company. MIREM and Trimble Land Administration have made a good start at providing transparency of the Mozambique mining sector, however there is room for improvement. The platform allows users to view all application and active mining licenses, and by clicking on them individually detailed information is shown. There is a search functionality, but it is only programmed to search by license or agreement code, or company name. Thus, when information is needed for extraction of a specific mineral (in this case graphite), the user is forced to click through each individual application or active mining license. This is a very tedious process, especially considering the countless active squares that are shown (figure 3). The portal could improve the search functions to include mineral-based searches. Another possibility is to introduce filter options to improve the overview (e.g., filters of licenses state, whether in application or granted; license type; mineral type; etc.). Overall, the user friendliness could be greatly improved, which also further improves transparency.

Aside from the local actors, the Global North plays a role in driving the energy transition with its growing mineral demands, and as such should also anticipate the global impacts. It is ironic that the energy transition in the Global North is being stimulated in order to preserve the environment and counter climate change effects. Meanwhile, this drives mineral extraction practices to enable the transition, which has negative environmental impacts elsewhere. Therefore, actors in the Global North should also assume responsibility for supporting and guiding the mining activity in a just and sustainable way wherever they can. In the first place, there must be recognition of international linkages driving extractive projects. Then, strategic groups, policy makers and academics should consider what influence or supportive role we may be able to play. One very concrete opportunity is to provide support in the monitoring process, as this study has done using RS and GIS. This research has demonstrated and exemplified remote monitoring (I.e., using satellite images, RS, and GIS techniques) can contribute to support in monitoring of local contexts affected by mining. RS and GIS data helps to meet the need for objective assessments, data and monitoring. The advantage too is that this does not require many resources, because it can be conducted remotely and there are free software options. Open-source software such as Google Earth Engine and R programming offer possibilities for monitoring LULC changes which can provide valuable data to the local actors (e.g., government officials, local level planners and development practitioners). Thus, actors in the Global North can provide their expertise and there are ample possibilities for contributing.

9. Conclusion

This study sought to answer the research question of what the socio-environmental impact is of an expanding frontier of graphite mining stimulated by the energy transition in Cabo Delgado, Mozambique. This question was addressed by combining two methodologies, namely an analysis using RS and GIS techniques in combination with a qualitative data analysis using interviews. The RS and GIS analysis demonstrated where the mines themselves are expanding, as well as surrounding changes in the landscape resulting from the mine's presence. The developed areas in the villages outside the concession area are expanding because of migration and resettlement dynamics. Inside the concession area, separate from where the mine itself operates, there is some regrowth following the displacement of the local population. This indicates the heterogeneous nature of change occurring in the early phase of mining operations. Overall, the vegetation in extraction areas decreases, which is associated with issues of loss of biodiversity, desertification and damage to ecosystems. The interview analysis further established the displacement and resettlement findings, as this emerged as a frequently addressed theme. Additionally, the analysis provided further insight on environmental impacts of water and air, as well as livelihood impacts. Thus, the combination of methods provided a more comprehensive picture of the socio-environmental impacts in Cabo Delgado following the opening up of graphite extraction projects. Then, taking a step back, what does this imply about the driving force behind such developments? The energy transition is inextricably linked to mineral extraction as visions of a carbon neutral future demand more green minerals to create the technologies. Connections between sustainability in the Global North, and the processes it puts into effect in the Global South, should not be overlooked. The energy transition promotes sustainability, however, zooming out to preceding activities of mineral extraction frontiers reveals this transition also drives processes which threaten sustainability.

