



WHITE PAPER

Building disaster and climate resilience through Development Minerals



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Acronyms



ACP	African, Caribbean and Pacific Group of States
ASM	artisanal and small-scale mining
CE	circular economy
CLAIM	Climate and Impacts on Mining
CPF	Centre for Policy Futures
ESAT	Environmentally Safe Aggregates for Tarawa
EU	European Union
FRDP	Framework for Resilient Development in the Pacific
GEM	Geoscience, Energy and Maritime
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
MRD	Mineral Resources Department
NDMO	National Disaster Management Office
OPC	ordinary Portland cement
PDNA	Post Disaster Needs Assessment
PIFS	Pacific Islands Forum Secretariat
PRP	Pacific Resilience Partnership
PSIDS	Pacific Small Island Developing States
RDLA	Rapid Damage and Loss Assessment
SDG	Sustainable Development Goals
SIDS	Small Island Developing States
SMI	Sustainable Minerals Institute
SPC	Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
TC	tropical cyclone
UNDG	UN Development Group
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United National Environment Programme
UQ	The University of Queensland
USP	University of the South Pacific
WB	World Bank
WCDRR	World Conference on Disaster Risk Reduction

About the authors



The Development Minerals Strategic Program at **The University of Queensland's** Sustainable Minerals Institute, undertakes research, education, technical assistance and capacity building on the local materials most important for local development. Development Minerals are crucial for infrastructure, housing, road-building, manufacturing and agriculture and support the livelihoods of millions of people working in domestic artisanal, small- and medium-sized businesses. The program works with a wide range of international development partners to improve sustainability and human development outcomes and to help realise the UN Sustainable Development Goals (SDGs).

The **Pacific Community** (SPC) is the principal scientific and technical organisation in the Pacific region since 1947, owned and governed by 27 country and territory members. SPC supports its Pacific members through the provision of critical data, applied science and technical expertise. SPC's Geoscience, Energy and Maritime (GEM) Division has more than 50 years of expertise providing robust technical assistance and advice to support decision making about the region's geological resources. GEM leads SPC's work in operationalising the Framework for Resilient Development in the Pacific (FRDP) by providing coordinated technical support to SPC's members based on national and regional priorities in the areas of disaster and climate risk management.

This research received funding support from the ACP–EU Development Minerals Programme (implemented by UNDP) and the Australian Government Research Support Program.

The **ACP–EU Development Minerals Programme** is an initiative of the African, Caribbean and Pacific (ACP) Group of States, coordinated by the ACP Secretariat, financed by the European Commission and United Nations Development Programme and implemented by UNDP. This capacity building programme aims to build the profile and improve the management of Development Minerals in Africa, the Caribbean and the Pacific. The sector includes the mining of industrial minerals, construction materials, dimension stones and semi-precious stones.

The **United Nations Development Programme** (UNDP) is the lead UN agency fighting to end the injustice of poverty, inequality, and climate change. Working with a broad network of experts and partners in more than 170 countries, UNDP helps nations to build integrated, lasting solutions for people and planet. In the Pacific, UNDP provides regional and country support to 10 countries (Federated States of Micronesia, Fiji, Kiribati, Republic of the Marshall Islands, Nauru, Palau, Solomon Islands, Tonga, Tuvalu, and Vanuatu) and regional support to five countries (Cook Islands, Niue, Papua New Guinea, Samoa, and Tokelau), together with a total population of 2.4 million. UNDP is the implementing partner of the ACPEU Development Minerals Programme.

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Introduction



Disasters are a global concern that extend well beyond national borders. They cause significant losses to both lives, livelihoods, and property. The United Nations Office of Disaster Risk Reduction (UNDRR) estimates that disasters cause on average economic destruction of USD 300 billion per year, with 200 million people affected.¹ Disasters are a regular occurrence in the Pacific, causing substantial harm to the communities and economies of the region, with several Pacific Small Island Developing States (SIDS) regularly topping global disaster risk rankings.² Many of these disasters are associated with climate-related hazards, including cyclones, floods, landslides and droughts, which are all influenced by climate change. Pacific SIDS are all low greenhouse gas emitters, contributing only 0.03% of total greenhouse gas emissions,³ but are among the most vulnerable to the impacts of climate change.

