Authors
Hugo Lapeyronie
Etienne Espagne
Coordination
Hugo Lapeyronie (AFD)

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Energy transition minerals and the SDGs. A systematic review

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Energy transition minerals and the SDGs

A systematic review

AUTHORS

Hugo Lapeyronie
Agence française
de Développement (AFD),
Université Paris 1
(Panthéon-Sorbonne)

Etienne Espagne
World Bank,
Centre d'études et de recherches
en développement international
(CERDI)

COORDINATION

Hugo Lapeyronie
(AFD)

Abstract

In order to meet the climate objectives set by the Paris Agreement, all countries will have to operate a dramatic structural change by replacing most fossil energy sources with renewable ones that are expected to be highly mineral intensive. This material intensity of the low-carbon transition may notably threaten different dimensions of the 2030 Agenda.

In this paper, we provide a systematic review of the links between the mining territories that are essential for the energy transition and the sustainable development goals defined in 2015 by the United Nations. Since much of this demand for minerals will be directed to developing countries, the geographical scope of this review is limited to these countries.

We identify in this systematic review 97 relevant academic articles, which we consider to be a relatively low number in view of the importance of these minerals for both the success of the 2030 agenda and the critical issue of their sustainable supply. Our quantitative and qualitative analyses of the literature show a very heterogeneous - yet coherent - coverage of the energy transition minerals. We find that the extraction of ETMs is undoubtedly related to environmental degradations, especially related to SDG 15. The relatively small amount of empirical evidence found for some of the most important mineral producing countries such as China illustrates the lack of reliable information on the already existing impacts of the extraction of the minerals used in the energy transition. The available evidence suggests that mining territories that depend on fast declining ore grade (i.e., copper) or naturally low-grade minerals (i.e. platinum) and whose supply chain is pressurized by the energy transition could have great difficulty to capture the benefits of the coming mining boom independently of any good governance improvements. On the opposite, provided that the negative externalities of mining are well managed, the mining territories that depend on recently industrially exploited (i.e. Lithium) and naturally high grade minerals (i.e. iron, manganese) could be able to rip off some benefits from the energy transition. The methodological improvements recently made in the monitoring of industrial mines, notably using remote sensing approaches, could help to better understand these emerging threats for the 2030 Agenda.

Keywords
Sustainable development goals (SDGs), Energy transition minerals (ETMs), Systematic review

JEL Classification
F63, Q01, L72

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Minerais de la transition énergétique et ODD

Une revue systématique

Résumé
Afin d'atteindre les objectifs climatiques fixés par l'accord de Paris, tous les pays devront opérer un changement structurel radical en remplaçant la plupart des sources d'énergie fossiles par des sources d'énergie renouvelables qui devraient avoir une forte intensité minérale. Cette intensité matérielle de la transition vers une économie à faible émission de carbone peut notamment menacer différentes dimensions de l'Agenda 2030. Dans cet article, nous proposons une revue systématique des liens entre les territoires miniers indispensables à la transition énergétique et les Objectifs de développement durable définis en 2015 par les Nations unies. Étant donné qu'une grande partie de cette demande de minerais sera dirigée vers les pays en développement, la portée géographique de cette revue est limitée à ces pays. Nous avons identifié dans cette revue systématique 97 articles académiques répondant à nos critères d'inclusion, ce qui nous semble être un nombre relativement faible au regard de l'importance de ces minéraux à la fois pour le succès de l'agenda 2030 et pour la question critique de leur approvisionnement durable. Nos analyses quantitatives et qualitatives de la littérature montrent une couverture très hétérogène - mais cohérente - des minéraux de la transition énergétique. Nous constatons que l'extraction des minerais de la transition énergétique (MTE) est indubitablement liée à des dégradations environnementales, notamment en lien avec l'ODD 15. La quantité relativement faible de preuves empiriques trouvées pour certains des plus importants pays producteurs de minéraux tels que la Chine illustre le manque d'informations fiables sur les impacts déjà existants de l'extraction des minéraux utilisés dans la transition énergétique. Les données disponibles suggèrent que les territoires miniers qui dépendent de minerais à la teneur décroissant rapidement (comme le cuivre) ou de minerais à faible teneur (par exemple le platine) et dont la chaîne d'approvisionnement est mise sous pression par la transition énergétique pourraient avoir de grandes difficultés à tirer profit du prochain boom minier, indépendamment de toute amélioration de la bonne gouvernance. A l'inverse, à condition que les externalités négatives de l'exploitation minière soient bien gérées, les territoires miniers qui dépendent de minéraux récemment exploités industriellement (par exemple le lithium) et naturellement à haute teneur (fer, manganèse) pourraient être en mesure de tirer certains avantages de la transition énergétique. Les améliorations méthodologiques récemment apportées au suivi des mines industrielles, notamment par des approches de télédétection, pourraient aider à mieux comprendre ces menaces émergentes pour la réussite de l'Agenda 2030.

Mots-clés
Objectifs de développement durable (ODD), Minéraux pour la transition énergétique (MTE), Revue systématique

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1. Introduction

The green energy transition describes the process of reducing greenhouse gas emissions by replacing most of the existing fossil fuels energy infrastructures with renewable energies. On average solar panels, wind turbines, and all the infrastructure needed for a green electrified energy system (batteries, network grids...) are more mineral intensive than their fossil fuels counterparts (IAE, 2021). For example, a standard electric vehicle requires more than six times the amount of minerals than its fossil fuels equivalent.

The minerals that are essential for renewable energies are sometimes designated as the "Energy transition minerals" ("ETMs" hereafter). Besides the needs of the energy transition, the demand for most of these minerals will also be increased by the digital sector and the rest of the economy. For example, lithium, nickel, and cobalt are essential components of *Li-on* batteries that can be found in products as diverse as electric vehicles or smartphones.

This reliance of the green energy transition on minerals could lead to a massive increase in global demand for mineral resources. The International Energy Agency (IEA) anticipates that to achieve an energy transition fast enough to reach the Paris agreement, the global demand for mineral resources will be multiplied by four by 2040. If the world economies target carbon neutrality in 2050, the demand for mineral resources could be multiplied by six. However, still according to the IEA, this demand will only be met by creating an unprecedented number of new mines and by expanding existing ones.

The impact of mining on sustainable development is a debated topic. At the macro level, a large part of the literature has been devoted to the "resource curse" debate, which remains largely unsettled (Savoia & Sen, 2021). At the mine level, whether a mine has a positive or negative impact on the host community is also a challenging topic. An influential article by Aragon and Rudd (2013) notably suggested that gold mining had a positive economic impact on the local communities in Peru. However, outside the economic spectrum, detrimental impacts of mining are consistently found in the health of the local population and the environment.

The literature on mining and (sustainable) development has been mainly dedicated to non-ETM minerals - especially gold and coal - two of the most numerous types of mines in the world (S&P, 2022). Yet, the demand of the latter is expected to decrease rapidly to meet the climate objectives, while the former is not expected to play a significant part in the energy transition. Simplistic knowledge transfer from one mineral to another is questionable since minerals are not mined in the same places, with the same methods, nor by the same actors.

Unlike other types of minerals, the production of ETMs is notably characterized by its current high geographical concentration (IEA, 2021). Due to the unequal distribution of geological endowments, developing countries[1] are expected to host a large part of the many new mines that would need to be built to meet the demand for energy transition minerals. Beyond

[1] In this study, this corresponds to the countries of the "High income" classification but includes Uruguay and Chile. See more information in the Method section.

the geology of these countries, low social and environmental standards should attract mining companies, reducing the cost of their operations (World Bank, 2020). An important part of the supply of the minerals of the energy transition could therefore depend to a large extent on the countries that have the longest way to go to achieve the 2030 Agenda.

Mining territories in developing countries and their communities are at the frontline of the energy transition (Sovacool, 2020). Their involvement is yet crucial for the proper functioning of a mine, as local protests can slow down production or even stop it completely (Temper & Shmelev, 2015). Thus, some authors consider that the poor consideration of mining communities' sustainability in the current mining paradigm would currently represent the main risk to the supply of metals for the energy transition, before the risks of depletion of resources (Mudd, 2020).

Despite the increasing importance of this issue, little is known about the possible impacts of an increased mining pressure on the economic, social, and environmental sustainability of these mining territories located in the Global South. Pioneering studies from Sovacool (2020, 2021) on the disastrous conditions of cobalt mining in the DRC have shed light on an important research agenda regarding ETM mining territories. The objective of this systematic review is therefore to locate and synthesize the relevant literature on the mining territories producing the minerals needed to build the green technologies that look at the possible impact of their extraction. More specifically, this systematic review seeks to answer the two following research questions:

- RQ1 - What is known about the sustainable development of the ETM mining territories of the Global South? What are the results of the empirical analyses?
- RQ2 - How does the extraction of Energy Transition Metals can impact the success of the 2030 Agenda in the mining territories of the Global South?

In this review, we define a mining territory as an area "organized by and for the mining activities" (Rossi et al., 2021). Based on the insights from social and economic geology, we assume that each mining territory can be differently affected by the minerals produced in it. This notably contrasts with previous systematic reviews on the mining sector and the 2030 agenda that do not offer a separate analysis of mineral resources' impact.

Due to the wide scope of the 2030 Agenda, this systematic review adopts a mixed-method approach that combines quantitative and qualitative studies in the same synthesis as it facilitates the cross-disciplinary dialogue needed to deal with the relevant literature. One of the objectives of this review is to disentangle the main factors identified in existing empirical investigations that create variation in the impacts found in ETM mining territories. To help us with this task, we structure the synthesis around a new conceptual framework where these factors have a place to influence how the extraction of a mineral can impact a given territory.

Our quantitative and qualitative analyses of the literature show a very heterogeneous - yet coherent - coverage of the energy transition minerals. We identified 97 relevant academic articles, which we consider to be a relatively low number given the importance of these minerals for both the success of the 2030 agenda and the critical issue of their sustainable supply. We find that the extraction of ETMs is undoubtedly related to environmental degradations, especially SDG 15. The relatively small amount of empirical evidence found for some of the most important mineral-producing countries, such as China, illustrates the lack of reliable information on the already existing impacts of the extraction of the minerals used in the energy transition. The available evidence suggests that mining territories that depend on declining ore grade (i.e., copper) or naturally low-grade minerals (i.e. platinum) and whose supply chain is pressurized by the energy transition could have great difficulty to capture the benefits of the coming mining boom independently of any good governance improvements. On the opposite, provided that the negative externalities of mining are well managed, the mining territories that depend on recently industrially exploited (i.e., lithium) and naturally high-grade minerals (i.e., iron, manganese) could be able to rip off some benefits from the energy transition.

This systematic review contributes to the existing literature in several ways. First, it is an addition to the (local) resource curse because it proposes potentially new mechanisms related to the nature of the energy transition minerals. Second, it contributes to the fast-rising literature that explores this emerging typology of minerals used for the energy transition, which has been highlighted by recent reports from the World Bank (2020) and the International Energy Agency (2021). In a more general manner, this review could help empirical researchers on what and how to look for when assessing mining territories' sustainability.

This article is structured as follows. First, we present the analytical framework in which this systematic review is embedded by defining the main concepts structuring our research questions. We then explicitly detail the systematic review design and the synthesis strategy. In a third section we present the results of the systematic review, both quantitatively and qualitatively. Finally, we draw some public policy recommendations based on the results of this review.

2. Analytical framework

2.1. The Energy Transition Minerals

The typology of Energy Transition Minerals recently emerged to designate the minerals that are essential to building renewable energies and their infrastructure (such as electric grids). In 2017, the World Bank Group published what is, to our knowledge, the first list of energy transition minerals by an international institution. In May 2021, the International Energy Agency (AIE) developed an alternative list reflecting more advanced projections of a decarbonized global energy mix. Finally, at the end of 2021, the IMF also started to use the "energy transition metals" terminology as a new category to look at in their monitoring of commodity prices.

The minerals composing the lists developed by both institutions depend primarily on projections made by energy modelers on the future world energy mix and hypotheses on the mineral content of future renewable technologies. For example, an energy mix that relies heavily on hydrogen would require large quantities of platinum for the fuel cells needed to produce it.

Table 1. List of the Energy transition minerals

IEA	World Bank	Identified in this review
Arsenic Boron Cadmium Chromium Cobalt Copper Gallium Germanium Graphite Hafnium Indium Iridium Lead Lithium Magnesium Manganese Molybdenum Nickel Niobium Platinum Rare earth elements (Neodymium, Dysprosium, Praseodymium, Terbium, others) Selenium	Aluminum Chromium Cobalt Copper Graphite Indium Iron Lead Lithium Manganese Molybdenum Neodymium Nickel Silver Titanium Vanadium Zinc	Aluminum (Bauxite) Chromium Copper* Cobalt* Lead Iron* Lithium* Manganese* Molybdenum Nickel* Platinum* Rare earth elements (Neodymium, Dysprosium, Praseodymium, Terbium, others)* Silver* Tantalum Tin* Tungsten Titanium*

Silicon Silver Tantalum Tellurium Tin Titanium Tungsten Vanadium Zinc Zirconium		

* The article includes an in-depth review of these minerals.

Table 2 presents a list of energy transition minerals provided by the International energy agency (IEA) and the World Bank (WB). The list provided by the IEA is much more extensive than the one of the World Bank as it intends to look deeper into the mineral requirements of green technologies and the possible supply chain disruptancies.

Even though the number of minerals included in this list seems quite large, it excludes many important minerals. First, this list does not include any fossil fuel minerals such as coal or lignite, which extraction is expected to be considerably reduced in the coming decades. Construction minerals such as sand and cement, which are the most extracted type of material (in tonnage), are not included. Most of the precious minerals, such as gold, diamonds, or emeralds, are also not included. Finally, phosphate and potash, which are essential inputs for agricultural production, are also excluded.

The 32 ETMs displayed in table 2 exhibit large disparities in terms of production. Some metals are massively extracted from small and artisanal mines, while others are entirely produced in industrial mines. Some, such as copper, have a long production history and are extracted in hundreds of mines around the world. Others, such as lithium, have only been industrially mined for a few decades and are still currently extracted in only a handful of extraction sites.

Looking at this list, it would be tempting to imagine that each of these minerals has one or several dedicated mine somewhere in the world. In fact, a large part of the extraction of energy transition minerals occurs in polymetallic mines. Due to their geochemical proximity, some minerals are often found in a sufficiently high grade to be economically extracted from the same ore bodies. This is, for example, the case of molybdenum, whose production depends almost exclusively on the production of copper. Most metal mines are therefore commonly labeled by the primary metal they produce leading to some confusion on what exactly is produced. This tends to invisibilize the mining origin - and the territorial roots - of the minerals in this list, as many authors tend not to specify the full polymetallic nature of the mine they study. This review will therefore pay particular attention to companion metals when they are mentioned.

2.2. Previous reviews

Adopted in September 2015, the 2030 Agenda introduced 17 Sustainable development goals designed to address the economic, social, and environmental dimensions of sustainable development[2]. The 17 SDGs act as a framework to guide public and private action toward a more sustainable world. As an essential human activity, mining is central to any development agenda. Interestingly, no direct reference to mineral extraction is made in the SDGs. Nevertheless, according to a UNDP white paper published soon after the SDGs adoption, mining activities are closely connected to each of the 17th goals. Despite recognizing possible frictions between the mining sector and each development goal, this economic activity is thought to help countries implement them (Sonesson et al., 2016). Indeed, for each goal, it identifies the possible ways this sector can effectively contribute to the achievement of the 2030 Agenda.

Table 2. The 17 Sustainable Development Goals (SDGs)

GOAL 1	No Poverty
GOAL 2	Zero Hunger
GOAL 3	Good Health and Well-being
GOAL 4	Quality Education
GOAL 5	Gender Equality
GOAL 6	Clean Water and Sanitation
GOAL 7	Affordable and Clean Energy
GOAL 8	Decent Work and Economic Growth
GOAL 9	Industry, Innovation, and Infrastructure
GOAL 10	Reduced Inequality
GOAL 11	Sustainable Cities and Communities
GOAL 12	Responsible Consumption and Production
GOAL 13	Climate Action
GOAL 14	Life Below Water
GOAL 15	Life on Land
GOAL 16	Peace and Justice Strong Institutions
GOAL 17	Partnerships to achieve the goal

The SDGs have consequently been used as a framework to analyze the impacts of mining activities on sustainable development by various actors. Fraser (2021) states that the "SDGs provide a context for discussing issues at the nexus of mining and community interests and for facilitating multi-stakeholder collaboration for solving problems related to specific goals." The United Nations have laid down the foundation of this type of analysis by publishing a report soon after introducing the SDGs that identifies the possible synergies between the mining sector and the 2030 Agenda (Sonesson et al., 2016). Researchers have also used the SDGs to assess the mining sector's contribution to sustainable development. This gave rise to a relatively large literature from different academic fields, including Public Health, economics, and environmental sciences. Finally, the mining sector itself has integrated

[2] https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1

the Sustainable development goals into its strategy. This can be seen in some of the biggest mining companies' annual reports but also in some certifications schemes such as the International Council on Mining and Metals (ICMM) mining principles, whose guidelines are directly derived from the SDGs[3].

Several literature reviews, systematic literature reviews, and reports have recently tried to organize and synthesize this relatively large body of literature that has emerged following the 2030 Agenda adoption. Table 3 below presents a list of the principal previous reviews of literature that we were able to identify. As it is indicated in this table, none of them pay specific attention to the energy transition minerals. They all chose to study the mining sector without paying specific attention to the extracted material. In addition, the collected papers in these reviews tend to dramatically favor two minerals: coal and gold mining.

The absence of a clear distinction between the minerals extracted makes these reviews impracticable for policy recommendations related to the impact of the energy transition on mining territories. Moreover, the lack of consideration for the diversity of minerals means that these reviews are not exhaustive, as they miss an important part of the literature of interest. They especially miss most of the available literature on ETMs, as other minerals tend to mask them. These limits motivate the conduct of a new systematic literature review.

