Journal of Environmental Management 338 (2023) 117811

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Understanding the cumulative socioenvironmental impacts of energy transition-induced extractivism in Mozambique: The role of mixed methods

Emilinah Namaganda *, Kei Otsuki, Griet Steel

Department of Human Geography and Spatial Planning, Utrecht University, the Netherlands

ARTICLE INFO

Keywords:
Energy transition
Resource frontiers
Extractivism
Socioenvironmental impacts
Mixed methods

ABSTRACT

The global energy transition is very resource intense, and scholarship is rapidly increasing to show its impacts in various resource extraction frontiers in the global South. These emerging studies are clarifying the social and environmental impacts of extracting particular energy transition resources (ETRs). However, there is still limited attention on the cumulative socioenvironmental impacts of extracting multiple ETRs from the same region. This paper proposes to mix geospatial and qualitative research methods to examine the cumulative socioenvironmental impacts of ETR extraction. We apply these mixed methods to study the impacts of an expanding frontier of graphite and natural gas extraction in Mozambique. The geospatial results show that patterns in socioenvironmental changes, including a surge in built-up and bare areas and water-covered surfaces, and a shrinkage of vegetated areas – some of which are ecologically sensitive, are starting to emerge in the project areas. In combination with qualitative methods, we identified additional impacts including an increase in solid waste and air and noise pollution, and an inception of extractivism-associated conflict in certain project areas. When single commodities are analyzed, using single methods, some of these impacts may be overlooked or underestimated. In order to fully understand the sustainability implications of the energy transition process, it is instrumental to combine geospatial and qualitative research methods to monitor the cumulative socioenvironmental impacts at its upstream end.

1. Introduction

In the near to long term future, the global transition from fossil fuels to low-carbon energy sources will be one of the main drivers of extractivism and its impacts on societies and environments in Africa (Church and Crawford, 2018; Lèbre et al., 2020). Following the 2015 Paris agreement on climate change, it has become urgent for countries worldwide to reduce the greenhouse emissions from their energy sectors, thereby justifying the transition to low-carbon sources (Hund et al., 2020). Furthermore, goal seven – of the sustainable development goals (SDGs) – aims to ensure access to clean energy for all people across the globe by 2030, further compelling the energy transition (Murshed, 2022; Murshed et al., 2022; Viegas Filipe et al., 2021). As a result, by 2040, the world will require at least four times the quantity of minerals demanded today to construct low-carbon technologies such as solar photovoltaic plants, wind farms, and electric vehicles (Hund et al., 2020). Studies have shown that a substantial proportion of these energy transition resources (ETRs) – including cobalt, platinum, and graphite – will likely be sourced from Africa (Church and Crawford, 2018; Lèbre et al., 2020).

Although previous exports of minerals and other raw materials have contributed to the incomes of African countries (UNCTAD, 2022), preceding studies have also documented negative socio-economic and environmental impacts which have accompanied extractivism on the continent. These negative impacts constitute involuntary population displacement (Aboda et al., 2019), 'land grabbing' (Zoomers, 2011), environmental pollution (Bassey, 2012), labour exploitation (Tsurukawa et al., 2011), militarization and conflict (Obi, 2014), and overall maldevelopment (Carmody, 2016; Hickel et al., 2022; Rodney, 1973). Besides these documented impacts of extractivism, the anticipated speed and scale of ETR extraction which may encompass both 'traditional' and new minerals will likely introduce novel impacts that need to be understood (Church and Crawford, 2018; Kramarz et al., 2021). Furthermore, less-understood impacts may stem from the employment of new

---

* Corresponding author.
E-mail addresses: e.namaganda@uu.nl (E. Namaganda), k.otsuki@uu.nl (K. Otsuki), grietsteel@hotmail.com (G. Steel).

https://doi.org/10.1016/j.jenvman.2023.117811
Received 17 December 2022; Received in revised form 6 March 2023; Accepted 24 March 2023

mechanisms of extraction by new and old actors in both brownfields and new frontiers (Kramarz et al., 2021; Owen et al., 2022). However, within global sustainability discourses, the socioenvironmental consequences of energy transition-induced extractivism[1] have been obscured by a preoccupation with adopting the use of low-carbon technologies (Owen et al., 2022; Sovacool et al., 2020).

It is important therefore to examine the localized impacts that may accompany ETR extraction in Africa. In this paper, we focus our attention on the cumulative socioenvironmental impacts that may derive from the confluence of multiple ETR-extracting projects in the same region, in some countries. Following Franks et al. (2013), we define cumulative impacts as the incremental and combined impacts of two or more projects on the society and environment of a defined area. We propose a mix of geospatial and qualitative research methods as a potent but underutilized approach to grasp the cumulative impacts of ETR extraction. Understanding the combined consequences of ETR extraction that could be overlooked during analyses of singular projects, using single methods, enables us to address a concern raised by other researchers (e.g., Kramarz et al., 2021; Sovacool et al., 2020) of the risk of unintended effects when tackling climate change.

We apply the mixed methods to explore the cumulative socioenvironmental impacts of ETR extraction, to the case of Cabo Delgado Province in Mozambique. Mozambique is a top recipient of foreign direct investments in Africa, the majority of which are directed toward the extraction and export of fossil fuels and minerals (UNCTAD, 2022). We focus on Cabo Delgado Province because it hosts multiple ETRs, including Africa's third largest natural gas project and one of the world's largest graphite reserves. Due to its lower carbon emissions compared to oil and coal, natural gas is viewed by proponents as a 'bridge fuel' to low-carbon energy sources (Delborne et al., 2020). Graphite is essential in the manufacture of lithium-ion batteries that power electric vehicles (Hund et al., 2020). Even Tesla (a leading electric vehicle company) anticipates to acquire its graphite products from Cabo Delgado's reserves (Syrah Resources, 2021). As we present our findings of the cumulative socioenvironmental impacts of ETR extraction in Cabo Delgado, we discuss the underutilized opportunities in employing mixed methods to study the emerging impacts of ETR extractivism in Mozambique, which are likely to expand across the African continent and other global South countries.

2. Studying ETR frontier expansion in Africa: the role of mixed methods

The continued concentration of ETR extraction in Africa and other global South countries, with minimal processing and use therein, facilitates the accumulation of the negative socioenvironmental impacts of extractivism in these parts of the globe (Murshed et al., 2022; Sovacool et al., 2020). If neglected, these negative impacts could jeopardize the realization of SDGs 12 and 10 which aspire for 'responsible consumption and production patterns' and 'reduced inequalities', respectively (Brown et al., 2022; Hund et al., 2020). Scholars and development institutions have called for smarter and more responsible forms of resource extraction (Banza et al., 2019; Kramarz et al., 2021). However, questions remain about the ways to systematically study the impacts of the rapidly-expanding frontiers of ETR extraction (Agusdinata et al., 2018; Dorn and Peyré, 2020).

Several authors have studied the impacts of ETR extraction in Africa by zooming in on a particular commodity (e.g., Banza et al., 2019; Keita and Traore, 2020; Namaganda et al., 2022). These authors selected their case studies on the basis of outstanding factors such as the scale of the extractive project, the severity of the project impacts, the fragility of the socio-political context within which the project is situated, and often an amalgamation of these and other factors. Therefore, the studies provide insight into the impacts of extracting ETRs like cobalt (Democratic Republic of Congo), bauxite (Guinea) and natural gas (Mozambique) from the studied contexts. However, given the co-existence of some ETRs in the same region (see Lèbre et al., 2020; Owen et al., 2022), commodity- or project-focused assessments may overlook or underestimate the impacts materializing from the extraction of co-located ETRs. The studies that have already explored the impacts of multiple ETR projects focus either on the social (e.g., Cole and Broadhurst, 2020; Marais et al., 2020) or environmental (e.g., Brown et al., 2022) impacts. Hence, the cumulative socioenvironmental impacts of ETR extraction remain less understood. The field of cumulative impacts assessment and energy transition research have largely remained disconnected. Cumulative impacts assessment (CIA) involves a constellation of methodologies and approaches to identify and evaluate the significance of impacts from multiple sources and estimate the overall potential impact to inform management decisions (Judd et al., 2015). Investigating cumulative socioenvironmental impacts in Africa is often inhibited by under-resourced governments, civil society, and academic institutions (Antwi et al., 2022).