One of the most critically affected parts of society from a disaster is the built environment, particularly the housing and infrastructure sectors, including roads, bridges, water and sewage services, telecommunication networks, airports, and recreation facilities.⁴ The damage to such infrastructure affects communities and stifles the rescue and recovery process, with affected communities often cut off from access and supplies.⁵ After the disaster, significant resources and capacities are required to rebuild damaged housing and infrastructure to ensure continuity of life within the affected communities. Such resources may include finance, materials, available workforce, and time, among others.

An important concept that has emerged in recent years in efforts to minimise such impacts is that of disaster resilience, which describes “the ability of individuals, communities, organisations and states to adapt to and recover from hazards, shocks or stresses without compromising long-term prospects for development”.⁶ **One essential and, until now, under-recognised aspect of disaster and climate resilience is the affordability, accessibility and diversity of minerals and materials available for (re)construction, especially due to the large volumes required.** The mineral dimensions of resilience can be considered through the concept of **mineral security**, which exists when all people have sufficient and affordable access to the minerals necessary for human development, including for shelter, mobility, communication, energy and sustenance.⁷

Development Minerals in the form of construction materials, such as sand, gravel, crushed stone, cement, and dimension stones, are critical to disaster and climate resilience. Development Minerals refer to the local minerals, mined by local people, for local development and they support disaster resilience in the Pacific in multiple ways. First, they are used in the construction of resilient infrastructure and adaptation solutions such as coastal protection. Secondly, they are essential for reconstruction of infrastructure and homes following disaster events. Thirdly, the choice of construction materials and how they are sourced can help to reduce risk or make it worse. Fourth, they are the primary materials needed for renewable

1. Wallemacq Pascaline, Debarati Guha-Sapir and Denis McClean. *The Human Cost of Natural Disasters: A Global Perspective*. (Brussels; Geneva: Centre for Research on the Epidemiology of Disasters; United Nations Office for Disaster Risk Reduction, 2015)

2. See www.WorldRiskReport.org

3. PCC, 'Working Group II Impacts, Adaptation and Vulnerability' (Intergovernmental Panel on Climate Change, 2011), <https://www.ipcc.ch/working-group/wg2/>.

4. Dilanthi Amarathunga and Richard Haigh, eds. *Post-Disaster Reconstruction of the Built Environment: Rebuilding for Resilience*. (Chichester, West Sussex, UK ; Ames, Iowa: Wiley-Blackwell, 2011).

5. Pascaline et al., *The Human Cost of Natural Disasters*

6. Emilie Combaz, 'Disaster Resilience: Topic Guide' (Birmingham, UK: GSDRC, University of Birmingham, 2014), 2.

7. Daniel M. Franks, Julia Keenan, and Degol Hailu. 'Mineral Security Essential to Achieving the Sustainable Development Goals'. *Nature Sustainability* 6, no. 1 (10 October 2022): 21-27.

energy and low-carbon development. Finally, the quarry sector, which supplies these materials can be a source of post-disaster employment, especially if resilience is built into the sector. Together, these factors demonstrate a significant opportunity for enhancing disaster and climate resilience in the Pacific through strengthening the responsible supply of Development Minerals.

There are several critical barriers which undermine the role of Development Minerals in supporting disaster and climate resilience. Most significantly, key international frameworks and tools, such as the Global Facility for Disaster Reduction and Recovery's (GFDRR) Post Disaster Needs Assessment (PDNA) guidance, do not explicitly address where and how key construction materials will be sourced in the event of a disaster. Furthermore, most disaster planning frameworks almost completely ignore the quarry sector, one of the key sources of construction materials that are necessary for rebuilding the affected infrastructure. In addition, the diverse impacts of disasters and climate change on the quarry sector are poorly understood. Until now, decision-makers have lacked a common framework for understanding, assessing, and managing these impacts. Global transitions to a low carbon and circular economy offer significant opportunities to enhance the resilience of Development Minerals in the Pacific and strengthen mineral security. However, there has been insufficient work in translating these circular economy opportunities to the context of Development Minerals.

