Comment

An illegal gold mine in Triángulo de Telembí, Colombia.

DANIEL MUNOZ/AFP VIA GETTY

Impacts for half of the world's mining areas are undocumented

Victor Maus & Tim T. Werner

As the race to extract minerals and metals for clean-energy technologies accelerates, researchers must take more steps to map and study mines globally.

Mining is a crucial industry — from iron and copper to gravel and sand, we depend on it for the basic building blocks of the modern world. It is a fast changing sector, as the clean energy transition and digitalization boost demand for materials such as cobalt and lithium and curb the need for others, such as fossil fuels. Yet we know surprisingly little about what's going on in the sector globally and how mining affects the environment and communities near mines.

Much of what we do know isn't good. Climate change isn't the only problem associated with coal mining, for example[1]. In Indonesia, the world's biggest coal exporter, rainforests are being cleared for coal mines and these mines pose safety risks — since 2011, more than 40 people, mostly children, have drowned in poorly managed coal pits[2,3]. The demand for materials, and the rush for lithium in particular — which is used in batteries for electric vehicles — is raising concerns that the global appetite for energy is coming at too great a cost. In 2022, in Serbia, for example, massive protests over fears of habitat destruction and toxic-waste spills led to licences being revoked for a proposed lithium mine.

Because no mine is immune from risk or controversy, independent research is essential to decipher the extent of its risks and impacts and to build trust with the public. However, enormous data gaps prevent this. There's no comprehensive inventory of the world's hundreds of thousands of mine sites and exploration zones. Publicly available data on mine production, waste, pollution and consumption of water and energy are widely lacking. A large share of global mineral production might be illegal — for example, more than 80% of gold mined in Colombia and Venezuela comes from illegal operations, according to the United Nations Environment Programme[4].

These gaps leave researchers with a fragmented view of the industry and hamper their ability to track decarbonization strategies and inform policies and decision-making.

Whether it is coal for business-as-usual, lithium for batteries, cobalt for smartphones or neodymium for wind turbines, all future pathways require mining, and at a cost. We can't manage what we can't measure, and so it's time to address the 'known unknowns' of the mining sector. Here, we propose four key steps.

Spotlight the weaknesses in mining data

First, researchers must be frank about the information they are dealing with. Global mining studies rely largely on data contained in company reports. Compilations exist, such as the S&P Capital IQ Pro database, which is the basis of nearly all worldwide assessments published in the field. But this database sits behind a paywall and is incomplete.

For example, after combing almost 120,000 square kilometres of mining areas identified globally using satellite images[5,6], we found that only 44% of the mines we detected had production information noted in the S&P database (see 'Missing mines'). There is no pattern to the gaps — data are missing for all types of commodity and locality and for all sorts of reasons, from scant reporting to illegal activities, as inferred from satellite images and other sources of information. Historic and abandoned sites are typically unrecorded. And the job of finding and compiling data from company websites and reports is too vast to complete.

Researchers persist in using the S&P database – it's often the only choice available. But few acknowledge, let alone attempt to account for, the limitations and biases within it. Common types of analysis make gross oversimplifications. For example, risks are often inferred from mine locations alone, and by assuming that the intensity of mining is the same worldwide[7,8]. Yet, treating mines as dots on a map doesn't account for differences in the scale of impact between sites. An underground shaft opening will lead to different types of damage compared with open-pit excavations and waste-disposal areas.

What should researchers do? At a minimum, until more data are available, we suggest that global mining studies should include statements of data bias and completeness. These might include: the extent of potential unofficial mining and commodity trading in a study area, based on media reporting and national accounts. They might state whether sample bias can be quantified or results tailored to reflect it, and how the absence of site-specific data affects results in a sample. Statements should report the extent to which official statistics or data compilations are complete, and whether any other corporate factors might contribute to reporting bias.

Such statements will not weaken the impact of research. Highlighting that the impacts are under-measured only makes the call to action louder.

Gather and share mining data openly

Second, researchers should do more to coordinate their efforts and pool data. Most studies of mining impacts are local and focused on small areas. But as the scale of mining grows, it's crucial that global impacts are addressed.

