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Compound exposure: Climate change, vulnerability and the energy-extractives nexus in the Pacific

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ABSTRACT

A global push for an energy transition to combat climate change is fuelling demand for energy transition minerals and metals (ETMs) needed for renewable energy-systems. As the primary solution to our planetary problem, the energy transition helps to enlarge the extractive industries and increases the pressure to extract ETMs from places already acutely exposed climate change, like the Pacific Islands region. In this paper we develop the concept of compound exposure to examine the combined effects of extraction and climate change in the Pacific. Drawing from a global dataset of ETM projects, we have created a first-of-kind sub-set of ETM projects in the Pacific, mapped against indicators of environmental, social, governance and climate vulnerability for the places where those projects are located. We found higher levels of situated vulnerability around ETM projects in the Pacific compared to global results. A rush for the resources in the Pacific will compound the consequences of climate change and the multiple stressors associated with resource extraction and will enlarge exposure to harm. We argue that extractivist solutions to climate change work to close off other pathways and amplify the worst effects of compound exposure in the Pacific, and beyond.

1. Introduction

The effects of anthropogenic climate change are incontrovertible (IPCC, 2022). On the other hand, the solutions to our crisis are subject to relentless controversy and dispute. One of the most strongly promoted pathways out of this planetary problem is a transition to renewable energy-systems. Building these new systems will, however, require vast amounts of minerals and metals. Modelling by the International Energy Agency predicts that by 2040 the total global mineral demand for new energy technologies is set to double under the United Nations' Stated Policies Scenario and quadruple under the Sustainable Development Scenario (IEA, 2021). This demand is increasing the pressure for more metal mining, much of which will occur in ecologically sensitive environments and in the territories of Indigenous peoples (Luckeneder et al., 2021; Owen et al., 2023). Simply put, the prevailing pathway to address climate change locks-in an extractive-hegemony, whereby mining becomes essential for planetary survival.

The need for more resources to build 'clean' energy-systems is paradoxically both a consequence and a driver of climate change and the expansion of the extractive industries. There are many places around the world, such as the Pacific Islands region, where increased demand for these resources will have a compounding effect: it will intensify the socio-economic, political and ecological pressures of extraction, which in turn will diminish local capacity to respond to the effects of climate change. At the same time, the effects of climate change will ensure that extractive activities and their impacts are more volatile. Together, these processes, drivers and consequences form an 'energy-extractives nexus' that must be understood if we are going to avoid the production of sacrificial zones on the path to global sustainability (Bainton et al., 2021).

In this paper we introduce the concept of compound exposure to show the contradictions found in the primary solution to climate change – where the solution, in the form of low-carbon energy-systems that are very mineral intensive serves to compound underlying forms of vulnerability and enlarge exposure to harm. This same solution also contributes to climate change and influences local responses to environmental hazards, thus compounding the localised effects of climate change. In developing this concept, we extend and link the scholarship on mining and climate change (e.g. Bebbington et al., 2015) and the justice impacts of supplying raw materials for renewables (e.g. Heffron,

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2020; Sovacool et al., 2020) together with the scholarship on vulnerability to climate change in the context of multiple stressors (e.g. Kennedy et al., 2023; McCubbin et al., 2015; O'Brien et al., 2004; Räsänen et al., 2016). Compound exposure draws attention to the pre-existing vulnerabilities in those places where extractive projects are located or planned. These vulnerabilities span various social, ecological and governance dimensions, and include the already existing effects of climate change and the legacies of resource extraction. Once we understand these relationships and feedback loops, we can begin to grasp the future forms of exposure that will accompany the expansion of the extractive industries under changing environmental conditions.

We develop this concept in the context of the Pacific which has a devastating history of resource exploitation and is acutely exposed to the effects of global climate change. The Pacific Ocean and its islands are also rich repositories of the resources needed for the development of low-carbon energy-systems and technologies, otherwise termed energy-transition minerals and metals or 'ETMs' (Lèbre et al., 2020). At present there is insufficient knowledge of these orebodies and the costs of extracting and processing them to be able to assess their economic viability. However, given the global demand for ETMs we expect there will be increased pressure to access those resources. To characterise the idea of compound exposure, we have isolated a Pacific sub-set from a global dataset of projects that are extracting or proposing to extract ETMs. Our Pacific sub-set also maps the pre-existing levels of vulnerability in the locations where those ETM projects occur, including exposure to climate change. The indicators reveal higher levels of situated vulnerability surrounding ETM projects in the Pacific compared with most ETM projects in other parts of the world. A rush for the resources in the Pacific is thus likely to create new patterns of harm in places already exposed to multiple intersecting vulnerabilities.

The remaining body of this paper is organised into five sections. The next section introduces the Pacific setting. Section three outlines our methods, followed by the findings for the Pacific sub-set which we compare with the global dataset. We then elaborate upon the concept of compound exposure to show how situated vulnerabilities influence extractive outcomes and the capacity to respond to environmental change. We conclude that in order to avoid the worst effects of compound exposure in places like the Pacific, we need greater coordination across global and regional scales around the supply and consumption of natural resources.

2. Plunder and peril in the Pacific

The Pacific stretches from the east coast of Australia across a vast expanse of ocean to the west coast of America. Powerfully described as a 'sea of islands' (Hau'ofa, 1994), the Pacific is comprised of some 22 'small island developing states' or 'large ocean island states' as most Pacific Islanders prefer to see them.[1] The plundering of the provinces for their rich natural resources has a long pedigree that began in the nineteenth century as colonial powers progressively encompassed Pacific places and peoples. The plundering persisted as independent Pacific nations then committed themselves to extractive-led development, while various French territories, such as New Caledonia, continued to experience forms of neo-colonial exploitation that transferred wealth and resources back to the European continent. In recent years, the region was thought to provide approximately 2 m tonnes of copper, nickel, gold, manganese and aluminium per annum to the global marketplace, worth around US$2.6bn (The Guardian, 2021).

The last few decades have seen a new 'scramble for the Pacific' (Fache et al., 2021). As foreign powers and private corporations compete for access to territories and resources, Pacific nations are entering into new deals and new alliances and signing offtake agreements that reshape regional power dynamics. Former colonial powers, including the United States, have been unsettled by the presence of new players like China, Indonesia, India and Taiwan who exercise considerable economic and diplomatic influence in the region to reinvent the geopolitical order in diverse and unpredictable ways.

Familiar patterns of social and environmental harm have been witnessed at extractive projects across the Pacific region. For example, the extensive exploitation of phosphate from Nauru and Banaba completely decimated these island landscapes (Teaiwa, 2015). In New Caledonia nickel mining has generated fierce conflicts over environmental impacts, Kanak land rights, and the distribution or 'rebalancing' of economic and political power between local regions and the French metropole (Filer & Le Meur, 2017; Horowitz, 2009). Similarly, in Papua New Guinea, the social and environmental impacts of the massive Panguna copper mine on the island of Bougainville sparked a ten-year civil war that cost thousands lives, while the abandoned mine site and its toxic overflows have been the subject of a human rights investigation (Regan, 2017; Tetra Tech Coffey, 2024). On the opposite side of the country, the giant Ok Tedi gold and copper mine became one of world's worst extractive legacies when the government permitted the operator to dump millions of tons of mine waste in the local river system (Kirsch, 2014). Meanwhile, the extraction of gold and bauxite in Solomon Islands has fuelled various kinds of human and ecological violence that extend beyond the boundaries of these contentious projects (Allen, 2013).