Table 3. Previous systematic reviews

Reference	Scope	Type[4]	SD strategy	Mine Inclusion
Mancini and Sala (2018)	Review of the social impacts from the mining sector	SR	SDGs Social and Economic pillars	All mines (including quarries)
Monteiro et al. (2019)	Explore the literature on the link between mining and sustainable development.	SR	All 17 SDGs	All mines (including quarries)
Boldy et al. (2021)	Review the academic literature examining mining impacts to Ecosystem services.	SR	Only ecosystem services	All mines (including quarries)
Mactaggart et al. (2016)	Synthesize health outcomes in mining communities.	SR	Health outcomes	All mines (including quarry)
Sonesson et al. (2016)	Map the linkages between mining and the SDGs	Report	All 17 SDGs	All mines (including quarries)
De Haan et al. (2020)	Review the ASM impacts on the SDGs	Report	All 17 SDGs	ASM only

3 https://www.icmm.com/en-gb/our-work/supporting-the-sustainable-development-goals

4 SR: Systematic Review, LR: Literature Review

Baum & Benshaul-Tolonen (2021)	Extractive Industries and Gender Equality	LR	Only goal 5	All mines (including quarries)
Ismail S.N. et al. (2021)	Research trends in mining accidents study: A systematic literature review	SR	Only goal 8	All mines (including quarries)
Iguma Wakenge et al. (2021)	From 'conflict minerals' to peace? Reviewing mining reforms, gender, and state performance in eastern Democratic Republic of Congo	SR	Only goal 16	ASM only
IRP (2020)	Mineral Resource Governance in the 21st Century	Report	All 17 SDGs	All mines (including quarries)
Schwartz et al. (2021)	A Review of the Scope of Artisanal and Small-Scale Mining Worldwide, Poverty, and the Associated Health Impacts	LR	Goals 1 & 3	ASM only

2.3. Mining territories' sustainability

Mining activities have a deep and complex influence on the space where a mine operates. They have the potential to generate substantial environmental and social degradation in areas that are difficult to identify and define. Most of the time, these areas are studied independently from the geology/nature of the extracted mineral, as seen in many cross-country investigations (Rossi et al., 2021). The fact that the geology of the mines studied is given no or low importance tends to preclude any indication of variation that might exist between mining areas. Indeed, without considering the geology of mining, any conclusion drawn for a mineral would be valid for all, regardless of the possible characteristics of each one of them.

Conscious of these limitations, several research initiatives have recently emerged to give more importance to the nature of the ore in the analysis. Economic geology pays attention to the minerals used in the economy and how their geology conditions their use. More recently, social geology was conceptualized in 2017 by Michel Jebrak to give more importance to the geology of minerals regarding the social and environmental impacts of a mine.

Echoing these research fields, we define a mining territory as an area "organized by and for the mining activities" (Rossi et al., 2021). According to this definition, a mining territory can encompass the area within the immediate perimeter of a mine, be an intra- or inter-country region such as the Copperbelt, or an entire country if the influence of the mining sector characterizes it. This definition allows one to conceptualize a mine's influence on its surroundings regardless of any arbitrary factors, such as the distance from the mine. In this conception, mining territories can take different forms depending on the mineral mined, its location, and extraction method, among other things. Accordingly, this definition is wide enough to include impacts located in the vicinity of a mine that encompasses a region or even an entire country. Mining communities are hereafter all bodies of population living in these specific areas.

In the context of this systematic review, this concept of mining territories constitutes both a motivation and a guide to study different minerals separately. Mining territories are at the junction between most of the SDGs and the mining sector. Previous literature, such as Rossi et al. (2021) and Erb et al. (2021), have paved the way for the differentiation of the minerals and their impacts, providing some tools for analyzing and synthesizing this literature.

3. Methodology

3.1. Systematic review design

A systematic review is a methodology to synthesize existing (academic) knowledge in a rigorous and transparent manner to make this knowledge more suitable for decision-making (Hagen-Zanker & Mallett, 2013). They differ from "classical" literature reviews by adopting an explicit and rigorous methodology but also by their ability to produce new knowledge from existing studies. By reviewing the available literature, systematic reviews also pave the ground for future research, highlighting gaps and weaknesses in the literature.

A scoping phase of the literature revealed that the subject of this review - the mining and sustainable development literature - was scattered between several academic fields. This is in part due to the broadness of the 2030 agenda, which conveys 17 dimensions of sustainable development with themes as varied as health, biodiversity, or governance. This diversity of academic disciplines and methodology that constitute sustainable development studies are, in a way, at odds with systematic reviews' "original spirit," which requires homogeneity among the studies under review. To cope with this challenge, previous systematic reviews have responded by limiting their analysis to narrative synthesis.

Some recent systematic review guidelines explicitly advise using a Mixed Methods Reviews (MMR) approach when reviewing the SDGs to capture the broadness of their scope (Oliver et al., 2018). By facilitating the combined review of quantitative and qualitative studies, MMR are specifically designed to compile very heterogeneous bodies of literature. The possibility to review multiple academic fields increases the policy relevance of the analysis and helps to fill potential gaps in the literature.

3.2. Scope of the study

The focus of this systematic review is on the literature looking at the empirical evidence related to the sustainable development of ETM mining in the Global South. As it is standard in systematic reviews, we organized our inclusion and exclusion criteria according to the Population Exposure Comparator Outcome (PECO) elements:

Population

- Mining territories of the global south (as defined below)

Exposure

- Extraction of an identifiable Energy transition metal or several in the case of polymetallic mines according to the lists developed by both the International Energy Agency (IEA, 2021) and the World Bank (WB, 2020).

Comparator

- Temporal (before/after, continuous time series, interrupted times series), spatial (distance), or between groups (control/intervention, socioeconomic, gender, racial/ethnic)

Outcome

- Explicit primary data sources and methods (no conceptual papers, literature reviews, or commentaries), whether it is a quantitative or qualitative study.
- Unambiguous impact of the extraction of an ETM on one of the SDGs
- The causality runs explicitly from the extraction of an ETM to a sustainable development outcome.

Other

- Peer-reviewed academic papers only
- Published after 2000 and in English

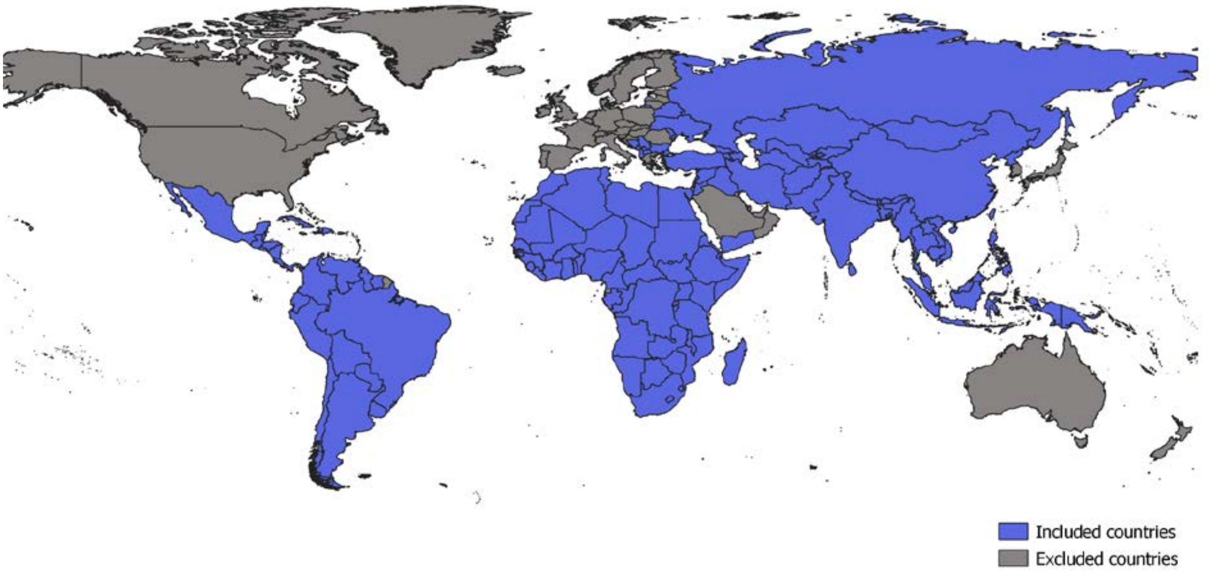
The inclusion and exclusion criteria objective is to capture the literature that can give us valuable information on ETM mining territories in the Global South. It is designed to only select studies that make an explicit link between the extraction of an ETM and socioeconomic outcomes that can be related to the 2030 agenda.

More precisely, we want to know what and how these impacts have been measured until today and what is missing. For that purpose, we restricted the scope of this review to collect only impacts (unique for each SDG dimension) originating from an empirical research methodology. This restriction has two advantages. The first one is that it avoids the potential biases in a literature that is very politicized and prone to greenwashing. The second advantage has to do with the difficulty of this literature to make empirical analyses. We hope that collecting the results from various empirical approaches will help us lay down the ground for new measures. Additionally, we restricted the scope of this systematic review to the energy transition minerals as defined by the World Bank (2020) completed with the one of the International Energy Agency (IEA, 2021), as these two lists are becoming a standard for linking energy transition and mineral resources.

For the selection of countries, we exclude the category of High-Income countries according to the World Bank classification[5]. We make this choice because the demand for minerals for the energy transition is expected to come largely from high-income countries, while supply is expected to come mainly from middle and low income (IEA, 2021). The latter are, moreover, the most vulnerable territories for the 2030 Agenda's success. We make two exceptions to the World Bank classification by including Chile and Uruguay as they are often included among the Global South countries.

[5] https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

Global South map



The limitation of this study to peer-reviewed academic articles reflects our willingness to highlight the different outcomes between various methodologies and academic disciplines. Consequently, we won't collect every existing impact on mining territories but only the ones identified with a scientific methodology. Studies proposing unproven impacts (i.e., without an explicit methodology) on one of the 17 sustainable development targets are thus excluded. Finally, we restricted our scope to articles published after 2000 to exclude potentially out-to-date mining practices but also as it echoes the launch of the Millennium Development Goals.

An important design choice for this systematic review is related to pollution and involves Goal 12 on sustainable consumption and production. Mines are widely recognized as being very polluting entities. An important part of the literature that can be related to geochemistry multiplies field analyses around mining sites to quantify these types of pollution. Though this literature is valuable for the identification of the types of pollutants, it usually gives no information on the actual impacts of these pollutants on any of the SDGs. In addition, dealing with every article related to mining pollution would have led to an unmanageable amount of articles. Therefore, these articles have been discarded when not relevant for the evaluation of the sustainability of a mining territory. This partly explains the limited number of articles identified for Goal 12 in this review.

It is also worth mentioning that in some regards, this study looks at the impact of Goal 12 on all the other SDGs in the specific case of the mining sector. The content of Goal 12 is closely related to mining activities, as many mining externalities can be found in this objective. However, as we are interested in the impact of the mining sector on a territory, we only include the gains or losses for Goal 12 generated by the mining activity on the other actors in the territory.

3.3. Search strategy

Given the scope of this systematic literature review, the search strategy faced several challenges. First, preliminary searches revealed that the relevant literature was scattered across several academic fields. It also revealed that the term "Sustainable development goals," as it has been used by other reviews, was too restrictive, with some disciplines or researchers being less likely to refer to the SDGs. Moreover, a restriction to the literal SDGs keywords would have excluded any relevant articles that were published before 2015. Finally, the fact that previous reviews tended to leave out articles on materials other than gold or coal prompted us to turn to a more comprehensive search strategy.

To access the relevant literature, we searched three large and recognized academic bibliographic databases: Scopus, Web of Science, and EBSCO host. These three databases were selected for several reasons. First, they have a large multidisciplinary scope[6] which is necessary to deal with the literature on SDGs. A more technical reason is related to the size of the queries supported (up to 1000 keywords) by their search engine, making it possible to include the large number of keywords that make up our search equation. Finally, these databases are identified by Gusenbauer and Haddaway (2020) as being among the 14 bibliographic databases "well-suited" for systematic reviews, the other 11 being in large part dedicated to the medical science field. As these three databases accept Boolean search, we defined a series of equations that allow us to precisely target the relevant literature. We structured these equations with four components, organized with the "and" Boolean operator as follows:

SDG component: The literature dealing with the Sustainable development goals is infamously known to be hard to capture from bibliographic databases. For that purpose, we took advantage of a list of keywords developed by Scival (Jayabalasingham, 2019). For each SDG, Scival provides an array of keywords specifically designed for searches in academic databases. In opposition to other reviews that include the string "Sustainable development goals," the Scival keywords list allows us to target articles dealing with themes that can be linked to a sustainable development goal without explicitly mentioning it. Inclusion of the string "Sustainable development goal" would have excluded all relevant work previous to the 2030 agenda.

Mining activities component: The second component of our search equation is a vector of keywords about the mine and the mining production system. During the scoping phase, we realized that some articles did not specifically mention the word "mine" (or mining) in the abstract and were therefore excluded from search results. Therefore, we developed a more comprehensive list related to the mining production vocabulary. It is based on our own personal knowledge and the R package *litsearchr* that helped us extract the most relevant mining synonyms from previously identified papers (Grames et al., 2016).

Geographic component: The third component of this equation is the list of countries called here "Global South" according to the World Bank classification of countries by income (see above for more information).

[6] Gusenbauer and Haddaway (2020) estimate that Scopus, Web of Science and EBSCO host contain respectively more than 70 000 000, 73 000 000 and 32 000 000 academic articles.

Exclusion component: Finally, we also excluded some specific keywords from the search. These keywords originate mostly from the literature on "data mining" that frequently appeared in our results. We also excluded articles mentioning gold, oil, or coal in their titles. During the scoping phase, articles containing one of these terms in their title were systematically out of the scope of this review.

Given the scope of this study and the technical limitations of the bibliographic databases, we performed seventeen unique searches in each database. For each individual search, only the SDG component was modified to match the sustainable development goals. Two complementary search methods were also added. We first checked the references collected by previous similar systematic reviews. We then looked for potentially missing articles in all the articles collected during the initial bibliographic search published in 2020, 2021, or 2022. Finally, we also looked at the finding of the systematic reviews previously mentioned.

3.4. Coding strategy and data extraction

This section details the process of data extraction from the studies collected in the bibliographic search. The choice of a Mixed Method Review design involves determining an appropriate coding strategy that can deal with qualitative and quantitative results. Following guidance from the Joanna Briggs Institute (Stern et al., 2020), we chose an integrated convergent coding strategy. Accordingly, each mining activity's impact on mining territories, whether it comes from quantitative or qualitative analysis, is coded into a single categorical variable. For that purpose, each impact identified in the literature is coded as either positive, negative, or neutral.

In accordance with the scope of this review, we only looked for explicit SDGs impacts on mining territories, i.e., that it can be unambiguously related to one of the targets of the seventeen SDGs. For example, an increased number of schools would not be considered as an SDG impact because it can't be related to any SDG target. However, an increase in the average education rate can be related to SDG's target 4.1. In this way, we want to avoid collecting impacts resulting from announcement effects embedded in some mining companies' CSR initiatives.

Finally, for each article, we only selected unique combinations of mining territory characteristics and impacts on an SDG target. In the same article, an SDG target can have several entries, but the underlying impact mechanism is only counted once. For example, target 8.5 ("Full employment and decent work with equal pay") could have several entries identified in the same study if the impacts leading to a success or a failure of this target are different.

The main advantage of this coding strategy is to put qualitative and quantitative studies on a similar level, without any methodological *a priori*. It, therefore, allows one to clearly analyze how a mine's impact on a mining community can vary according to the discipline and the methodology used. However, this coding strategy does not come without several caveats. In quantitative studies, the direction of an impact is most of the time clearly stated. In qualitative studies, however, the process of identifying an impact is more complex and needs to be done rigorously. Similarly, considering the various academic disciplines included in this systematic review, one must be careful not to misinterpret results from diverse academic disciplines.

To avoid any risks of bias due to misinterpretation of the results, we limited the data extraction to what appeared to be clear and unambiguous impacts on an SDG target. These impacts can be identified as positive, negative, or neutral. We stuck to the authors' personal conclusions and recorded textual elements as quotes in the database to be double-checked by each author.

Key study descriptors were also recorded for each article. A complete list of these variables can be found in annex. It consists of the variables that are common to many studies and the most likely to influence the implementation of the 2030 agenda in mining territories. Finally, each article was summarized for the qualitative analysis, and its original contributions were extracted.

4. Results

4.1. Quantitative synthesis

In this section, we investigate the results of this systematic review quantitatively. As it is common in systematic reviews, we first screened[7] articles based on their titles, their abstract to finally conduct a complete review of the remaining articles. In each of these steps, we selected the articles based on the inclusion and exclusion criteria described above. The articles that fully met the inclusion criteria formed the basis of our database. This screening process was conducted with the Eppi Reviewer Web software[8]. For each selected article, we extracted a series of relevant variables. The variable selection process was done incrementally. When an element appeared too important to be not included, it was added to the extracted series and was collected in the previously collected articles.

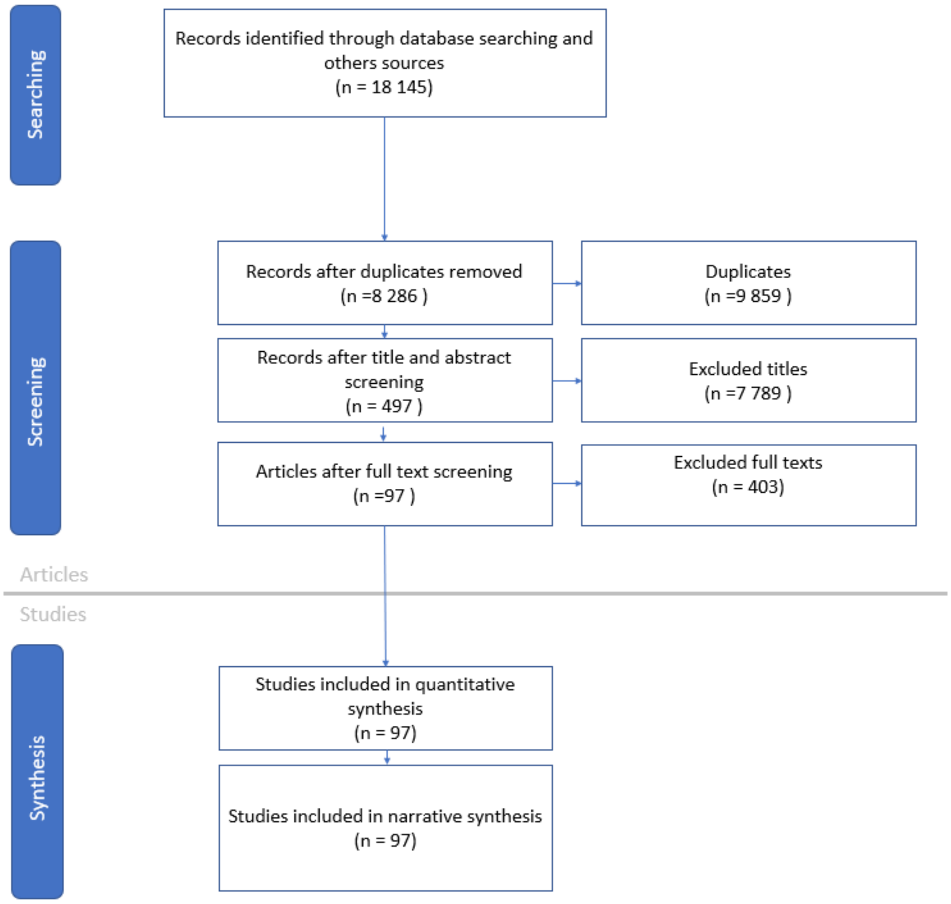
[7] The screening refers to the process of study selection based on the results from academic bibliographic database searches.