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Appendix 1: Overview of mines and licensing in Cabo Delgado

Leading Company	(Subsidiary) Local company	Locality and District	Mineral	Type of license	Date License application	Date License Acquired	Date License Expiration	Area (km²)
AMG Graphite	GK Ancuabe Graphite Mine	Metoro & Acuabe, Ancuabe	Graphite	Mining concession	15-07-93	05-08-93	05-08-28	33.3
Syrah Resources	Twigg Exploration e Mining	Balama, Balama	Graphite, Vanadium	Mining concession	08-07-13	06-12-13	06-12-38	110.6
Battery Minerals	Suni Resources (Montepuez)	Mirate, Montepuez	Graphite, Vanadium	Mining concession	09-05-17	22-02-18	22-02-43	36.7
	Africa Rare Metal Mining Development Company	Mirate, Montepuez	Graphite, Gold	Mining concession	17-05-18	11-03-19	11-03-44	61.8
	Tchaumba Minerais	Mirate, Montepuez	Graphite	Mining concession	24-05-18	26-03-19	26-03-44	30.2
	Duplo Dragão Industrial	Balama & Kwekwe, Balama	Graphite	Mining concession	13-04-18	08-05-19	08-05-44	93.1
	Duplo Dragão Industrial	Kwekwe, Balama	Graphite	Mining concession	13-04-18	18-06-19	18-06-44	145.4
Triton Minerals	Grafex	Metoro & Acuabe, Ancuabe	Graphite	Mining concession	17-11-17	07-08-19	07-08-44	102.7
	Sun Mining	Meza, Ancuabe	Iron, Graphite, Gold, Ruby	Mining concession	06-03-19	09-09-20	09-09-45	15.0

Battery Minerals	Suni Resources (Balama)	Balama, Balama	Graphite, Associated Minerals	Mining concession	28-06-19	23-07-21	23-07-46	15.4
	Dombeya Mineracao	Mazeze, Chiure	Graphite, Base Metals	Mining concession	07-08-20	24-11-2021	24-11-2046	543.5
	G5 Resources	Palma	Aquamarine, Cassiterite, Emerald, Ilmenite, Magnetite, Monazite, Morganite, Ruby, Rutile, Tourmaline, Zircon	Exploration license	25-07-2018	29-10-2018	29-10-2023	19911.51
	G5 Resources	Palma	Heavy sands, Gemstones, semi-precious stones	Exploration license	24-04-2017	30-11-2017	30-11-2022	8831.71
	Chelsia Group Mozambique	Mueda	Garnet, Associated minerals, Ruby	Exploration license	12/10/2016	10/7/2017	10/7/2022	3911.56
	Khensane Mocambique - Sociedade Unipessoal	Mueda	Graphite, Associated Minerals, Gold	Exploration license	18-08-2015	02-05-17	02-05-22	8548.09
	COMAL - Companhia de Madeira	Mueda	Lead, Copper, Associated Minerals, Nickel, Gold, Palladium, Platinum, Zinc	Exploration license	03-09-15	24-10-16	24-10-21	2514.63
	Ingoane Minerais	Mueda	Copper, Iron, Nickel, Gold	Exploration license	31-01-11	23-05-11	23-05-16	2682.09

	COMAL - Companhia de Madeira	Mueda	Lead, Copper, Associated Minerals, Nickel, Gold, Palladium, Platinum, Zinc	Exploration license	03-09-15	25-11-16	25-11-21	8340.1
	Arenitos	Mueda	Graphite	Exploration license	14-08-13	22-05-15	22-05-20	12224.18
	COMAL - Companhia de Madeira	Mueda	Lead, Copper, Associated Minerals, Nickel, Gold, Platinum, Zinc	Exploration license	05-08-15	04-08-16	04-08-21	18909.73
	Ngurreta Distribuidora	Mueda	Copper, Base Metals, Nickel, Platinum	Exploration license	25-05-17	04-07-18	04-07-23	16735.97
	Vale Projectos e Desenvolvimento Mocabique		Platinum group minerals	Exploration license	23-08-10	30-09-13	30-09-18	7696.85
	RQL Graphite Resources	Montepuez, Mueda	Graphite, Associated Minerals	Exploration license	22/04/2015	21-06-16	21-06-21	12522.47
	Conceitos Mining	Mueda, Muidumbe	Aquamarine, Emerald, Graphite, Marble, Quartz, Ruby, Sapphire, Topaz, Tourmarine	Exploration license	19-01-16	10-04-18	10-04-23	17125.05
	Zambezia Minacao	Montepuez, Mueda	Graphite, Associated Minerals, Gold, Platinum, Ruby	Exploration license	06-03-14	19-02-16	19-02-21	24315
	Mineral Stream	Mueda	Graphite, Base Metals, Gemstones, Associated Minerals, Platinum group Minerals, Rare Earths	Exploration license	02-07-12	20-10-14	20-10-19	22743.43

