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Energy transition minerals and their intersection with land-connected peoples

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John R. Owen[1,2], Deanna Kemp[2] ✉, Alex M. Lechner[3], Jill Harris[2], Ruilian Zhang[2] & Éléonore Lèbre[4]

Rapidly transitioning the global energy system to renewables is considered necessary to combat climate change. Current estimates suggest that at least 30 energy transition minerals and metals (ETMs) form the material base for the energy transition. The inventory of ETMs indicates a high level of intersectionality with territories less impacted by the historic forces of industrialization. To identify the current global footprint, 5,097 ETM projects were geo-located against indicators for indigeneity, human modification of land, food production, water risk, conflict, as well as capacity measures for project permitting, consultation and consent. Study results differentiate ETMs to improve visibility over linkages between technology, resources and sustainability objectives. Our analysis reveals that more than half of the ETM resource base is located on or near the lands of Indigenous and peasant peoples, two groups whose rights to consultation and free prior informed consent are embedded in United Nations declarations.

The climate crisis is the product of a gross imbalance between historical industrialization and the natural world. Limiting global warming to 2 °C would require a 70% reduction of carbon-dioxide emission reductions by 2050[1]. Rapidly transitioning the global energy system from fossil fuels to renewables is considered necessary for addressing climate change. There is a growing awareness that the mineral resource base and the associated local conditions required to support this transition are problematic. However, the social and environmental crisis associated with climate change tends to overshadow the fact that climate mitigation solutions will introduce new impacts and dynamics as resources are extracted to support the transition. Considerations about the local effects of resource extraction are superseded by concerns about the possible severity of climate change and the urgent need to act. Until these local considerations and pressures are better characterized, current climate solutions risk increasing the rate of industrialization, thereby exacerbating the originating problem. This paper characterizes the competing sustainability objectives found at the intersection between mining for the energy transition and territories less impacted by the historic forces of industrialization.

There is no single or standardized set of estimates on the volume of mineral resources needed to support global changes in energy technology and infrastructure. A recent working paper developed by the International Monetary Fund (IMF) confirms the high level of "uncertainty around the underlying metals consumption scenarios"[2]. The authors of the IMF working paper attribute the uncertainty to "technological change that is hard to predict, but which may allow for more possibilities to substitute certain metals" and "the speed and direction of the energy transition depends on policy decisions, which are equally difficult to forecast." These factors are reinforced in the International Energy Agency's (IEA) *World Energy Outlook Special Report*, which states "the largest source of demand variability comes from uncertainty around the stringency of climate policies"[3].

Current analyses include at least 30 energy transition minerals and metals (ETMs) as forming the material base for the energy transition[4,5]. The IEA projects lithium to have "the fastest growth, with demand growing by over 40 times by 2040, followed by graphite, cobalt and nickel (around 20–25 times)"[3]. Copper and iron are ubiquitous metals and are essential for power generation, transportation and use. UNEP's GEO-4 Policy First scenario predicts a 275% increase

[1]Centre for Development Support, University of the Free State, Bloemfontein, South Africa. [2]Centre for Social Responsibility in Mining, Sustainable Minerals Institute, The University of Queensland, Brisbane, Queensland, Australia. [3]Urban Transformations Hub, Monash University Indonesia, Banten, Indonesia. [4]Sustainable Minerals Institute, The University of Queensland, Brisbane, Queensland, Australia. ✉e-mail: d.kemp@smi.uq.edu.au

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in copper demand by 2050[6]. Building a low-carbon energy system to meet the world's electricity needs by 2050 will require 1.3 billion tonnes of iron[7]. Electric vehicles require numerous ETMs, including lithium, cobalt and nickel, each vulnerable to supply constraints[8]. Moreover, the rapid growth in hydrogen technology as an energy carrier is a key driver for "demand for nickel and zirconium for electrolysers, and for platinum-group metals for fuel cells"[3]. Although scaling up the supply of ETMs is necessary to meet heightened demand, resource extraction is a highly contingent solution that intensifies competition between climate change mitigations, environmental values, land use and the protection of land-connected peoples' rights.

Our analysis is anchored to the world's source of ETM supply; that is, to mining project locations[9–11]. We use a publicly available dataset[12] to examine specific sustainability trade-offs of ETM mining in the context of the global energy transition. Mining activities are associated with extensive land appropriation and degradation, with a footprint of at least 101,583 km^2 (ref. [13]). We describe the application of international sustainability policies and mandates on mining-affected land and people. The intersectionality of rights and interests in these project locations is integral to understanding global systems effects of finance, regulation and technologies for resource extraction[14]; systems that are predicted to expand and intensify as demand for minerals grows[15].

To identify the current global footprint of ETMs, 5,097 projects were mapped. This set of projects includes both current and future possible mines. Geo-referenced locations for projects were analysed using indicators for land ownership and use, human modification of land, food production, water risk, conflict, as well as national capacity measures for protecting land-connected peoples' rights. We develop a novel set of indicators to examine systems for ETM project permitting, consultation and consent. In combination, these indicators capture a prominent set of contemporary sustainability objectives relating to the environment, human rights and development[16]. Application of these indicators enable our characterization of the intersection between mineral resource extraction and land connectedness.

The focus of our analysis is the lands of Indigenous peoples and peasants as reflected in the *United Nations Declaration of Indigenous Peoples* (UNDRIP)[17] and the *United Nations Declaration on the Rights of Peasants and Other People Working in Rural Areas* (UNDROP)[18]. As some of the least industrialized lands on Earth, these locations constitute our 'geographies of interest'. Recent estimates suggest that Indigenous peoples exercise some form of territorial control over 30% of the world's land surface[19]. No equivalent estimate exists for peasant land. In addition to formally controlled territories, our study acknowledges Indigenous peoples' lands where collective rights could be asserted but where state recognition may be absent. We also include lands and territories over which peasants may be expected to hold collective rights to land. The study estimates the extent and core sustainability issues associated with the overlap between these geographies of interest and global ETMs. Our analysis reveals that more than half of the ETM resource base is located on or near the lands of Indigenous and peasant peoples (see Methods for definition of 'near').