In each instance mining projects have given rise to accelerated forms of social disintegration, entrenched new forms of inequality (Bainton & McDougall, 2021), induced gendered impacts (Macintyre, 2011), created livelihood deprivations and contests over scarce resources (Beer & Schwoerer 2022), threatened cultural heritage (Bainton et al., 2012), and displaced people from their customary lands. Landscape transformations have remade Indigenous lifeworlds and irreversibly reshaped senses of place (Rumsey & Weiner, 2004), while the privatisation and enclosure of common property combined with resource governance failures ensure that extractive capital accumulates elsewhere with little local benefit (Bainton & Skrzypek, 2021). We anticipate that these effects are likely to become more severe as the demand for ETMs increases in response to calls for urgent action on climate change (Skrzypek et al., 2022).

Climate change is an existential threat to Pacific lives. Across the region, the impacts of climate change are experienced in diverse ways in different locations, including sea-level rise, desertification, increased soil salinity, flooding, as well as permanent loss of land through shoreline erosion (Kumar, 2020). Many Pacific communities frequently endure extreme weather events, such as cyclones (Ballard et al., 2020; Chand et al., 2020). These events have long-lasting consequences, particularly in countries with limited infrastructure or capacity to mitigate and respond to environmental hazards. While other parts of the world are experiencing similar threats, the twin issues of land availability and climate displacement are especially problematic in Pacific nations (Ramsay et al., 2023). Exposure to climate risks raises critical and unprecedented questions about sovereignty, security and continued statehood of low-lying Pacific states that have already begun losing their land to sea-level rise (Kelly & Foth, 2022; Rayfuse & Crawford, 2012). And generally, we find there is a concentration of risk and exposure to harm to a much higher degree than in most other parts of the world. The 2021 World Risk Index, which assesses disaster risk for 181 countries around the world, observed that the Pacific (or Oceania, as it is named in the report), has the greatest levels of disaster risk due to 'high exposure to extreme natural events' (Mucke, 2021). Three Pacific nations – Vanuatu, Solomon Islands and Tonga – were named as the three most at-risk countries in the world, with Papua New Guinea ranking 9th, Fiji 14th and Kiribati 19th. These types of risk rankings merely confirm what

[1] The 22 Pacific Islands states comprise Fiji, New Caledonia, Papua New Guinea, Solomon Islands and Vanuatu (collectively called Melanesia); American Samoa, Cook Islands, French Polynesia, Niue, Pitcairn Island, Samoa, Tokelau, Tonga, Tuvalu and Wallis and Futuna (collectively called Polynesia); and Federated States of Micronesia, Guam, Kiribati, Marshall Islands, Nauru, Northern Marianas and Palau (collectively called Micronesia).

Pacific leaders have long known. The Pacific Islands Forum *Boe Declaration on Regional Security*, endorsed by Pacific leaders in 2018, declared climate change to be 'the single greatest threat to the livelihoods, security and wellbeing of the peoples of the Pacific' (PIFS, 2018). Four years later, at a meeting in Fiji, the Pacific Islands Forum leaders declared a climate emergency in the Pacific (PIFS, 2022a).

Exposure to the effects of climate change is exacerbated by pre-existing socio-economic vulnerabilities and inequalities that persist throughout the region (Weir et al., 2017). For many Pacific countries, extreme environmental events stretch existing capabilities and limited economic resources. In this context, there is a push to utilise the region's natural resources to stimulate economic growth and boost local capacity to deal with these events. As the global demand for ETMs increases the pressure to extract resources from the Pacific, we find mixed views throughout the region. Some Pacific leaders want to secure the development opportunities that mining can create, while others are concerned about the wide-reaching effects of mining on their peoples and environments. These debates include highly contentious conversations about implementing untested seabed mining technologies in the region (Bainton & Skrzypek, 2022; Childs, 2019; Lilford & Allen, 2023). While some Pacific states, including Fiji, Vanuatu, Samoa, Palau and the Federal States of Micronesia have called for a moratorium on seabed mining activities, others, such as Cook Islands, Nauru, Tonga and Kiribati, have decided to sponsor seabed exploration projects within their territory or within international waters.

The double bind facing the Pacific is perverse and pernicious. Pacific countries desperately need world leaders to act to stop the world from overheating. But this same situation, and the vulnerabilities that persist throughout the Pacific, also provides the pretext to extract more resources from the region. Major mining companies have seized this opportunity, strategically rebranding themselves as producers of 'green metals' and the providers of 'transformative' or 'nation-building' opportunities. Assessed from this vantage point, mining will provide the materials for a global energy transition to address the climate crisis and provide the economic base to sustain Pacific nations and build their capacity to adapt to a changing climate. The Pacific faces a perilous future if climate action is not achieved quickly enough – but large parts of the Pacific may also become 'sacrifice zones' (Scott & Smith, 2017) in the pursuit of raw materials for the primary solution to this problem.

3. Methodology

To put the aforementioned perils, paradoxes and pressures into perspective we have mapped ETM projects in the Pacific. We drew on an approach developed by our colleagues at The University of Queensland who sought to assess 'supply risks' for the energy transition (i.e. risks confronting ETM mining projects). A primary output of their work was the development of a global dataset of ETM projects and the situated risks proximate to these projects.[2] In this approach, 'projects' are defined as any formally registered resource regardless of its development status.[3] Working with a consolidated list of ETMs, and data drawn from the S&P Capital IQ Pro database, one of the most comprehensive and up-to-date sources of global mining data,[4] our colleagues in Queensland identified some 5097 ETM mining projects worldwide (including in the Pacific). They then applied a set of spatial indicators that serve as proxies for different kinds of risk to undertake a global analysis of the situated environmental, social and governance risks for ETM mining projects.

Drawing from this global dataset we have identified 163 projects extracting or projecting to extract ETMs within the Pacific region – which we refer to as 'the Pacific sub-set', constituting 3.2 % of the global sample. Those projects can be found in 41 % or nine out of the 22 Pacific nations. Table 1 sets out the 29 ETMs found globally[5] while Table 2 and Fig. 1 show the nine Pacific nations where ETM projects are located, and the primary commodities being targeted. Most of these projects are land-based and will require large-scale open-cut or underground mining operations that will generate widespread social and environmental harm. Nine of the Pacific projects are for seabed minerals and metals that will require novel and largely experimental extractive technologies if these projects are developed, which will very likely produce unanticipated outcomes and impacts.[6] Only 17 % of projects in the Pacific sub-set are at the operational-stage, while 83 % are classed as early-stage projects, pointing towards future extractive pressures. In comparison, 27 % of projects in the global dataset are at the operational-stage, while 73 % are classed as early-stage.