[8] https://eppi.ioe.ac.uk/CMS/Default.aspx?alias=eppi.ioe.ac.uk/cms/er4&

4.1.1. Descriptive statistics

Number and types of articles

Figure 1. ROSES FlowChart[9]

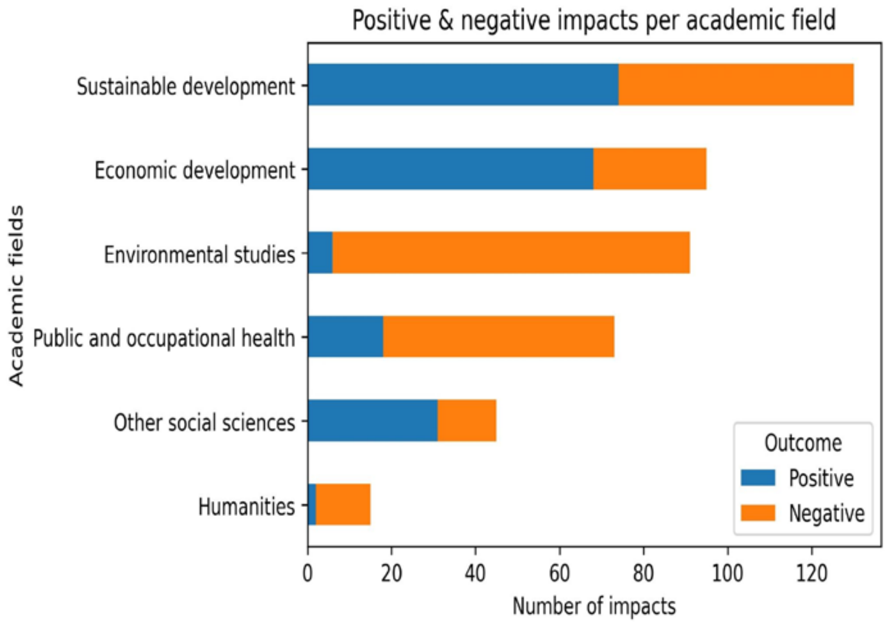


The search from bibliographic databases and through iterative phases (snowballing) have allowed us to collect 18,145 references, from which 9,859 duplicates were eliminated. The screening phase resulted in a first selection of 497 articles (N) after reading the titles and the abstracts. These articles were then all downloaded and read in full to finally reach a collection of 97 articles. From these studies, we were able to derive 354 unique impacts (n) that can be related to one of the seventeen sustainable development goals. According to Figure 2, the included articles span across many academic disciplines: Development economics (n=14), Sustainable development (n=19), Public and occupational health (n=18), and environmental studies (n=30). This diversity can also be seen in academic journals, with the majority of studies being published in interdisciplinary journals such as Extractive Industry and Society (N=11), Resources Policy (N=9), or Journal of Cleaner Production (N=4).

[9] Adapted from Haddaway et al. (2017).

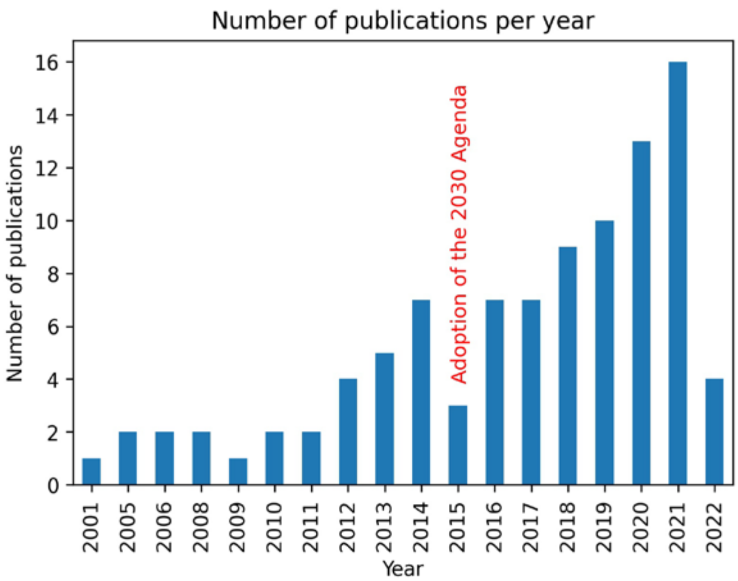
Our database is dominated by quantitative analyses (N=57), while purely qualitative analyses are much more limited (N=30), as are mixed-methods (N=7) analyses. This diversity in the types of analysis confirms the choice of not restricting this review to quantitative studies, as we would have missed a large part of the relevant literature. In general, quantitative studies tend to produce more numerous and varied impacts than qualitative analyses, the latter focusing on a very limited number of dimensions that can be related to the 2030 Agenda.

Figure 2. Impacts per academic field



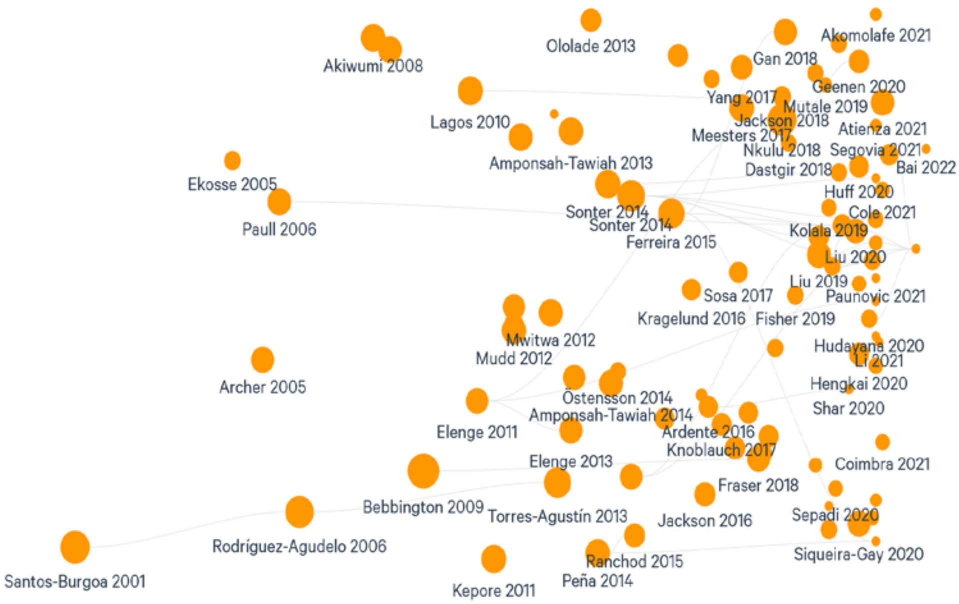
From the collected literature, we can observe in Figure 3 a significant increase in the number of published articles in recent years. In fact, the majority of the identified articles have been published in the last five years. One part of the explanation can be found in the date of adoption of the 2030 agenda, which occurred in 2015. Their adoption influenced various academic fields, including the mining literature, to pay more attention to sustainable development topics. An additional explanation could also be found in the increasing understanding of the link between mining and sustainable development, as some of the most recent articles clearly make explicit in their study.

Figure 3. Publication per year



Finally, a look at the network structure of the collected literature in Figure 3 indicates that the first included studies are relatively isolated from each other. This literature initially tends to be developed around the study of specific minerals or geographic areas. However, the more recent the articles, the more interconnected they are with others. It can be suggested that this marks the beginning of a more uniformed literature dealing with the subject of ETMs. This trend this trend is expected to be reinforced by the recent (2021) formalization of this typology of minerals (Energy transition minerals) by several international institutions.

Figure 4. Citation Map presented by years

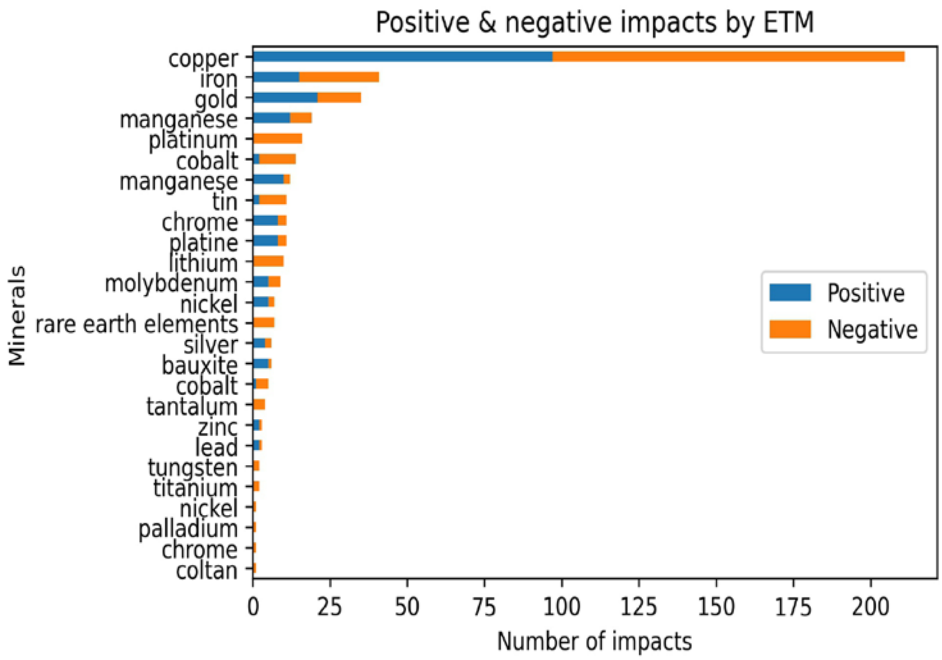


Mineral and Geographic coverage

Energy transition minerals deposits are unequally distributed among Global South countries. Only a small proportion of them produce these minerals. This unequal geographic distribution is reflected in our database since the included countries are only a tiny fraction of the Global South countries.

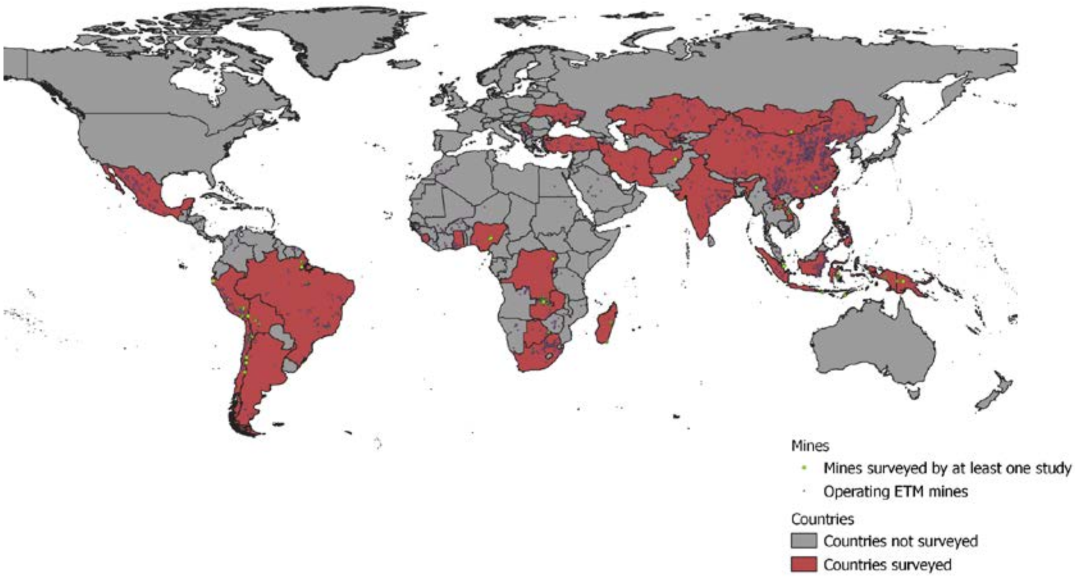
As we can observe in Figure 5, a large part of the impacts we extracted is related to copper mining territories (n=211). This is not surprising considering the number of copper mines worldwide and its industrial production history. It has thus well-identified geographies with two clusters easily distinguishable: the Zambian Copperbelt that comprises the south of the Democratic Republic of the Congo and two South American countries that are Chile and Peru. We can also find an important number of impacts for iron as it is another important industrial base metal. However, the geographical distribution of iron mining is more limited, occurring only in Brazil and South Africa.

Figure 5. Positive and negative impacts identified per ETM



Regarding the ETM list, we can observe the absence of several minerals, such as Vanadium or Zirconium. The minerals depending on a low number of industrial mines are less likely to have an entry in our database. Also, the minerals that are commonly extracted as by-products of other minerals tend to be missing. However, this does not mean that these minerals are not extracted from one of the mines included in our database. The presence of secondary minerals is sometimes omitted because researchers have no knowledge of it or because the quantities extracted from these ores are sometimes insufficient to justify their mention. Gold remains an important by-product of many ETMs, especially for copper and silver. Copper mines are also co-producing many ETMs such as cobalt, zinc, molybdenum, or nickel.

Figure 6. GPS location of mine level studies



In this systematic review, we collected the GPS location of mines for mines' level studies. In total, we collected information on 67 geolocation data directly in the article or by finding GPS coordinates thanks to the mine's name. As we can see in Figure 6, the collected mines only represent a very fraction of the existing industrial mines in developing countries. Another essential element to notice here is the recurrence of some mines and geographic areas. The available knowledge on ETM's impacts for the entire database is concentrated in two geographic clusters. The first is located south of the African continent, composed mostly of copper, cobalt, and platinum mines. The other can be found in the West of South America and consists of copper (molybdenum) and lithium mines. For example, we have several studies on lithium related to The Salar de Atacama (inside the Lithium triangle) but also many studies that looked at the same area, namely the Copperbelt with the Copper-Cobalt mines of Kolwezi in DRC and Solwezi in Zambia.

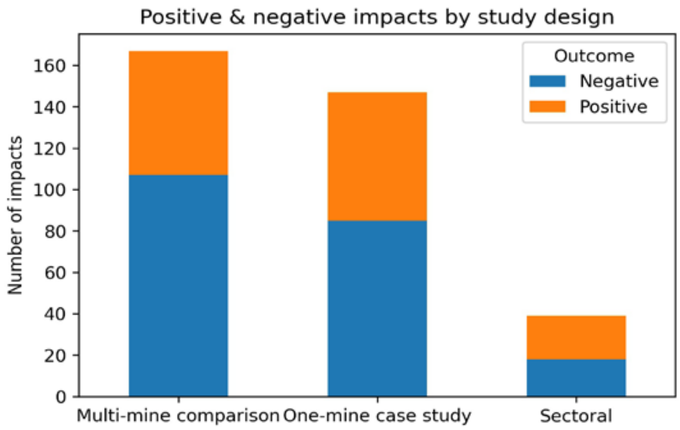
Interestingly, some minerals are clearly more studied in some academic fields than others. This is notably the case of recently industrialized minerals such as cobalt and lithium that are almost exclusively studied by the humanities and sustainable development fields. Also, toxic metals such as manganese have more entries in P&O health than in any other academic discipline.

Methodology used

This systematic review was designed to integrate all the empirical investigations regardless of the academic field. It is therefore interesting to look more precisely at the methodologies used to produce these studies.

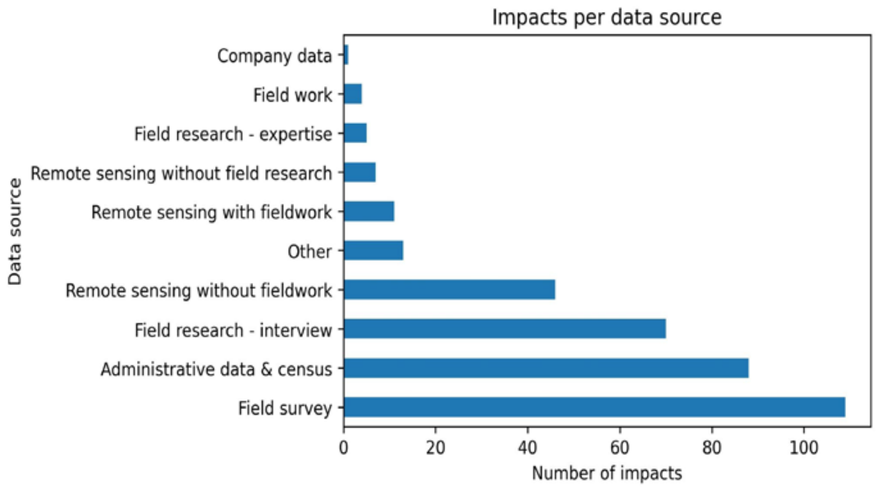
When investigating mining impacts, the first methodological choice researchers have to make is related to the scope of the study. For a given mineral, it is possible to study impacts at the level of one mine, between several mines, or less frequently for the entire sector. As we can see in Figure 7, Sectoral analyses are the rarest because they require large amounts of data that are often aggregated for the entire mining sector and not dedicated to a specific mineral. In our database, multi-mines comparisons mostly look at no more than three mines. Finally, one-mine case studies are the preferred choice of analysis for many researchers as the link between the extraction of a mineral and its consequences are easier to make. Recent articles using modern techniques such as remote sensing should theoretically be able to analyze a more significant number of mines. However, such large-scale analyses remain very limited.