Developing ETM projects to mitigate the effects of historical industrialization will paradoxically involve encroaching on landscapes with high levels of ecological and cultural integrity and traditional forms of land tenure and ownership[20–22]. Approving and permitting the development and expansion of these projects will test the protections available to Indigenous and other land-connected peoples and the lands and territories over which they hold collective rights and entitlements.

Results

Indigenous peoples' and peasant land

UNDRIP and UNDROP aim to protect land-connected groups generally located in the least industrialized regions of the world or where land is essential to upholding universal human rights. These groups are typically connected to land, territory and surrounding natural resources; are non-dominant, minority or face discrimination; and have distinctive social and political systems, culture and language. UNDRIP and UNDROP affirm the right of these groups to make key decisions about development on their lands and territories. Extracting more ETMs to advance the energy transition will extend the global mining land footprint presenting significant threats to social and environmental sustainability. Processes of self-determination tend to see Indigenous peoples prioritize cultural and ecological values over indiscriminate industrial development[22]. Increases in global demand for ETMs is likely to impose unprecedented pressure on these rights-holding groups. Indigenous peoples' and peasant lands are at the forefront of competing sustainability objectives where the location and likely social and environmental trade-offs associated with resource development have not previously been established.

Mapping the global inventory of ETMs indicates that a high proportion of ETM projects are in geographies covered by these two UN instruments (Fig. 1a). Across the sample of 5,097 ETM projects, 54% of projects are located on or nearby Indigenous peoples' lands, with 29% of these projects on or near lands over which Indigenous peoples are recognized as managing or exercising some form of control or influence over land for the purposes of conservation[19]. These geographies are most relevant to UNDRIP. For UNDROP, the spatial analysis reveals that 33% of projects are located on or nearby peasant land. Combined, 69% of ETM projects are on or near land that qualifies as Indigenous peoples' or peasant land. Considering the potential for overlapping identities across these two demographic groups, we tested for co-occurrence of land type. Approximately 1 in 5 (18%) projects in our sample qualify as being located on or near both Indigenous peoples' and peasant land.

Differentiating the bundle of ETMs by individual commodities reveals the types of source conditions associated with the energy transition and the competing sustainability objectives we have identified. We find that the commodities with the highest proportion of reserves and resources on or near Indigenous peoples' land are lithium (85%) and manganese (75%) (Fig. 1b, and Supplementary Table 1 for results of all ETMs and Supplementary Fig. 1 for regional maps). For land occupied by peasant populations, the commodities with the highest proportion of reserves and resources are graphite (83%) and platinum (82%). Manganese (63%), platinum (46%) and rare earth elements (42%) overlap both types of territory. Given the critical nature of these individual commodities for decarbonizing the global energy system, identifying the overlap between ETMs and territorial rights to understand land pressures and to test alignment across sustainability objectives is needed.

Low-carbon energy technologies use different combinations of ETMs. The source locations of specific technologies are presented in Fig. 1b. For instance, lithium-ion batteries are the dominant energy storage technology for electric vehicles[8]. These batteries require five key ETMs: graphite, nickel, manganese, cobalt and lithium[2]. Renewable technologies require different combination of ETMs that have different locations, giving contrasting sustainability profiles. The vast majority of graphite resources are located on or near peasant land; lithium resources are primarily on or near Indigenous peoples' land; manganese has the highest proportion of resources on lands that overlap both types of land; and nickel and cobalt suggest similarly complex landscape interactions. Solar photovoltaic power, by contrast, is dominated by aluminium, copper and silver[2]. Aluminium, a refined product derived from bauxite, has the highest proportion of resources overlapping one or both geographies of interest, while copper and silver resources offer a relatively diverse mix of source locations, with a predominance of Indigenous peoples' territories.

Our results show regional variation in the intersectionality between ETMs and Indigenous peoples' and peasant land (Fig. 1a). The Middle East shows the highest proportion of projects located on or near Indigenous peoples' land (82%), although this region has a relatively small number of disclosed ETM projects. Otherwise, the