To overcome these barriers, this White Paper aims to support government, development partners, and other stakeholders to build disaster and climate resilience, through the Development Minerals sector. Situated in the Pacific context, the paper integrates knowledge from collaborating partners with leading research and best practice. It informs readers concisely about these complex issues and presents our collective philosophy in responding to these matters to inform robust decisions.

Specifically, this paper aims to support the regional and international community that works in disaster response by:

1. Advancing global discourse on the role of Development Minerals in building disaster and climate resilience and strengthening mineral security;
2. Presenting tools and frameworks to inform decision-making; and
3. Providing options and recommendations to inform policy and frameworks governing the sector.

With the support of collaborators and partners, it is hoped that the paper will enhance preparedness for, resilience to, and recovery from, disasters and climate change by enhancing knowledge and policy for the sector.

To support these aims, the White Paper includes five core chapters:

- *Chapter 1* introduces key concepts and examines the current state of play in disaster planning and the various international frameworks that have been developed to address the risks of disasters and to minimise the risks to life, livelihoods, and communities. Building on this knowledge, the chapter scopes how pre-disaster planning and support can be enhanced by improving the availability of sustainable materials for reconstruction.
- *Chapter 2* maps the important roles Development Minerals play in climate adaptation and mitigation and provides a brief synthesis of the impacts of climate change on the quarry sector. It introduces the Climate and Impacts on Mining (CLAIM) framework – a new framework for understanding diverse climate change impacts in the mining sector and how it can help government and industry understand and prepare for the full range of impacts that climate-related natural hazards may have on the quarry sector.
- *Chapter 3* analyses key frameworks commonly used to assess and manage disaster risks. This analysis includes an assessment of the extent to which construction materials and other Development Minerals are considered in these frameworks and highlights the risks of their absence. This supports recommendations to refine these frameworks to enhance resilience in the Pacific through Development Minerals.
- *Chapter 4* introduces circular economy principles, and briefly synthesises current research on its application to the quarry sector and disaster resilience. In doing so, it identifies a range of circular economy opportunities which government and industry could implement to support disaster resilience in the Pacific.
- *Chapter 5* draws from the preceding chapters to identify ways forward to strengthen disaster resilience and mineral security. This includes **11 key recommendations** for governments, international development partners, the private sector, research institutions, and the public.

Throughout these chapters, case studies provide vivid examples of opportunities for enhancing resilience through Development Minerals by drawing lessons from previous disaster events in the Pacific and beyond.



Chapter 1

The central role of Development Minerals in disaster resilience

Development Minerals are minerals and materials that are mined, processed, and used domestically, in industries such as construction, manufacturing, and agriculture.⁸ They include industrial minerals and construction materials like clay, lime, gypsum, sand, gravel, crushed rock, marble, granite, and sandstone. Development Minerals have traditionally been neglected by policy makers, international development agencies, and others in part due to their low price per unit of volume when compared with high-priced minerals like copper, iron ore, and gold.⁹ This has led to a perception that they are of low value when in fact they comprise 84% of global mineral production by volume and are of immense importance to local development, particularly in developing countries.

Tens of millions of people worldwide derive a livelihood from Development Minerals, working in quarries, artisanal and small-scale mining enterprises, or in one of the many related downstream industries such as brick- or glass-making. Development Minerals are literally the materials that underpin development and are therefore of critical importance to achievement of the Sustainable Development Goals. As Franks argues, these minerals include “the clay bricks and roof tiles that provide shelter, the mineral fertilisers fundamental for agriculture, the garnet that filters water or the gravel and stone that builds bridges and paves rural roads”.¹⁰

Unlike energy and metallic minerals (including

so-called “critical minerals”), whose value is mostly derived from global markets, the value of Development Minerals is in their local and domestic processing and use. In comparison to the metals sector, Development Minerals have closer links with the local economy, and have the potential to generate more local jobs, with a greater impact on poverty reduction. Take the example of sand, which accounts for over 70% of all minerals extracted worldwide each year. According to the United National Environment Programme (UNEP), sand is essential for infrastructure and economic development, “providing livelihoods within communities and maintaining biodiversity”.¹¹ It is also linked to all 17 of the Sustainable Development Goals (SDGs). Despite its importance, the extraction of sand is largely ungoverned in many parts of the world and results in significant adverse environmental and social impacts. UNEP and others have even referred to a global “sand crisis” that demands immediate action by governments and other stakeholders to prevent sand extraction overtaking natural replenishment of supplies.