Following the approach developed by our colleagues, we then used the Pacific sub-set to map the situated forms of vulnerability in the places where these ETM projects are located. This provided the basis for a comparison between the Pacific sub-set and the global dataset. For our purposes, we inverted the point of focus from 'supply risks' to the risks to people and places. In other words, we have focussed on pre-existing vulnerability (i.e. the contextual factors that may amplify exposure to the social and environmental harm arising from increased pressure to extract in these places under volatile environmental conditions). We made other minor adaptations to our colleagues' methodology, where certain measures were replaced or complemented to cover gaps in data

Table 1
Consolidated list of energy transition minerals and metals.

Consolidated list of Energy Transition Minerals and Metals		
Bauxite (Aluminium)	Lead	Silver
Chromium	Lithium	Tantalum
Cobalt	Magnesium	Tellurium
Copper	Manganese	Tin
Gallium	Molybdenum	Titanium
Germanium	Nickel	Tungsten
Graphite	Niobium	Vanadium
Indium	Platinum	Zinc
Iridium	Rare earth elements	Zircon
Iron Ore	Selenium	

Source: Owen et al., 2022a

[2] This approach was first developed by Valenta et al. (2019), and then repeated and refined across subsequent studies led by different authors within the Sustainable Minerals Institute at The University of Queensland (see Lèbre et al., 2020; Owen et al., 2023; Owen et al., 2022a; Owen et al., 2022b; Svobodova et al., 2022). In each instance the methodology changed slightly to reflect an explicit purpose.

[3] Although geological surveys reveal a much wider occurrence of ETMs throughout the Pacific, following the definition of projects established by Valenta et al. (2019), we have limited our analysis to actual projects because there is a greater likelihood these resources will be developed and exploited at a future point in time.

[4] As of November 2021, it maintains records on 36,395 geolocated mining projects worldwide at all development stages, from early-stage exploration, to preproduction, operating and closure, across all commodity types.

[5] This consolidated list was first developed by Owen et al. (2022a) based on sources provided in the report for the World Bank by Hund et al. (2020), the report for the International Institute for Sustainable Development by Church and Crawford (2018), and the International Energy Agency's report on critical metals (IEA, 2021).

[6] Our Pacific sub-set, which relies on data from the S&P Capital IQ Pro database, does not capture the full extent of seabed mining activities in the Pacific. Throughout international waters (known as the Area), extensive exploration activities are underway, especially in the Clarion-Clipperton Zone. These activities are led by a wide range of countries and companies (Miller et al., 2018).

Table 2
Pacific Islands countries with identified ETM projects.

Pacific Islands countries	Number of ETM mining projects	Primary commodities targeted
Cook Islands	1	Manganese, copper, cobalt, nickel
Fiji	21	Copper
Indonesia (Papua and West Papua)	18	Copper
New Caledonia	19	Nickel
Nauru	1	Manganese, cobalt, copper, nickel
Papua New Guinea	87	Copper, nickel
Solomon Islands	12	Bauxite
Tonga	2	Nickel
Vanuatu	2	Copper

dimensions (communities, land uses and social vulnerability) include communities in proximity to the project, the existence of competing land uses, and social vulnerability metrics in the region. The governance dimension aggregates several indicators measuring levels of corruption, freedom, rule of law, political stability, and the quality of regulations and public services. Table 3 presents each dimension and briefly explains their relevance for understanding vulnerability in resource extraction settings, while Table 4 sets out the various measures used for each dimension.

As international institutions and nation states work to solve the climate crisis, we draw attention to the fact that the primary solution is being developed under already perceptible conditions of climate change. To explore how climate change may exacerbate situated vulnerabilities around ETM projects in the Pacific we included several measures on climate change. These form part of the 'extreme events'

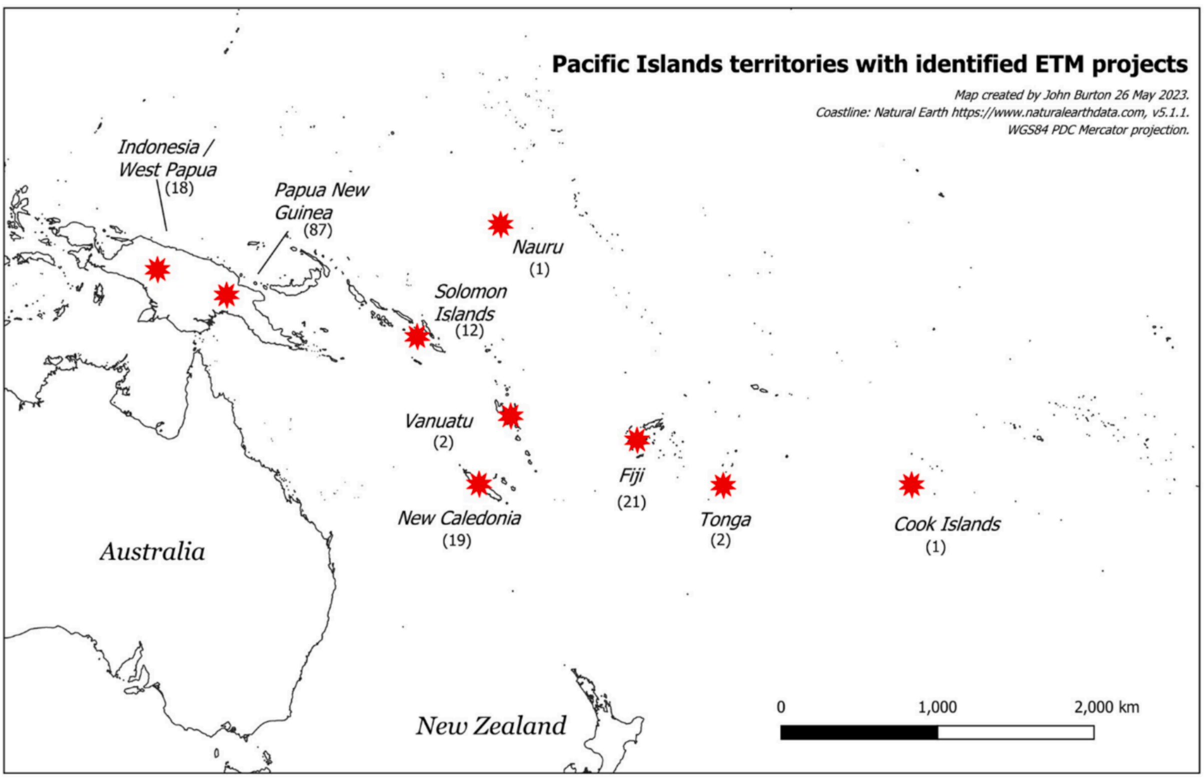

Fig. 1. Pacific Islands countries with ETM projects.

for the Pacific region, including a layer for extreme weather events, datasets for Indigenous landownership[7] and as we discuss below, indicators for climate change.