However, recent advances in geospatial techniques – especially remote sensing and GIS – present new opportunities to tackle the cumulative impacts of extractive projects on the continent. Remote sensing and GIS enable a characterization of the spatial and temporal dimensions of the projects at various stages of their development, which can facilitate an analysis of their socioenvironmental impacts (Lechner et al., 2019; Werner et al., 2020). For years, extractive companies have voluntarily harnessed these technologies for exploration, environmental impact assessments, and overall mine management (Werner et al., 2019). However, the companies tend to focus their assessments on the social and environmental impacts within their concession areas and the immediate surroundings, which is often the minimum geographical scope prescribed by the government regulations (Firozjaei et al., 2021; Werner et al., 2019). Hence, the companies and governments might, intentionally or unintentionally, overlook the impacts that may extend beyond the immediate surroundings of the projects (Rudke et al., 2020).

Therefore, civil society organizations and academics can engage geospatial techniques to verify and complement the project-led analyses (Werner et al., 2019; Lechner et al., 2019). In the past, many civil society and research institutions have only minimally exercised GIS and remote sensing to assess socioenvironmental impacts owing to a lack of resources, data, and technical expertise (Rudke et al., 2020). The recent proliferation of open-access global satellite data (e.g., Landsat and Sentinel) and geospatial analysis software (e.g., QGIS and Google Earth Engine) is expanding the potential role of geospatial tools in socioenvironmental analyses (see Liu et al., 2019; Teichtmann, 2022). Africa-specific data sources are also increasingly being developed (Kamoga, 2022). Furthermore, the increased prevalence of free code sharing platforms such as Github and BitBucket, where remote sensing and GIS users can share workflows of their analyses, provides new spaces for interested actors to acquire geospatial knowledge and to build on one another's expertise (see Teichtmann, 2022).

Although GIS and remote sensing are beneficial for studying socioenvironmental change, without incorporating people's perspectives on the land-use and land-cover (LULC) transformations observed, some important dynamics might be overlooked (Lechner et al., 2019; Brown et al., 2022). Social impacts such as conflicts and some environmental impacts such as water pollution are often invisible remotely, especially when they are still at a small scale (Werner et al., 2019). Therefore, ethnographic or other qualitative methods such as interviews, focus group discussions (FGDs), and observation can complement the geospatial approaches to enable an accurate assessment of the impacts (Cope and Elwood, 2009; Lechner et al., 2019). There is a growing need for methodological approaches that can integrate the social and environmental implications of the expanding frontier of ETR extraction

---

[1] By energy transition-induced extractivism, we refer to the large-scale export of unprocessed or barely processed resources, particularly minerals and metals which are critical to the energy transition, from extractive economies.

(Brown et al., 2022; Dorn and Peyré, 2020). In the following sections, we introduce the ETR projects in Cabo Delgado Province, and elucidate how we applied mixed methods to explore their socioenvironmental consequences.

3. Natural gas and graphite projects in Cabo Delgado, Mozambique

Cabo Delgado is a rural agricultural province in northern Mozambique. Table S1 (supplementary material) shows that agriculture is still the predominant livelihood source for over 80 percent of the province's population. Fortuitously, Cabo Delgado is rich in minerals and hydrocarbons including ETRs such as graphite, vanadium, nickel and more (MIREME and Trimble Land Administration, 2022). Therefore, Mozambique's government has been keen to support extractive investments in the province to diversify Cabo Delgado's economy and also contribute to national development. The province attracts investments from transnational extractive companies eager to benefit from the energy transition or from countries like the United States and China that are keen to increase their energy security by creating assured access to ETRs (Hanlon, 2022). Of the ETRs found in Cabo Delgado, graphite and natural gas extraction are the most advanced. The province has granted up to eleven graphite mining licenses to various companies, three of which are currently active mining concessions: Twigg Exploration and Mining is located in Balama District (henceforth Twigg); GK Ancuabe Graphite Mine (henceforth GK) is located in Ancuabe District; and finally, Suni Resources is located in Montepuez. We take Twigg and GK as case studies of the socioenvironmental impacts of graphite extraction[2] (see Fig. 1).

Twigg is owned by the Australian-based Syrah Resources and is situated on one of the world's largest graphite reserves, with ores estimated at 107 million tons as of 2021 (Syrah Resources, 2021). The mine, located on an 11000-ha DUAT (a state-granted 'right to use and benefit from land') was developed between 2013 and 2017 and commenced commercial operations in early 2018.[3] Twigg currently exports its mined graphite to the United States, China, Europe, and India (Syrah Resources, 2021). The GK mine, which is located on a 3325-ha DUAT, commenced operations in 1994. However, the company stopped production in 1999 as a result of high energy costs and low graphite prices. In 2017, the Mozambique government re-opened the mine under the new ownership of the German-based AMG Graphite.

The natural gas reserves in Cabo Delgado are estimated at 100 trillion cubic feet and are the third largest in Africa (Africa Oil and Power, 2020). The reserves were discovered between 2010 and 2013 by US-based company Anadarko (which sold its operation stake to French Total in 2019) and Italian Eni. The Mozambican government awarded licenses for offshore gas extraction, onshore processing into Liquefied Natural Gas (LNG), and the sale of LNG on domestic and international markets to three consortia of oil and gas companies led by Total, Eni, and US-based ExxonMobil. To develop the onshore gas processing facilities, in 2012, the Mozambican government granted the gas projects Total (hereafter Total, the largest user of the onshore facilities) a DUAT of approximately 7000-ha. However, since 2021, the project suspended its activities due to health and economic restrictions introduced by the Covid-19 pandemic and security pressures from an armed insurgency in the province. Table S2 summarizes the key information about the three projects considered in this study.

The graphite projects have been beneficial to Cabo Delgado's economy by contributing to the province's revenue and employment (see Tables S1, S3, S5 and S6). The investments toward the gas project also contributed significantly to bolstering Mozambique's economy, prior to project suspension (Bruna, 2022). However, preceding research has uncovered negative impacts linked to the ETR projects including involuntary population resettlement (Namaganda et al., 2022; Wiegink and Kronenburg, 2022), and contribution to the ongoing armed insurgency which has spread from the natural gas toward the graphite areas (Alberdi and Barroso, 2020; Hanlon, 2022). However, the preceding studies largely depended on qualitative and single-case study designs. Hence, the cumulative socioenvironmental impacts of the multiple ETR-extracting projects in the province have received less attention. In the next sections, we discuss how we have applied mixed methods to examine the cumulative impacts of the graphite and natural gas projects.

4. Data collection, processing, and analysis

During 2018, 2020 and 2021, three phases of qualitative research were conducted in Cabo Delgado. The first author, together with local research assistants held semi-structured interviews and FGDs in the communities hosting the three extractive projects described above, in the neighboring towns and cities which host the relevant institutional actors, as well as in Maputo, Mozambique's capital. Overall, we elicited information about the socioenvironmental impacts of natural gas and graphite extraction from 338 community members (69 percent male[4] and 31 percent female) and 77 institutional actors (constituting government, civil society, private sector, and academia) (see Tables S7 and S8). The interview transcripts were analyzed in NVivo to identify key themes on the socioenvironmental consequences of the projects.

After qualitative field data collection, we conducted a remote sensing analysis to examine the historical and current environmental impacts of natural gas and graphite extraction in Cabo Delgado (see Table S9 for the satellite images used). As a proxy for change in the environment, we used LULC change in the projects' DUAT and surrounding areas[5] over the past six years (2015–2021). The study areas were classified under three main LULC classes, namely: 1) built-up and bare areas; 2) densely vegetated areas; and 3) sparsely vegetated areas. Depending on the area geography, wetlands (natural gas project area) and surface water (graphite project areas) were also included as distinguishable classes. All satellite images were processed and analyzed in RStudio Version 2022.07.2 + 576 (RStudio Team, 2022) and ArcGIS Pro Version 2.8.3 (ESRI, 2021). For transparency and reproducibility, a detailed script of the workflow is also publicly available at the first author's GitHub account (see Section 6 of the supplementary data).