Figure 7. Design choice



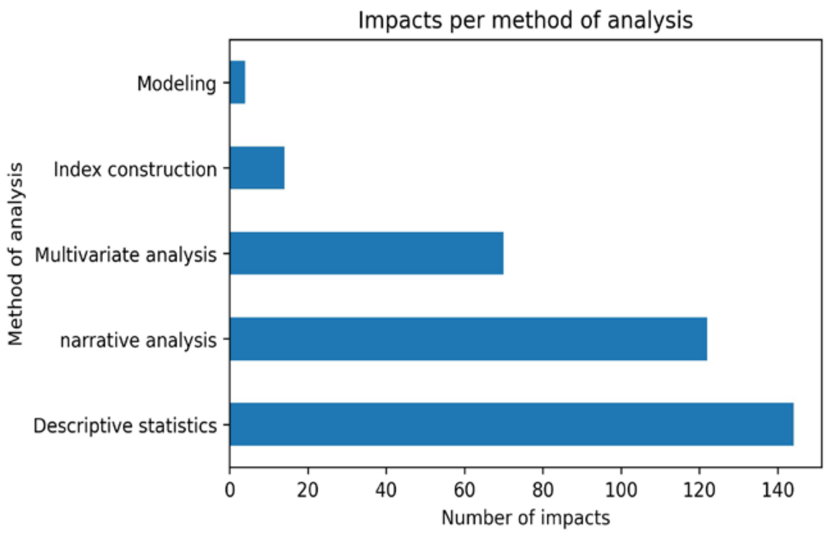
This choice of scope is obviously limited by the source of data. In our database, we can see in Figure 8 that most data come from field research, that is, the collection of data directly by a researcher on a mining site. Another essential source of data comes from administrative surveys and censuses, mainly from the national statistics bureau or local governments. Fields interviews that consist of collecting oral interviews, often with key members of the community, the government, or the mining company, are also important sources of data. We also distinguished remote sensing data that were crossed with a ground-based investigation and those that did not. Most remote sensing impacts are identified without any ground verification. Finally, it is surprising how few studies are based on data provided by mining companies, which tend to confirm the opacity of the sector.

Figure 8. Source of data



The way these data are analyzed is important to understand and compare the impact we identified. As we can see in Figure 9, the analysis of the impact of ETM's extraction is largely dominated by descriptive statistics. Here, narrative analyses are defined as unquantified impacts resulting from the analysis of interviews or the local documentation come in second. This means that most of the impacts we identified result from a methodology with no or limited quantitative analysis. Multivariate analyses[10] that notably can infer statistical causal relationships have only been found in limited numbers. Finally, the use of modeling has only been identified in a handful of studies.

Figure 9. Identified impacts per method of analysis



[10] Include simple linear regression and multiple regression.

Sustainable development impacts

In terms of sustainable impacts, our database is rather heterogeneous. As indicated in Table 4, we found that impacts associated with Goal 15 (Life on Land) and Goal 3 (Good Health and Well-being) were the most numerous in our database, with 52 impacts each. We presume this domination is related to the toxicity (for humans and the environment) of some ETMs minerals that make them essential topics for public health studies. This toxicity comes from the chemical nature of these minerals themselves or the toxicity inherent to other metals released during the extraction process. This focus on SDG 15 can perhaps also be explained by the shift to new geographies that are impacted by the extraction of these minerals, on which little evidence is available.

Goals 3 and 15 are closely followed by the goals related to the economic impacts (Goal 8 on Decent Work and Economic Growth & Goal 9 on Industry, Innovation, and Infrastructure), with 87 impacts in total. This is not surprising if we consider the importance of the natural resource curse in the literature on natural resources.

However, some SDGs have only a few entries in our database. For example, we expected to collect much more impact for Goal 7 on affordable and clean energy because mines are known to be essential energy consumers. But what is perhaps the most surprising is the low number of entries for Goal 1 on the end of poverty despite the importance of these questions in the rest of the mining literature. A first explanation could be that the frontier between some of Goal 1 and 8 targets is sometimes thin; thus, some impacts could have been wrongly imputed to Goal 8. Another explanation would be that as most ETM are industrial minerals, most authors have taken an "industrialist" point of view rather than a "developmental" one.

Table 4. Number of impacts per Sustainable development goal

SDGs		Number of impacts
GOAL 3	Good Health and Well-being	52
GOAL 15	Life on Land	52
GOAL 8	Decent Work and Economic Growth	48
GOAL 9	Industry, Innovation and Infrastructure	39
GOAL 6	Clean Water and Sanitation	29
GOAL 2	Zero Hunger	25
GOAL 10	Reduced Inequality	20
GOAL 1	No Poverty	19
GOAL 4	Quality Education	14
GOAL 11	Sustainable Cities and Communities	13
GOAL 5	Gender Equality	12
GOAL 16	Peace and Justice Strong Institutions	7
GOAL 13	Climate Action	7
GOAL 7	Affordable and Clean Energy	7
GOAL 17	Partnerships to achieve the Goal	6
GOAL 14	Life Below Water	3
GOAL 12	Responsible Consumption and Production	1

The repartition between positive and negative impacts illustrated in Figure 10 is relatively homogeneous. This illustrates that there are no clear-cut arguments pro or against mining ETMs in the literature considering the potential impacts on the 2030 Agenda. However, the picture is very different when looking at the specific impact of each SDG. Some SDGs indicate an unambiguous direction regarding the success of the 2030 agenda. Goal 3 on health is notably characterized by its high number of negative impacts as it reflects the toxicity of some of the ETMs for the surrounding populations.

Regarding the environmental goals - that is, Goals 13, 14, and 15 - the picture is clearly (and logically) negative. While we identified only a few impacts for Goals 13 and 14, all were found negative. For Goal 15 on terrestrial biodiversity, we found almost exclusively negative impacts; the only positive impact collected can be considered anecdotal. This confirms the destructive nature of this type of activity on the environment.

Impacts on Goals 4 on Education and 5 on gender equality are mostly found to be positive. As we will see in the second part of this review, these goals are susceptible to benefit from mining companies' Corporate social responsibility (CSR) programs. Finally, the results for the economic pillar of the 2030 agenda - Goals 8, 9, and 10 - show more mixed results, which is somewhat coherent with the resource curse literature.

Figure 10. Positive and negative impacts by SDG

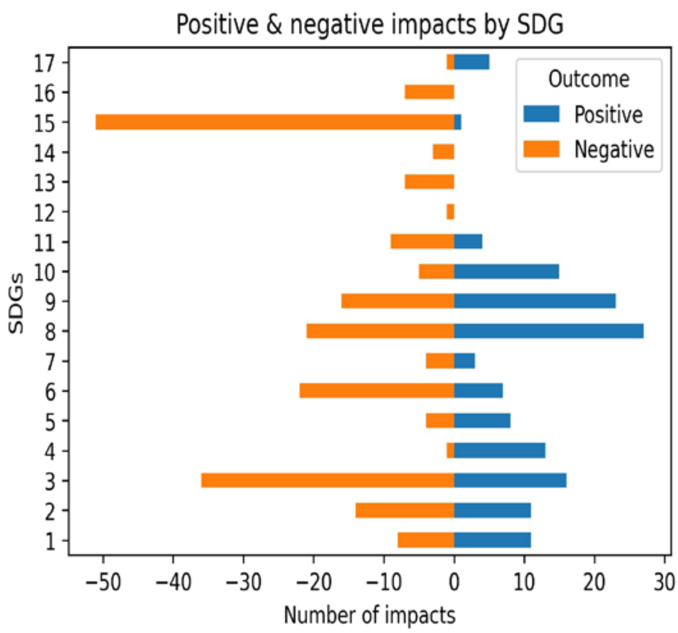
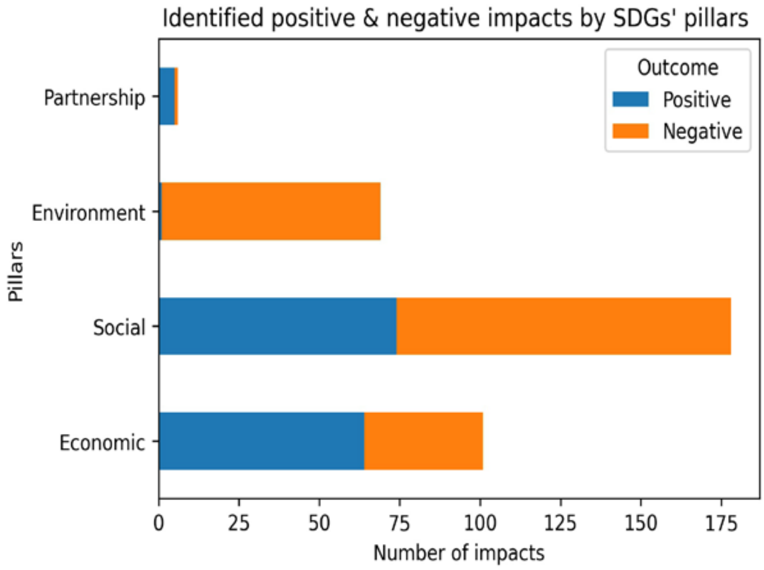


Figure 11. Positive and negative impacts aggregated by SDG' pillars



4.1.2. Comments

From this mapping exercise, we can draw some intermediary conclusions. One of the most striking results of this quantitative analysis of the literature is the relatively low number of available academic articles dealing with the ETM mining territories located in the Global South**.** This number is, however, in line with previous systematic reviews. To give some comparison, in a large-scope systematic review of all the seventeenth SDGs and all the types of minerals, Monteiro et al. (2018) identified 115 eligible studies. Even though our search strategy has some obvious limitations,[11] we must acknowledge that the available literature is very scarce, especially if we consider the radical changes to come because of the energy transition.

Besides the relatively low number of collected studies, we can also point out the absence or underrepresentation of important elements in our database. First, the scope of ETMs collected compared to the list established by the IEA, and the World Bank is arguably limited. More importantly, some minerals appear completely absent from the strand of literature studied in this review. Indeed, minerals such as Arsenic, Boron, or Gallium are missing. For some, it is simply because they are not (much) extracted in any Global South countries. For others, it is possible that these minerals are essentially exploited as co-product of other minerals and therefore are neglected by researchers. Finally, it can also mean that they have not been studied for their possible impact the sustainable development of a territory, indicating a gap in the knowledge of the Energy transition mineral.

Some geographies are also missing or are under-represented despite their importance in the mineral supply chain. The most obvious example is China, which has only a few entries in this database. This is a very surprising result as China is probably the most mining-intensive country in the world (S&P, 2022).

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11 See the "limits" section for further details.

China is the primary producer of Zinc, Lead, and Rare Earths; thus, it explains why these minerals have only a few records each. A large part of Africa and the Arabian Peninsula are also missing, but their importance regarding the supply of most ETMs is negligible. We can give two explanations for these missing geographies. The first one is related to our search strategy and, specifically, the choice of language. We came across numerous non-English publications, Spanish, French, and above all, Chinese. A second explanation would be the opacity of some countries regarding the mining sectors, which could slow down academic research on the most strategic metals for them.

In this statistical analysis, we observed that the impacts of the extraction of ETMs are relatively homogeneous for the social and economic pillars of the 2030 Agenda. This is coherent with the importance taken by the resource curse debate, which has not been settled yet. Unsurprisingly, the environmental impacts appear clearly negative as it is difficult to expect a positive contribution from this sector. It is worth mentioning that an exception does exist but remains anecdotal[12].

Regarding the methodologies employed by the collected studies, the choice of data sources and the empirical approaches are illustrative of some of the challenges this literature faces. First, most identified impacts come from descriptive statistics or narrative analyses. This topic is too little investigated by some quantitative research fields, notably economic ones. Consequently, most of the existing empirical analysis can only suggest evidence of causal relationships between ETM extraction and impacts on the 2030 Agenda.

However, the difficulty of accessing data in the mining context has recently benefited from advances in satellite data analysis. Indeed, we have observed more and more articles using these data, which offer better geographical and temporal coverage. This has particularly benefited deforestation and land use studies, providing a better understanding of the footprint of these mining sites.

Finally, these statistics should be interpreted with caution. Above all, they illustrate the results of bibliographic searches and not the literature itself. Consequently, they reflect all the possible biases that arise from our search and data extraction methodologies. Moreover, the association of impacts to some SDGs is subject to human error and the understanding of the 2030 agenda by the authors of this review. That is why we need to strengthen our investigation with a qualitative synthesis.

4.2. Qualitative synthesis

In this second part, we try to identify and highlight the relevant characteristics of the extraction of energy transition minerals that are important to anticipate the upcoming pressures on the sustainable development of ETM mining territories. For that objective, we synthesized the main results identified in the literature and illustrated how the extraction of each metal can contribute to the success of the 2030 Agenda. From the results obtained, we derived a conceptual framework and organized the qualitative synthesis accordingly.

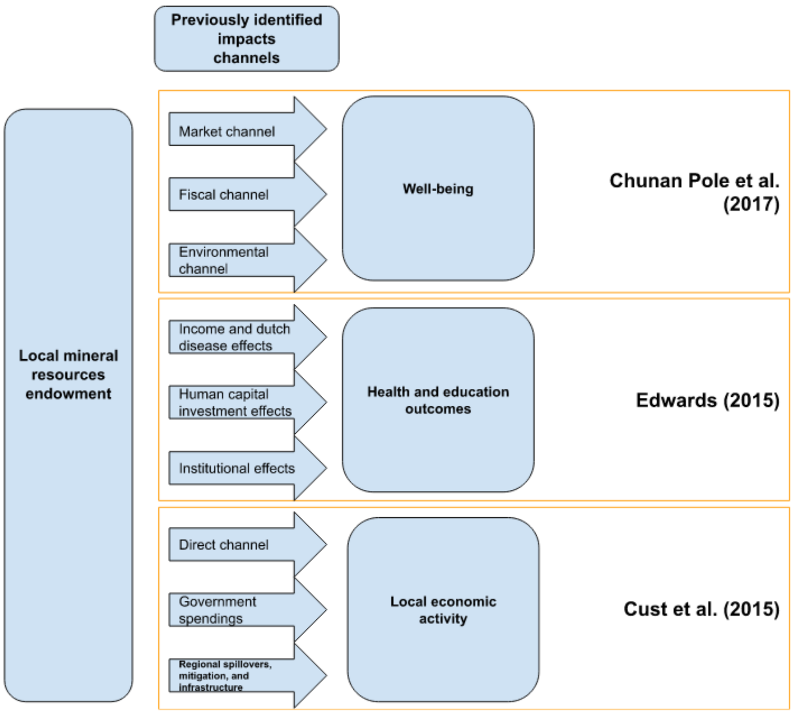
[12] Ardente et al., 2016 identified a higher number of mammals in the area impacted by the mine.

4.2.1. Sustainability framework

The interest of systematic reviews lies in their capacity to structure existing knowledge in a way that generates new ones (Waddington et al., 2012). To facilitate the understanding of how an increased mining activity caused by the energy transition could impact mining territories, this section is built around a new conceptual framework.

Mining's impact on sustainable development is complex to apprehend and is therefore often associated with a conceptual framework. We can mention the ones by Edwards (2016), Cust (2015), and more recently by Chunan-Pol et al. (2017). They independently created similar three-channel frameworks through which a mine can affect mining territories and communities. For example, the latter is organized as follows: A market effect channel that refers to direct effects of the mining activities such as job creation and spillover effects to non-mining sectors. A fiscal channel that is referring to the increase in revenue for the government. Finally, an environmental channel referring to pollution and natural resources used by the mining activities, which can affect the health and resource access of the mining community.

Figure 12. Existing conceptual frameworks used in previous studies



However, regarding the collected literature and the scope of this review, these pre-existing conceptual frameworks summarized in Figure 12 are too reductive in their scope for being used as the main support of this synthesis. In particular, they do not leave any special place for variation between the different types of mines.

First, they are not designed to integrate the geological nature of each mine, which is the prime source of variation we try to highlight in this review. In addition, none of them integrate mining companies' corporate social responsibility (CSR). These initiatives by mining companies account for an important part of the literature we collected and appear to be an essential element for understanding mining impacts on populations. Mining communities are at the center of these initiatives that sometimes aimed at guaranteeing the mining company a social license to operate (SLO) from the mining community. Finally, these previous conceptual frameworks tend to exclude or leave only a marginal place for the environmental degradation caused by mining. This clearly contrasts with the results of our interdisciplinary review, where these impacts are very present. Moreover, the environmental degradation does not impact the mining communities as would have highlighted a socio-ecological approach.

To organize and synthesize the collected literature, we decided to design an alternative framework to highlight the possible variations between ETMs extraction for their impact on the 2030 Agenda. This conceptual framework differentiates from previous ones in two ways. First, it uses the concept of mining territories as its primary source of inspiration, meaning that it leaves room for ETMs to have differentiated impacts. The second main change is the socio-ecological inspiration, where the impact of mining on the environment and the populations are interlinked.

Like the previous frameworks, we structure this conceptual framework around three channels through which ETM mining can impact positively or negatively mining territories:

- **Production externalities channel**. Refers to the effects attributable directly to the mine activities and operations. It encompasses all positive and negative externalities that can be related to the SDGs.
- **Corporate social responsibility channel**. Refers to the sustainable development strategies put in place by the mining company with the explicit objective (or not) of obtaining a social license to operate.
- **Socio-ecological channel**. Refers to the nexus between environmental degradation and mining communities' development in the territories of ETM extraction.

According to the mining territories literature, each of these channels is susceptible to be affected by the geological nature of the considered deposit. The contribution of transition minerals to sustainable development appears to be under the influence of several factors that are unique for each mineral:

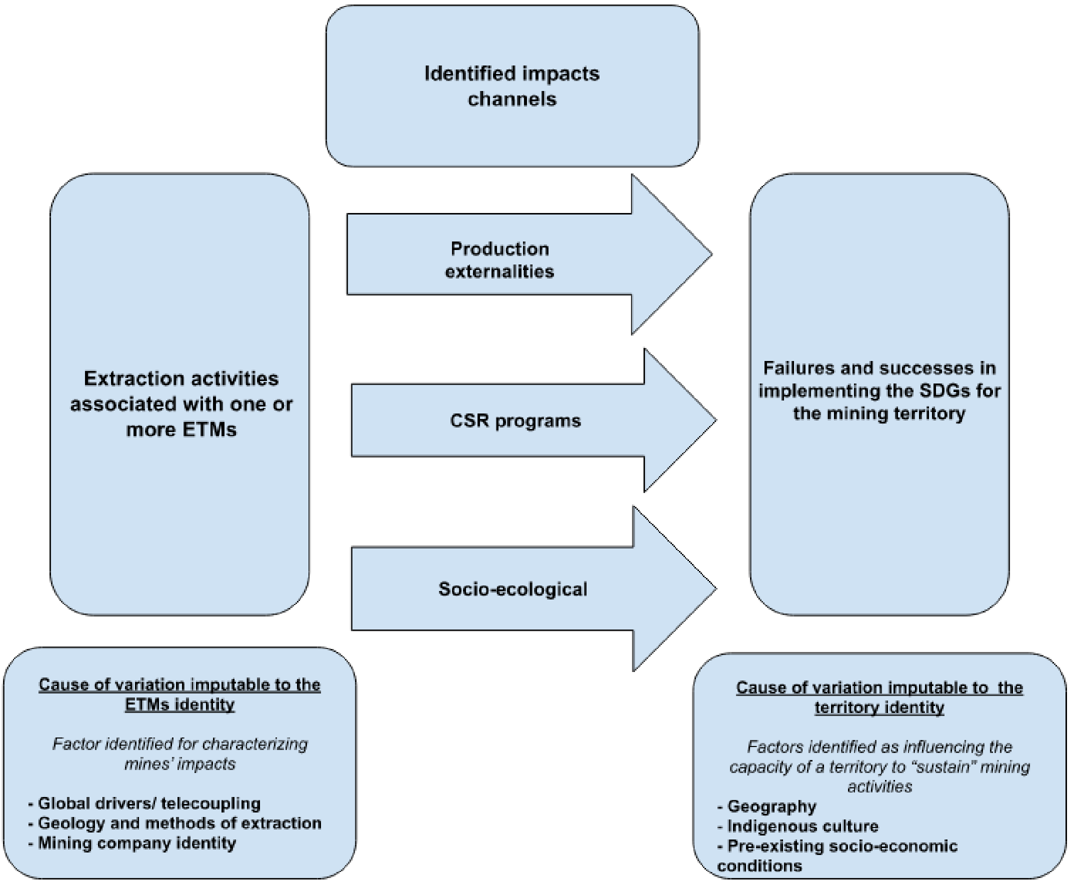
- **Geology**. The geochemical nature of the ore but also its geometry and its concentration.
- **Mining company identity**. Its country of origin (headquarters), culture and past experiences.
- **Macroeconomic/Global drivers**. World prices, competition, global suppliers.