We used a set of 23 spatial indicators aggregated into seven dimensions of vulnerability: extreme events, water, conservation, communities, land uses, social vulnerability and governance. The three environmental dimensions (extreme events, water and conservation) cover the proximity of mining projects to key biodiversity conservation areas, risks related to the availability and quality of freshwater resources in the region, and the possibility of extreme weather or seismic events that may trigger mine waste containment breaches. The three social

category and reflect the level of exposure a mining project and host communities have to climate change as well as national-level vulnerability to climate change. Measures included in our analysis are the anticipated average changes in annual temperature and precipitation as well as changes in temperature and precipitation seasonality (WorldClim, 2020); and the percentage of population exposed to sea-level rise and coastal flooding.[8] This last measure represents a different scale as it reflects the pressures being felt by populations at a national level, rather than local conditions around the project, which are targeted by the high-resolution climate dataset.

4. Vulnerability in the Pacific

Overall, compared to the global dataset the Pacific sub-set points to high levels of situated vulnerability around ETM projects in the Pacific

[7] For example, the Indigenous Peoples Land map by Garnett (2018), used by Lebre et al. (2020), does not include data for Fiji, Solomon Islands and Papua New Guinea. Whereas the data set used by Owen et al. (2023) recognises the United Nation Declaration of Rights of Indigenous Peoples (UNDRIP) status of people in the Pacific. We complemented this with the dataset developed by LandMark (2022).

[8] Adapted from Neumann et al. (2015) projections.

Table 3
Situated vulnerability dimensions.

Dimensions		Description and relevance
Environment	Extreme events	Extreme weather and seismic events can compromise the integrity of mining voids and mine waste facilities. Failure to contain mining waste has consequences with severity varying between chronic toxic seepage to catastrophic tailings dam failures. These risks often remain after the mine stops operating (regardless of the actual project status: care and maintenance, suspended operations, formally closed, or abandoned etc.).
	Water	Mining operations have high freshwater requirements and compete with other water users in places where water is scarce. Too much water is also a challenge for miners as uncontrolled water flows come into contact with reactive minerals and generate toxic seepage.
	Conservation	Mining activities involve deep land transformation and other impacts (e.g. noise and vibration) that directly impact local ecosystems. This category considers the proximity of mining projects to key biodiversity and conservation areas.
Social	Land uses	Mining activities require access to land and compete with pre-existing land uses including agriculture, artisanal and small-scale mining, and subsistence livelihoods that depend on natural resources.
	Communities	Mining activities affect communities living in the direct proximity of the project, with economic and physical displacement occurring as well as the influx of people attracted to economic opportunities. Communities living in the wider area of economic influence around the project can also be affected by either chronic or catastrophic impacts. Changes affect communities from early exploration stages to post-closure. This category also includes the project's proximity to Indigenous land as Indigenous peoples generally experience higher levels of vulnerability to mining development.
	Social vulnerability	Pre-existing factors of social vulnerability influence the ability of local communities and the wider society to cope with mining-induced impacts, along with climate impacts. This category encompasses metrics on socio-economic inequalities at the national scale, age dependency (reflective of economic pressures at the household level) and human development (covering measures of health, education and income).
Governance	Governance	Robust governance systems ensure mining revenues are distributed fairly, and that citizens are protected against adverse impacts, whereas poor governance systems create a permissive environment for suboptimal industrial practices.

across all seven dimensions considered in this study. When compared with the average results in the global dataset of ETM projects, the Pacific consistently scores higher. This provides compelling reasons for concern about increased pressure to extract more resources from the region. Fig. 2 illustrates the differences between the Pacific sub-set and the global dataset, and Table 5 provides a summary of these results.[9] In the following subsections we elaborate upon the data, contextualised where appropriate, within climate change projections for the Pacific.

[9] Note: for ease of reporting and summary, some measures have been aggregated where these measures identify similar forms of vulnerability, and where the global comparison is the same (i.e. Conservation measures, and Communities).

Table 4
Data sources and measures for vulnerability dimensions.

Dimensions		Measure of vulnerability	Data source
Environment	Extreme events	Seismicity	Giardini et al. (2003)
		Tropical cyclones	UNEP & GRID (2014)
		Climate change – projected changes in temperature	Fick and Hijmans (2017)
		Climate change – projected changes in precipitations	
		Climate change – percentage of 2030 population exposed to sea-level rise and coastal flooding	Neumann et al. (2015)
	Water	Mining sector overall water risk	Gassert et al. (2013)
	Conservation	Protected areas (located within)	UNEP-WCMC, IUCN & NGS (2022)
		Key biodiversity areas (located within)	BirdLife International & KBA Partnership (2019)
		Biodiversity hotspots (located within)	CEPF (2020)
Social	Land uses	Croplands	Waldner (2016)
		Forest land	JAXA Alos (2017)
	Communities	Maximum population density in a 10 km radius	Florczyk et al. (2019)
		Maximum population density in a 100 km radius	
		Proportion of projects on Indigenous peoples lands	Garnett (2018)
		Percent of Indigenous and community lands in country	LandMark. (2022)
	Social vulnerability	Human development index	UNDP (2018)
		Age dependency ratio	CIESIN (2018)
		Gini index (income inequality)	World Bank (2019)
Governance	Governance	Control of corruption	World Bank (2020)
		Political stability and absence of violence/ terrorism	
		Rule of law	
		Voice and accountability	
		Government effectiveness	
		Regulatory quality	

4.1. Extreme events: seismicity, cyclones, precipitations, and sea-level rise

Pacific ETM projects are located in places that are highly vulnerable to extreme events such as earthquakes, tropical cyclones and sea-level rise, with wide-ranging implications. For example, failure to ensure the long-term stability of infrastructure, mining voids (open pits and underground workings) and waste storage facilities will result in health and safety impacts for workers and local communities, and environmental damage. Globally we have seen the damage and loss of life caused by catastrophic tailings dam failures (e.g., Hopkins & Kemp, 2021), and there are also past examples from the Pacific where extreme weather and seismic events affected tailings storage infrastructure and led to environmental devastation, as was the case at the Gold Ridge mine in Solomon Islands (Nanau, 2017) and the Ok Tedi mine in Papua New Guinea (Banks & Ballard, 1997). The risk of seismic events has also provided justification for the use of controversial deep-sea tailings placement methods at numerous mines in Papua New Guinea – a practice that is otherwise banned in most jurisdictions (Kwong et al., 2019). Exposure to these extreme events also creates significant challenges to