	Reddys Global Industries	Muidumbe	Graphite, Associated Minerals	Exploration license	15-03-17	21-06-17	21-06-22	18062.76
	Reddys Global Industries	Muidumbe	Graphite	Exploration license	15-03-17	06-07-17	06-07-22	13664.95
	Shiloh Resources	Muidumbe	Graphite, Associated Minerals	Exploration license	15-03-17	21-06-17	21-06-22	16393.92
	Gal Resources	Muidumbe, Mueda	Aquamarine, Beryl, Corundum, Emerald, Garnet, Ruby, Sapphire, Tourmaline	Mining concession	13-05-15	28-06-17	28-06-42	12820.73
	Mavanda Minerals	Macomia	Graphite, Base Metals, Gemstones, Associated Minerals, Platinum group Minerals, Rare Earths	Exploration license	05-07-12	08-07-13	08-07-18	13136.94
	COMAL - Companhia de Madeira	Meluco	Graphite, Base Metals, Gold, Palladium, Gemstones, Platinum, Silver	Exploration license	03-09-15	30-05-16	30-05-21	18379.62
	Mwiriti Mining 18	Montepuez	Graphite, Base Metals, Associated Minerals, Gold	Exploration license	10-04-17	28-02-19	28-02-24	13008.16
	Mwiriti Mining 16	Montepuez	Graphite, Base Metals, Associated Minerals	Exploration license	02-03-17	28-08-17	28-08-22	13995.67
	Gems Way	Montepuez	Beryl, Corundum, Graphite, Associated Minerals, Gold	Exploration license	17-05-16	25-11-16	25-11-21	19746.79

	Matuto Land Mining	Montepuez	Beryl, Corundum, Graphite, Garnet, Morganite, Gold, Ruby, Tourmaline	Exploration license	19-08-16	30-11-17	30-11-22	9517.33
	EME Investimentos	Montepuez	Graphite, Base Metals	Exploration license	06-10-15	21-07-17	21-07-22	2776.95
	Stratum 9673 Sociedade Mineira	Montepuez	Cobalt, Copper, Associated Minerals, Nickel	Exploration license	09-10-18	23-02-21	23-02-26	1448.48
	EME Investimentos	Montepuez	Graphite, Base Metals	Exploration license	06-10-15	13-07-17	13-07-22	6637.53
	RQL Graphite Resources	Montepuez	Graphite, Associated Minerals	Exploration license	26-05-15	13-04-16	13-04-21	13012.31
	Weihai International Economic & Technical Cooperative	Montepuez	Graphite, Associated Minerals, Ruby	Exploration license	30-03-17	06-11-17	06-11-22	3452.3
	Vale Projectos e Desenvolvimento Mocabique	Montepuez	Base Metals, Precious Metals, Industrial minerals	Exploration license	18-12-06	26-03-07	26-03-12017	24538.83
	Africa Yuxiao Mining Development Company	Montepuez	Graphite, Associated Minerals	Exploration license	11-08-16	11-09-19	11-08-24	12021.4
	Mwiriti Mining 11	Montepuez	Graphite, Base Metals, Associated Minerals, Gold	Exploration license	03-02-17	13-11-17	13-11-22	16784.56
	Africa Yuxiao Mining Development Company	Montepuez	Graphite, Associated Minerals	Exploration license	11-08-16	18-06-18	18-06-23	18842.71