The sheer number of mines poses a challenge for data collection and makes fieldwork impractical. Australia, for example, has more than 95,000 historic and active mineral extraction sites, many of which are remote[9]. One effort to collate data on these sites took a dedicated specialist more than 20 years[10]. Another database, which includes production information on 1,171 global metal and coal mines, was collected by manually reviewing more than 1,900 documents provided by mining companies in a variety of languages[11].

"The mining industry needs to improve the quality and quantity of data that it publishes."

Such hard-won data must be shared, and recognition given. Several journals, including *Scientific Data*, which is part of the Nature Portfolio, offer researchers a platform for doing so, and many journals and funding agencies have enforced open data-sharing policies. However, there is still an accessibility problem. Most data sets accompanying research articles are hard to reuse – they might be inadequately documented, with unclear coverage limits, collection protocols and licensing and usage terms. Such barriers are leading to inefficiencies, duplicated efforts and missed opportunities for collaboration. Mining data from government agencies and non-governmental organizations (NGOs) are also largely invisible and under-used, even though the owners of such data might be willing to share them.

Coordinated efforts, good data management practices and tools to facilitate knowledge discovery will be required to fully understand the environmental and societal impact of the global mining sector. Adopting findability, accessibility, interoperability and reusability (FAIR) principles will be pivotal[12]. Specifically, data should be deposited in long-term repositories, such as Zenodo and PANGAEA. Attaching an open licence to data, such as those available through Creative Commons, is crucial. It is also key to provide metadata, data-collection protocols, usage notes, and adhere to robust open data encoding standards, especially for spatial data (such as GeoPackage; https://www.geopackage.org).

Chromite, a source of chromium, is extracted from the mountains in Dewalak, Afghanistan.

MARCUS YAM/*LOS ANGELES TIMES*/GETTY

Tackle the lack of transparency in mining data

Researchers must find the root causes of information gaps that are due to a lack of historical accountability and issues with confidentiality, commercial interests and regulation. The complexities of appropriate reporting, a lack of standardization and extra costs also make it challenging to find accurate mining data.

For example, Indonesia produces around half of the world's supply of nickel, which is needed for electric-vehicle batteries. The Mandiodo nickel mining block of Sulawesi, Indonesia, stands out in satellite imagery, with its expansive vegetation clearing and operations in close proximity to waterways. The region hosts a mix of large formal mines and smaller mines, yet there's little public information on either.

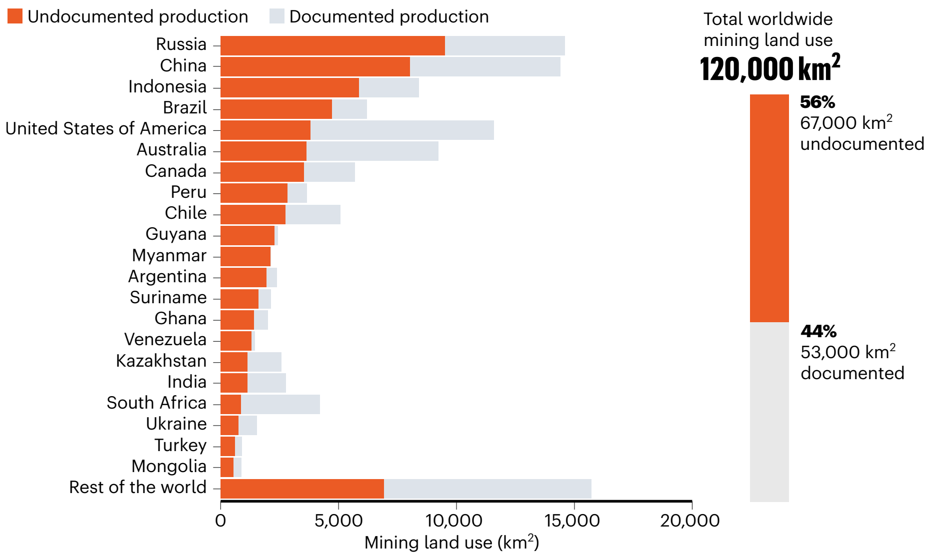
The vast realm of small, artisanal and illegal mines that are not bound by standard reporting requirements is a global problem. The extent of small-scale mining on mineral production varies between commodities and countries, but it is massive. Illegal sand mining, for example, is prevalent in at least 70 countries[13].