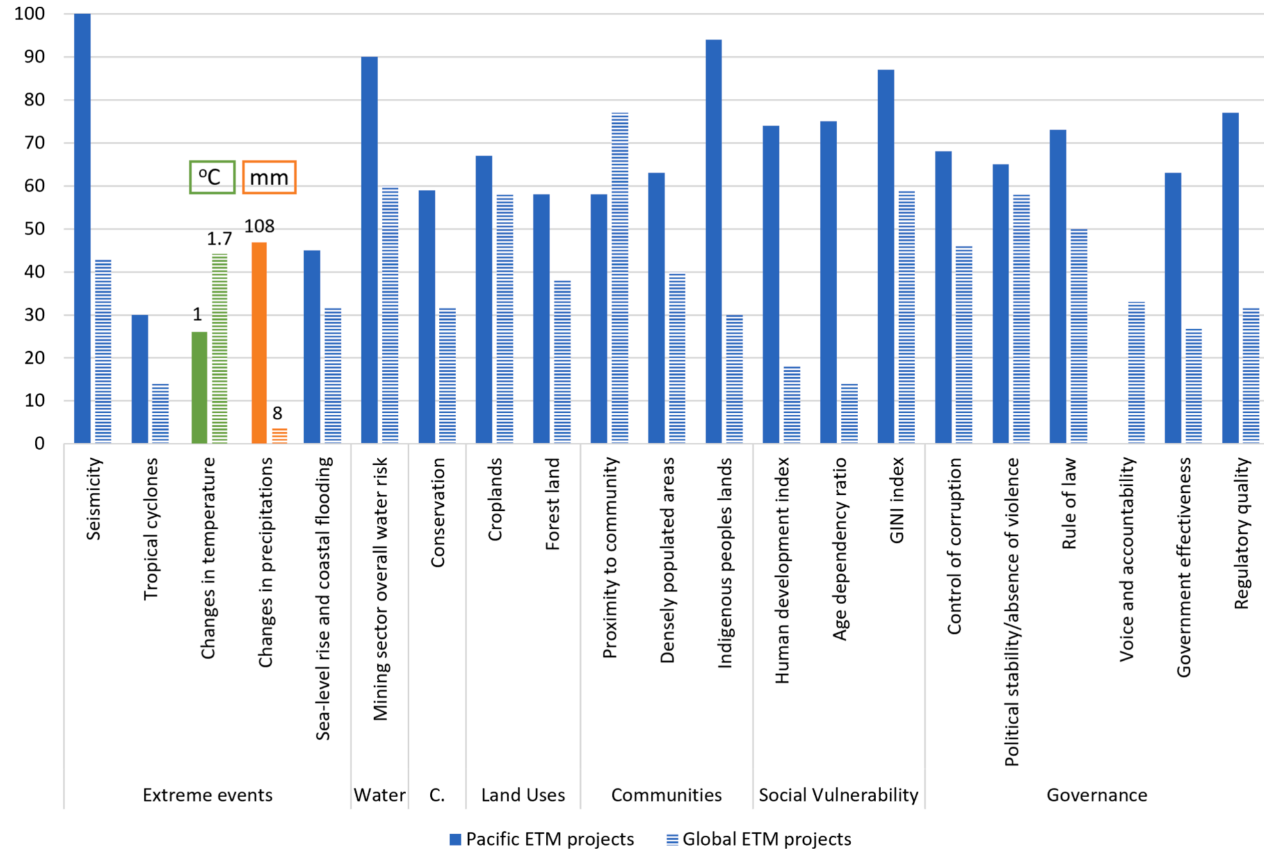

Fig. 2. Pacific sub-set compared with the global dataset (% of ETM projects).

mine site remediation and rehabilitation. Projected changes in temperature ranks lower in the Pacific than in the global dataset. However, as the world's climate changes, climate modelling for the Pacific (RCCAP, 2021) suggests that countries across the region can expect heavier rainfall events, more heatwaves, and more intense tropical cyclones – further exacerbating the region's vulnerability to extreme weather events while increasing mining-related risks.

4.2. Water

90 % of Pacific ETM projects are in places above the medium water risk threshold, compared to 61 % in the global dataset. This means that 9 out of 10 projects face difficult freshwater conditions, and mine developers may struggle with getting fresh water supplies for mining operations; controlling water flows on site and keeping reactive minerals away from water; securing fresh water supplies to nearby mine-affected communities; and avoiding acid and metalliferous drainage into local aquifers. Climate change in the region is already evident through increasing unpredictability of freshwater supplies linked to heavier rainfall events on the one hand, and more severe drought events on the other. For example, in July 2017 operations at the aforementioned Ok Tedi mine were suspended due to a drought caused by an El Nino effect (Jorgensen, 2021; Mudd et al., 2017). Climate predictions suggest this volatility will increase further in the current projections period (by 2050).

4.3. Conservation

59 % of Pacific ETM projects fall in a key conservation or biodiversity area, compared to 32 % of ETM projects globally. Of the three biodiversity measures used for the analysis, Biodiversity Hotspots is the prevailing type in the Pacific region. Biodiversity hotspots are defined as areas meeting two criteria: 1) contain at least 1,500 species of vascular plants found nowhere else on Earth; and 2) have lost at least 70 percent of its primary native vegetation. This means biodiversity in the proximity of ETM projects is particularly high and already at risk. Future modelling suggests that climate change will further intensify impacts on biodiversity in the region (Taylor & Kumar, 2016) across terrestrial, freshwater, and marine ecosystems (Kingsford & Watson, 2011). In the Pacific, mining activities inevitably create environmental burdens that negatively affect local ecosystems, as well as the people that depend on them, in some cases standing in direct competition with conservation efforts. This is the case in Solomon Islands, for example, where the World Heritage Committee placed East Rennell on the List of World Heritage in Danger, citing threats from bauxite mining in the western part of the island, changing weather patterns and rising sea levels (Kiddle, 2020).

4.4. Land uses

The average percentage of forest land around Pacific ETM projects is 60 %, compared to a 40 % global average. Some 67 % of Pacific ETM projects intersect with croplands, compared to 58 % globally. This means there are high levels of competition over land. As mining developers undertake land clearing at the exploration and construction stages, and then progressively acquire land when operations expand, the area of land available to local communities decreases and local land uses, including gardening, farming, and hunting grounds, as well as alluvial resources for small-scale mining, are threatened. The latter is the case at the proposed Frieda River copper project in Papua New Guinea, where the land requirements for the project would encompass the rivers and streams where local communities mine for alluvial gold which forms the basis of their livelihood (Bainton et al., 2020; Hamago et al., 2023). Some Pacific nations have already started losing land to rising seas (e.g.

Table 5
Vulnerability profile around ETM projects in the Pacific and comparison with global data.