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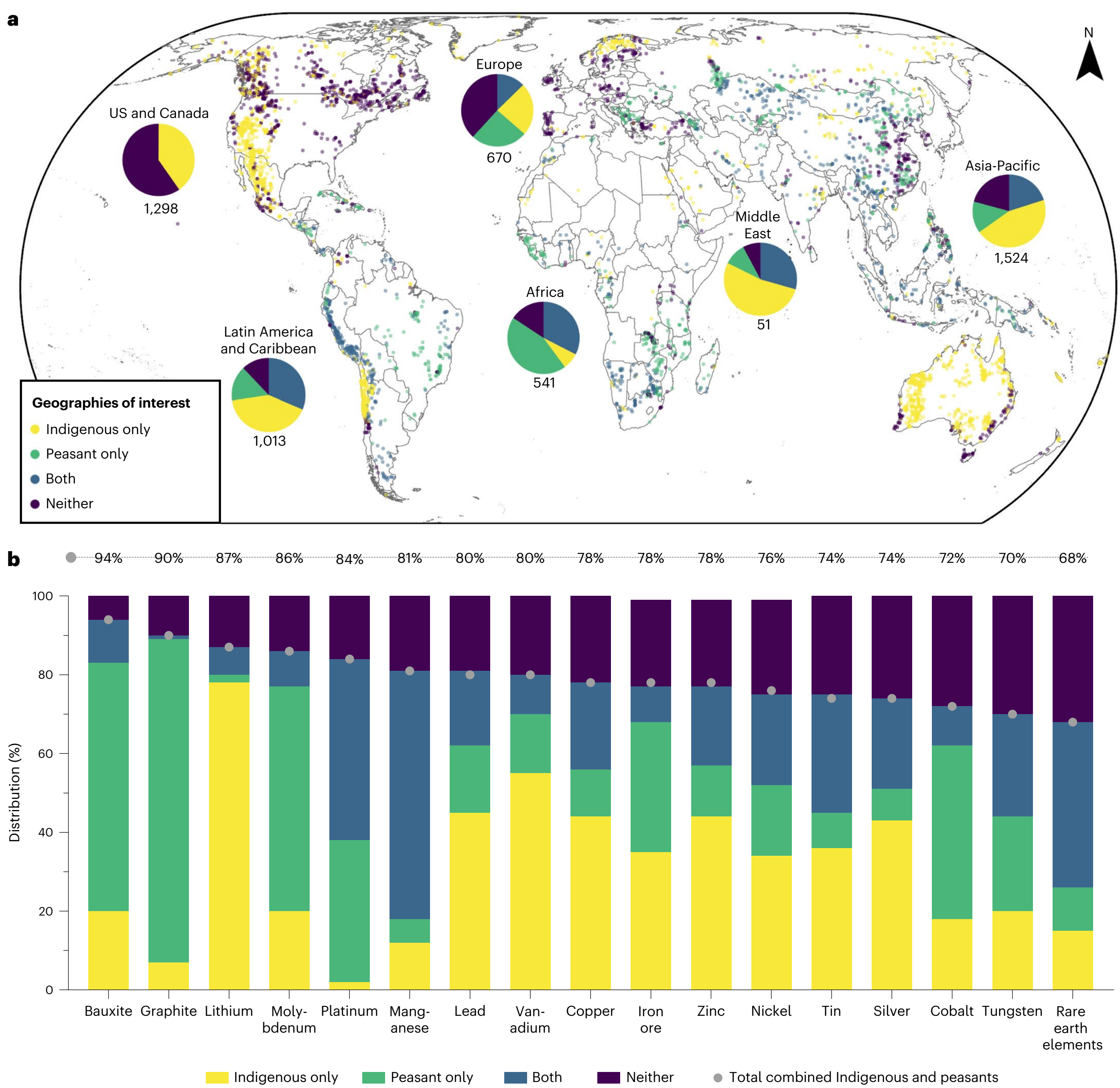

Fig. 1 | Distribution of ETMs by Indigenous peoples' and peasant land. a, Geographic distribution of mining projects, $n = 5{,}097$. **b**, Distribution of energy transition minerals and metals reserves and resources. The selected 17 minerals and metals have the highest number of extractive projects worldwide. Percentages at the top of the figure represent those for the 'total combined Indigenous and peasants' variable.

Latin America and Caribbean region has the highest proportion of projects located on or near Indigenous peoples lands (73%). Africa has the highest proportion of projects located on or near land that meets the criteria for peasant land (77%). Reflecting the rich and complex history of settlement, conflict and displacement in Africa, this region has the highest proportion of projects located on or near both Indigenous peoples' and peasant land (33%). The United States and Canada region and parts of the Asia-Pacific region (for example, Australia) have significant Indigenous populations but due to their development status were excluded from the analysis for peasant populations (Methods). In summary, the results describe the regional application of UNDRIP and UNDROP in the context of mineral extraction for ETMs.

Local context vulnerability and ETMs

Multiple international policy objectives, even those stemming from single institutions such as the UN and multi-lateral development banks, promote goals that raise compatibility questions with respect to climate change and the spread of industrialization. The UN Sustainable Development Goals (UNSDGs) outline 17 thematic targets with the collective objective of addressing climate change, water and food crises, systemic poverty, conflict, well-being and inequality[16]. For example, Goal 2 "End hunger, achieve food security", requires markedly improved access and security of tenure over land for small-scale food producers, including Indigenous peoples and peasants. The focus of Goal 6 is the availability and sustainable management of water with the outcome

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being universal equitable access to affordable drinking water. Goal 16 promotes peaceful and inclusive societies by reducing causes of violence and protecting fundamental freedoms.

Relatedly, the UNDRIP establishes a universal framework of minimum standards for the survival, dignity and well-being of Indigenous peoples and elaborates on existing human rights standards and fundamental freedoms. Adopted by the UN General Assembly (UNGA) in 2007, the declaration requires participating states to provide redress when Indigenous peoples' cultural, intellectual, religious and spiritual property is taken without their free, prior and informed consent (FPIC), or when there has been a violation of their laws, traditions or customs (Article 11.2). UNDRIP also requires FPIC before Indigenous peoples are displaced from their lands or territories (Article 10); when adopting and implementing legislative or administrative measures that may affect them (Article 19); and when hazardous materials are to be disposed of or stored on the lands or territories of Indigenous peoples (Article 29).

In 2018, following decades of grass-roots advocacy, the UN formally adopted UNDROP. According to Van der Ploeg's[23] estimates over a decade ago, peasants constitute 40% of the world's population. A recent report released by the UN Office of the High Commission for Human Rights found that peasants represent 80% of the world's hungry and 70% of people living in extreme poverty. Mining activities heavily impact land and water, have a high association with conflict[24] and increasingly interface with rights holding groups represented by UNDRIP and UNDROP. Approximately a quarter (23%) of ETM projects on or near Indigenous peoples' or peasant land are located within 50 km of recent violent conflict, compared with 20% of ETM projects globally. The results show that 71% of projects on or near Indigenous peoples' or peasant land are in food insecure jurisdictions compared with 60% of ETM projects globally. Further, 62% of projects on or near Indigenous peoples' and peasant land are in high water risk locations, compared with 53% of projects globally. These results indicate high context vulnerability surrounding the global stock of ETM commodities.