Even for legal mining, data availability is an issue, which is often compounded by corruption and lax oversight[14]. Some NGOs, research institutions, governments and mining companies are working to boost the transparency of mine permits, resource estimates, complex ownership structures, production activities and sustainability performance – through groups such as the International Sustainability Standards Board, the Extractive Industries Transparency Initiative, the Global Reporting Initiative and Transparency International.

The mining industry needs to improve the quality and quantity of data that it publishes. Although many companies do not release information, others produce detailed sustainability reports. For those in highly regulated environments, this can be a considerable effort. Yet sustainability reports can be of limited use to researchers because they tend to be aggregated at the level of a company, and don't break down data for specific sites[15].

MISSING MINES

More than half of the global mining areas (56%) visible from satellite images have no production information listed in a global compilation* from the S&P Capital IQ Pro database.



*Specific countries listed account for 90% of global undocumented area

SOURCES: REFS 5 & 6; S&P CAPITAL IQ PRO; V. MAUS *ET AL. SCI. DATA* 7, 289 (2020).

To be clear, we do not advocate for a deluge of new reports that will be cumbersome for companies to produce and for others to interpret. Instead, we advocate for centralized interoperable public data repositories that are simple for companies to upload information to and for the public to access. Such online platforms could, for example, integrate information such as the geographical location of mines, production quantities, water and land use, waste generation and ownership. Private and public funding would be needed to develop these repositories, and an organization to run them would need to be nominated, for example, the International Council on Mining and Metals. Researchers should help by defining sets of essential variables that the mining sector must disclose.

Use remote sensing and artificial intelligence to fill data gaps

Trusted, independent ways to verify what is reported and to fill gaps when information is missing need to be developed. For example, historic or abandoned mines do not have a company that can provide reports on them, yet these mines present a continuing burden, environmentally and financially, on society. They can become sources of environmental disasters owing to the collapse of waste dams or acid mine drainage (as happened at Mount Morgan in Queensland, Australia, where acid mine drainage caused ecological dead zones in the downstream Dee River[16]). For sites that undergo exploration drilling, but have no mining impacts yet, we also know very little.

Remote-sensing techniques can help: satellite data, sensors in smartphones and unmanned aerial vehicles could supplement reported data sources for mining sites. Some of these technologies are already used to monitor mining operations (such as land subsidence in mines) and assess the land footprints of mines[5,6].

Researchers could use such data to estimate the extent of deforestation caused by mining, assess the risks to nearby communities, pinpoint pollution sources and evaluate the effect of mining on regional development. Yet, mapping of mines is still not automated. On a global scale this requires visual analysis of tens of thousands of satellite images, which is time-consuming and requires expert skills[5,6]. Given the rapid and dynamic growth of the mining industry, manual analyses will prove too inefficient to provide frequent updates to accurately reflect land-use changes.

Automation is difficult owing to the complexity of mining operations. Although algorithms excel at recognizing objects with consistent patterns, they struggle with the irregular and diverse structures of mines, such as pits, tailings dams (which are used to store waste materials and water left over from processing ore), waste piles and processing facilities. Mines vary greatly in size, shape and arrangement and their components can be spread over kilometres. Even experts in satellite-image interpretation disagree about which areas constitute parts of a mine.

Researchers are advancing towards automatic detection of specific mine components, such as tailings[17] and open pits[18], using artificial intelligence (AI). However, so far, these methods have only been applied to known mining areas. The challenge in expanding these techniques is the immense amount of data required to train AI models, which in this case aren't available. A vast collection of expert-labelled images would be needed so that the AI system can learn to identify mines correctly. But the labelling process is time-consuming and requires specialist knowledge.

Collaborative efforts are needed to create extensive, global data sets that can be used to train AI. Researchers must establish guidelines and agree on a consistent definition of mine land use. Similar steps will need to be taken to independently produce other types of spatial data and information about mining sites, including waste and pollution. Given the scale of the challenge, research investments of millions of dollars are needed to support interdisciplinary research teams in collecting data, methodological innovation and analysis.

Such investments are crucial as the need for minerals increases, especially for clean technologies, which are estimated to demand up to six times more minerals by 2040 compared with 2020 for a 'net zero' emissions pathway[19]. Mining will inevitably expand, including in environments that have been relatively untouched. Now is the time to ensure we have the best possible data to assess what the impacts and risks will be.

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