Dimensions		Results (for measures of vulnerability surrounding ETM projects in the Pacific)	Comparison with global average for ETM projects worldwide
Environment	Extreme events	100 % of Pacific ETM projects are in locations above the medium risk threshold (0.8 m/s2) for seismic risk.	Higher
		30 % of Pacific ETM projects are in places exposed to tropical cyclones.	Higher
		On average, in the locations of Pacific ETM projects, annual mean temperature is expected to increase by 1.00 °C by 2040.	Lower
		85 % of Pacific ETM projects are in places that are expected to see an increase in precipitations due to climate change. On average, annual precipitations are expected to increase by 108 mm, which is about 14 times the global average.	Higher
		45 % of Pacific ETM projects are in countries where more than 10 % of the population is exposed to sea-level rise and coastal flooding.	Higher
	Water	90 % of Pacific ETM projects are in places above the medium risk threshold (score of 2) for water risks in the mining sector.	Higher
	Conservation	59 % of Pacific ETM projects fall in a protected area, key biodiversity area, or biodiversity hotspot.	Higher
Social	Land uses	67 % of Pacific ETM projects have croplands in a 10 km radius around the project.	Higher
		Across the Pacific ETM projects, the average percentage of forest land in a 10 km radius around the project is 58 %.	Higher
	Communities	58 % of Pacific ETM projects are located nearby a community.	Lower
		63 % of Pacific ETM projects are in densely populated areas, i.e. with maximum population density above 10,000 people per square km.	Higher
		94 % of Pacific ETM projects fall in or near Indigenous peoples land.	Higher
	Social vulnerability	74 % of Pacific ETM projects are in jurisdictions with low to medium human development.	Higher
		75 % of Pacific ETM projects are in jurisdictions with an above median age dependency ratio.	Higher
		87 % of Pacific ETM projects are in jurisdictions with an above median GINI (measure of income inequalities).	Higher
Governance	Governance	68 % of Pacific ETM projects are in jurisdictions with negative scores on the control of corruption indicator.	Higher
		65 % of Pacific ETM projects are in jurisdictions with negative scores on the political stability absence of violence indicator.	Higher
		73 % of Pacific ETM projects are in jurisdictions with negative scores on the rule of law indicator.	Higher
		0 % of Pacific ETM projects are in jurisdictions with negative scores on the voice and accountability indicator.	Higher
		63 % of Pacific ETM projects are in jurisdictions with negative scores on the government effectiveness indicator.	Higher
		77 % of Pacific ETM projects are in jurisdictions with negative scores on the regulatory quality indicator.	Higher

Tuvalu, Kiribati, Marshall Islands, and Solomon Islands which hosts 12 bauxite projects), and many low-lying areas are grappling with increased soil salinity and coastal flooding. As the climate continues to change, increasingly unpredictable and extreme weather patterns coupled with issues of water availability place additional pressure on food production across the region, which is likely to further intensify competition over land.

4.5. *Communities: Population density and Indigenous peoples' land*

Two population density measures were adopted to assess community vulnerability. The first one relates to the presence of communities within the direct area of influence of the project, estimated to be a 10-km radius around the project. According to this measure, 58 % of Pacific ETM projects are located close to communities, which is a high proportion, but lower than the global average. The second measure relates to population density in a 100-km radius around the project. This measure provides information on the population residing within the wider area of economic influence of the project and affected by mining operations. According to this measure, Pacific ETM projects are, on average, in more densely populated regions compared to ETM projects in the global dataset. Generally speaking, densely populated regions correspond to a more diversified and resilient economy that may not entirely depend on extractive-related development – resulting in lower vulnerability. However, accounts from across the Pacific region observe very high levels of dependency on resource extraction projects for economic opportunities as well as access to services and infrastructure (e.g. UNDP, 2014). This dependency can be observed even in cases where extractive projects are still in the exploration phase and their future remains uncertain, such as the Frieda River project (Skrzypek, 2020). To an extent, this can be attributed to the state's persistent absence around extractive projects in the Pacific (Bainton & Skrzypek, 2021), resulting in situations where extractive companies are forced to assume government roles (Bainton & Macintyre, 2021). The composition of local populations also warrants examination, as extractive projects often generate high levels of in-migration, increasing both the population and the pressure on local resources (Bainton & Banks, 2018; Bainton, 2017). As we have witnessed at many projects in Papua New Guinea and Solomon Islands, in-migration has resulted in conflict between locals and 'outsiders' and increased the level of volatility throughout the district.

Further, 94 % of Pacific ETM projects are located on or near Indigenous peoples' land, compared to 30 % identified in the global dataset.[10] The international discourse of Indigeneity seldom resonates in the Pacific, partly because it usually rests upon images of a minority population subsumed within a majority non-Indigenous nation-state (Bainton, 2020: 11-14), and because Pacific Islanders generally identify themselves in other ways that stress their customary ties to land and sea. Nevertheless, the legal recognition of customary land tenure rights (Crocombe, 1971) means that most ETM projects in the Pacific will need to acquire land and transform land relations in locations where communities have strong ties to land, and likely suffer from high levels of poverty and political marginalisation. Even where population density is zero in the location of the project, Pacific peoples will have cultural and spiritual ties to the land and may rely on the land for livelihoods and exercise customary rights in or near the project area. These cultural and spiritual ties extend beyond terrestrial zones into coastal areas and open seas which can make it harder to identify resource owners and rights holders and the potential social impacts of seabed mining projects, which has certainly been the case in countries like Cook Islands (Petterson & Tawake, 2019) and Papua New Guinea (Filer & Gabriel, 2018).

4.6. Social vulnerability

Social vulnerability measures are high in the places where ETM projects are found in the Pacific. Three quarters of these projects are in jurisdictions with low levels of human development and high levels of age dependency, compared to only 18 % of projects in the global set. Some 87 % of Pacific ETM projects are in jurisdictions with high income inequalities, compared to 59 % of global ETM projects. Together, these measures signal poverty, insecurity, demographic pressures and low levels of education and health. These low-level baseline conditions mean local populations are often ill-prepared to cope with the impacts of extraction. Mining developments generate socio-economic changes at all stages of the mine lifecycle and often accentuate these vulnerabilities. A frequent example is when mining projects displace communities and progressively acquire their land for mining purposes, drastically reducing their resources for subsistence farming and other livelihood activities (Bainton et al., 2022). Environmental and demographic impacts associated with climate change (i.e. displacement due to loss of land and extreme events), will exacerbate such vulnerability in the region.[11]

4.7. Governance

The Pacific sub-set shows higher levels of vulnerability in relation to governance failures around Pacific ETM projects than the global average across the six governance indicators considered in this study. High levels of corruption present in some Pacific countries mean that public power is often exercised for private gain and indicates that extractive revenues are likely to be captured by a small group of elite and private interests without benefiting local populations (Allen & Porter, 2016; Burton & Haihuie, 2017; UNDP, 2014). Limited regulatory capability and low-quality public services generally signal that populations are unlikely to be protected from negative impacts generated by extractive activities. This is particularly problematic when it comes to new extractive developments like seabed mining. The technological, environmental, and social uncertainties associated with seabed mining expose the governance gaps surrounding this frontier industry. The ill-fated Solwara 1 project in Papua New Guinea (Filer et al., 2021) highlighted the need for new regulatory systems capable of dealing with the unique social and environmental features of seabed mining rather than relying on regulatory processes designed for terrestrial activities (Kung et al., 2021). Political instability and the absence of the rule of law indicate the potential for resource conflicts and that societal rules may not be enforced. This can lead to situations where property rights are not upheld, and local landowners attempt to reclaim control – through violent or legal battles – over customary land acquired for extractive activities (Bainton, 2021). The only governance measure where Pacific ETM projects score positively is 'Voice and Accountability', which indicates a certain degree of democracy and freedom of expression. However, the average score for this measure (21 %) is still below the global average of 34 %. Critically, as we discuss below, the impacts associated with a changing climate burden already strained governance systems throughout the region, while the global push to extract ETMs under changing climate conditions challenges resource governance frameworks and diverts attention away from other critical issues, like dealing with climate change.