There is variation in context vulnerability across commodity groups (Fig. 2, Supplementary Table 2). The findings show that while many ETM projects in our geographies of interest (that is, the lands and territories of Indigenous peoples and peasants) are found in areas with generally high levels of water risk, some commodities are particularly exposed. Bauxite, the top ETM in terms of proportion of resources on or near Indigenous peoples' or peasant land, has a low exposure to water risk. The other four top ETMs, graphite, lithium, molybdenum, and platinum, are some of the most exposed commodities to water risk. For ETM projects on or near Indigenous peoples' or peasant land that are proximate to recorded conflict events[25], the highest proportion of resources is platinum (74%), followed by tin (48%), silver (42%) and graphite (37%). Broadening the definition of conflict to national level conditions through the Global Peace Index[26] increases scores for platinum to 99%, followed by molybdenum (88%) and tin (86%). Adding food security drastically increases the number of ETM commodities with high contextual risk factors. Based on these findings, more than a third of ETM projects on or near Indigenous peoples' or peasant land face a co-occurrence of water risk, conflict (local and national) and suboptimal food security conditions. Platinum has by far the highest co-occurrence of water risk, food insecurity and conflict conditions, with 91% of reserves and resources on or near Indigenous peoples' or peasant land with these three contextual risks, followed by molybdenum (76%) and graphite (74%).

National measures for permitting, consultation and consent

Six mainstream national capacity measures for permitting, consultation and consent were applied to the 3,538 ETM projects located on or nearby Indigenous peoples' or peasant land (Methods). These measures reflect the roles played by states in upholding UN-level sustainability objectives, and include (i) resource governance, (ii) regulatory quality, (iii) education, (iv) freedom of the press, (v) civil liberties and (iv) corruption. Taken together, these six national measures serve as proxy indicators for state processes of permitting, consultation and consent.

For this sample of ETM projects, 43% (1,516) are in jurisdictions that score above the medium risk threshold for resource governance, 37% (1,308) for regulatory quality, 53% (1,882) for education, 59% (2,091) for press freedom, 49% (1,744) for the civil liberties and 60% (2,110) for corruption. Overall, 60% of projects in the geographies of interest are in jurisdictions where the majority of measures contain scores above the medium threshold. Viewed by commodity, 99% of reserves and resources for platinum in the sample are in jurisdictions where the majority of measures exceed the medium threshold. This is followed by tin (97%), graphite (93%), rare earths (93%) and cobalt (83%) (Supplementary Table 3).

Combinations for permitting, consultation and consent were also examined against the contextual factors analysed above (that is, water, food and conflict). In total, 49% (1,724) of projects in this sample are in jurisdictions where the majority of measures for both permitting, consultation and consent, and water, food and conflict exceed the medium risk threshold. The top five countries that exceed the medium threshold in the majority of both sets of measures were China (311 projects), Mexico (212), Peru (186), South Africa (135) and Brazil (116) (Supplementary Tables 4, 5). Finally, the proportion of ETM reserves and resources for this sample with a majority of combined measures above the medium threshold is highest for platinum (91%), graphite (84%), bauxite (78%), molybdenum (78%) and tin (77%) (Supplementary Table 3).

Discussion

The local or 'source level' effects of globally intensifying industrial mining on Indigenous peoples' and peasant lands are already evident given mining's well-documented social and environmental impacts[27–29]. Decades of detailed case study research reveal hard trade-offs between resource extraction and environmental and social values[11]. Many of the world's 'complex orebodies'[30]; that is, projects exhibiting elevated risk across multiple concurrent domains, remain undeveloped due to the constraints and consequences of bringing these underground resources to the Earth's surface, and then to global markets. Heightened demand for ETMs, and the price incentives offered to resource developers, could usher in a new generation of mining projects in which global sustainability objectives and local operational impacts will become fundamentally incompatible. This collision will involve both new complex orebodies and existing projects, in addition to managing the present distribution of impacts associated with the current global energy system[31–34].

Where large-scale mining projects interact with territories with high ecological and cultural values and traditional forms of land tenure and ownership, the effect is a basic incompatibility between the preserve and protect functions of UN instruments, and the extraction of the orebody. Existing mining projects exemplify these policy tensions for two reasons: (i) they form the evidence base for future sustainability outcomes and (ii) their expansion will support the material demands of the global energy transition. We provide global case evidence of these tensions below.

Resource extraction, human rights and sustainable development

Mineral resource extraction impacts on the core elements of the UN SDGs. The effects of mining are cumulative, cutting across multiple sustainability objectives and commodity types. The Porgera gold mine in the highlands of Papua New Guinea, for example, carries the consequences of a large-scale industrial project (i) rushed into production, (ii) on customary land, and (iii) in a remote low governance area with high levels of poverty. Design features permitted in the early phases of the project have plagued the community, and include riverine tailings disposal, short-term strategies for land acquisition and the relocation