Access to supplies of Development Minerals is particularly critical during post-disaster reconstruction due to disruptions to transportation networks such as roads and bridges, which may be damaged, as might the quarries where many critical reconstruction materials are sourced. This situation requires post-disaster reconstruction and planning teams be proactive to ensure plans are in place to secure key materials in sufficient quantities at the right time.

8. Daniel M. Franks, ‘Reclaiming the Neglected Minerals of Development’. *The Extractive Industries and Society* 7, no. 2 (April 2020): 453–60.

9. Franks.

10. Franks, 2.

11. UNEP, ‘Mineral Resource Governance and the Global Goals: An Agenda for International Collaboration – Summary of the UNEA 4/19 Consultations’. Nairobi, Kenya: United Nations Environment Programme, 2022, 1.



Water sourced from a concrete well on Kiritimati Island, Kiribati.

Development Minerals are essential building blocks for human development.



1.1 Mineral Security

Mineral security exists “when all people have sufficient and affordable access to the minerals necessary for human development, including for shelter, mobility, communication, energy and sustenance”.¹² Disasters can create, or exacerbate existing, situations of mineral insecurity and mineral poverty, and place huge demands on the availability of key resources needed for shelter, transportation and communications.

Mineral security is also closely linked to food, energy and water security. Despite the importance of minerals to sustainable development, they are not featured within the SDGs or their constituent targets. The absence of minerals from many international frameworks¹³ demands careful attention and critical reflection if we are to successfully advance sustainable development and human security.

12. Daniel M. Franks, Julia Keenan, and Degol Hailu. ‘Mineral Security Essential to Achieving the Sustainable Development Goals’. *Nature Sustainability* 6, no. 1(10 October 2022): 21–27. 25 p.

13. UNEP. ‘Mineral Resource Governance and the Global Goals: An Agenda for International Collaboration – Summary of the UNEA 4/19 Consultations’. Nairobi, Kenya: United Nations Environment Programme, 2022.

1.2 Pre-disaster planning

Pre-disaster planning refers to two different, but closely related, planning processes that outline the measures to be taken by governments, NGOs, communities, and other stakeholders to address the impacts of disasters. Pre-disaster *response* planning focuses on how to respond and cope in the immediate aftermath of a disaster, whether natural or human induced.¹⁴ Its focus is on reducing loss of life and livelihoods and might include planning to provide emergency food and water supplies, shelter, medicines, and medical care.¹⁵ These responses are typically short term. Measures to improve preparedness might entail establishing early warning systems, developing contingency plans, training (e.g., in search and rescue), and stockpiling equipment and supplies.

By contrast, pre-disaster *recovery* planning involves planning the short-, medium-, and long-term measures necessary for communities to recover from a disaster. Here, the focus is not on immediate emergency response, such as the provision of food or shelter but, as the UNDRR explains, on “restor[ing] or improving livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities”.¹⁶ Pre-disaster planning must anticipate the wide range of issues that may be encountered following a disaster, and develop recovery scenario plans and build capacity to improve outcomes. Leading practice is now “rebuilding for resilience”¹⁷ and “building back better”, which the GFDRR defines as, “an approach to post-disaster recovery that reduces vulnerability to future disasters and builds community resilience to address physical, social, environmental, and economic



Disaster response team on Kadavu Island in Fiji after an earthquake in 2019.