After establishing two kinds of data—geospatial and qualitative—we analyzed for LULC change (Fig. 2). First, we established the changes in LULC between 2015 and 2020/2021 from the satellite images. Then, we analyzed for any changes in LULC that were mentioned by the interviewees or FGD participants. Finally, we established the overall change in LULC for each project using the changes that could be clearly established from the satellite images, supplemented with the changes that were identified from the qualitative data. We based on the results of LULC across the three project areas to establish early patterns in the socioenvironmental impacts of ETR-extractivism in the province.

5. Results: socioenvironmental impacts of ETR frontier expansion

The results of our remote sensing analysis point to a general increase in built-up and bare areas in the graphite and natural gas project areas and their surroundings over the past six years. They also show a decrease

---

[2] Suni Resources is not included in this study because of its smaller scale compared to the other projects and the more recent commencement of its activities.

[3] https://www.twigg.co.mz/.

[4] Interviewees self-identified as either male or female.

[5] The surrounding areas include all the communities which are identified as most-directly by the activities of each project (PACs), according to stakeholder interviews and project social and environmental impact assessments.

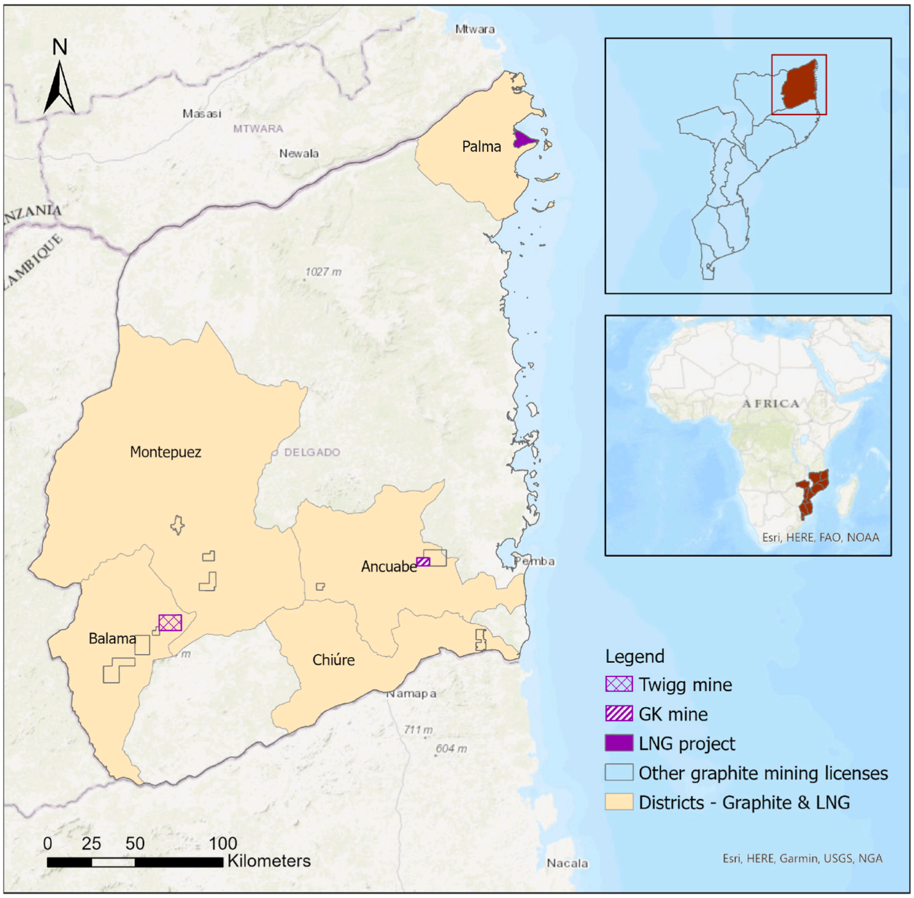

Fig. 1. Graphite and onshore natural gas concession areas in Cabo Delgado Province. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

in vegetation (see Tables 1 and 2). In the natural gas project area and surroundings, we also find a decrease in wetlands whereas in the graphite project areas and their surroundings, we also find slight increases in surface water.

A substantial amount of the increase in built-up and bare areas in the project areas and their surroundings aligns with the expansion of project-related facilities such as resettlement villages, employee camps, processing plants, and access roads. During the field research, it became clear that the increase in built-up and bare areas in the Twigg project area (see Fig. 3) and close to the Pirira community is due to the construction of an employee camp and a processing facility. For instance, 94 percent of Twigg's workers were Mozambican nationals, but only 50 percent[6] of these were from the neighboring local communities (Twigg Exploration and Mining Limitada n.d.). In the Total project area (Fig. 5), the increase in built-up and bare areas is a result of the project's construction of an employee camp, a resettlement village and access roads. Similar to Twigg, the majority (90 percent) of the workers in the natural gas project were Mozambican, as of February 2020 (see Table S4). However, only 23 percent of the Mozambican workers were from the local communities. Due to the considerable number of workers from outside Cabo Delgado, the gas project employed a fly-in-fly-out labour arrangement wherein non-local workers were flown back-and-forth between an on-site employee camp and their provinces or countries of origin (PS1, May 2021).

Outside the DUAT areas, we also find increases in built-up and bare areas which are associated with the expansion of project-related infrastructure and activities (e.g., roads leading to project facilities, community development projects such as boreholes, training schools, and worker housing). Surrounding the Total project, an employee of an NGO, which has been working in Cabo Delgado for close to two decades, noted the increase in infrastructure following the commencement of the project as follows: 'I knew Palma before the megaprojects were installed. To get from Mocímboa da Praia to Palma was martyrdom, but I went there a few years ago and they already had improved roads' (NGO16,[7] November 2021). In the communities affected by the Twigg project, such as Ntete and Nacole, community members noted that the project had constructed a range of infrastructure including boreholes, classrooms, and a police station (Ntete13,[8] September 2020; Nacole23, September 2020). Also, in the GK project surroundings, interviewees noted that the project had constructed classrooms and boreholes in communities like Muagide and Nakhumi (Muagide01, September 2020; Nakhumi02, September 2020). The increases in built-up and bare areas in the surroundings of the DUAT areas are especially visible in the towns closest to the projects (henceforth project towns) namely Balama Sede, Silva Macua, and Palma Sede (Figs. 3–5).

We also observed infrastructure (including private residences and businesses e.g., banks and retail stores) not related to the projects which contribute to the increases in built-up and bare areas in the project surroundings. However, given that the project host areas are still rural

---

[6] It was unclear from the project website how many people worked for the project. In 2017, this number was about 523 people (Philips, 2020). However, the project laid off many workers in 2020/2021 due to the Covid-19 pandemic.

[7] The institutional interviews are numbered from one within each category (NGO — non-governmental organization, GOV — government, PS — private sector, ACA — academia).

[8] Community interviews are numbered sequentially within each community.

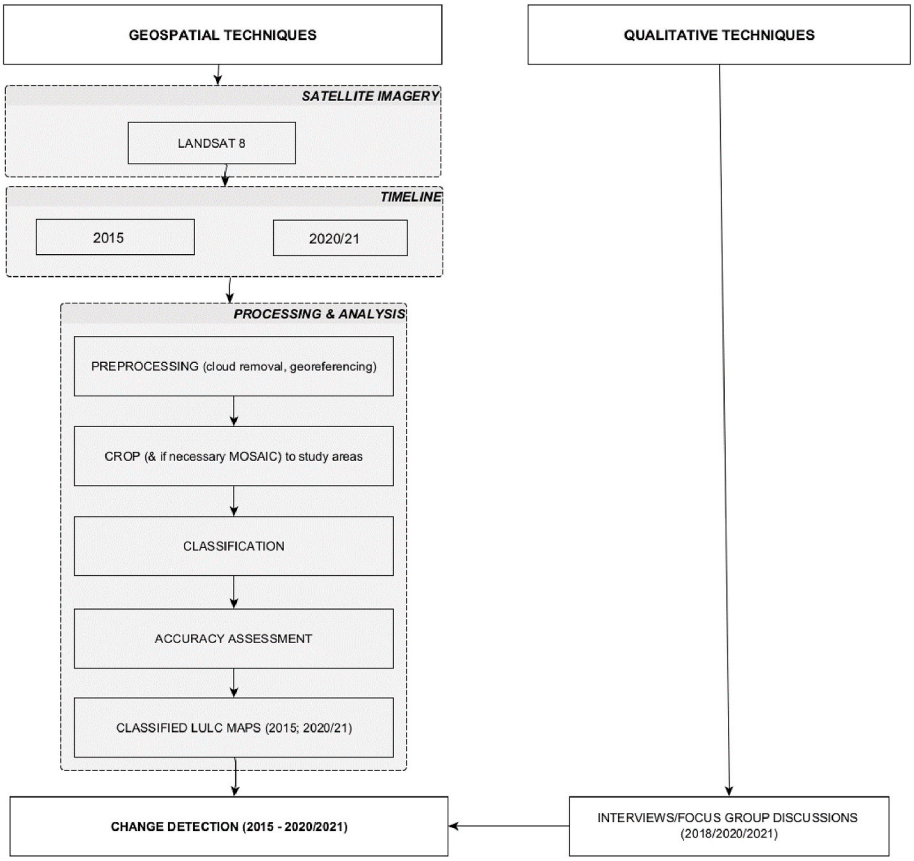

Fig. 2. Data collection, processing, and analysis workflow.