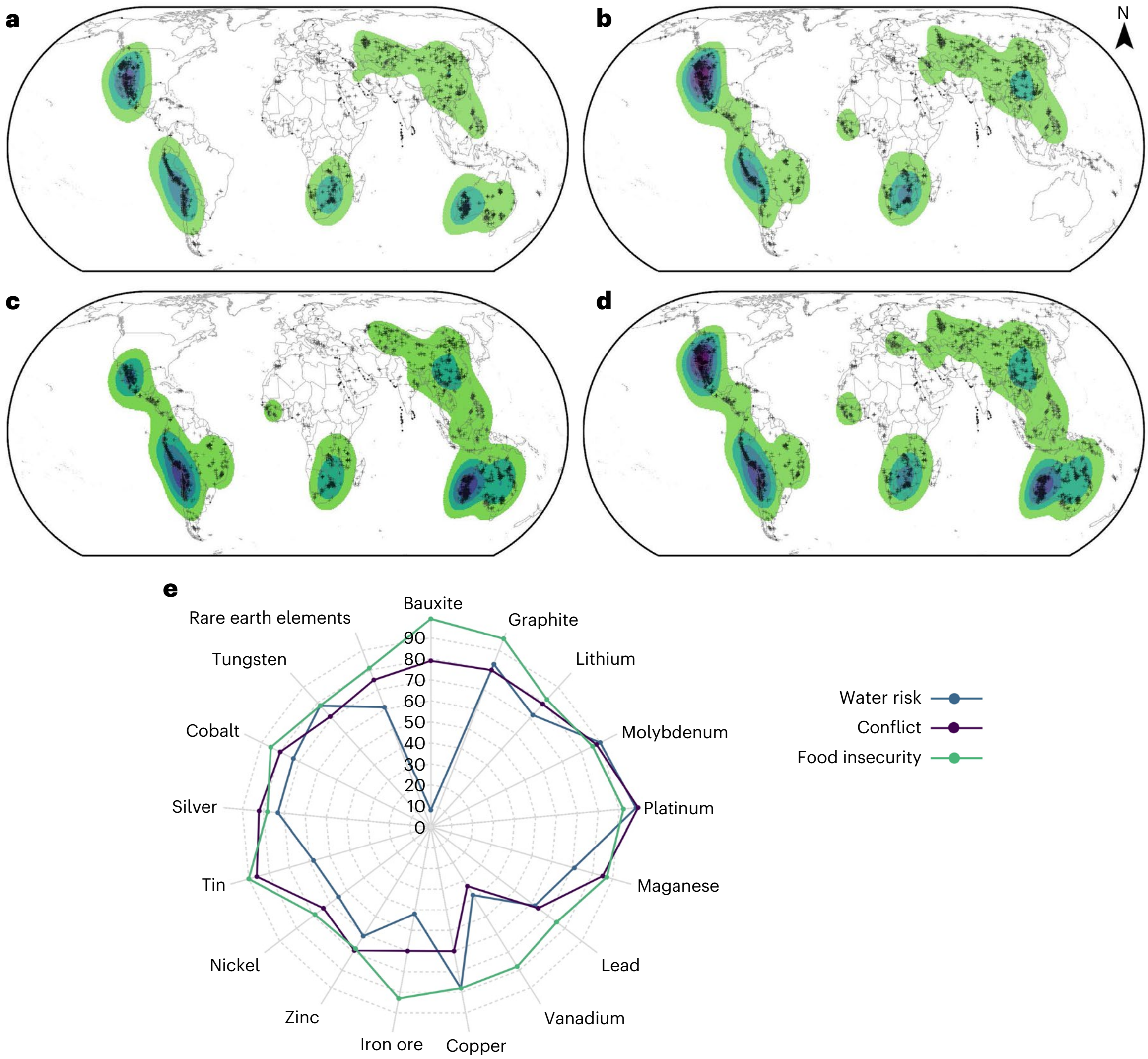

Fig. 2 | Distribution of energy transition minerals and metals by water risk, conflict and food insecurity. a–**c**, Spatial distribution and global hotspot density maps of mining projects on or near Indigenous peoples' or peasant land with water (**a**), conflict (**b**) and food insecurity (**c**) risks (n = 3,538). **d**, Spatial distribution of projects on or near Indigenous peoples' or peasant land and global hotspot density map for all three contextual factors (n = 3,538). Hotspot analyses conducted using kernel distance estimation. **e**, Distribution of energy transition minerals and metals reserves and resources.

of human settlements, and a heavy-handed approach by the state to managing local conflict. Population influx has occurred to the extent that neither the government nor the project are able to manage rights over land, project benefits, or basic social and environmental impact management[35]. Successive project expansions over thirty years have produced a waste footprint that has encroached on food production areas and water sources necessary for meeting household subsistence. Remote sensing for the period 1987–2017 shows that the combined land areas used for mine pits and mine waste in Porgera expanded by 4,179%[36].

Russian-owned Nornickel is the world's top producer of palladium and nickel and a major producer of copper, platinum, cobalt, silver and gold, supplying 37 countries. A major polluter, in 2018 the company emitted more sulphur dioxide than the entire United States[37] and is responsible for the Arctic's largest industrial disaster following a diesel fuel spill in 2020. Elsewhere, the historic top tier polymetallic project, Bawdwin, with an estimated 20 million tonnes in silver and lead reserves, is located in an active conflict zone in the Shan State of Myanmar. Mogalakwena is the world's largest open pit platinum operation, with 117,200,000 ounces of reserves. In 2008, an investigation by the South African Human Rights commission found that people had been forcibly displaced and denied access to water, sanitation and electricity, and faced air and water pollution, disruption to food security and loss of cultural heritage through the removal of grave sites.

Across these projects, chronic overcrowding, food and water insecurity, serial unmitigated population displacement, frequent outbreaks of tribal or ethnic violence and resource-related conflict, repeated claims of human rights abuse, and severe environmental damage not only impede but directly undermine the UN SDGs and the more fundamental instrument, the UN Universal Declaration of Human Rights.