14. European Civil Protection and Humanitarian Aid Operations, ‘Disaster Preparedness Factsheet’ (European Commission, 22 July 2022), https://civil-protection-humanitarian-aid.ec.europa.eu/what/humanitarian-aid/disaster-preparedness_en. Accessed 20/10/2022

15. Federal Emergency Management Agency, ‘Pre-Disaster Recovery Planning Guide for Local Governments: FEMA Publication FD 008-03’ (U.S. Department of Homeland Security, February 2017)

16. UNDRR, ‘Sendai Framework Terminology On Disaster Risk Reduction: Recovery’ (United Nations Office for Disaster Risk Reduction, n.d.), <https://www.undrr.org/terminology/recovery>. Accessed 27/10/2022

17. Federal Emergency Management Agency (2017)

vulnerabilities and shocks”.¹⁸

At the community level, pre-disaster recovery entails not only restoring or rebuilding infrastructure, housing, services, economic activity, and the physical environment, but also re-establishing civic and social leadership, the environment, and the broad social fabric of the community.¹⁹ Planning should be as broad and inclusive as possible, taking into account the needs of communities as determined through consultation, particularly the needs of vulnerable and disadvantaged groups whose ability to recover following a disaster might be limited.

For both response and recovery, pre-disaster planning requires an understanding of risks, such as the likelihood and consequences of a disaster occurring, and should anticipate community needs. Planning also requires clear allocation of lines of authority and responsibility.

Pre-disaster planning has received increased attention in recent years due to the growing number and size of humanitarian disasters occurring globally. Climate change, rapid urbanisation and industrialisation, and most recently the COVID-19 pandemic, have all triggered or exacerbated crises that have led to humanitarian disasters. Over the past decade, a range of governments and international institutions such as the EU and UN have developed new methods, guidelines, and frameworks to ensure more effective responses to disasters, with the *Sendai Framework for Disaster Risk Reduction 2015–2030* a notable example.²⁰ A key objective of such frameworks is to improve ‘disaster preparedness’, which the United Nations Office on Risk Reduction (UNDRR) defines as “the knowledge and capacities developed by governments, response and recovery organisations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely imminent or current disasters”.²¹



Land reclamation for housing development on Tongatapu Island, Tonga.

18. GFDRR, ‘Building Back Better in Post-Disaster Recovery’ (The Global Facility for Disaster Reduction and Recovery, n.d.), https://www.gfdr.org/sites/default/files/2017-09/Building%20Back%20Better%20Guidance%20Note_0.pdf. Accessed 03/02/2022 19. Federal Emergency Management Agency (2017)

20. ‘DG ECHO Guidance Note: Disaster Preparedness’ (European Commission, 2021)

21. UNDRR, ‘Sendai Framework Terminology On Disaster Risk Reduction: Preparedness’ (United Nations Office for Disaster Risk Reduction, n.d.), <https://www.undrr.org/terminology/preparedness>. Accessed 20/10/2022



Reconstruction of a school in Fiji with resilient concrete materials designed to withstand future cyclones. Note: this photo was taken in 2023, seven years after the school was damaged by Cyclone Winston in 2016.

1.3 Post-disaster reconstruction and resource availability

Target D(d) of the Sendai Framework emphasises the reduction of disaster damage to critical infrastructure and disruption of basic services among affected communities across the globe by 2030. There is, therefore, a need to design and construct infrastructure that is more resilient to disasters and climate change. Reconstruction and rehabilitation programmes are typically initiated to cushion the effect of the disaster on public infrastructure facilities and to facilitate the recovery of affected communities. The construction sector has a significant role to play

in contributing to society's improved resilience. Resilient infrastructure is that which is designed and developed so that it can resist or change in order to reduce vulnerability and enable society to continue functioning economically and socially when subjected to a hazard event.²² Resilient infrastructure has the capacity to withstand adverse environmental conditions such as disaster damage. Post-disaster, the reconstruction programme must focus on the reinstatement of destroyed structures and on mitigation and long-term sustainability. Building back better has been defined as an approach to post-disaster recovery that reduces vulnerability to future disasters and builds community resilience to address physical, social, environmental, and economic vulnerabilities and shocks. Building back better emphasises building stronger, safer, and more

22. Amaratunga and Haigh, *Post-Disaster Reconstruction*

disaster-resilient infrastructure. Development Minerals are essential to the build back better agenda, especially construction materials like sand, aggregates, and cement, which are often needed to replace damaged substandard building materials.