	Africa Yuxiao Mining Development Company	Montepuez	Graphite, Associated Minerals	Exploration license	12-08-16	05-10-17	05-10-22	16161.5
	J Chana Moz Research Exploration Oil & Gas Company	Montepuez	Graphite, Ruby	Exploration license	10-03-17	15-06-17	15-06-22	7935.87
	Easter Mining Development A	Montepuez	Graphite, base Metals	Exploration license	06-10-15	25-07-16	25-07-21	10009.69
	Easter Mining Development B	Montepuez	Graphite, base Metals	Exploration license	19-10-15	07-11-17	07-11-22	7731.04
	Easter Mining Development C	Montepuez	Graphite, base Metals	Exploration license	06-10-15	21-07-16	21-07-21	13596.53
	Cabo Delgado Partners	Montepuez	Aquamarine, Graphite, Garnet, Base Metals, Platinum Group Minerals, Gold, Ruby, Sapphire	Exploration license	14-04-16	30-11-16	30-11-21	16261.24
	Messalo	Montepuez	Lead, Copper, Graphite, Manganese, Gold, Zinc	Exploration license	27-09-19	08-03-21	08-03-26	12321.99
	Paraiso Real	Montepuez	Graphite, Ruby, Sapphire	Exploration license	26-11-14	17-05-16	17-05-21	13712.47
	Yola	Montepuez	Graphite, Garnet, Associated Minerals, Ruby, Sapphire	Exploration license	09-09-15	12-07-16	12-07-21	12936.4
	Mwiriti Mining 9	Montepuez	Graphite, Base Metals, Associated Minerals, Gold	Exploration license	02-03-17	23-08-17	23-08-22	19812.44

	Mwiriti Mining 7	Montepuez	Graphite, Base Metals, Associated Minerals	Exploration license	02-03-17	23-08-17	23-08-22	11396.28
	Matuto Land Mining	Montepuez	Graphite, Garnet, Gold, Quartz	Exploration license	27-03-17	03-07-19	03-07-24	8298.61
	Mwiriti mining 8	Montepuez	Graphite, Base Metals, Associated Minerals	Exploration license	02-03-17	20-02-18	20-02-23	8616.4
	H.D. Kutsaka	Montepuez	Lead, Copper, Graphite, Associated Minerals, Nickel, Gold, Silver, Vanadium, Zinc	Exploration license	30-05-17	30-11-20	30-11-25	7258.99
	Alstones	Montepuez	Graphite, Associated Minerals, Ruby	Exploration license	23-02-15	10-08-15	10-08-20	10082.89

Appendix 2: list of codes for interview data analysis

Category	Code	Description
Socio-economic impacts of mining	Communication and involvement in the mining project	Statements about the role, communication and relation to the mine of the concerned community member(s)
	(economic) displacement	Mention of losing access to farmland, or other assets that are part of their livelihood, specifically related to the presence of the mine/company
	Resettlement	Change in place of residence, work or other related to the presence of the mine/company
	Opportunity	Statements about what new opportunities the presence of the mine/company brings, particularly in terms of employment
	Compensation / commitment	Statements of the provisions and promises the mine has pledged to communities, ranging from community wide provision to individual compensation
	Before/after comparison	Statements that highlight differences from before the mines' presence and after
	Attitude to mine	Statements about how the interviewee perceives the mine, expressed opinions about mining, etc.
	Conflicts or competing interests	Descriptions of issues arising that cause conflict between the mine and PACs
Environmental impacts	Environmental impacts	In reference to environmental impacts in general / as a whole
	Land impact	Mention of change in land (e.g., cover, fertility, etc.) following the coming of the mining project
	Spatial impact	Mention of spatial changes
	Water impact	Mention of change in water (e.g., quality, quantity, etc.) following the coming of the mining project
	Air impact	Mention of change in air (e.g., quality) following the coming of the mining project
	Vegetation impact	Mention of change in vegetation following the coming of the mining project
	Access to any natural resources	Mention of change in access to resources following the coming of the mining project
	Sustainability	Mention of concepts or practices related to sustainability ('green' / 'renewable')

Legal frame	Licensing process / requirements	Statements about procedures for attaining a license to conduct mining activities
	Monitoring	Statements about arrangements, forms and types of monitoring
	Responsibility	Statements about who is responsible for what: keeping regulatory standards, ensuring safety, etc.
	Regulation	Statements about the legal frame, applicable laws or regulatory standards
	Mine information	Factual statements about the operating timeline, locations etc. of the mine