Waste and catastrophic disasters

The global mining industry produces several billion tonnes of liquid and solid waste per annum[38]. As demand and the exploitation of lower grade ETM ore at greater depth has grown, the volume of ETM mine waste has increased exponentially[39]. At the surface, mine waste prevents other land uses, including conservation, farming, forestry, and for cultural and religious purposes. Mine waste also drives large-scale industrial disasters. In 2014, a 4 km^2 tailings storage facility at the Mount Polley gold and copper mine in Canada's British Columbia emptied a slurry of tailings (crushed rock) and mine process water into local creeks and

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pristine lakes. The slurry raised the Polley Creek by 1.5 metres, and carried trees, mud and other debris into the ecosystem, disrupting shorelines, human settlements and fish habitats, places inhabited and used by First Nations groups[40]. In 2019, the Samarco disaster in Brazil killed 19 people, with mine waste and debris flowing more than 600 km through the River Doce to the sea. In 2019, another 270 people perished in the Brumadinho tailings disaster, Brazil's worst recorded industrial accident. The local impact of these successive failures threatens a multitude of sustainability objectives, including life itself. For survivors, this includes the most basic of human needs: safe access to potable water and sanitation, food and shelter after the disaster.

Destruction of irreplaceable heritage

For Indigenous peoples and peasants, culture and heritage are perennial elements that embed connection to land[41] and are fundamental to claims and visions for self-determination and nation building. In most mining jurisdictions, states prioritise the macro-economic contribution of mining over culture and heritage. One of the most public and egregious cases of neglect occurred in 2020, in the Pilbara region of Western Australia, when Rio Tinto legally destroyed two ancient and sacred caves in the Juukan Gorge to expand an iron ore mine. The 46,000 year-old site contained artefacts with genetic links to the present day traditional owners, the Puutu Kunti Kurrama and Pinikura peoples. Despite their known significance, the caves were not listed on the national heritage register, enabling a state minister to grant pre-approval for destruction of the caves. In Western Australia, these approvals are routinely underpinned by negotiated agreements offering traditional owners monetary compensation to waive their statutory rights, and refrain from disrupting a company's right to destroy their heritage or disparaging them from exercising that right. The deleterious effect on sustainability objectives include local economic dependence, the destruction of irreplaceable heritage, and the silencing of Indigenous voices. Here, the tensions between sustainability objectives are obvious. Iron ore is a vital ETM, whereas its extraction can undermine others sets of objectives and rights.

Future ETM projects

The profile of greenfield projects in the future pipeline exhibit many of the same underlying characteristics as the projects in our global dataset[12]. Resolution Copper (United States), Tampakan (Philippines) and Pascua Lama (Chile) are prominent examples where contestation over sustainability objectives have surfaced in the pre-development stage. Our results show that 68% (n = 2,409) of the 3,556 early stage ETM projects are located on or near Indigenous peoples' or peasant lands. Water stress is present in 59% of these projects, 64% are in close proximity to conflict conditions, and 67% in jurisdictions with marginal food security (Supplementary Table 6). Cumulatively, 65% of greenfield ETM projects on or near Indigenous peoples' and peasant land have profiles that show high levels of concurrent risk across two or more context metrics (water, conflict, food insecurity).

The present threat to planetary limits caused by over-industrialization is indeed alarming. Re-balancing these limits through the prism of energy and new technology creates further conditions of imbalance and erodes important sustainability objectives that are necessary for the protection and preservation of the world's ecosystems and universally agreed human rights of historically marginalized peoples. It is vital that the world's policymakers better recognize this tension and insist that conditions at the source of minerals supply are factored into decisions about climate-mitigation strategies. This will help to ensure that global climate solutions do not inadvertently or irrevocably undermine parallel sustainability endeavours.

Methods

This paper analyses the overlap between ETM mining locations and the identified geographic areas in which Indigenous peoples and peasants are likely to have interests reflected by two UN declarations: UNDRIP and UNDROP. These instruments symbolise landscapes with high ecological and cultural values, considerably less industrial impact than other areas of the world. We are cognizant of recent and contemporary debates regarding the categorisation of peoples and the identity politics associated with the criteria and definitions offered across different international instruments[42,43]. The emphasis in our study is on the rights and connections to land that are reflected in these instruments. It is important to note that this research is not a definition setting exercise but is rather focused on areas over which historically land-connected people may be expected to justifiably exercise various rights and claims. We argue that these areas provide an indication of the potential scope of overlap between the future supply of ETMs and historically agreed protocols with respect to the use of lands over which groups within the purview of UNDRIP and UNDROP have recognised rights or have claimed rights. These protocols, if observed, have direct implications for how discrepancies between sustainability objectives will be managed or traded-off into the future. The methodology presented below estimates the spatial extent of Indigenous peoples' and peasant land, their intersection with ETM mining projects, as well as the presence of (i) specific contextual factors relevant to the mine-community interface and (ii) permitting consultation and consent measures.

ETM list

This first step in the method involves identifying the mineral and metal resources needed in the energy transition. To arrive at a definitive inventory of ETMs, we consolidated materials lists from three landmark reports from the International Energy Agency[8], the World Bank[2] and the International Institute for Sustainable Development[3]. The resulting list comprises 29 Energy Transition Minerals and Metals (ETMs), see Supplementary Table 7. It includes (i) specialty commodities used in low-carbon energy technologies (for example graphite and lithium), and (ii) major commodities used in low-carbon energy infrastructure (for example iron and copper). Demand for specialty ETMs will depend on the pace and scale of technological development, roll-out and implementation. The assumption is that major ETMs (aluminium, copper, iron, lead, nickel and zinc) will be needed irrespective of which technologies dominate the market.