The magnitude of the disaster sometimes requires complete reconstruction or repair of varying degrees. Post-disaster reconstruction becomes extremely complicated and involves coordination by many organisations.²³ Irrespective of the magnitude of the damage, the infrastructure network breakdown undoubtedly aggravates the post-disaster reconstruction work.

After a disaster, some infrastructure damage

is beyond repair and requires complete reconstruction. However much the replacement of such infrastructure is needed to normalise the communities' lives, there is a need to build additional structures to avert future disasters. For example, the accessibility of emergency services, such as the extension of relief resources to the affected communities, evacuation of the affected people and reconstruction of the affected communities relies on a good quality road network.²⁴

All these works require a significant amount of construction materials, however, to date they have been an absent dimension of the discourse and practice of post-disaster construction.

Box 1: Assessing quarry sector damage following Tropical Cyclone Yasa

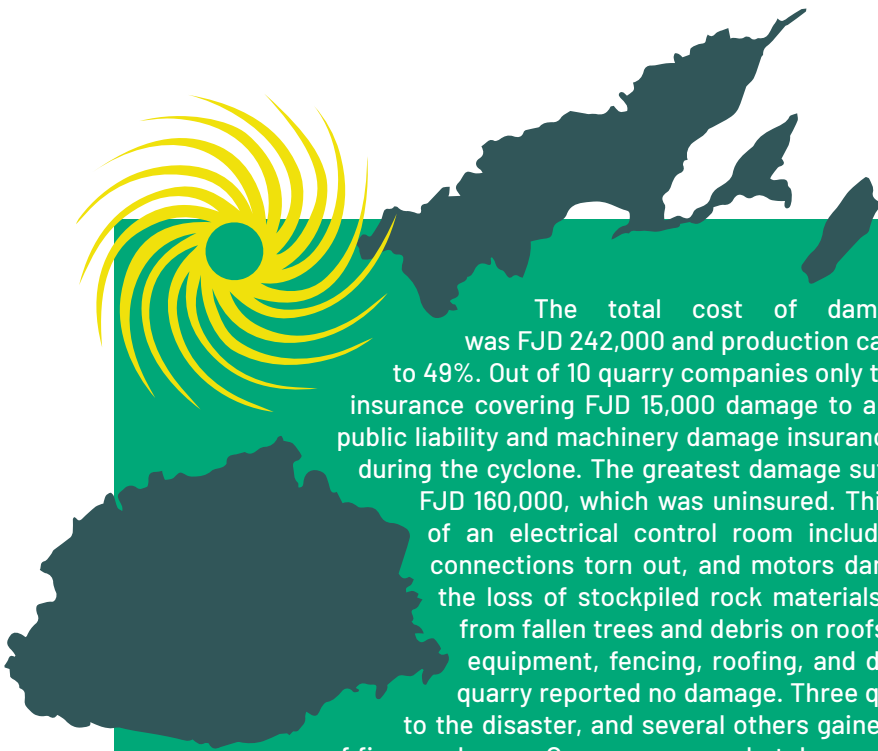
At the time of *Tropical Cyclone Winston* in 2016, the Fiji quarry sector was already under strain, with demand for quarried materials dramatically increasing in recent years, driven by infrastructure projects. In early 2017, Fiji suffered major shortages of construction materials, especially cement, which led the Director of Fiji's Mineral Resources Department to call for major changes to Fiji's future disaster planning, regulatory and policy responses. A Post Disaster Needs Assessment (PDNA) was published in May 2016 funded by ACP-EU NDRR Program. The PDNA for *Winston*, like most PDNAs, did not assess the quarry sector, even though this sector is arguably, the most important provider of raw materials for the recovery effort. Analysis of the mining sector was restricted to the small number of Fiji's metal mines (which consists of just of two active mines), neglecting analysis of the state of the 43 river dredging sites, and 29 hard rock quarries.²⁵

Fiji learnt from the experience of *Winston* and when the next Category 5 Cyclone (*Yasa*) struck in December 2020, the Fiji Mineral Resources Department (MRD), The University of Queensland and The Pacific Community developed a 'Damage and Capacity Assessment Tool for the Quarry Sector' (see Appendix 1). MRD undertook field assessments using the tool at 10 quarries in affected parts of the country.