Table 1
LULC areas (Km^2) for the Twigg, GK and Total concessions and surrounding areas.

Location	LULC		2021/20	2015	Difference	
Palma	Built-up-bare		33.54	22.19	11.35	
	Vegetation	Dense vegetation	56.39	35.69	20.70	−10.43
		Low vegetation	172.83	203.96	−31.13	
	Wetland		26.91	36.07	−9.16	
Balama	Built-up-bare		132.2	93.3	38.9	
	Vegetation	Dense vegetation	51.3	65.41	−14.11	−39.28
		Low vegetation	283.54	308.71	−25.17	
	Water		3.41	3.03	0.38	
Ancuabe	Built-up-bare		45.78	29.35	16.43	
	Vegetation	Dense vegetation	20.64	51.04	−30.40	−16.43
		Low vegetation	319.18	305.21	13.97	
	Water		0.174	0.171	0.003	

Table 2
LULC areas (km^2) for the Twigg, GK and Total concession areas.

Location	LULC		2021/20	2015	Difference	
Palma	Built-up-bare		15.36	10.14	5.22	
	Vegetation	Dense vegetation	0.76	0.99	−0.23	−7.20
		Low vegetation	40.55	47.52	−6.97	
	Wetland		6.36	7.73	−1.37	
Balama	Built-up-bare		25.08	15.83	9.25	
	Vegetation	Dense vegetation	18.60	21.24	−2.64	−6.61
		Low vegetation	67.12	74.05	−6.30	
	Water		0.36	0.04	0.32	
Ancuabe	Built-up-bare		2.72	1.04	1.68	
	Vegetation	Dense vegetation	5.97	12.76	−6.79	−1.78
		Low vegetation	24.49	19.48	5.01	
	Water		0.14	0.04	0.1	

and without large-scale economic activities outside of the extractive projects, we found that most infrastructure and activities are related to project activities. For example, new bank branches have opened up in project towns with the aim to leverage the new banking services demand brought by paid workers. Two banks in Balama Sede (BCI and Standard Bank) even started a collaboration with the Twigg project to provide project workers with personal development loans. An interviewee who worked in the Twigg project for three years explained the initiative as follows: ‘The company encouraged us to take out loans which we would pay back slowly from our salaries over five years’ (Ntete41, September 2020). Therefore, some of the infrastructure growth in surrounding project areas was instigated by project activities.

The direct and indirect increases in built-up areas in both the DUATs and surrounding areas was often preceded by a clearing of, and therefore a decline in, vegetation and wetlands from the affected areas. A comparison of project DUAT areas in 2015 and 2020/2021 clearly shows transitions from vegetation or wetland areas to built-up and bare areas (Figs. 3–5). This transition is most vivid in the Twigg and Total projects which were developed from scratch. In contrast, we note more limited changes in the case of the GK project area which was first developed in

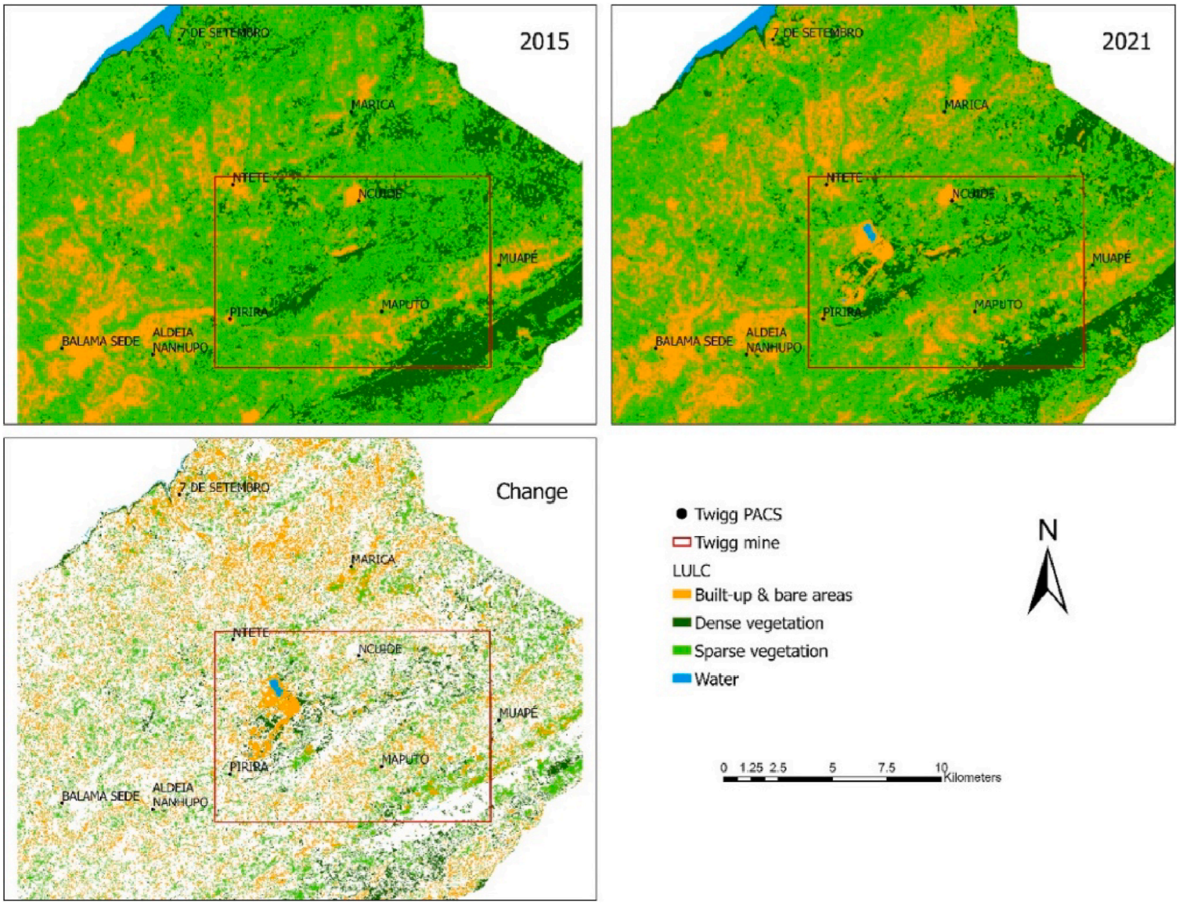

Fig. 3. LULC change in the Twigg project area. The change map indicates the classes to which the LULC changed. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

the 1990s. In the case of Twigg, the project, in collaboration with the government, displaced over 600 households from their farmlands in the communities that are now under the project's DUAT area (including Pirira, Ntete, Ncuide and Maputo). Replacement land was found in neighboring communities (including Marica, 7 de Setembro, and Muape). As a result, the replacement lands have been cleared of vegetation both by the resettled communities and the project. Similarly, the Total project displaced close to 2000 households from their homes, farmlands and fishing grounds in Quitupo and Maganja and relocated them to Senga and Mondlane, a process which has also been accompanied by the clearing of vegetation to create new settlements and farmlands.[9] Residents displaced by the Total project described the process as follows: 'Now we are going to [new] areas and burning shrubs to create lands for cultivation' (FGD, Quitupo, May 2018). Moreover, as a result of the decrease in vegetation and wetlands due to project-related activities, the projects were 'contributing to a fragmentation of endangered ecosystems' (GOV8, December 2021) such as mangroves in the Total project area and Miombo woodlands in the Twigg project areas (see Coastal and Environmental Services, 2015; Total, 2020 for overlap between the projects' DUAT areas and sensitive ecosystems).