Finally, we consider the influence of three factors that are idiosyncratic to each territory:

- Its geography
- Indigenous culture and traditions regarding mining activities
- Its socio-environmental preconditions (pre-mining)

This framework has two primary objectives. It intends to structure the qualitative analysis, clarifying the functioning of mining territories. It is also built so it can be used for guiding future empirical analyses and future empirical work addressing causal relationships.

Figure 13. New conceptual framework for the ETM mining territories



4.2.2. ETM mining territories

In this section, we discuss the impacts on the 2030 agenda collected in this review and organize them by mineral. In this way, we highlight the source of variation that can contribute to explaining why ETMs mining territories experience different outcomes in terms of sustainable development. We synthesize the literature by portraying each territory, making clearer the way they contribute to (or deter) the 2030 agenda. These portraits are only created for the minerals with enough literature.

Copper mining territories

Copper is perhaps the most important mineral of the energy transition. It is essential for practically all electrical applications as it enters the composition of most cables, motors, and generators. Thus, copper is involved in virtually every aspect of the energy transition, making its exploitation critical.

Copper is mainly extracted from large open-pit mines, essentially from porphyry copper deposits. Its purification and refining processes are energy and water intensive. It relies on hydrometallurgy or pyrometallurgy that necessitates a lot of heat to produce the copper cathodes used in the industry. In developing countries, most of the production is divided between national mining giants such as Codelco, the Chilean national mining company, or international giants such as Rio Tinto or Freeport-McMoRan.

Copper has a long production history in the Global South. It benefits from an extensive literature, arguably the biggest in our article collection. An important part of the collected articles is located in the Andean region (Peru and Chile), which has been industrially exploiting copper since the 19th century. The other important area for copper production is located in the southern part of Africa, comprising Zambia and the DRC, where industrial copper exploitation dates back to the middle of the 20th century. Other notable production and most recent locations can be found in Mongolia with the recently opened giant Oyu Tolgoi mine and in Laos, where an important copper-gold mine is currently exploited.

Copper mines are characterized by their massive size, some being among the largest mines in the world. This can be explained by their low average ore grade, especially in Latin America, where these grades are particularly low compared to other geographies (Crowson, 2012). Copper mining in our database is almost exclusively occurring in open pit mines. Copper mines often co-produce gold as companion metal, with 12 mines being copper-gold in our database. Copper deposits are also rich in other essential minerals for the energy transition, such as cobalt in Africa or molybdenum in Chile.

Copper is historically linked to industrialization. Therefore, a large part of the copper mining literature is devoted to its contribution to economic development that we can relate to SDGs 8 and 9. Partly due to their size and their long industrial history, copper mines are thought to be in the capacity to trigger the development of networks of local suppliers and buyers. This hypothesis is not supported by Atienza et al. (2021), who only found weak evidence of backward and forward industrial linkages in the perimeter of copper mines in Chile. In fact, most existing linkages were found in metropolitan areas, which are more likely to host international suppliers. This isolation of copper mines from the rest of the economy is recurrent in copper territories. Kraglung and Carmody (2016) additionally found mixed evidence of copper mines integration in the local economy surrounding Zambian copper mines.

On a more macro scale, with a DSGE modeling exercise on Chile, Fuentes and Garcia (2016) determined that an increase in the price of copper led to a positive contribution of the mining sector to the GDP of Chile. It was also found to positively impact non-copper mining employment and contribute to employment and wages in the copper mining sector. In the Chuquicamata copper mine, Lagos and Blanco (2010) found a 93% correlation coefficient between the regional GDP and the regional copper production. This suggests that copper mines may contribute to economic growth through other channels than direct industrial linkages.

The economic impact of copper mines is more visible on employment. In Laos, the Sepon copper-gold mine has had a massive impact on local employment, with two-thirds of the neighboring households having found a job in it (Jackson, 2018). In Zambia, the copper resources boom of the 90s drastically reduced the unemployment rate (Lippert, 2014). Similar results are found by Ostensson (2014), who concluded that copper mining contributed to direct and indirect job creation in the leading copper-producing countries: Chile, DRC, and Zambia. This contribution of mining to the creation of local employment led Takame Tiamgne et al. (2022) to conclude that high employment generated by copper mines was the key to the mine's contribution to the local economy. Indeed, the spending of direct and indirect local employees could be large enough to develop the local economy.

This somewhat positive picture of copper mining on economic development needs to be nuanced. In Zambia, the jobs provided in copper mines seem to be of low quality - mainly constituted of short contracts - and rapidly decreasing with the fall in copper prices (Kolala & Bwalya Umar, 2019), making the mining benefits essentially national rather than local. Moreover, this massive and rapid job creation mechanism contributes to poor working conditions. In the Ruashi copper-cobalt mine, Elenge and Brouwer (2011) identified many chronic diseases related to the disastrous working conditions and poor methods used in the copper mines of DRC.

Beyond economic contributions, copper mines were also found to impact many other aspects of the 2030 Agenda. A first area of potential contributions is related to the size of copper mining projects, which suggests that the companies undertaking them have significant financial capabilities and, therefore, the capacity to engage in large corporate social responsibility (CSR) programs. Indeed, a recurring illustration is that copper mines tend to foster infrastructure development directly for or ultimately shared with the local communities (SDG 9). A typical example would be the development of road networks (Lechner et al., 2019) used by both the mining company and by locals.

Beyond infrastructures, these large CSR programs are particularly effective for education (SDG4) and gender equality (SDG5). On education, we found several attested contributions related to scholarship provision (Jackson & Dear, 2016) or the increasing education rate (Van Alstine & Afionis, 2013). In Zambian copper mines, women seem to have increased access to positions of responsibility. On the other hand, in Chilean mines, working in the copper mines tends to reinforce gender inequalities within the household. The isolation of the copper mines tends to reinforce inequalities in accessing employment, favoring households where the husband is absent for several weeks to work in remote mines and a wife who is forced to do the vast majority of the housework (Segovia et al., 2021).

On health, the picture of copper territories' contribution to the SDGs is more ambiguous. The fact that copper mining companies are large entities with potentially important CSR policies suggests they can effectively contribute to the health of local populations. This is confirmed by a case study on the Trident mine in Zambia. A Health impact assessment (HIA) looking at the health of children before and after the opening of the Trident copper mine conducted by Knoblauch et al. (2017) showed better health outcomes for various non-communicable diseases (such as malaria and anemia). Another HIA on the Trident copper mine indicated that the mining company operating this mine was able, through community health interventions and development initiatives targeting women, to effectively reduce the prevalence of HIV among women in the perimeter of the trident copper mine (Knoblauch et al., 2018).

However, the large size of copper mines also contributes to the aggregation of many people in the proximity of the mine (urban mining), leading to many health issues. First, populations gathering in the vicinity of a mine are at risk of being contaminated by various pollutants. While copper itself does not present a significant risk of toxicity, its smelting process has been found to have important adverse effects on birth weight for the surrounding communities due to the exposition of heavy metals. When associated with cobalt, a much more toxic element for human health, disastrous health effects can be found. The aggregation of large population bodies around copper mines also risks the transmission of communicable diseases, reinforcing the need for large health programs.

Moreover, this massive population aggregation around copper mines can be associated with urbanization and the development of urban mines. Mining operations in the proximity of residential areas (sometimes only a hundred meters) profoundly affect the housing structure and living conditions. The vibrations generated by the explosives and the truck's passage can fragilize the structure of buildings, while loading the air with toxic particles, greatly reducing the livability of these cities.

The environmental footprint of copper mines also tends to favor the development of conflicts with the local communities. The water requirements of copper processing inevitably lead to conflicts over water, such as with the Atacameño community of Chiu Chiu recorded in Chile (Camacho, 2012). Lungu (2008) found evidence of water made unfit for consumption in Zambia due to leaks from pipes carrying slurry. The most notable effect of copper mines' footprint in these areas has been the reduced land availability for agriculture and the decline of field productivity due to pollution, notably dirt.

However, despite a significant environmental footprint, copper territories seem to offer opportunities for agricultural development as mines direct and indirect job creation create new market opportunities. Using remote sensing, Lechner et al. (2019) and Ang et al. (2021) confirmed this expansion of cultivated areas in the perimeter of two copper-gold mines. Mblima (2021) found that the loans provided at low-interest rates by mining companies for the surrounding farmers were effective in improving the diversification and quality of farm fields. However, in Peru and Mongolia, Bebbington and Bury (2009) and Meesters and Behagel (2017) found that copper mines were leading to a decrease in the water availability for agriculture.

Environmental degradation in copper mining areas is essentially linked to land use dynamics. We found much evidence linking copper exploitation to deforestation made necessary for clearing for the mine' operations and infrastructures. On biodiversity, the pollution in the form of heavy metals generated by copper extraction leads to important modification in the soil chemistry. As a result, it favors the most stress-resistant plants and changes the vegetal species composition (Fazlioglu et al., 2021). The disturbance generated by copper mines also affects mammal communities, reducing their composition and size (Shar et al., 2020).

The size of copper mines and the associated metallurgical process make this activity energy-consuming. When connected to the national grid, it can reduce the availability of electricity for the rest of the population. This can be clearly observed in DRC and Zambia, where copper mines are found to consume up to 20% of the total electricity produced (Imasiku & Thomas, 2020). Logically high greenhouse gas emissions are resulting from copper extraction activities. These mines can emit 2,32 tons of Co2 emissions per ton of copper extracted as measured in the Batu Hijau open-pit mine in Indonesia (Murakami et al., 2020).

Iron mining territories

Iron is used in the composition of many green energies, notably in their structure (wind turbine masts, electric car bodies…) or for producing various alloys. Although the production of iron specifically for the energy transition is relatively small, its supply remains nevertheless essential for its realization.

Like copper, iron is an old industrial metal and is essentially extracted in large open pits. Its extraction is marked by the scale of its operations, often nested in large industrial complexes. An example of these vast mining complexes is the Sishen mine in South Africa, which has been in activity since 1953 and has had many expansions, notably to answer the foreign demand (notably Chinese) (Louw & Marais, 2018). The Sishen mine is analyzed by both Louw and Marais (2018) and Tarras-Wahlberg et al. (2017), in which the nearby town of Kathu plays a central role. The recently opened S11D mine in Brazil is another good illustration since it is the biggest mining complex in the world. However, Iron mining in Brazil has some clear distinctive features as most mines are located in the Iron Quadrangle, a forested area in the Southeast of the country. The Brazilian mining complexes are often accompanied by large water reservoirs and are isolated from the rest of the economy. In the case of the Alegria mine, the iron concentrate is transported to the port through two 400 km pipelines (Ferreira & Leite, 2015).

Surprisingly, the available literature on iron is quite limited. The world's biggest producers of iron located in the Global South are Brazil 2nd, China 3rd, India 4th, and South Africa 7th, which all have entries in the database. However, Brazil is the focus of most of the available literature addressing essentially the environmental impacts of iron extraction. Part of the explanation lies in the location of the Brazilian mines - most of them being in the amazon forest - with important implications for the environment and the indigenous communities.

The large footprints of iron mines and their location in remote areas in Brazil inevitably lead to many negative impacts related to deforestation. This footprint is notably caused by the method of extraction, most of these mines being open pits. Nevertheless, the footprint of iron mines in the remote areas of the Amazonian Forest is also the results of the infrastructures needed to support the mining activities (roads, railways, pipelines…). In addition, communities' development in the vicinity of the iron mine in these forested areas is found to significantly increase the area deforested (Sonter et al., 2014).

Iron mining in Brazil affects some of the most unique ecosystems on the planet. An interesting illustration is related to Cangas, which are gaps in the Amazonian Forest sheltering a unique biodiversity of medium-sized plants. The iron concentration in these areas' soil explains the appearance of this vegetation. The Cangas thus represent biomarkers of the presence of an iron deposit. These areas are logically the most affected by the exploitation of iron in Brazil, reducing their occurrence in the amazon forest (Nascimento et al., 2020).

In addition to its impacts on areas of exceptional biodiversity, iron mining also affects ecosystem quality by emitting toxic substances. In the case of Brazil, Ferreira et al. (2015) quantified these emissions to a potentially affected fraction of species (PAF) of 20.8 PAF m2 per tons of iron concentrate produced. This ecotoxicity takes the form of emissions of "such as chromium, nickel, zinc, and copper, either in the elementary form as in the ionic form" (Ferreira et al., 2015). These emissions notably originate from tailings dams at the origin of the diffusion of copper, nickel and cadmium ions found in water bodies.

However, Iron mining in Brazil is also characterized by another strand of the literature. Brazilian iron ore mines are the subject of numerous publications related to industrial accidents and particularly dam failures. Indeed, iron ore mines use retention ponds to prevent the discharge of wastewater directly into rivers and other ecosystems. These basins can reach enormous sizes, forming small lakes retained by dams within the forest. Due to heavy rainfall during the rainy season, these dams, usually made of earth, can break down. Brazilian mines are regularly affected by dam failures, with catastrophic results regarding sustainable development. This was infamously the case of the Fundao dam, which ruptured in 2015, killing 19 people and damaging the surrounding ecosystem (Coimbra et al., 2019).

Beyond serious environmental damages caused by iron mining, the extraction of this mineral has other complex socio and economic impacts. Louw and Marais (2018) propose a broad overview of the Sishen mine impact in South Africa, notably looking at the fiscal linkages with the nearby town of Kathu. They found that the mine was indeed contributing to the town's budget but that the revenues were very volatile, as they were affected by iron price variation. For the Sishen Mine, Tarras-Wahlberg et al. (2017) identified good education levels in the local communities. However, they found that the same communities experience difficulties accessing the employment provided by the mining company. In a study looking at the linkages between the entire iron sector and the SDGs in South Africa, Cole and Broadhurst (2021) have drawn a rather positive picture of this sector, contributing to most of the social and economic SDGs.

Finally, a life cycle analysis of the Germano mine in Brazil revealed the massive GHG footprint of iron mines with 13.32 kgCO2eq/ tons of concentrate (Ferreira et al., 2015). It was confirmed by a similar study in the Chinese iron sector that pointed out the higher average GHG emissions per iron mine, with up to 39 CO2e/tons of ore.

Lithium mining territories

Lithium is the key element of the so-called Li-ion batteries to which it gave its name. This technology is the most used in electric cars because of its high performance. In an average battery car, there can be, depending on the technology, about 8kg of lithium [13](Nature, 2021).

The history of lithium exploitation is much more recent than any other Energy transition mineral. Its production started industrially in the early 1990s and remained very geographically concentrated, being only exploited in a few places on the planet. Lithium is the only transition mineral whose exploitation method differs significantly from traditional mining methods. In the Andean region, lithium is mostly extracted from brine mining, which is the pumping of water containing dissolved lithium. To separate the lithium from the water, the brine is pumped to large evaporation pools where lithium can be extracted.

The Salar de Atacama is undoubtedly the most studied area for lithium extraction. Two mine operators are reported active in this area: Sociedad Química y Minera de Chile and Albemarle. As lithium industrial exploitation is relatively recent, the literature on lithium is logically limited. As noted by Liu and Agustina (2019), there is a considerable deficit of literature regarding the economic and social impacts of lithium extraction in the Andes, having found no academic literature on the subject. Since their publication, we found only one article looking at this dimension of sustainable development published by Liu and Agustina (2020) themselves. Looking at the SQM brine exploitation in the Salar de Atacama, they found that lithium extraction was creating jobs for miners. However, at the same time, the average employment of the territory decreased.

Part of the explanation could be found in another strand of the literature, investigating the various conflicts over lithium extraction water footprint. Because of its particular extraction method, lithium consumes a lot of water. In these desertic territories where water is extremely scarce, conflicts with populations are inevitable. Lithium extraction contributes to land desertification (Liu et al., 2019; Lorca et al., 2022) which itself contributes to the loss of natural vegetation due to water exhaustion (Liu et al., 2019). The pumping of water in the same sources as the local populations reduces the availability of water for other economic usages, such as agriculture, inevitably leading to a loss of land productivity (Kalazich et al., 2019).

Cobalt mining territories

Cobalt is another essential component of some battery technologies, notably the Li-on ones that are used in most EVs. Its proportion in such batteries can even be higher than lithium, with an average of 14kg per battery (Nature, 2021).

In the collected literature, cobalt mining only occurs on the African continent, specifically in DRC and Madagascar. This result is not surprising as DRC is by far the first producer of cobalt.

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13 https://www.nature.com/articles/d41586-021-02222-1

On the industrial scale, cobalt territories are often confounded with copper and nickel territories, where it is extracted as a co-product of these two minerals. However, an important part of cobalt is provided by artisanal mining. In fact, the literature we identified on cobalt is essentially related to its artisanal exploitation. This form of cobalt exploitation attracted much attention due to its rapid development and the multiple reports of child labor (Sovacool, 2020).