23. J Le Masurier, J O B Rotimi, and S Wilkinson, 'Comparison between Routine Construction and Post-Disaster Reconstruction with Case Studies from New Zealand', in *Proceedings 22nd Annual ARCOM Conference*, ed. D Boyd (Birmingham, UK: The Association of Researchers in Construction Management (ARCOM), 2006), 523-30.

24. Shohel Amin, Umma Tamima, and Luis E. Amador-Jiménez, 'Optimal Pavement Management: Resilient Roads in Support of Emergency Response of Cyclone Affected Coastal Areas', *Transportation Research Part A: Policy and Practice* 119 (January 2019): 45-61; Md. Shohel Reza Amin, Umma Tamima, and Luis Amador, 'Towards Resilient Roads to Storm-Surge Flooding: Case Study of Bangladesh', *International Journal of Pavement Engineering* 21, no. 1(2 January 2020): 63-73.

25. UNDP, 'Disaster Reconstruction and Quarried Materials: Promoting Resilience in a Neglected Sector' (United Nations Development Programme, 2017).



The total cost of damage to the 10 quarries assessed was FJD 242,000 and production capacity was reduced on average to 49%. Out of 10 quarry companies only two held any insurance. One had insurance covering FJD 15,000 damage to a shed. The other company had public liability and machinery damage insurance only but suffered no damage during the cyclone. The greatest damage suffered by any single quarry was FJD 160,000, which was uninsured. This damage involved destruction of an electrical control room including all cables being exposed, connections torn out, and motors damaged. Other damage included the loss of stockpiled rock materials and binders, and the impacts from fallen trees and debris on roofs, offices, control rooms, power equipment, fencing, roofing, and damage to equipment. Only one quarry reported no damage. Three quarries reduced employees due to the disaster, and several others gained employees for a net increase of five employees. One quarry was shut down completely during COVID-19. Two companies that were producing at 100% before the storm were reduced to 50% and 20% respectively. The company with the greatest damage was operating at 30% before Yasa but reduced to 0% capacity after the cyclone. Another company operating at 80% was reduced to 20% capacity post-Yasa. Three companies retained 100% production capacity, and the rest were reduced to varying degrees of capacity from 20% to 50%.

The tool assisted MRD to assess damage to quarries caused by *Cyclone Yasa* and the ability of the sector to supply the materials required for reconstruction. This data was essential to informing Fiji's recovery efforts, and we recommend similar post-disaster quarry assessments are embedded as best practice globally moving forward.

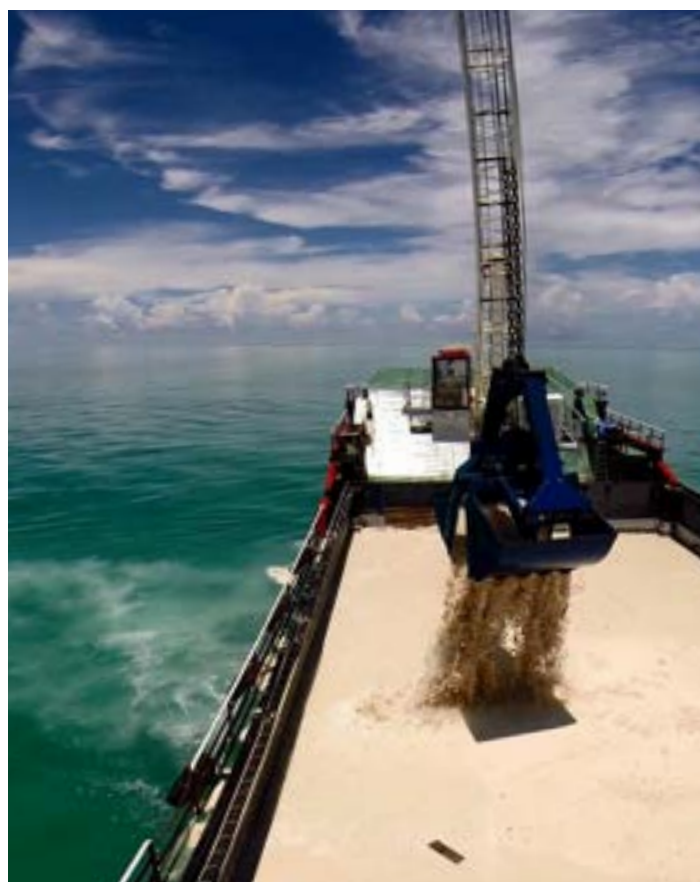
1.4 Sourcing of sustainable construction materials