5. Compounding the energy-extractives nexus

The Pacific sub-set provides the first regional-scale picture of vulnerability around ETM mining projects in the Pacific. It exposes the underlying contexts that shape extractive outcomes and influence capacity to respond to the combined shocks and stresses of extraction and climate change. Although we have considered vulnerability across several distinct categories it is important to note that situated vulnerabilities interact with each other, often generating complex, multi-dimensional vulnerability that is greater than the sum of its parts. For example, a remote community with limited access to drinkable water, exposed to extreme weather events, in a jurisdiction with weak governance systems that fail to recognise how people are affected by extractive activities, experiences multiple dimensions of vulnerability at a time. These different vulnerabilities not only co-exist but converge and compound – often leading to new patterns of risk and harm. The same principal logic provides the foundations for thinking about compound exposure, which we now discuss in detail.

Compound exposure points to the fact that certain regions, sectors, ecosystems and social groups will be simultaneously confronted by the consequences of climate change and a multitude of other stressors including those extractive activities that supposedly underpin global solutions to halt runaway climate change. This idea extends the work of

[10] We note that more recent analysis by Owen et al. (2023) has placed this global figure at 54%. We have retained the earlier figure (30%) because our analysis was conducted before Owen et al. completed their study. Regardless of the difference, the figure for the Pacific is still significantly higher than the global figure.

[11] Pacific Islanders displaced by the impacts of climate change are often referred to as 'climate refugees' – although this is a contentious designation, as discussed by Barnett and Chamberlain (2010).

other scholars who have studied the relationship between global processes and local vulnerabilities (e.g. Leichenko & O'Brien, 2008; Kelman et al., 2015). It also provides us with a specific language to describe a contradictory process where the dominant solution to a particular issue exacerbates underlying risks for the most vulnerable regions and people.

Our Pacific sub-set highlights a multitude of stressors that are present around ETM projects in the Pacific and the complex interrelationship between them. These stressors, or vulnerabilities, will be exacerbated by the pressure to extract ETMs under changing environmental conditions. To help illustrate this point, we have developed a basic model of compound exposure in the Pacific (Fig. 3). The model emphasises interdependencies, showing how Pacific peoples and places are subject to, interact with, and influence broader global processes. Moving from left to right we can see a feedback loop between resource extraction and climate change that is reinforced by the need to access ETMs in the name of a global energy transition. As extractive activities are conducted under changing environmental conditions these extractive contexts will become more volatile, enlarging localised exposure to harm. The arrows travel in both ways because some Pacific leaders prioritise extractive-led development and these decisions also help to reproduce the global extractive industries. Extractive impacts will be increasingly amplified by the effects of climate change, which are disproportionately experienced throughout the Pacific. At the same time, Pacific Islanders are among the most vocal proponents of climate action and work tirelessly to influence international debates and decisions, while locally proposed mitigation and adaptation strategies may be more or less successful depending upon pre-existing factors and conditions. Finally, these situations are not static: new forms of vulnerability are likely to aggravate each other because they will overlap or interact across space and time. We need to consider how vulnerability may accumulate or recede in certain places and periods – across the mine lifecycle, for example – and the changes that occur as the feedback loops between problems and proposed solutions compound over time.

The vulnerabilities embedded in Pacific settings influence the degree of magnitude of exposure to harm and how people may respond to the compounding effects of the energy-extractives nexus. Likewise, dependency upon resource extraction influences how some states and their citizens might understand and respond to climate threats and impacts and the options that are available to them. For example, in Papua New Guinea, the state's commitment to extractive-led development tends to manifest in a peculiar form of state absence in those areas where state presence and interventions are most needed on the ground (Bainton et al., 2021). The well-documented inability of the Papua New Guinean state to regulate the worst excesses of the extractive industries gives us little confidence that the state can protect the rights and interests of its people as future extractive activities occur under more extreme environmental conditions. Various forms of governance vulnerability (or failure) are also present in the state's action on climate change, including tensions between the goals of REDD + projects that aim to reduce emissions by preventing deforestation, and the pressure to clear land for extractive projects and their supporting infrastructure (Bingeding, 2018).

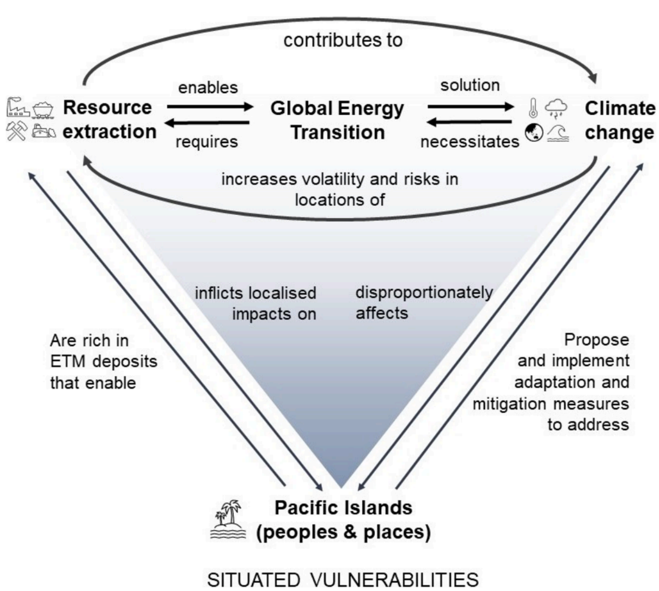

Fig. 3. Compound exposure in the Pacific.

This same process can also unfold in the opposite direction as climate change pushes countries towards or back to extractive futures. Nauru is a case in point. On all measures, Nauru is a vulnerable Oceanic state thoroughly dependent upon extractivism. After nearly a century of phosphate mining most of the island has been transformed into a barren lunarscape. When the phosphate boom went bust, Nauru agreed to host Australia's maritime asylum seekers in what became a form of 'human extractivism' (Morris, 2022). With no alternative economic opportunities, and an import-dependent economy, the state has partnered with The Metals Company (a Canadian seabed mining exploration company) to commence seabed mining activities in the Clarion-Clipperton Zone – a polymetallic-nodule-rich area of the Pacific Ocean stretching between Hawai'i and Mexico. If seabed mining is the only pathway for Nauru to obtain economic independence and secure funding for climate adaptation measures, this survival strategy also positions them as a lead proponent for a frontier industry. In promoting seabed mining, Nauruan leaders and The Metals Company see themselves contributing to global climate mitigation efforts by supplying the raw materials for renewable energy technologies. In this case, pre-existing vulnerability across environmental, social, economic and governance dimensions has overly determined how this island nation and its leaders are responding to the threat of climate change and the risks to continued sovereignty and statehood.