The empirical literature we collected confirmed these concerns. We identified much evidence pointing out the dangerous working conditions in artisanal cobalt mining. First, in the area of Ruashi, artisanal mining is responsible for many diseases related to working conditions, such as repeated eye trauma, pulmonary disease, or skin hazards due to permanent immersion in polluted waters (Elenge & Brouwer, 2011). Studying the relationship between urbanization and mining in Congolese cobalt mining towns, Geenen (2021) found additional negative externalities in the context of the artisanal sites surrounding the city of Kolwezi. She confirmed the presence of child labor in the extraction sites. The poor working conditions were also found to increase drug usage "in order to be courageous." The proximity of artisanal mining sites with relatively large towns such as Kolwezi - with a population of over 500,000 - is specific to cobalt extraction and generates specific issues linked to this urban mining context. It notably facilitates the presence of children on the mining sites. This type of mining-town architecture might also be why Banza Lubaba Nkulu et al. (2018) found convincing evidence of heavy metal poisoning due to cobalt exposure among children living in Kolwezi. Moreover, the proximity of mining activities, which involves the construction of many shafts and tunnels, fragilizes the structure of the houses located in the town.

However, in the same case study context of Kolwezi, Geenen (2021) was able to find a positive contribution of artisanal cobalt mining. She estimated that from each pit, between USD100 and USD200 of cobalt was extracted every day. This positive economic contribution is even more evident in the case of industrial cobalt, where the Tenke Fungurume copper-cobalt mine is estimated to have created from 7000 to 10200 direct, indirect, and induced employment (Östensson, 2014).

Finally, it is worth mentioning that we found little evidence of the possible environmental damages generated by cobalt mining. The only occurrence of such damages was found in the case of the Ambatovy nickel-cobalt mine in Madagascar, where Devenish et al. (2022) illustrate the successful efforts of the mining company to protect the surrounding forests.

Nickel mining territories

Nickel is the third essential element in many Li-ion battery technologies, where it is used in the composition of the cathode. On average, an electric car's battery contains 35kg of nickel as it gives better performance in terms of autonomy and power to this battery technology (Nature, 2021). Its production relies mainly on open-pit mines with two main types of nickel deposits: Sulfide and Lateritic. The latter necessitates, on average, a much heavier refining process to attain a high level of purity. The Global South is home to some of the world's largest nickel producers. Two of them appear in our database; Indonesia is currently the main Nickel producer in the world[14] and Madagascar. In both locations, most Nickel deposits are from this second type. It is important to note here that New

[14] https://www.usgs.gov/centers/national-minerals-information-center/nickel-statistics-and-information

Caledonia, one of the most important nickel producers, is not included in the perimeter of this review as this territory is administratively attached to France.

One key characteristic of nickel is that it is extracted mainly in tropical rainforests, a biome that is exceptional from the point of view of its biodiversity but also in terms of carbon sequestration. For two of the main nickel producers, the production of nickel consequently contributes to reducing this biome. Using remote sensing, Devenish et al. (2022) found that the Ambatovy Nickel mining activities are linked to the destruction or substantial degradation of 2,064 ha of forest.

Tropical rain forests are important not only for their biodiversity but also for the many communities that depend on them. The massive loss of forested areas threatens traditional livelihoods and thus contributes to increased poverty. This link is clearly highlighted by Hudayana et al. (2020), who find that around the Bahodopi mine in Indonesia, local communities have had to gradually turn away from their traditional activities based on agriculture and forestry. However, Zainuddin Rela et al. (2020) found that if the mining company provides the appropriate CSR program, it can improve the community resilience and adaptation capabilities, that is, the community preparedness for natural disasters or conflicts.

However, the link between nickel mining and systematic deforestation can be broken. Devenish et al. (2022) show that nickel exploitation is possible with no net forest loss. By proactively planting new forest areas on former farming areas, the mining company has been able to avoid 94% of the forest loss caused by the mine. This is a unique case in our database, as the authors suggest that it is the first measured case of no net loss. It is, however, important to note that the authors suspect that this preservation of forest areas has been done at the expense of local communities. Indeed, although not measured in the study, the mining company has managed to conserve the same amount of forest space by buying up fields from local people to plant trees. The authors notably report that farmers are not always adequately compensated.

Manganese mining territories

Manganese is an important component of several battery technologies, as it helps extend the life of batteries or can sometimes replace lithium. On average, the battery of a Li-ion electric car contains 20kg of manganese (Nature, 2021).

The collected literature conveys two very different pictures of manganese mining. The first one is related to large-scale mining, situated explicitly in the Molango Basin, one of the main Manganese deposits in the world (Torres-Agustin et al., 2013). These territories are organized so that local populations, manganese mines, and refining infrastructures are entangled in a small number of valleys (Rodriguez-Aguledo et al., 2006). Manganese, in high concentrations, is very toxic to humans. Rodriguez-Aguledo et al. (2006) found convincing evidence that manganese exposure led to the development of neural disorders in these areas. Manganese in these territories was also associated with the development of many non-communicable diseases, such as important loss of cognitive capacities (Santos-Burgoa et al., 2001), impairment of long-term memory and learning abilities for children (Torres-Agustín R et al., 2013). This health impact is not uniquely related to Mexico since Banza Lubaba Nkulu et al. (2018) found that the artisanal exploitation of cobalt-manganese deposits in the

Democratic Republic of the Congo was associated with oxidative DNA damage in children working and living in the mining site. In China, Manganese mining was also associated with agriculture productivity losses and traditional livelihood alterations that the mining company had difficulty to compensate (Yang et al., 2017).

On the other hand, another strand of the literature is much more optimistic about the contribution of manganese mining to the sustainable development of mining territories. Fisher et al. (2019) investigated the case of artisanal mining in the Noelmina catchment in Indonesia. They found out that local farmers were able to alternate between agriculture and mining during the off-season. Contrary to artisanal gold mining, artisanal manganese is not subject to any "gold rush" and is consequently not associated with negative effects such as violence or criminality. On the contrary, Fisher et al. (2019) find that manganese mining provides a good supplemental income of US$15-66 per week during the operating period. Part of this income is dedicated to the purchase of necessities, on children's education and about 10% is dedicated to the purchase of agricultural supplies, contributing to the development of agriculture. In addition, since manganese mining requires clearing and plowing land, farmers see this activity as an opportunity to expand their land.

Silver mining territories

Silver is a critical component in the dominant technologies of solar panels, where it is used as a paste to transfer electric current. Its importance lies in the fact that it is the metal with the highest electrical conductivity, thus improving the efficiency of solar cells[15]. In the articles we collected, silver mines are mostly situated in South America. It is often extracted in association with gold in medium size open-pits mines located in mountainous areas.

According to Ruiz-Castell et al. (2012), silver deposits are often associated with toxic elements such as lead, cadmium, and arsenic. In South America, silver territories have sometimes been in continuous exploitation for centuries and have accumulated a lot of mining waste. This has dramatic consequences for the local communities, who are particularly exposed to air and river pollution in these landlocked valleys.

As with other minerals extracted in this area, the main issue is water. Though mining companies are found to be able to provide new revenue sources for the local population and technical training for the local youth, the water issues regularly cause violent disputes. Similarly, in Argentina, though the mining company financed water development, the integration of rural populations into the water system has overloaded the capacity of the system, already stretched by the needs of the silver mine.

15 https://resourceworld.com/how-much-silver-is-needed-for-the-solar-panel-industry/

REE mining territories

Rare Earth Elements (REE) are composed of 17 elements, the 15 lanthanides, scandium, and yttrium. Rare earth elements are used in various elements of green technologies. One of the most important uses is for the creation of permanent magnets constituting the turbines of wind turbines, which can be composed of neodymium, praseodymium, dysprosium, and terbium[16].

Contrary to what their name suggests, REEs are not particularly rare; some of them, on the contrary, are very abundant. The production of Rare Earth Elements is, however, very geographically concentrated. China possesses the vast majority of the world's production capacities. This is clearly reflected in the literature since all the REE articles are on mines located in this country.

Due to their importance, REEs are frequently extracted as companion metals, but this is not reflected in our database. When mined on their own, they are extracted from two types of deposits which are generally distinguished by their potential to produce light Rare Earth Elements or heavy Rare Earth Elements. In South China, their extraction requires complex methods comparable to the one used to recover gold because REE deposits occur in the form of ions (Wu et al., 2021). In south china, the extraction of rare earth has mostly been done with low-cost – artisanal like – leaching methods. This is because this type of deposit is found in scarce and small areas dispersed across South China (Wu et al., 2021).

REE mining is known for the massive environmental degradation that its extraction generates. Li et al. (2021) state that the different methods used in the history of REE exploitation in China - pool leaching, heap leaching, and "in situ" leaching have had different impacts on the environment, the latest having better outcomes (Li et al., 2021). An analysis of the entire REE mining sector in China by Bai et al. (2022) found that its extraction contributed to lower soil quality for agriculture (Goal 2) and to the loss of ecosystem services (Goal 15), while smelter activities are found to be correlated to air pollution. These results are corroborated by studies at the mine level in the Lingbei and Southern Jiangxi areas, where REE mining contributed to 60.75 km² of desertified land and 7.35 km² of vegetation loss (Hengkai et al. 2020 & Li et al. 2021). However, to our knowledge, there is no available information dealing with the economic and social impacts of REE mining.

Platinum mining territories

For the energy transition, platinum is essentially used in fuel cells to convert hydrogen into electricity, especially for hydrogen cars. As it is not yet well developed, the demand for platinum is still limited (IEA, 2021).

South Africa is by far the biggest producer of platinum in the world. Platinum ore's average grade is particularly low compared with other ETMs, with about 4.4 g per ton of material extracted. This means that the extraction of platinum generates proportionally more waste than the other ETMs. This is particularly concerning since platinum mines in South Africa tend to be situated in direct proximity to

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16 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC122671/jrc122671_the_role_of_rare_earth_elements_in_wind_energy_and_electric_mobility_2.pdf

populated areas. Platinum extraction places attract a lot of workers, because platinum is partly extracted in underground mines, which on average, require more miners. These populations tend to live in close proximity to the platinum mines forming mining towns (Cole and Broadhurst. 2021).

As many platinum mines are adjacent to cities, the literature finds evidence for many health issues, notably air diseases related to mine dust (Ololade & Annegarn, 2013; Cairncross & Kisting, 2016). These conditions are also favorable to the development of communicable diseases such as HIV (Cairncross & Kisting, 2016). Additionally, even if platinum mines are large employers, unemployment remains an issue in these communities, increasing the criminality rate (Ololade and Annegarn et al., 2013). The sudden influx of populations with a mine opening unsurprising leads to the development of slums with poor housing conditions (Cairncross & Kisting, 2016). This situation can lead to violent protests, such as the infamous one in the Marikana mining community in 2012.

Due to their low average ore grade, platinum mines are associated with large footprints on the environmental pillar. On water, a platinum mine located North East of the country has a measured water footprint of 2 229 × 103 m^3 per ton of refined platinum (Ranchod et al., 2015), a large part being supplied by the Limpopo Basin, which supplies 68.3% of the global platinum mining industry (Meißner, S., 2021). Finally, Mudd (2012), with an analysis of the entire South African platinum mining sector, confirms that platinum mines' particularly high-water needs are related to the low average ore grade. In addition, platinum mines are also found to be much more energy intensive than the average gold mines (Mudd, 2012).

Tin mining territories

Similar to copper, tin is involved in virtually all green technologies. It is essential to the soldering of all electrical components, which makes it indispensable to an energy transition that will reinforce the electrification of our societies[17].

Like cobalt, tin extraction can take place in large industrial mines or artisanal ones. In our database, artisanal mining can sometimes operate in the same territories as industrial mines. This is the case in Indonesia, the second largest tin exporter. Indonesia has a long tin mining history and even has a region that some call the Tin Belt (Tassri et al., 2019). Tin mining was historically done onshore but is now developing more and more offshore, near the shoreline. A specific technique of extraction is then required. This involves dredging the sand from the seabed from a barge and then processing the ore on the ground. (Rosyida et al., 2019).

In Indonesia, onshore tin mining is found to be positively associated with the oil palm culture, with significant plantation extensions noted in the tin mining regions. However, tin mining is detrimental to other agricultural activities due to lower land availability and the deterioration of the remaining fields (Rosyida et al., 2019; Syahrir et al., 2020). Overall, onshore tin mining considerably degrades the vegetation cover, with a measured loss of 188,07 km2 for the sole Bangka Regency area (Tassri et al., 2020). The holes left by tin exploitation filled with water contributed to malaria outbreaks in the mining communities (Syahrir et al., 2020).

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[17] https://www.woodmac.com/news/opinion/tin--the-forgotten-foot-soldier-of-the-energy-transition/

For the fishermen living close to the operation of suction dredges, offshore tin mining also considerably affects their activities due to the turbidity of the water, reducing their fish consumption and related revenues (Rosyida et al., 2019). The loss in these traditional economic activities is partially compensated by mining employment, with up to one-third of the household depending directly on the revenues from the mining company in the case of the Bangka Island area (Rosyida et al., 2019).

A different picture of tin mining can be found in Bolivia, whose geography drastically differs from the ones in Indonesia. In Bolivia, tin mining was not significantly associated with any health issues (Ruiz-Castell et al., 2012) or water issues (Archer et al., 2005). The pollution that affects the health and water sources of the inhabitants in this mining territory is suspected to result from other economic activities.

Titanium mining territories

Titanium is used in various fields of the energy transition, in particular for its structural properties, but it could also soon find use in new battery technologies[18].

Titanium is mostly extracted from two types of mineral ore: Rutile and Ilmenite. These ores are often exploited from black sands that can be found on the coastline or in the river beds (placer deposits). Their exploitation is, therefore, often based on dredging operations, that is, the suction of sands which can, in some cases, be done from a barge.

In the case of the QMM mine in Madagascar, titanium is extracted from heavy black sands (containing rutile and ilmenite) that are located on the coastline and in direct proximity to the sea (Huff & Orengo, 2020). The construction of a port for the mine's needs deeply affected the capacity of fishermen to access fishing areas, drastically reducing their revenues from this activity (Huff & Orengo, 2020). To compensate for the loss of local communities, the mining company, through its CSR program, financed skills training to work in the mine and scholarships. However, locals were not able to compete with foreign workers. In Sierra Leone, the long history of titanium exploitation from placer deposits substantially degraded at least 66 Km^2 of land (Akiwumi and Butler, 2008).

4.2.3. Drivers of SDGs in ETMs territories

This section aims to highlight the main factors that are affecting the success or failure of implementing the 2030 Agenda. Following the previously mentioned conceptual framework, we divided the collected literature according to the three channels. Each channel indicates a possible way through which ETM mining can affect positively or negatively the 2030 Agenda. In table 5, we summarized our main finding regarding the three channels.

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18 https://tdma.info/the-role-of-titanium-dioxide-in-enabling-renewables-and-energy-efficiency/

Table 5. Summary table of the main channels and identified mechanisms

Main channels	Key mechanisms identified	Main conclusions
Mining externalities	● Economic development ● Health/Pollution and occupational outcomes ● Environmental degradation	The extraction of ETMs has some (but not systematic) capacity to provide economic development due to a significant financial footprint (especially in terms of employment). However, this positive contribution to the 2030 Agenda is largely hindered by pollution, health problems, and environmental degradation. Goals 3 and 15 seem particularly (and consistently) threatened by the demand for ETMs.
CSR programs - Mining involvement in the sustainable development of the territory	● Infrastructure development ● Provision of social programs ● Unsuitable CSR design	Mining companies can effectively contribute to the economic and social SDGs. This is imputable to their important financial capabilities and an increasing responsibility towards the SDG success transferred from the government. However, these initiatives must not be mistaken with compensations in response to negative externalities, even though the frontier can sometimes be thin. CSR initiatives are dependent on the mining company culture, expertise, and willingness, which can vary a lot. CSR programs' effectiveness can be hampered for various reasons, including unsuitable design and insufficient dedicated financial resources.
Socio-ecological linkages	● Water usage ● Soil occupation ● Environmental degradation (and traditional livelihoods)	Usage conflicts over natural resources are recurrent in ETM mining territories. The environmental footprint of mining conflicts with many dimensions of the SDGs. It threatens traditional livelihoods, farming, and other economic activities that are essential for the indigenous populations. This sometimes generates resentment among local populations which make the 2030 Agenda particularly difficult to implement.

Mining externalities (positive & negative) from the extraction of an ETM

How ETM Mining shapes the economic development of a territory

The potential contributions of the mining sector to local economic development have been invoked for many years to justify the promotion of this sector in Global South countries. The ETM literature makes no exception, with goals 8 on decent work and economic growth and 9 on sustainable industrialization being overrepresented. Indeed, many of these studies explicitly or implicitly assume that mining investments and operational expenditures could be large enough to trigger sustainable economic development. The amount of investments required for modern ETM mining projects - that can appear "disproportionate" when compared to the economy of some countries - is suspected of having the potential to dynamize entire territories, even beyond the mining sector.

For various historical reasons, Chile benefits from decent literature on the economic impact of its mining sector. Despite the apparent isolation of many of its mines, copper extraction in Chile appears to have various positive macroeconomic effects, to begin with a positive contribution to GDP growth (Fuentes & García., 2016). However, Atienza et al. (2021) temper these outcomes, finding only weak linkages with the overall economy of Chile. A first explanation would be that many suppliers of the copper industry are global actors and do not have many local anchors. On that topic, Atienza et al. (2021) find a decreasing relationship in the backward and forward linkages to local supply networks due to the increase of a globalized supply network of the copper industry. Moreover, mining companies' headquarters tend to be localized in large metropolitan areas most often far away from the production site. The latter tend to attract disproportionately low value-added suppliers such as construction or food.

The contribution of the ETM mining sector to local economic development is more explicit regarding job creation. Though highly capitalistic, modern industrial mines require a lot of workers. Several studies in our literature confirm this. In a multi-country comparative analysis of copper mining sectors, Östensson (2014) found that copper mining contributed positively to job creation through direct, indirect, and induced employment in Chile, DRC, and Zambia. In other ETMs, similar results can be identified for other industrial metals. For example, in Indonesia where 1500 residents of the Bahodopi mining community are employed in Nickel mining activities (Hudayana et al., 2020).

However, job creation is complex and depends on several external factors. It is deeply affected by the average world prices. Industrial metals such as copper follow cyclical price paths. In Zambia, the mining boom occurring in the 1990s substantially reduced the average unemployment rate (Lippert, 2014). Mining booms (i.e. resulting from a world price increase) contribute to foster local spillovers. Fuentes H. and Garcia (2016), estimating a DSGE model calibrated on the Chilean economy finds weak but existing positive linkages between the copper mining sector and the rest of the economy after simulating a 1% copper price increase.