Mining project data

This second step identifies a global set of mining projects extracting or projected to extract ETMs. Mining project data was sourced from the S&P Capital IQ Pro database (formerly S&P Global Market Intelligence). As of November 2021, the S&P database maintains records on 36,395 geolocated mining projects worldwide at all development stages, from grassroot exploration to closure[44]. The S&P database is one of the most comprehensive and up-to-date sources of mining data[10,30]. It is reflective of current investments and metal market interests. Resources that sit outside of a project boundary are generally not covered by the database. Similarly, informal mining activities such as artisanal and small-scale mining are typically not covered for ETM commodities.

From the 36,395 geolocated mining projects in the database, 20,683 are extracting or projected to extract ETMs according to the list shown in Supplementary Table 7. ETMs may either be the primary target commodity or mined as a by-product (for example, silver as a by-product of gold extraction). In polymetallic orebodies, several ETMs may be extracted as part of the same project. For this study, we selected projects with records containing reserves and resources. This subset of 5,097 projects (about 25% of all ETM projects) represents known ETM deposits where investment was committed towards either defining the orebody or mining development[12]. Projects that have not reported reserves and resources are typically in early stage of development (before resource definition), have ceased to operate, or have not disclosed the information publicly. Current reserves and resources

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estimates are used as the basis for understanding projects' relative contribution to future global supply. Supplementary Table 7 shows the number of projects for each of the 29 ETMs.

Proximity of ETM projects to geographies of interest

A complete global delineation of Indigenous peoples and peasants lands does not exist. To overcome this deficit we developed proxies to test against several global GIS datasets. We began by establishing inclusion criteria to estimate the proximity of projects to our geographies of interest. This centred on a 10-km buffer around project coordinates to capture direct proximity to three relevant land types: Indigenous peoples' land, crop land and pasture land. The 10 km buffer serves two purposes: (i) it represents the direct area of influence around a mining project, and (ii) it accounts for location errors and the coarseness of global GIS datasets. Buffers of 20 km and 100 km were then applied to approximate average population densities around ETM projects and to focus the analysis on the least populated and least industrialized areas. Buffer radiuses and population density thresholds were determined through a series of internal validity checks (Supplementary Note 1). Supplementary Tables 8–10 test the influence of different radius and threshold choices. The application of additional GIS datasets refined the criteria for an ETM project's proximity to our geographies of interest. For example, the Indigenous peoples land proxy considered the ecological zones in which Indigenous peoples are often connected. The following paragraphs provide additional methodological detail for each geography of interest.

Indigenous peoples' land data

The GIS dataset developed by Garnett et al.[19] was used as a base plate for showing the global distribution of Indigenous peoples' territory. Using the geo-spatial coordinates of mining projects known to be on, or in close proximity to Indigenous peoples' land, we map Garnett and colleagues' records against geographical areas where Indigenous, tribal groupings or strong claims to customary tenure are active or have been recognized and supported by state instruments. We included a 10 km radius from the geo-referenced point of the project to allow for location errors or the potential for claims to arise over adjacent land areas. This effectively increases the coverage of Garnett and colleagues' polygons by 10 km for each identified project.

In identifying areas where Indigenous peoples' rights have not been extinguished by historical processes of conquest and colonization or subsumed by mass urbanization and industrialization, we applied the following additional criteria. First, arid, polar and tropical rainforest climatic regions were selected[45]. Second, a population density threshold was set at an average of 100 people per km^2 within a buffer of 100 km radius around the project location[46]. These two criteria reflect the low level of industrial disturbance on remote desert, forested and arctic landscapes, and the more general constraint on development imposed by systems of inalienable group tenure. As a verification step, known ETM projects were checked for coverage (Supplementary Note 1). The addition of land cover and population density criteria vastly improved coverage over Latin America and the Pacific, two regions where Indigenous and or customary rights are present, but which do not feature in the data set of Garnett et al. See Supplementary Table 11 for the list of datasets used in this step of the procedure. Accounting for transient or nomadic groups across these geographies will require new methods of approximation, and this represents a limitation in both our approach and that of Garnett et al.

Peasants land data

The literature indicates that these landscapes are predominantly agricultural and increasingly exposed to industrialization and urbanization pressures as cities and large regional centres expand. Population densities have been historically low, however with the encroachment of cities and the gradual incorporation of peasant workers into seasonal waged labour, these economic systems are becoming more difficult to distinguish[47]. Even with these expanding pressures, scholars such as Van de Ploeg[23], have reported increases in the number of peasants arguing that they still constitute approximately 40% of the world population (see also ref. [48]).

At the time of writing, no single publicly available global spatial dataset exists through which to map the extent of peasant lands. Their marginal status relative to urban settlements, the market economy and formal land tenure systems create distinct challenges in terms of selecting stable global-scale identifying criteria. The data presented in this study represent a first approximation of the likely extent of mining projects and their intersection with peasant lands. The construct used in this paper applied the following logic recognizing the high potential for error and the opportunity for future improvements in subsequent research. First, all Organisation for Economic Co-operation and Development (OECD) countries were excluded from the set. This generates a 'less developed or developing country only' sample. It can be argued that some OECD countries (for example Chile and Hungary) contain peasant populations, but for our purposes we have opted for a more conservative frame of analysis to avoid overstating the extent of peasant land and its impact on future ETM supply. We have also allowed for an overlap between Indigenous peoples and peasant populations where people (i) living in remote locations in non-OECD countries, or (ii) who fall within the spatial dataset of Garnett et al.