To recap, there is an overall reduction in vegetation in the three concession areas and their surroundings. However, in some sections of the GK and Total areas, we find increases in sparse and dense vegetation, respectively (see Tables 1 and 2). In the Total area, some of the increase in dense vegetation is linked to missing data. In the images used for this area, especially the 2020 image, some of the areas were covered by clouds. We masked out the clouded areas during image analysis. Therefore, when comparing the 2020 and 2015 images, this might falsely indicate an increase in dense vegetation for the Total area. Additionally, in both the GK and Total areas, the increases in dense or sparse vegetation may be more linked to seasonal changes in land cover than changes in land use. That is, the same vegetation may be classified as sparse or dense during different years depending on the climate characteristics at the time when each image is taken. This may explain why in the absence of any known change in land use, we may still see some changes in vegetation in the images (Tables S10, S11, and S12 — the confusion matrices demonstrate that there were a few instances when it was difficult to distinguish between sparse and dense vegetation). The challenge of detecting land use changes that contrast the known land uses was not as pronounced in the Twigg area. This is likely because most of the area included in the study was being affected by changes in land use which superseded the seasonal influences.

In the Twigg and GK areas, we also found slight increases in surface water. These increases are due to the construction of project facilities, namely infrastructure to access water for mine activities or wastewater disposal. For example, the Twigg project rehabilitated the nearby Chipembe Dam and increased its retention capacity to use some of the dam's water for its activities. The project also constructed a mine tailings dam that is visible as one of the areas inside its DUAT that contributes to an expansion in water-covered areas (Fig. 3). Although not visible from the satellite images, some community members in Pirira, the village closest to the Twigg mine facilities, reported occasional flooding of their farmlands due to overflows of the mine's tailings dam. An interviewee affected by this situation explained it as follows: 'When it

---

[9] The project was still in the process of finding alternative fishing grounds for the fisherfolk.

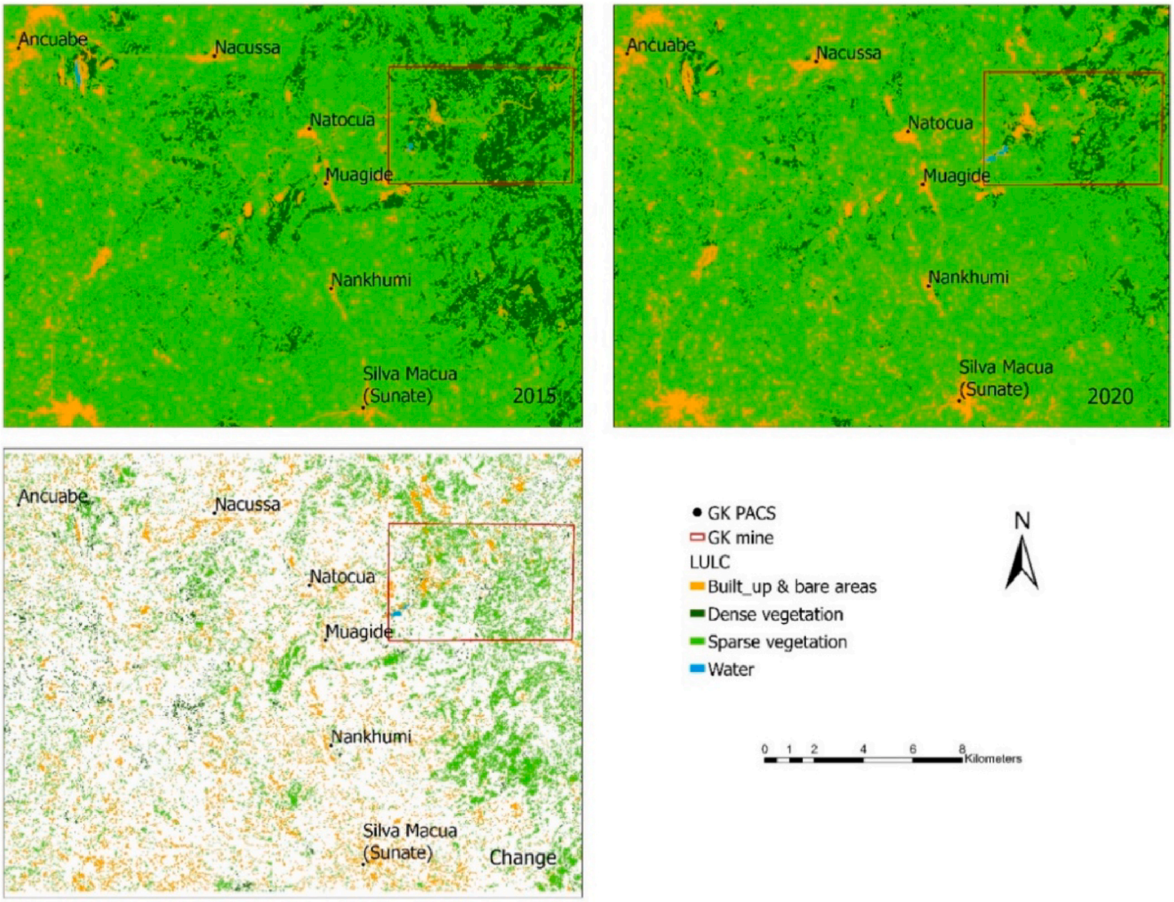

Fig. 4. LULC change in the GK project area. The change map indicates the classes to which the LULC changed. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

rains, they release water from their dams, it comes here to Pirira and causes our crops to rot' (Pirira10, September 2020). Therefore, the Twigg and GK projects contribute to land cover changes in the areas where they operate, with consequences for the neighboring communities.

We discovered other socioenvironmental impacts linked to the ETR projects that did not emerge in the remote sensing and GIS analysis, but which were discussed in the interviews or FGDs. These impacts included increases in solid waste, air and noise pollution, and road degradation in project area surroundings; a restriction in communities' access to natural resources; and inception of project-associated conflict in the province. As the projects develop, workers and immigrants continue to flow into the towns neighboring the projects, and several small and medium-sized businesses erupt along the main roads. This increases consumption and generates solid waste in project areas. However, public solid waste disposal facilities are not keeping up with this pace. An officer from the Provincial Ministry of Environment stated: 'We are not sufficiently prepared to have adequate infrastructure for solid waste disposal. So, solid waste management is a problem in almost all the places near the big companies' (GOV8, December 2021). Improper solid waste management was affecting sanitation in these areas.

The projects also contribute to air and noise pollution: particulates are emitted from project facilities (particularly Twigg) and increased vehicle traffic creates dust and noise near access roads. A geological technician from the Provincial Department of Mineral Resources explained why graphite was more likely to cause air pollution in this manner: 'Graphite is very light, so it flies high up and when the wind ceases, it falls and affects even relatively distant communities' (GOV1, July 2021). At least 35 interviewees in Nanhupo, Mualia, Ncuide, Ntete and Pirira reported an increase in graphite dust in the air, on their crops and trees, and in some of their water sources. The increase in project-related vehicle traffic also contributes to the degradation of local roads, many of which are not yet equipped for the increased load brought by project vehicles (GOV8, December 2021). Finally, a surge in project activities restricts community access to natural resources, for example the ability to collect wood for cooking and constructing houses. An interviewee from Muagide gave the following example: 'GK forbade forest access. We are limited because that road [through the forest] used to allow cars. We used to transport bamboo, wood and we used to work machambas [farmland] there' (FGD, Muagide001, September 2020). Therefore, the projects disrupt the livelihoods and environment of neighboring communities.