As stated above, we anticipate that the expansion of the extractive industries under conditions of climate change will exacerbate old forms of harm and produce novel, compounding forms of exposure throughout the region. We also expect that projects that were once considered too risky or costly for development may have their viability reassessed. Where some extractive projects were previously justified in terms of national-level benefits (that supposedly outweigh local-level harms), some new projects and expansions will be justified in terms of planetary necessity. We can see these types of arguments in relation to seabed mining. These developments are assisted by the discourse of 'green extractivism'. According to this narrative there are no losers: countries and communities can leverage ETM extraction to meet their development goals, while the expansion of extractive industries is essential for life on earth. This discourse is underpinned by linguistic and policy shifts that depict future energy-systems as supposedly 'greener' and 'cleaner' (ignoring the social and ecological destruction already integral to the supply chains for new technologies) while some commodities are recategorized as belonging to the 'old economy' and others are labelled as essential to the 'new economy' or even the 'green economy'. Such sleights of hand also hide the fact that very little data exists to show whether the resources extracted in the name of climate solutions are used for these purposes, or whether they are sold to other markets for other purposes like weapons technology.

Even if the ETM projects we have identified in the Pacific do not advance to full-scale exploitation, the pressure to mine and the focus on extractive-led development (i.e. to pursue it, defend it or oppose it) diverts attention from other development pathways and diminishes local, national and even regional capacity to respond to climate change and implement other policy priorities. In other words, the presence of the extractive industries in the Pacific is hegemonic with serious consequences for climate change interventions – an observation that we elaborate upon in our conclusion.

6. Conclusions: Policy implications and the case for planning

Action on anthropogenic climate change is desperately needed. World leaders, including those from the Pacific, speak daily of 'the climate emergency' and call for urgent solutions. A global transition to low-carbon energy-systems is promoted as the primary solution – which is fuelling the demand for ETMs. In this paper we have examined how pressure to extract ETMs transforms pre-existing vulnerability and amplifies exposure to harm in regions such as the Pacific. By connecting-up data across scales we have highlighted the place of the Pacific in global datasets and in global issues. Even though the Pacific sub-set is small compared to the global dataset (at just 3.2 % of total ETM projects identified worldwide), this fact also underscores its importance: the seemingly insignificant number of projects in the Pacific is easily overlooked, along with the perverse pressures and perils facing Pacific peoples and places.

Our work underscores the call for planetary policies and greater coordination around the supply of natural resources in ways that are sensitive to regional circumstances (Ali et al., 2017). From a global perspective, the type of vertical analysis we have conducted helps to identify resource rich regions that are more likely to experience compounding forms of exposure if there is a rush for their resources. To help inform decisions around responsible resourcing for renewables similar studies could be replicated across other regions, such as Africa and Asia which are set to become major centres of supply. Our approach also complements detailed sub-national analysis of ETM projects which can identify issues and impacts obscured by aggregate national-level data sets, especially in OECD countries in the top quartile of the United Nations' Human Development Index (see for example, Burton et al., 2024 for an analysis of ETMs across Australia's Indigenous Estate). We think a focus on vulnerability is crucial because conventional environmental, social and governance (or 'ESG') frameworks favoured by corporations and their lenders, and increasingly government strategists, overly emphasise investment risks, conceal entrenched disadvantage and obfuscate the real costs of mining benefits (Owen et al., 2021). Our analysis also helps to address the blinds spots that are created by an overreliance on local assessment and permitting processes for new mines. Ordinary impact assessment processes simply cannot grapple with the feedback loops or the larger threat-solution relationship of the sort we have discussed, whereby the most vulnerable places and peoples are subject to more complex forms of exposure to supposedly help solve planetary problems that they are not responsible for.

One conclusion we can draw from the Pacific sub-set is that we already understand a good deal about the impacts that will accompany increased pressure to access resources in the Pacific. Another conclusion is that there are many unknowns when it comes to the energy-extractives nexus and its convergence with climate action. The concept of compound exposure, supported by our Pacific sub-set, points to a range of macro-dynamics that are supressed by the logics of extractive capitalism. There is a need for greater scrutiny of the relationship between global warming scenarios, changes across various forms of vulnerability, and the future geography of resource extraction understood at different scales. In undertaking this analysis, we are prompted to ask, for example, what are the effects of adding new extractive projects to a particular region, and how would changes in other stressors shape these outcomes? What are the critical tipping points at which the combination of extractive effects, climate impacts and embedded vulnerabilities create a failed state or a series of regional failures? Is it possible to meet global ETM requirements without exploiting the most vulnerable regions in the world? And on what basis might it be determined that some regions should be excluded from exploitation? Answering these kinds of questions will require the development of novel data infrastructures and the building of effective institutions capable of dealing with increasing levels of complexity. It will also require more cohesive policy and planning processes that link global climate solutions with local and regional risks – by considering the differences and interdependencies between them. The point being that the current extractive-hegemony works to lock us into knowing less at a time when we urgently need to know a lot more. Our preliminary analysis draws attention to convergences and feedback loops, and points to the possibilities for building tools that can guide the development of interconnected governance processes that will avoid the catastrophes of compound exposure.

Pacific leaders are acutely aware of the contradictions underpinning global responses to climate change and the economic and geopolitical forces fuelling demand for their resources. To help Pacific nations navigate these turbulent seas, the recently launched *2050 Strategy for the Blue Pacific Continent* (PIFS, 2022b) sets a policy path for developing natural resources, achieving sustainable futures, and managing climate change. Described as 'the guiding star' for the Pacific, the strategy declares 'the need for urgent, immediate and appropriate action to combat the threat and impacts of climate change'. This pressing objective is paired with the equally pressing need for 'strengthened ownership' and 'sustainable management and development' of the region's natural resources to facilitate socio-economic growth and improve local livelihoods. Central to the ambition to 'strengthen the resilience of Pacific economies' is the stated need to increase the role of the private sector in areas such as mining.

The 163 ETM projects we have identified demonstrate the potential role the extractive industries could play in assisting Pacific nations to 'accelerate their economic growth aspirations' (PIFS, 2022b). The very high levels of vulnerability surrounding these projects also points to the possibility that the Pacific could become a poorly regulated regional quarry to supply the rest of the world with raw materials. As extractive companies court Pacific leaders and seek access to their resources in the name of a global climate solution, we need to ask who stands to gain the most from these arrangements and who has the most to lose. The current situation highlights the need for careful policy positions that consider how extractive activities simultaneously support *and* undermine sustainable development goals and the capacity and capability to manage and adapt to climate change.

CRediT authorship contribution statement

Nicholas Bainton: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Emilia E. Skrzypek:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Éléonore Lèbre:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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

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Data availability

Data will be made available on request.

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