Kolala & Bwalya Umar (2019) find more mixed results at the local level in the case of Zambian copper, displaying a negative trend in Konkola Copper Mines' permanent labor, relying increasingly on short-term contracts. In addition, copper price variation and increased mechanization of the mining process tends to reduce the overall labor force needed in copper mining sites. This phenomenon of precarisation of the workforce was previously identified by Lungu (2008), who finds short-term and unsecured contracts. On the contrary, Lippert (2014) finds modest but existing local spillovers dependent on the global copper prices boom.

According to Cole & Broadhurst (2021), to be successful in providing economic development, the stage of the mine and the commodity prices are critical because the community must be able to absorb mine workers. In their study, Cole & Broadhurst (2021) demonstrates that the rapid expansion of PGM mining in poor and remote areas leads to the worst outcomes for mining communities.

The findings from Fisher et al. (2019) contrast these results. The artisanal exploitation of manganese in Indonesia is a source of local economic development, providing better and more stable revenues to the mining communities. The relatively low and stable manganese prices (compared to gold) partially explain why there is no evidence of a "gold rush" with the known associated impacts.

Finally, the positive impact of mining ETMs on economic development can be attributed to the privatization process of national mines. The vast privatization programs that have occurred in the 1990s in the Zambian mining sector have been found to have increased the employment in that sector Lungu (2008). This suggests that the company identity matters for the sector's contribution to the goals 8 and 9. Kragelund and Carmody (2016) add this initial evidence suggesting that employment creation is not restricted to western companies' investment, as BRICS mining companies could also positively affect the average employment rate. In addition, BRICS mining companies were also found to be more effective at developing strong and reliable links with the rest of the Zambian economy.

Health/Pollution and occupational outcomes

Goals 3 and 8 address health and occupational outcomes in mining communities. As described above, ETM mines have a positive contribution to job creation. This positive outcome must be put in perspective with the working conditions in the mining sector. Elenge and Brouwer (2011), in a field study in the cobalt-copper artisanal mining sector in the Democratic Republic of the Congo, record dangerous working conditions. They find a wide range of work-related diseases and injuries, such as the loss of audition, chemical contamination, or respiratory problems. A possible explanation for these poor working conditions could be related to the high degree of competition between miners. This competition is exacerbated by the absence of exclusive rights for artisanal miners, which makes their access to the deposit only conditional on their productivity. This consequently favors the development of dangerous working behavior in order to differentiate themselves from the other miners. The poor working conditions in artisanal cobalt mines also tend to favor substance abuse among miners (Geenen, 2021).

Poor working conditions are not exclusively found in artisanal mining. Miners in underground copper mines were significantly associated with tuberculosis, notably due to silica exposure in often poorly ventilated tunnels (Ngosa & Naidoo, 2016). In a survey of Ghanaian bauxite and manganese mining, Amposah-Tawiah et al. (2014) found that excessive workloads negatively impacted the well-being of mining employees in Ghana. Their psychological health was also negatively affected by the use of obsolete mining equipment, often dumped by parent companies operating in the global north.

Beyond occupational outcomes, economic linkages must also be tempered by the pollution generated by ETM mining activities. Heavy metal poisoning is a non-communicable disease for which the evidence is almost exclusively found in the public health literature. It can affect populations in direct contact with the metals (mineworkers) or people living in the vicinity of the mine exposed to dust and smelter fumes. Heavy metal poisoning varies with the type of metal, each type of mine having a specific exposure mechanism.

A first exposure mechanism that is identified in the case of ETMs can be related directly to the nature of the metal extracted. In this literature strand, some metals stand out from the other ETMs. For instance, manganese is a very toxic metal that is found to have detrimental health effects for both the mine workers and the local populations. Mexico is one of the leading producers of manganese, and the populations are therefore exposed. Santos-Burgoa *et al.* (2001) found a particularly strong effect on children living near a manganese mine whose neurocognitive development was found altered. This result is confirmed by Torres-Agustín *et al.* (2013), who identified a link between manganese exposure and immediate recall loss. For their part, Arrieta and Guillen (2018) noticed a birth weight reduction in children whose mothers were exposed to manganese. Adults are affected too, especially mineworkers for whom mild syndromes such as skin rashes and headaches were found. In the case of manganese, a recurring exacerbating factor was the proximity of smelters to inhabited areas.

Beyond the exposure of the metal extracted in the mine, mining communities are also exposed to all the other metals found in the same body of ore. Manganese and cobalt are two toxic elements that can be found in high concentrations in the human body because of the exploitation of a copper mine. Cadmium is also known for its toxicity. It is an important by-product in many Chinese mines, such as the tungsten-molybdenum mines (Cui et al., 2018), and was found to generate renal damage.

This means that non-toxic metals such as copper can have a negative effect through the presence of other metals. Thus, heavy metal pollution varies according to the polymetallic composition of body ores. The need for a wider variety of minerals for the energy transition means that these complex and potentially toxic polymetallic body ores are more likely to be exploited than in the past.

A second mechanism identified for heavy metal poisoning would be the proximity of the extraction infrastructures (mining pits, smelters, roads...) and the mining communities. Indeed, large bodies of population tend to gather around the mining sites, either to work in the closeby mine or try to "ripple off the benefits of an increased mine activity." This behavior has a direct consequence in terms of public health. In the case of cobalt, Banza Lubaba Nkulu (2018) found that its artisanal extraction was related to diseases due to manganese and uranium exposure. This type of exposure seems again to affect children particularly. For cobalt, the spillage of bags full of dirt during transportation contaminates large areas away from the extraction site, exposing non-mining populations. However, these large population influxes to the mine also tend to favor the development of communicable diseases such as HIV, which showed a high incidence rate in the vicinity of a large copper mine (Kolala & Bwalya Umar, 2019). Finally, the large population accumulating in the vicinity of the mine that cannot be employed at the mine also tends to cause substance abuse (alcohol) and increased crime incidence. Platinum mines are noticeably known for the large populations gathering around the mining sites. In these mines, toilet overflows created significant health issues (Cairncross & Kisting, 2016).

Environmental degradation

Mining activities inevitably lead to environmental degradation due to its inherent destructive process. The extraction of ETMs makes no exception to other minerals, even though it has several key mechanics.

The first area in which their extraction is often pointed out is their contribution to GHG emissions. The mining and especially the refining processes are energy intensive and still primarily powered by coal power plants. Paradoxically, the extraction of ETMs produces large quantities of GHG emissions and contributes to global warming, even if part of these minerals are intended to be used to build renewable energies. The minerals that are produced in very large quantities are logically among the most significant contributors. Copper mines are good examples. The Phu Kham mine in Laos is found to have emitted 6101 tons of CO2 between 2007 and 2018 (Islam et al., 2020).

On a more local scale, mining ETMs directly contributes to a wide range of environmental degradation. First, mining being a process very dependent on water resources, ETM extraction is regularly found to contribute to the degradation of surrounding marine ecosystems. Indeed, the large quantities of water required by mining companies often force them to locate near water sources such as rivers. In some cases, this leads to the destruction of the ecosystems surrounding the mines. In Indonesia, the activities from the PT Freeport mine were found to disturb the nearby Ajkwa River due to the deposition of mining tailings in its headwaters (Paull et al., 2006). This kind of anthropogenic impact can have tremendous effects on marine biodiversity. Canak-Atlagic et al. (2021) noted in the case of the Pek River in Serbia an important drop in macroinvertebrate community diversity due to the nearby copper mine.

Brazil has particularly been affected by the degradation of marine ecosystems. The Brazilian forests are crossed by many rivers that are easily contaminated by the discharges of mining activities. Mining companies operating in these areas build giant reservoirs for the wastewater generated by the production activities to protect the rivers. These impoundments have repeatedly broken and spilled contaminated waters into the nearby rivers. Following the collapse of the Fundao dam, Coimbra et al. (2021) measured in the Doce river basin a significant increase in the eutrophication rate, elevated to the supertrophic stage which indicated a saturation in phosphorus and nitrogen.

Although the degradation of marine environments is increasingly studied, the prominent environmental degradation remains in the terrestrial domain. Among all, the destruction and degradation of forests is the most recurring impact found in the literature. The relative ease of measuring deforestation compared to other forms of environmental destruction may partly explain this. There is however a clear consensus on the contribution of the extraction of ETMs minerals to the loss of forest. The impacts of mining on the forest have almost exclusively been studied with remote sensing techniques, i.e., with data collected by satellite imagery. In 2014, Sonter et al. (2014) pioneered this literature by measuring the effect of iron exploitation in the Iron Quadrangle region in Brazil with satellite data. They found that the activity led to the disappearance of 7% of the native forests, which represent 63 000ha. In a completely different context, the exploitation of the Kansanchi copper mine in Zambia led to the destruction of 94 221 ha of forest, which is 34.23% of the total forest in the surrounding area (Takam Tiamgne et al., 2021).

More recent work on deforestation tried to assess the capacity of mining companies to compensate for the deforestation induced by mining operations by either protecting existing forests or developing new ones. In a breakthrough study, Devenish et al. (2022) found that the Ambatovy Nickel Cobalt mine located on the eastern side of Madagascar had managed to almost totally compensate for the forest it destroyed. This success was done by planting trees in a former farm field, achieving "Not net loss" of forest area.

While the case detailed by Devenish et al. (2022) shows that a mine can, in theory, commit to "no net loss" of forest area, one should not consider that a mine can avoid all impacts. If forested areas are indeed important, they do not exactly proxy biodiversity. Complex relationships have been found in the literature that notably has to do with the geological nature of the mineral extracted. We already mentioned Cangas that are systematically affected by iron exploitation. Shar et al. (2020) noted that some species of small mammals were positively affected by the distance from the mine. Other profound disturbances in biodiversity and ecosystems have been noted, but it should be noted that, in general, plant diversity and tree species are usually not captured by most empirical investigations. Indeed, the main empirical investigations on the link between ETM exploitation and the loss of biodiversity remain essentially limited to deforestation. In-depth biodiversity investigations are currently limited to a handful of mines' case studies and remain largely unexplored at broader levels.

<u>CSR programs - Mining involvement in the sustainable development of the territory</u>

This channel refers to the development strategies implemented by the mining companies and sometimes by local governments as part of the mining operations. In some cases, these initiatives directly address the 2030 agenda. For the mining company, these actions make visible the company's commitment to sustainable development and local communities under the form of Corporate Social Responsibility (CSR). CSR programs are defined here as concrete actions implemented by mining companies that can contribute to the SDGs.

Infrastructure development

Infrastructure development is one of the most known CSR development initiatives. This type of initiative directly echoes goal 9 on building resilient infrastructures but can also impact other goals. Roads and railroads creation or renovation are typical illustrations as they are included in many CSR packages (Jackson & Dear, 2016; Kepore & Imbun. 2011, Fisher et al., 2019; Landa, 2017; Lechner et al., 2019; Mbilima, 2019). These road networks are used as much by the local population as for the needs of the mining company. This is especially true in the case of new and remote mining territories where road building and other large infrastructure appear to be essential both for the populations and the mining company. Jackson and Dear (2016) recall, for example that the Oyu Tolgoi copper-gold mine in Mongolia new roads and an airport in order to connect the region to the rest of the country. Similar investment packages have been noted in the Zambian mine of Kansanshi (Van Alstine & Afionis, 2013).

There are other types of CSR infrastructure investment that can benefit the mining communities. Another recurring example of such CSR programs is related to water access and treatment. Mines require a lot of water to operate. These highly polluted waters can sometimes contaminate the waters used by local communities, which inevitably leads to conflicts. An interesting example of shared use can be mentioned in the case of a copper-molybdenum mine in Chile. The mining financed a water treatment plant for the mining community and reused the wastewater for its mining operations (Fraser, 2018). As a result, 99% of sewage water is now being treated with considerable improvement for the nearby river quality and for the people living on it.

Interestingly, we can find a similar infrastructure development process in the case of artisanal mines. While there is no large mining company (i.e., with CSR programs involved) involved, artisanal mines areas tend to have better infrastructures. To Fisher et al. (2019), local governments have more financial capabilities in these areas and which makes them keener to finance better infrastructures. For instance, in Indonesia, introducing a tax on artisanal manganese extraction allowed the local government to fund much-needed road and water projects.

Provision of social programs

The terminology of social programs is used here to designate all the initiatives financed by a mining company to proactively contribute to the well-being of mining communities and, by extension, a large part of the 2030 Agenda.

An illustrative health initiative can be found in Zambia's trident copper mine project. The mining company engaged in an extensive health program for the mining community during the project stage of the mine. Knoblauch et al. (2017) studied the results of this project and found a lower incidence rate for non-communicable diseases such as stunting or hookworm infection in the mining community than in the rest of the population. Similarly, mining companies can help contribute to goal 3 on health by financing health infrastructure such as a mine hospital and, in some cases providing free healthcare for the entire mining community (Kolala & Bwalya Umar, 2019). The capacity of a mining company to provide effective health infrastructure can be found in many geographies and for different minerals. In a case study on the iron Sishen mine in South Africa, the mining company provided healthcare services and facilities for an area beyond the mine's close vicinity (Mutale et al., 2019).

In mining company CSR programs, education also appears to be a priority. One recurring initiative is the provision of scholarships. The main target of these scholarships is technical training in mining-related programs. Such initiatives are designed to give local youth a chance to access employment in the mine (Fairlie Reinoso & Herrera, 2016). More advanced scholarships in mine-related programs can also be found. In Mongolia's gigantic Oyu Tolgoi copper-gold, the operator (Rio Tinto) financed graduate and post-graduate studies in western countries (Jackson & Dear, 2016).

Scholarships are not limited to mine-related education since Mbilima (2019) reports various types of scholarships for children living near the Lumwana copper mine, going from high school to tertiary education. An effective increase in the average education provision has been found in various contexts (Tarras-Wahlberg et al., 2017; Van Alstine & Afionis, 2013).

However, this type of education and health programs tend to present some limits regarding the capacity of mining companies to effectively contribute to the 2030 agenda. In another case study in the Zambian Copperbelt, Cairncross and Kisting (2012) noticed some discrimination among the beneficiaries of these healthcare programs. No health services were, for example, provided to contract workers or their families living in the vicinity of the mine. Moreover, education programs are also restricted to a limited amount of the population. Mutale reports that only 2% of the survey participants received education from the nearby mine school. Finally, our database also reports several gender equality programs. Pimpa (2019) reports that mining companies, through their CSR, can effectively promote gender equality, particularly by promoting the professional integration of women.

Compensational programs

A final type of CSR category found in the ETM literature for which the installation of a mine can, in some regards, contribute to the 2030 agenda has to do with compensational programs. When a mining company plans to build a mine in a populated area, it needs to make these people move elsewhere. This type of population displacement generally occurs when a population body "sits" on an exceptional mineral ore. In these cases, the mining company and the local government can take measures to displace the population. We found in the literature that displaced communities receive compensation in various forms. Some compensational programs are thus dedicated to ensuring that these populations live sustainably, which is in line with the 2030 agenda.

An illustrative case study in our database is related to the Mes Aynak copper mine in Afghanistan. To start the construction of the mine, the Chinese company operating this project had to move an entire community away from the extraction site. With the government's help, it relocated hundreds of people and financed a compensation program designed to improve the living conditions of the displaced people compared to before the mine. Dastgir et al. (2018) measured the effectiveness of this program in providing positive, sustainable outcomes. He found an increase in the consumption of medical care services previous to the displacement. He also found that people had access to new income sources sometimes related to the mining project (archeological work in the case of the Mes Aynak area). However, for Dastgir et al. (2018), compensational programs were unable to compensate for the loss of social capital. In these remote and traditional territories of Afghanistan, the complex social networks called qawm[19] were split apart by the construction of the mine, which fragilized the economic sustainability of the whole territory.

Unsuitable CSR design and limited financial capacities

In the case of the literature on ETM mining communities, several recurring factors tend to limit the contribution of these initiatives to the SDGs. The first element would be the recurring mismatch between the community needs and the CSR programs provided. Indeed, Corporate social responsibility, even when it relies on massive investment, does not always suit the needs of local communities (Mutale et al., 2019). Mining communities are often not involved in the CSR programs designed by mining companies which leads to programs which have more philanthropic objectives than promoting sustainable development. Kepore and Imbun (2011), studying the Ok Tedi mine in Papua New Guinea, looked at how the local population perceived the CSR initiatives of the mining company in terms of sustainable development. He found that local communities had extremely high expectations from the mining company regarding sustainable development. Kepore and Imbun (2011) estimated that it would not be possible for the mining company to meet all the demands of the local

[19] "Qawm is a solidarity network based on communal groups such as tribal zones, villages, ethnic groups, and extended families, that permeate through Afghan social life"

communities. It would simply have lacked the financial capacity to meet all these demands during the production time of the mine. Indeed, investigating the case of the Oyu Tolgoi mine in Mongolia, Meesters and Behagel (2017) suggest that CSR programs are not used for promoting sustainable development but as a technique to neutralize local disputes. Quoting Boutillier (2014), the authors assert that "properly managed, mining communities cannot stop the project".

A second explanation of why CSR programs fail to contribute to the 2030 agenda could be that poorly designed CSR programs tend to do more harm than good. Huff & Orengo (2020), for example, noticed that local communities are not only affected by the extraction but also by measures taken by the mining companies/state to mitigate the negative effects on the environment. The QMM project in Madagascar is a perfect illustration. The company delimited large conservation areas to protect the unique biodiversity of this area. By doing so, they restricted access to these areas that were crucial for the local populations. For Huyadana et al. (2020), CSR programs can even trigger communal violence when not designed appropriately. He noticed that such community violence was used as a negotiation strategy to gain additional compensation from the mining company's CSR program.

A third part of the explanation would be related to the amount of CSR programs. In the case of the Oyu Tolgoi mine in Mongolia, Jackson and Dear (2016) noted that the mining company budget for the CSR program was based on the size of the mining community which already lived in the mine surrounding before the beginning of the operations. The migration that followed the beginning of the operations saturated the program's capacities. In Zambia, Lungu (2008) reported that the privatization of the mining sector in the 1990s drastically reduced the size of the programs. When owned by the Zambian government, mining companies were very supportive of local communities. To keep the mining sector attractive, the Zambian government reduced the mandatory CSR program amounts to a very low level, drastically reducing the sector's contribution to local people.

Finally, a fourth part of the explanation could be related to factors related to the mine characteristics. Mbilima (2019), looking at the case of the Lumwana mine in Zambia, noted that the ore grade was directly related to the amount of CSR provided. Less profitable mines are thus less likely to provide large CSR amounts. This too often overlooked result is particularly concerning in the case of mines whose average ore grade is low, and the average world price of the extracted mineral does not compensate. Finally, for Van Alstine and Afionis (2013), the effectiveness of CSR programs also varies with each mining company. Each of them brings its financial capacities, program, expertise, and other elements defined in its corporate culture.