In the natural gas area, we found community discontent with the project's limited contribution to local employment and socio-economic development[10]. As highlighted above (Alberdi and Barroso, 2020; Hanlon, 2022), this discontent has contributed to the ongoing armed insurgency in Cabo Delgado. The insurgency has led to over 4000 fatalities and the displacement of almost one million people, as of October20, 22.[11] Hundreds of those displaced in the GK and Twigg project areas were struggling to access basic resources like land and the materials necessary for food cultivation. A community leader in Muagide [GK area] related the conundrum of the 225 refugees in his community as follows: 'They are willing to practice agriculture. But they do

---

[10] Interviews in Quitupo, Senga, Maganja and Mondlane in May 2018 (Table S7).

[11] See Hanlon (2022).

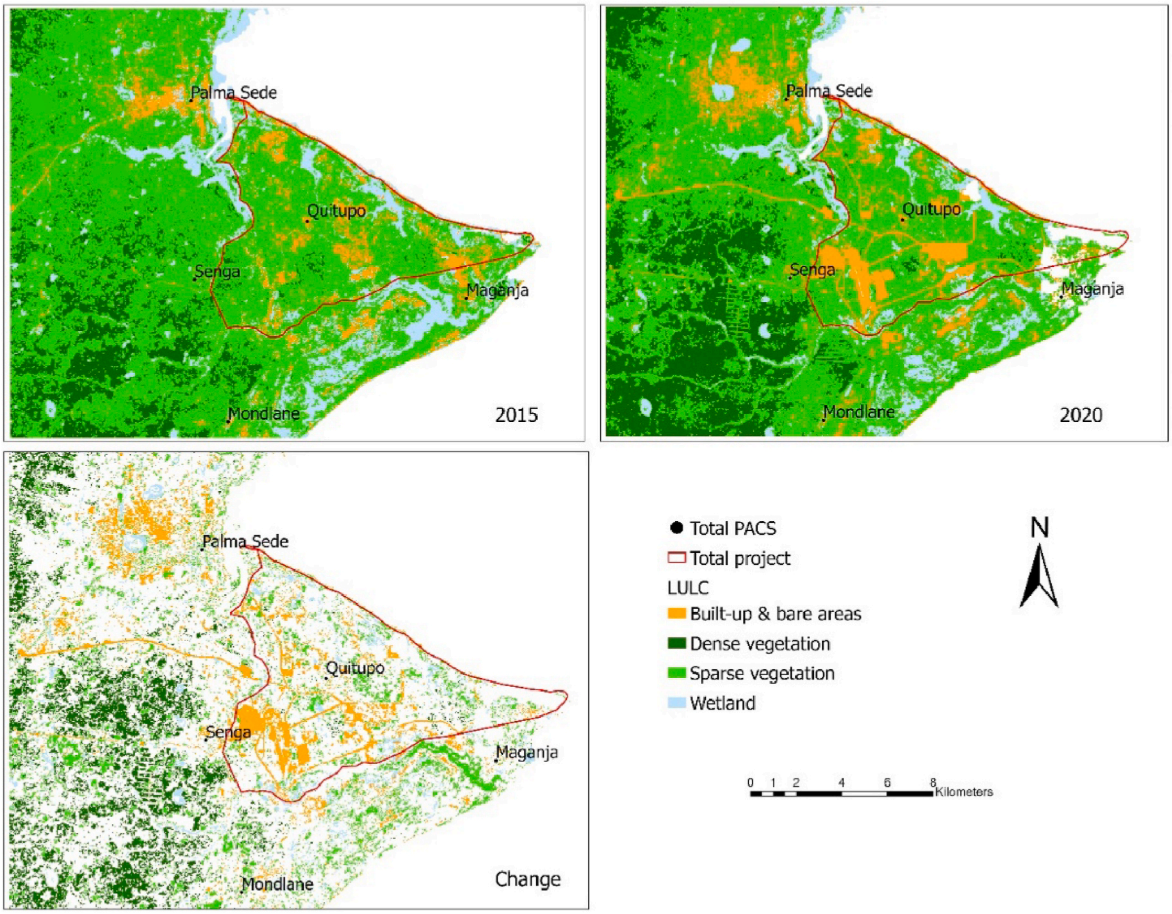

Fig. 5. LULC change in the Total project area. The change map indicates the classes to which the LULC changed. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

not have the necessary material such as machetes and hoes.' (FGD, Muagide001, September 2020). Therefore, the negative socio-economic consequences of the gas project were affecting communities in the graphite project areas.

Although the three projects had social and environmental management plans to address socioenvironmental issues, provincial agencies faced technical and financial difficulties in monitoring their implementation. An officer from the Provincial Department of Mineral Resources described some of the challenges in this way: 'We have few technicians, there are many companies, and the tendency is for the number to increase.' (GOV2, November 2021). Many agencies therefore only visited project sites once a year, if at all. As a consequence, government agencies often relied on the annual company reports within which they are obliged to self-report on their activities. In contrast to the government, the companies had more technical facilities available to conduct the necessary environmental quality measurements. This however offers possible avenues for the companies to abscond from their socioenvironmental management responsibilities. Interviews with company employees made clear that the companies are aware of the state's inadequacies in assessing and monitoring projects activities. Along these lines, a former employee at Twigg commented: 'I feel that Mozambique has not prepared to host such large-scale projects given its challenges in regulating, inspecting, and staffing the extractive sector. You know, companies only tend to comply with the legislation of the country where they operate' (PS1, May 2021). Civil society organizations helped to monitor the social effects of projects for example by examining the livelihood losses of the people affected by project-induced displacement and by supporting the affected communities in their negotiations with the projects for fairer compensation. However, because their activities were irregular and depended on the availability of often 'limited resources' (NGO9, November 2021), these organizations often failed to fully grasp the wider socioenvironmental changes that various projects induce.

6. The added value of mixed methods in studying the socioenvironmental impacts of ETR frontier expansion

Our study of the cumulative socioenvironmental impacts of ETR extraction in Cabo Delgado provides an in-depth understanding of the impacts of an expanding frontier of extractivism in the province. It reveals impacts that are distinct to projects or commodities, but also those that cut across the projects. The natural gas project which is located close to the coast impacts ecosystems such as mangroves, which are slightly different from those impacted by the graphite projects which are located inland. Besides the differences in socioenvironmental impacts due to physical geography, we also found differences linked to the materiality of the ETRs and the mechanisms used to extract them. Land-based open-cast mining, which is used in graphite extraction, for instance, releases mineral dust into the neighboring environments. This was not a significant issue in the natural gas extraction area. In addition, unlike the gas area, we found a slight increase in surface water in the graphite mining areas due to project activities such as the construction of a mine tailings dam. Conversely, in the case of natural gas, the combination of offshore drilling and onshore gas processing implied marine in addition to the terrestrial impacts. Fishing and inter-tidal gathering are some of the additional impacts which were not found in the case of the inland graphite projects. The impacts of the projects are also reflective of their stages of development (also see Werner et al.,

2020) and their location either in a brownfield or greenfield. For example, the increases in built-up and bare areas are largest in relation to the Total project which launched in 2012, followed by the Twigg and GK projects which launched in 2017. Meanwhile, between the Twigg and GK projects, more LULC changes were detected in relation to Twigg which is located in a greenfield in contrast to GK which is in a brownfield.

Across the three projects and their surroundings, our findings clearly show an overall increase in built-up and bare areas and a decrease in vegetation and wetlands. Such impacts are not completely surprising as they are typical of resource extraction projects (e.g., see Brown et al., 2022). However, their development across multiple projects, over a similar period of time, points to early change patterns in an expanding frontier of ETR extractivism. Knowledge of the incipient change patterns accompanying ETR extraction can be exploited to facilitate the advancement of desirable effects such as the increase or improvement in public infrastructure like roads, schools, and health facilities. It can also be harnessed to mitigate the accumulating negative consequences such as the degradation of multiple vital ecosystems and the increasing competition for resources like land, which is contributing to conflict and impoverishment in some project areas. Such extensive yet precursory knowledge may be essential when we need to evaluate the costs and benefits of the strategies we select (e.g., the adoption of particular low-carbon technologies) as we strive for global sustainability. Often, independent analyses (outside the government or private sector) of the socioenvironmental impacts of extractivism are conducted at very advanced stages of the extractive projects following an accumulation of irreversible negative impacts (Werner et al., 2019).