To capture the defining agricultural feature of peasants, two additional criteria were applied, one qualifying the presence of agricultural (croplands and pasture lands) in proximity to the project, and the second measuring rurality. Land areas classified as cropland or pasture using the Unified Cropland Layer[49] and the Global Pasture Lands[50] datasets were included (Supplementary Table 12) noting the relatively low levels of convergence between croplands and pasture with the conservation areas that are the primary focus of the work by Garnett et al. Regarding the rurality criteria, no town distances were used, given that encroachment and town–labour interactions have been identified as increasingly regular in the literature, and that large-scale mining projects are rarely established in densely populated areas due to the high economic values attached to built-up areas and their associated activities. Instead, the rurality criteria used a measure of population density, determined through a 'build and check' iterative process where known ETM projects were checked for coverage (Supplementary Note 1). Unlike the Indigenous peoples' land proxy developed above, using a 100 km radius for peasant lands draws in a large number of industrialized areas attached to major city centres. To narrow the focus to lands occupied by peasant groups, the radius was reduced to 20 km with an adjusted population density of 200 persons per km^2. Our process allows for a high level of confidence in terms of identifying agrarian landscapes in near proximity to resource projects, based on conservative application of the selection criteria with known exclusions that would otherwise qualify.

Contextual data on food security, water risk and conflict

To understand the effect of ETMs on key sustainability factors, three contextual measures were used. These measures are taken as factors that might further complicate or strain institutions or individuals and groups in terms of progressing identified sustainability goals. Thematically the following factors were included: conflict (at both national and immediately locality scale)[25,26], food insecurity (as a proxy for time-use, vulnerability and disparity in bargaining position)[51] and water risk (noting vulnerability, and high levels of competition among users)[52]. For each measure, a medium risk threshold was determined, and we assessed the proportion of projects in jurisdictions above that threshold (Supplementary Tables 13 and 14, and Supplementary Fig. 2).

National capacity measures

To understand the quality of institutional support for people who fall within the geographies of interest, six national measures were applied: (i) resource governance[53], (ii) regulatory quality[54], (iii) education[55], (iv) freedom of the press[56], (v) civil liberties[57] and (vi) corruption[58]. Taken together, these six measures provide a broad picture of national conditions around mining developments, including the quality of procedural safeguards and respect of rights and freedoms. These conditions underlie mine permitting and approval processes, as well as how mining developers consult and obtain consent from rights holding groups such as Indigenous peoples. For each measure, a medium risk threshold was determined and the proportion of projects in jurisdictions above that threshold assessed (Supplementary Table 15). A sensitivity test confirms the stability of the threshold measures used for (i) the national capacity measures and (ii) the contextual data (Supplementary Note 2, Supplementary Figs. 3, 4, Supplementary Tables 16–19).

Reporting summary
Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability
The dataset analysed during the current study is available in The University of Queensland repository. https://doi.org/10.48610/12b9a6e Source data are provided with this paper.

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Author contributions

The research was conceived and designed by J.R.O., D.K. and É.L.; methodological development for this paper were conducted by J.R.O., D.K. and É.L.; É.L. and R.Z. analysed the data; analytical tools and data visualization were provided by R.Z., J.H. and A.M.L.; A.M.L. and J.H. designed Figs. 1 and 2. The paper was written by J.R.O., D.K. and É.L.

Competing interests

The authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to Deanna Kemp.

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Corresponding author(s): Deanna Kemp

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Study description	The study extracts values from 19 spatial variables at the location of 5,097 mining projects. Mining projects are grouped by resources to obtain a risk profile for each of the 29 metal commodities studied. The study uses existing data and does not generate new data.
Research sample	Mining project data including latitude and longitude were extracted from the S&P Global Market Intelligence database, which is a commercial database that gathers public disclosure data, mainly reported by project owners. The 5,097 mining projects represent all records from the database that have declared reserves and resources for the metal commodities analysed. The 19 variables are compiled from 19 publicly available global datasets from 17 different sources including the United Nations, the World Bank, the World Resources Institute, the NASA Socioeconomic Data and Applications Centre, the European Commission Joint Research Centre, Transparency International and several academic sources.
Sampling strategy	Not relevant. The mining project sample is the maximum possible sample, and its size is limited by global data availability. The number of datasets chosen for the analysis also depends on the availability of global-level data and its ability to accurately characterize the environmental, social and governance aspects analyzed. The number of datasets is not a criteria for accuracy.
Data collection	Mining project data was extracted from the S&P Global Market Intelligence directly to an Excel file using the S&P database screener and Excel add-in. Spatial datasets were downloaded directly from their online repositories. Data was collected by the first and second authors.
Timing and spatial scale	S&P database extraction was in September 2021 and datasets were extracted between September 2021 and February 2022.
Data exclusions	The mining project sample excludes projects with no declared reserves and resources on the basis that the development of these projects is uncertain. Our global sample of mining projects is selected to be representative of the future global supply of energy transition metals. The same exclusion criteria was used in previous publications (Valenta et al. 2019, Lebre et al. 2020). This study twice excludes projects for sensitivity analysis. 1) Sensitivity analysis for Permitting, Consultation and Consent measures. We use ordinary least squares (OLS) regression model and the robust regression model (M estimation method) to test stability of each dimension. The test excludes 517 projects without values, and total 4580 projects are included (Supplementary Table 12 &13). 2) Sensitivity analysis for Local and National Contextual Factors measures. We use ordinary least squares (OLS) regression model and the robust regression model (M estimation method) to test stability of each dimension. The test excludes 328 projects without values, and total 4769 projects are included (Supplementary Table 14 &15).
Reproducibility	Not relevant. The study can be reproduced using the same existing data collected by the authors and following the same methodological steps detailed in the Method section and in the supplementary information. The study does not generate new data.
Randomization	The method selected for the sensitivity analysis did not require randomization. Two sets of robustness tests (ordinary least squares regression model and the robust regression model [M estimation method]) were used to confirm the stability of the dataset generated by different measures and thresholds and is described in the supplementary information.
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