Socio-ecological linkages

This third channel is found in an emerging literature trend on mining impacts. It considers explicitly or implicitly mining activities as integrated into a socio-ecological system in which the mining company and the local communities compete for natural resources.

Water

Water is a central element in many parts of mining operations. It is used to wash the extracted soil and separate valuable materials from non-valuable ones. In the socio-ecological system formed by mining territories, water resources are shared between the needs of the mining company, the mining community, and the natural environment. In the literature collected, this distinction between the various water usage appears to be particularly important to understand the sustainable development problems encountered in many mining areas. Its appropriation can be linked to several issues for the success of the 2030 Agenda.

The first series would be related to goal 1 on poverty and goal 16 on governance. This is especially true for the South American mining sector, an important part of which occurs in desertic and high-altitude areas where water is rare. In a multi-case study, Bebbington and Bury (2009) concluded that the activities of the Piura copper mine, located in the North-West of Peru, led 60% of the surveyed farmers to report reduced water availability. In these areas with low rainfalls, it reduced farmers' crop yields. The lack of recognition of indigenous rights, especially regarding water, is a recurring problem. The populations living near another copper mine called Chuquicamata saw their water rights "deemed as unused rights" and were consequently allocated to the mining sector (Camacho, 2012). These water access and rights issues have triggered many violent protests. An emblematic illustration would be the Aymara communities revolts over the water pollution caused by a silver mine located in the southeast of Peru (Fairlie Reinoso & Herrera, 2016).

While the deprivation of water rights and access is a particularly recurring issue, the partial or complete destruction of water bodies has also been studied in the ETM literature. In Papua New Guinea, mine tailings from the Ok Tedi gold-copper mine have permanently damaged the river from which many Papusian lives depend (Elenge & Brouwer, 2011). A similar case of river diversion for the needs of the mining operation was studied by Meesters & Behagel (2017) in Mongolia. These types of damage on rivers can have consequences not just on the surrounding populations but also affect populations potentially hundreds of kilometers downstream. Finally, the water intakes by mining deeply affect the surrounding ecosystems, as it contributes to land desertification in several mining territories (Lorca et al., 2022; Li et al., 2021).

Soil occupation

The success of some SDGs involves a considerable amount of land use. An obvious example is related to goal 2 for which the agriculture development goal requires much land surface. Modern mine operations are huge, and the available evidence confirms that ETM mines also share this characteristic. Open-pit mines are the most obvious example of the large footprint of mining activities since the extraction requires the removal of large spaces.

Most of the ETM mines in our database are of the open-pit type (N=49). Open pits mining notably makes low ore-grade deposits more profitable (Crowson, 2012). In addition to the space needed for the extraction process, mine operations require space for the tailings, the possible retention ponds, heavy machinery to crush the rocks, and many other infrastructures needed to support the extraction process.

The sum of all these elements that constitute the mine footprint and the possible tradeoff with the various dimensions of the 2030 agenda are complex to assess. Especially since this footprint is not a static element but is evolving dynamically with the production stages, these dynamics being hard to capture with conventional methodologies.

Remote sensing is a useful tool for studying the evolution of the mining footprint (Lechner et al., 2019). Again, the low average ore grade of ETM mines is pointed out as being a factor in increased soil occupation. Lechner et al. (2019), studying two mining project locations, found that in both projects, the share of undisturbed community land decreased proportionally to the increase in land disturbed by the mining community. This relationship gets stronger as the average ore grade decreases. For Islam et al. (2020), soil occupation is directly related to global factors, such as price variation or an increase in the demand for minerals.

Environment degradation (and traditional livelihoods)

As discussed above, mines significantly contribute to the degradation and destruction of the natural environment. Among all things, forests and their biodiversity content are the most affected. From a socio-ecological perspective, the degradation of the environment cannot be isolated from social issues. Deforestation creates many risks for the many communities that live out of forest exploitation for their livelihood. Mwitwa et al. (2012) studied the impact of deforestation on local communities in the context of the Chingola copper mine in Zambia. They found that this clearance of the forests for the mine needs had detrimental livelihood costs for the local communities that traditionally lived off forest products. It reduced the "qualities, quantities and availability" of non-timber forest products (NTFP), ultimately reducing households' income. It also reduced the food security that NTFPs were providing to these communities. Forests are not the only source of livelihood for mining communities affected by mining. While studying the consequences of the exploitation of the ok Tedi copper-gold mine in PNG, Kepore and Imbun (2011) noticed that the alteration of the river led to the loss of primary source of livelihood for the people who depended on it and this even far away from the mine.

However, environmental degradation and especially forest clearance can conversely be the result of local communities' development. Lehmann et al. (2017), investigating in the Gatumba mining district (GMD) in Rwanda (coltan), found that deforestation due to mining was boosted by cropland expansion. Mwitwa et al. (2012), looking at the mines of Lubumbashi (DRC) and Carajas (Brazil), found that forest cover significantly declined around mining towns. A phenomenon which according to Papyrakis et al. (2010) can be partly attributed to an increased charcoal production as in the case of the copper-belt. Similarly, in Brazil, Sonter et al. (2014) identified that most of the deforestation resulted from "the combined extent of mines, urban areas, plantations and fields".

5. Discussion and Public policy recommendations

5.1. Overall discussion on the review

Comments on the review results

The quantitative and qualitative synthesis gave two complementary pictures of the literature looking at the impacts of extracting energy transition minerals for mining territories. On the one hand, it showed that the available literature left some clear blindspots. The literature we were able to identify only covers a very small proportion of mines in developing countries. This knowledge deficit appears symptomatic of the little importance given to the mines of the transition until today, essentially due to an inappropriate consideration for the variation that is embedded in the geological nature of mines. However, these gaps are also attributable to the difficulty of collecting valuable data in mining areas, making the most common mines more likely to be selected in a study. This first result is concerning when we know how essential these mines will be for the sustainable development trajectories of many countries and territories.

The collected literature for this systematic review is extremely unbalanced. First, on the 2030 agenda, identified impacts are skewed towards the more economical ones, which may not be surprising given the historical role of these minerals in industrialization. We observed clear gaps in some SDGs, such as on energy (goal 7) or poverty (goal 1). Among all the minerals in the list of energy transition minerals, copper is by far the most studied mineral, with about half of the collected impacts. This result can be explained by the large number of copper mines in the world. Minerals that are going to be essential such as lithium or nickel have only, for now, been the subject of a very limited literature. That being said, the fact that the same mines are found several times in our database suggests that the choice of location for a study - and therefore of a mineral - is rarely based on the mineral nature of a mine but more likely on the ease of access to a particular mine or/and the probability for researchers to identify significant impacts. Hence, the largest mines are presumably overrepresented in our sample. Similarly, the mines more likely to have had "mediatic" impacts are also more likely to have been the subject of a study. This suspected selection of mines could bias our perception of this sector as these "extreme case" mines can be expected to have some of the largest (positive and negative) impacts on sustainable development.

On a methodological side, this systematic review helped to reveal some limits regarding how ETMs' impacts are studied. If almost every goal benefits some kind of empirical investigation, it is worth noting the relative scarcity of statistical investigations, especially time varying empirical strategies. Indeed, this literature is affected by a significant data deficit, as only little information is available to monitor the evolution of mining territories and communities, especially in a multi-mine context. The only noticeable exception is remote sensing empirical strategies that are - in some cases - able to offer a broad statistical overview of the 2030 Agenda in ETM mining territories. However, these analyses are essentially done at the level of a mine, which dramatically limits the conclusions that can be made about this sector in relation to the implementation of the energy transition. Overall, the lack of trustable statistical data prevents the finding of causal relationships.

Finally, we observed an increasing number of studies with an interdisciplinary focus in recent years (labeled here as sustainable development studies), including on the same level, sustainable development's economic, social, and environmental dimensions. This research design notably helps to highlight the existence of a rising literature looking at the complex socio-ecological systems impacted by ETM extraction. The synergistic relationship between environmental degradation and the mining communities appears indeed to be particularly important in the case of ETMs and essential to understand the impact of mining on SDGs.

Conceptual framework relevance

The approach by mining territories and the conceptual framework employed in this systematic review proved effective in disentangling the main sources of variation imputable to the extraction between the ETMs. In this review, we saw how much the method of extraction, the company origin and macroeconomic factors such as world mineral prices were essential to the understanding of mining impacts on mining territories. It confirmed the interest of having an approach able to study ETMs separately from other minerals but also able to highlight distinctions between the ETMs themselves.

For researchers interested in ETMs, this approach of mining used in this article has several advantages:

- First, it can help empirical researchers to disentangle how ETM mining characteristics could be associated with specific mechanisms impacting the 2030 agenda and what specificities are essential to look at in the perimeter of each mining territory.

- Second, it is flexible enough, so it does not restrict the potential influence of a mine on a territory to an arbitrary distance from the mine. There is no agreement on where to look when studying mining impacts. Most of the studies implicitly define a space in which the impact of mining occurs. It is sometimes imposed by the methodology they use, such as in the case of field interview studies where authors need to reach the mining community, either it lives in the vicinity (i.e., a few km around the mine) of the mine or hundreds of km away. Depending on the considered mine's influence space, these populations can be constituted of indigenous, mine workers, migrants, people living in the nearest cities, people in an entire region, and the population of an entire country. The same is valid for environmental impacts on which there is no consensus on their extent. The proximity of water makes these impacts potentially run hundreds of kilometers away. By crossing the scales of analysis, we know that the influence of a mine on the contribution to the 2030 agenda is much broader than the too much used "vicinity of the mine" perimeter.

- The third advantage of this framework is that it clarifies the existence of complex interactions between the mining communities and their environment. The socio-ecological mechanisms occurring in the mine surroundings are too often overlooked in the literature, even though the ETMs impact on the environment makes little debate.

- Finally, this framework helped to link the (un)sustainability of a mining territory and the potential disruption of the mine production. It can be used to identify the possible "trigger points" in ETM mining territories and guide the governance of the mining sector accordingly. Water appears to be a key triggering point for many mining communities, especially those affected by lithium and copper extraction, which may lead to mine blockages. In the context of climate change, where rainfalls are expected to be altered, this raises important questions about the living conditions of these communities and their acceptability of mining.

5.2. Current and expected contribution of ETM territories

Regarding the available literature, the assertion made by several researchers and international institutions that the energy transition should be considered as an opportunity for mineral-rich developing countries should be tempered. We found convincing evidence of positive economic outcomes from previous mining booms for several key minerals, especially copper, which is supported by a large amount of literature. However, given the academic evidence at our disposal, international institutions are not legitimate to say that the energy transition is an opportunity for all developing countries. The low availability of academic evidence makes these types of claims largely unfunded or based on transfer knowledge from other non ETMs minerals.
The current and empirically investigated evidence suggests that ETM mines' contribution largely varies across ETMs and across each SDG. In fact, the academic evidence suggests that the environmental pillar of the 2030 Agenda will not be achieved in most mining territories. For the economic and social pillars, the available empirical evidence is not sufficient to assert a systematic contribution of ETM mining to the 2030 Agenda. The orientation of this contribution is related at different levels to the type of ETM extracted, some displaying more explicit patterns than others.

CSR programs are the only convincing initiative that mining companies can deploy to promote the 2030 agenda efficiently. It is an interesting complement to the "natural economic effect" generated by mining activities as it targets other SDGs which are less likely to benefit from the "direct effect" of mining, such as health, education, and infrastructure. However, CSR programs' scope remains limited to very standardized and expected programs. Moreover, we found several ways CSR can fail in their contribution to the 2030 Agenda, especially since they are not always aligned with the expectations of locals.

In the collected literature, the mines presented as having low ore grades tend to be associated with the poorest performances regarding the 2030 agenda. Low ore grade mines generally exert a bigger pressure on both the environment and the populations as the pollution and soil occupation are directly related to it. As ETMs prices are expected to see their price increase sharply in the coming years (Pescatori et al., 2021), it means that lower-grade ore should become more and more economically profitable. As newly exploited ores are getting closer to the cities and biodiversity hotspots (Lèbre, 2020), the possible point of friction with the 2030 agenda can be expected to increase.

The results of this systematic review allow us to anticipate several trends that will affect the ETM mining territories. We can expect that this shift to transition metals will highlight contrasted trends between two types of mining territories:

- The mining territories that depend on fast declining ore grade (i.e., copper) and naturally low grade (i.e., platinum) whose supply chain is pressurized by the energy transition. These territories may find it difficult to capture the benefits of the coming mining boom. Considering the rarity of the metals they host, these territories are unlikely to be spared from mining activities.
- Mining territories that depend on recently industrially exploited (i.e., lithium) and naturally high-grade minerals (i.e., iron, manganese). If externalities such as water usage and heavy metal exposure are well managed, these communities could be able to rip off some benefits from the energy transition provided a good governance. Above all, most of these minerals can be mined elsewhere if the cost for mining communities is considered too high.

5.3. Public policy recommendations

By analyzing the main mechanisms at work in the mining territories of the energy transition, this systematic review has revealed that tough decisions were to come for policymakers. The energy transition could constrain policymakers to implement some necessary tradeoffs between the extraction of a critical mineral and the sustainable development of a territory. The results of this systematic review suggest that we most likely won't be able to achieve the 17th dimension of the 2030 agenda in these territories, regardless of any good governance. It is clear that local environmental goals are incompatible with the extraction of most of these minerals. In a seminal paper on cobalt extraction, Bebbington (2020) warned of the appearance of many areas whose sustainable development trajectories would be "sacrificed" for the energy transition which essentially occurs in the Global North.

By highlighting what makes ETMs have a differentiated impact on the 2030 Agenda, the results of this systematic review can be used to identify critical levers where public policy action can have an effective impact on mining territories:

- First, development strategies for mining territories should consider the geology of the mineral deposit. Depending on the type of metal mined, there should be priorities for action in promoting sustainable development. The ore grade of mined mineral, their potential toxicity, and their price on the international markets are among the factors that should be systematically taken into account by governments.
- Secondly, the development of CSR programs should be adapted to ETM mining communities. Compensation policies should be put in place for the mining communities that depend on a low-grade metal or has an impact on a critical natural resource. The extraction must be supported by the local communities, the company, and the government to work effectively. This could be done by developing "sustainable supply chains" with higher CSR standards and

the systematic application of mining standards (such as IRMA[20]). This also implies preventing highly visible impacts such as mining accidents (notably dam failure) or the destruction of archaeological materials.

- Thirdly, more attention should be put on the protection of natural resources and the competition over their access. The review showed how much ETM extraction was proven detrimental to the environment, making the success of goals 13, 14, and 15 in these territories highly questionable. Additionally, protecting natural resources is crucial for mining communities' acceptance of mining activities, as mines tend to lower or completely prevent them from accessing these resources.

Despite the evidence at our disposal, it is worth mentioning possible limits for policymakers' action in mining territories, notably due to the actors at play. Local governments are remarkably absent from many of the studies on mining territory, having little or no role in these analyses of the 2030 Agenda. Other missing actors in this literature are development banks and donors. On the other hand, mining companies are over-represented, sometimes literally acting as a substitute government. This picture of mining territories makes one think that mining companies bear most responsibility for sustainable development in these territories. The fact that mining companies are financing and deciding most of what is contributing to the realization of the 2030 Agenda is inevitably posing a risk, even though some are openly engaged in sustainable development initiatives. Moreover, despite all the financial capabilities of mining companies, they may only be able to meet some of the expectations for sustainable development, given the magnitude of the expectations placed on them.

Finally, in this systematic review that implicitly links geology and sustainable development, one must acknowledge that the choice of location for a mine depends primarily on the geology of a territory and not on the capacity of that same territory to benefit from the installation of a mine. The expectations that lie upon a mine installation are often too high. Despite all the financial capabilities of mining companies, they remain private actors driven by profits. Consequently, this echoes the decarbonisation divide narrative by Lorca et al. (2022), where mining territories of the Global South have to bear most of the cost of mining with little sustainable development perspectives.

5.4. Limits

This systematic review of the literature contains some caveats that need to be mentioned. A first and obvious limitation of this work would be the choice of the SDGs as the primary coding matrix for sustainable development. Among other things, it precludes the inclusion of potentially important topics, which are beyond the scope of the SDGs. We can mention for example the important work on the relationship between artisanal and industrial mining (see, for example, Katz-Lavigne, 2019) which are not included in this review. The use of keywords designed to capture academic articles related to the SDGs and not all sustainable development outcomes might also explain why most of our literature is concentrated after 2015.

[20] https://responsiblemining.net/

Another limit, as in every systematic review, can be found in our search strategy. Many studies do not mention (or poorly mention) the mineral extracted from the mine(s) under investigation and have consequently been excluded. This means that an important part of the existing knowledge could not be collected. To deal with this issue, one ideal search strategy would have to add to the search equation the name of every industrial mine (as in Haddaway et al., 2019). However, due to the large geographic scope of this review, the number of mines' names was beyond the capacities of most academic database searching tools. Given the scope of this literature review, this was hardly feasible.

6. Conclusions and implications for future research

This systematic review of the literature aimed at collecting and synthesizing the available empirical evidence on the ETM mines' impacts on the 2030 agenda. The use of the concept of mining territories helped to organize the existing literature in a way that highlighted the key characteristics of each mineral for their contribution to the 2030 agenda.

The analysis of the results suggest that scholars have not given enough importance to the minerals used to produce the green technologies. Too many minerals that are going to be massively exploited due to the energy transition are under researched. Part of the explanation lies in the difficulty to collect valuable empirical data from industrial mines but also in the lack of recognition of the role played by the geological nature of minerals in the analysis of mining impacts for sustainable development.

The mining territory approach and the conceptual framework we developed help to guide empirical research on what to look out and expect when a new mine starts producing these specific minerals. The available evidence we collected suggests that the exploitation of these minerals is hardly compatible with the achievement of the 2030 Agenda, as some minerals are particularly detrimental to certain goals, notably environmental ones. Due to the unequal distribution of geological resources, mining these minerals in Global South countries is inevitable. With the energy transition, we advise that the creation of mines that meet the needs of the energy transition should not be considered as development projects that are fully compatible with the 2030 Agenda. In the coming years, it will be important to rethink the unbalanced North-South relationship in mineral extraction to reduce this "decarbonation divide".

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Liste des sigles et abréviations

AFD	Agence française développement
ETM	Energy transition mineral
ICMM	International Council on Mining and Metals
IEA	International energy agency
IRMA	Initiative for Responsible Mining Assurance
SDG	Sustainable development goals
WB	World Bank

Agence française
de développement
5, rue Roland Barthes
75012 Paris l France
www.afd.fr

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