Combining remote sensing and GIS with qualitative research methods allows for an in-depth understanding of the socio-environmental impacts across expanding ETR extraction frontiers. We could not have systematically established the expansion of built-up and bare areas or the decline in vegetation across the three projects from qualitative methods alone. Conversely, the social impacts –such as the emergence of conflict or the increased amount of solid waste near the projects – that we uncovered through interviews and FGDs, were invisible via remote sensing. These examples illustrate the benefits in scale and depth that users obtain from mixed geospatial and qualitative techniques when analyzing the socioenvironmental impacts of the expanding frontier of ETR extractivism.

Another benefit of these mixed methods is that they allow the study of socioenvironmental changes when field research is complicated. Due to the Covid-19 pandemic and the armed insurgency in Cabo Delgado, conducting field interviews in the natural gas project area has been nearly impossible since 2019. However, we were able to assess the impacts of the project using interviews from 2018 and satellite images from 2015 to 2020. Our results also affirm how, in frontier locations like Cabo Delgado, government authorities have limited financial and technical capacity to monitor the socioenvironmental impacts of the expanding extractive industry comprehensively and regularly. However, the increase in open access data, analysis software, and code sharing platforms as utilized in this study[12] present avenues to minimize the financial and technical impediments to conducting broad-based analyses.

Despite these benefits, the utilization of mixed methods was not without limitations. The reliability of the quantitative data produced from geospatial techniques for instance depended on the quality of the images, which in turn was determined by factors such as their spatial resolution or the influence of cloud cover. We indicated that the accuracy of the absolute areas of LULC could have been impeded by cloud cover. That is why we validated the patterns of environmental change uncovered through the geospatial analysis with the qualitative methods.

7. Conclusions

This paper focused on the cumulative socioenvironmental impacts of energy transition-induced extractivism in Cabo Delgado. We aim to contribute to discussions of the wider implications of the ETR frontiers burgeoning in Africa and other global South countries. To achieve sustainable development goals seven (clean energy for all) and thirteen (climate change action) without compromising the remaining goals, it is necessary to understand the human and environmental costs of increased ETR extractivism. Combining remote sensing, GIS, and qualitative methods can be instrumental for analyzing the cumulative socioenvironmental impacts in areas where ETR extraction is quickly expanding in time and space. Our case study has shown that these mixed methods offer concrete tools to understand the impacts of ETR extraction in places where the technical and financial capacity of government and civil society organizations to conduct in-situ monitoring, is limited. Therefore, we recommend that any actors that invest in the extraction of ETRs in low-income regions also support the local capacity to utilize such mixed methods to anticipate, monitor, and address the impacts accompanying ETR extraction. We also posit that future studies should pay attention to two areas when employing a mixed-method design to understand the impacts of ETR extraction. First, if there are other extractive projects in the same area as the ETR projects, these should also be included in the cumulative socioenvironmental impact analysis, to ascertain a complete picture of the impacts of resource extraction in the era of global sustainability. Second, other research methodologies, such as in-situ measurements, which can determine any biophysical changes overlooked by remote sensing and qualitative techniques, can be added to the cocktail of methods utilized.

Credit authors statement

Emilinah Namaganda: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Visualization. **Kei Otsuki**: Writing – review & editing, Supervision, Funding acquisition. **Griet Steel**: Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We have shared a link to the GitHub account that includes the code used for data processing and analysis.

Acknowledgements

This study was funded by the Dutch Research Council (NWO) through the ASPASIA project. Field work in 2020 was partly funded by the Ronald van Kempen Urban Geography Fund of Utrecht University. The funding sources were not involved in study design; in the collection, analysis and interpretation of data; in the writing of the report; or in the decision to submit the article for publication. We thank Lúrio University which hosted the first author during fieldwork in 2021. We are also grateful to the field research assistants who helped collect data in Mozambique: Patrick Mollo, Carlos Viriato, Lucrécia Fonseca, Miguel Teodoro Sebastião, Joaquina Muroto, and Milda Come. We also thank Utrecht University students Simon Teichtmann and Liesanne Baak who conducted their theses with the InFRONT project and whose outputs contributed to the conceptualization process of this paper. An earlier version of the paper was presented at the 2022 EXALT conference and at the 2022 InFRONT and Gas Gospels project workshop. We express our gratitude to the participants of these events for their useful comments

---

[12] ArcGIS Pro is the only subscription-based software utilized in this study. However, GIS users can also use alternatives like QGIS to conduct similar studies.

and reflections. We are also extremely grateful to two anonymous reviewers whose comments improved the paper considerably.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.117811.

References

Aboda, C., Mugagga, F., Byakagaba, P., Nabanoga, G., 2019. Development induced displacement: a review of risks faced by communities in developing countries. Soc. Anthropol. 7, 100–110. https://doi.org/10.13189/sa.2019.070205.

Africa Oil and Power, 2020. Mozambique Special Report 2020. https://energycapitalpower.com/report/mozambique-covid-19-response-special-report-2020/. (Accessed 11 January 2021). accessed.

Agusdinata, D.B., Liu, W., Eakin, H., Romero, H., 2018. Socio-environmental impacts of lithium mineral extraction: towards a research agenda. Environ. Res. Lett. 13, 123001 https://doi.org/10.1088/1748-9326/aae9b1.

Alberdi, J., Barroso, M., 2020. Broadening the analysis of peace in Mozambique: exploring emerging violence in times of transnational extractivism in Cabo Delgado. Global Soc. 35, 229–246. https://doi.org/10.1080/13600826.2020.1772730.

Antwi, E.K., Boakye-Danquah, J., Owusu-Banahene, W., Webster, K., Dabros, A., Wiebe, P., Mayor, S.J., Westwood, A., Mansuy, N., Setiawati, M.D., Yohuno, P.T., Bill, K., Kwaku, A., Kosuta, S., Sarfo, A.K., 2022. A global review of cumulative effects assessments of disturbances on forest ecosystems. J. Environ. Manag. 317, 115277 https://doi.org/10.1016/j.jenvman.2022.115277.

Banza, C., Nkulu, L., Casas, L., Haufroid, V., Putter, T. De, 2019. Sustainability of artisanal mining of cobalt in DR Congo. Nat. Sustain. 1, 495–504. https://doi.org/10.1038/s41893-018-0139-4.

Bassey, N., 2012. To Cook a Continent: Destructive Extraction and the Climate Crisis in Africa. Fahamu/Pambazuka.

Brown, C., Boyd, D.S., Kara, S., 2022. Landscape analysis of cobalt mining activities from 2009 to 2021 using very high resolution satellite data (Democratic Republic of the Congo). Sustain. Times 14, 9545. https://doi.org/10.3390/su14159545.

Bruna, N., 2022. Green extractivism and financialisation in Mozambique: the case of gilé national reserve. Rev. Afr. Polit. Econ. 49, 138–160. https://doi.org/10.1080/03056244.2022.2049129.

Carmody, P., 2016. The New Scramble for Africa, second ed. Polity Press, Malden.

Church, C., Crawford, A., 2018. Green Conflict Minerals: the Fuels of Conflict in the Transition to a Low-Carbon Economy. International institute for sustainable development.

Coastal and Environmental Services, 2015. Parte II: avaliação do impacto ambiental, social, e de saúde: a proposta mina de grafite de Balama na provincia de Cabo Delgado no distrito de Balama no norte de MoçambiqueFebruary 2015, 1-445. Maputo.

Cole, M.J., Broadhurst, J.L., 2020. Mapping and classification of mining host communities: a case study of South Africa. Extr. Ind. Soc. 7, 954–964. https://doi.org/10.1016/j.exis.2020.06.007.

Cope, M., Elwood, S., 2009. Qualitative GIS: a Mixed Methods Approach. Sage.

Delborne, J.A., Hasala, D., Wigner, A., Kinchy, A., 2020. Dueling metaphors, fueling futures: "bridge fuel" visions of coal and natural gas in the United States. Energy Res. Social Sci. 61, 101350 https://doi.org/10.1016/j.erss.2019.101350.

Dorn, F.M., Peyré, F.R., 2020. Lithium as a strategic resource: geopolitics, industrialization, and mining in Argentina. J. Lat. Am. Geogr. 19, 68–90. https://doi.org/10.1353/lag.2020.0101.

Environmental Systems Research Institute (ESRI), 2021. ArcGIS Pro. Version 2.8.3. Redlands, CA.

Firozjaei, M.K., Sedighi, A., Karimi, H., Kiavarz, M., 2021. A historical and future impact assessment of mining activities on surface biophysical characteristics change: a remote sensing-based approach. Ecol. Indicat. 122, 107264 https://doi.org/10.1016/j.ecolind.2020.107264.

Franks, D.M., Brereton, D., Moran, C.J., 2013. The cumulative dimensions of impact in resource regions. Resour. Pol. 38, 640–647. https://doi.org/10.1016/j.resourpol.2013.07.002.

Hanlon, J., 2022. Debt trial, Rwanda trooops, US-China battle over graphite, domestic borrowing. Mozambique news reports and clippings 4 (December).

Hickel, J., Dorninger, C., Wieland, H., Suwandi, I., 2022. Imperialist appropriation in the world economy: drain from the global South through unequal exchange, 1990–2015. Global Environ. Change 73, 102467. https://doi.org/10.1016/j.gloenvcha.2022.102467.

Hund, K., La Porta, D., Fabregas, T.P., Laing, T., Drexhage, J., 2020. Minerals for Climate Action: the Mineral Intensity of the Clean Energy Transition, vol. 73. World Bank.

Judd, A.D., Backhaus, T., Goodsir, F., 2015. An effective set of principles for practical implementation of marine cumulative effects assessment. Environ. Sci. Pol. 54, 254–262. https://doi.org/10.1016/j.envsci.2015.07.008.

Kamoga, J., 2022. Uganda successfully launches its first satellite into space. East Afr. 8 November. https://www.theeastafrican.co.ke/tea/news/east-africa/uganda-launches-first-satellite-into-space-4012454. (Accessed 1 March 2023). accessed.

Keita, M., Traore, O., 2020. Environmental impact of open pit mining: case of bauxite mining in Guinea. a review. Int. J. Appl. Environ. Sci. 15, 167–177.

Kramarz, T., Park, S., Johnson, C., 2021. Governing the dark side of renewable energy: a typology of global displacements. Energy Res. Social Sci. 74, 101902 https://doi.org/10.1016/j.erss.2020.101902.

MIREME (Ministério dos Recursos Minerais e Energia de Moçambique)., Trimble Land Administration, 2022. Mozambique Mining Cadastre Map Portal. https://portals.landfolio.com/mozambique/pt/. (Accessed 6 September 2022). accessed.

Lèbre, É., Stringer, M., Svobodova, K., Owen, J.R., Kemp, D., Côte, C., Arratia-solar, A., Valenta, R.K., 2020. The social and environmental complexities of extracting energy transition metals. Nat. Commun. 11, 1–8. https://doi.org/10.1038/s41467-020-18661-9.

Lechner, Alex M., Owen, J., Li, M., Ang, E., Edraki, M., Aklima, N., Awang, C., Kemp, D., 2019. Historical socio-environmental assessment of resource development footprints using remote sensing. Remote Sens. Appl. Soc. Environ. 15, 100236 https://doi.org/10.1016/j.rsase.2019.100236.

Liu, W., Agusdinata, D.B., Myint, S.W., 2019. Spatiotemporal patterns of lithium mining and environmental degradation in the Atacama Salt Flat, Chile. Int. J. Appl. Earth. Obs. Geoinformation 80, 145–156. https://doi.org/10.1016/j.jag.2019.04.016.

Marais, L., Denoon-Stevens, S., Cloete, J., 2020. Mining towns and urban sprawl in South Africa. Land Use Pol. 93, 103953 https://doi.org/10.1016/j.landusepol.2019.04.014.

Murshed, M., 2022. Pathways to clean cooking fuel transition in low and middle income Sub-Saharan African countries: the relevance of improving energy use efficiency. Sustain. Prod. Consum. 30, 396–412. https://doi.org/10.1016/j.spc.2021.12.016.

Murshed, M., Khan, S., Rahman, A.K.M.A., 2022. Roadmap for achieving energy sustainability in Sub-Saharan Africa: the mediating role of energy use efficiency. Energy Rep. 8, 4535–4552. https://doi.org/10.1016/j.egyr.2022.03.138.

Namaganda, E., Otsuki, K., Steel, G., 2022. Learning from Africana critical theory: a historicized contextualization of the impacts of Mozambique's natural gas project. Extr. Ind. Soc. 10, 101075 https://doi.org/10.1016/j.exis.2022.101075.

Obi, C., 2014. Oil and conflict in Nigeria's Niger Delta region: between the barrel and the trigger. Extr. Ind. Soc. 1, 147–153. https://doi.org/10.1016/j.exis.2014.03.001.

Owen, J.R., Kemp, D., Harris, J., Lechner, A.M., 2022. Fast track to failure? Energy transition minerals and the future of consultation and consent. Energy Res. Social Sci. 89, 102665 https://doi.org/10.1016/j.erss.2022.102665.

Philips, J., 2020. Balama graphite project: developing the world's largest graphite mine. Syrah Resources, pp. 1–13. March.

Rodney, W., 1973. How Europe Underdeveloped Africa. Bogle-L'Ouverture Publications, Dar-es-Salaam.

RStudio Team, 2022. RStudio: Integrated Development for R. RStudio. PBC, Boston, MA. http://www.rstudio.com/.

Rudke, A.P., de Souza, V.A.S., Dos Santos, A.M., Xavier, A.C.F., Rotunno Filho, O.C., Martins, J.A., 2020. Impact of mining activities on areas of environmental protection in the southwest of the Amazon: a GIS-and remote sensing-based assessment. J. Environ. Manag. 263, 110392 https://doi.org/10.1016/j.jenvman.2020.110392.

Sovacool, B.K., Hook, A., Martiskainen, M., Brock, A., Turnheim, B., 2020. The decarbonisation divide: contextualizing landscapes of low-carbon exploitation and toxicity in Africa. Global Environ. Change 60, 102028. https://doi.org/10.1016/j.gloenvcha.2019.102028.

Syrah Resources, 2021. Annual Report 2021.

Teichtmann, S., 2022. A Proof of Concept for Mapping Environmental Change in Areas of Resource Extraction at the Source of Energy Transition Supply Chains: Using Open Access Satellite Data and Cloud Computing to Create Remote Sensing Time Series. Utrecht University.

Total, 2020. Mozambique LNG. Environmental Social and Health Impact Assessment Report. Executive Summary and Update.

Tsurukawa, N., Prakash, S., Manhart, A., 2011. Social Impacts of Artisanal Cobalt Mining in Katanga, Democratic Republic of Congo. Öko-Institut eV, Freiburg.

Twigg Exploration and Mining Limitada n.d. World's largest graphite producer. https://www.twigg.co.mz/(accessed 16 February 2023).

UNCTAD, 2022. Rethinking the Foundations of Export Diversification in Africa: the Catalytic Role of Business and Financial Services. United Nations Commission for Trade and Development, Geneva.

Viegas Filipe, E., Otsuki, K., Monstadt, J., 2021. Translating the sustainable development goals in national development planning: the case of Mozambique's energy for all programme. Sustain. Sci. 16, 1797–1809. https://doi.org/10.1007/s11625-021-01020-y.

Werner, T.T., Bebbington, A., Gregory, G., 2019. Assessing impacts of mining: recent contributions from GIS and remote sensing. Extr. Ind. Soc. 6, 993–1012. https://doi.org/10.1016/j.exis.2019.06.011.

Werner, T.T., Mudd, G.M., Schipper, A.M., Huijbregts, M.A.J., Taneja, L., Northey, S.A., 2020. Global-scale remote sensing of mine areas and analysis of factors explaining their extent. Global Environ. Change 60, 102007. https://doi.org/10.1016/j.gloenvcha.2019.102007.

Wiegink, N., Kronenburg, A., 2022. Surplus to extraction: resettlement as a "make live" intervention in Mozambique. Extr. Ind. Soc. 9, 101036 https://doi.org/10.1016/j.exis.2021.101036.

Zoomers, A., 2011. Introduction: rushing for land: equitable and sustainable development in Africa, Asia and Latin America. Devenir 54, 12–20. https://doi.org/10.1057/dev.2010.97.