Sustainable construction materials refer to those that are sourced in such a way that they do not inhibit the ability of future generations to meet their own needs or create significant disruptions to environments and communities. If appropriate safeguards are not in place, unsustainable extraction activities such as beach

mining can occur, causing damage to fragile coastal ecosystems and increased exposure of communities to coastal hazards.

For example, prior to 2008, sand and gravel were traditionally mined from the beaches of Tarawa, the most populated atoll in the Republic of Kiribati. This practice was recognised as being unsustainable, due to greatly exacerbated coastal erosion problems which were compromising communities and infrastructure in an environment already under threat from coastal hazards and climate change. Subsequently, between 2008 and 2016, the

Government of Kiribati and partners implemented a comprehensive plan to protect Tarawa's beaches and transition to a sustainable source of aggregates, named the Environmentally Safe Aggregates for Tarawa (ESAT) Project. The project identified an alternative sustainable source of aggregate located in a sediment sink in the Tarawa lagoon, conducted robust environmental and social assessments, supported artisanal and small-scale mining (ASM) beach miners to transition, banned beach mining, and successfully established a state-owned dredging operation to source sustainable aggregates from the lagoon.²⁶ This is an exemplary illustration of the positive outcomes possible when the sustainable sourcing of Development Minerals is given sufficient consideration on the disaster and climate agenda. It is important to note that Tarawa is a remote atoll, the geological context with the least variety of Development Mineral resources available, and thus has acutely limited options for sourcing aggregates sustainably. Yet despite this immense contextual challenge, the Tarawa community was able to successfully transition to a sustainable source of aggregates. Kiribati's success serves as an inspiration for other communities around the world to implement transitions to sustainable sources of aggregate.



Te Atinimarawa dredging operation (established by the ESAT project) sourcing sustainable aggregate from the Tarawa lagoon.

Building back better may not necessarily mean building back sustainably. Following a disaster, significant volumes of construction materials are required in a relatively short period of time, inevitably resulting in increased demands of construction aggregate supply chains. This is during a time when the supply chains may be adversely impacted by the disaster, and the transport networks needed to move materials from extraction sites are often cut off. These stresses can ultimately lead to supply shortages, which consequently create pressure to extract materials

from unlicensed sites and overlook usual approval processes which consider environmental and social safeguards. One of this report's authors witnessed this first hand following Cyclone Winston in Fiji, where materials were sourced from beaches and rivers without any due process or consideration of sustainability issues. This emphasises the need to consider Development Minerals during disaster planning and create resilience in Development Mineral supply chains, such as through strategic stockpiling of aggregates, or pre-identifying contingency extraction sites.

26. SPC, 'Environmentally Safe Aggregates for Tarawa (ESAT) Project Final Narrative Report 5 February 2008-31 December 2017 (Government of Kiribati, European Union, Pacific Community)' (Pacific Community, 2017).

Sustainable materials also have an element of circularity as they may be recycled and reused after their design period. In the case of disaster reconstruction, for example, concrete can be recycled to form aggregates and sand for construction. Other than disposal, concrete debris can be crushed and aggregates recovered to build other structures. Recycling such materials can reduce the environmental impacts of extraction from natural environments and lessen the impacts of disposal in landfills.

Sustainable sourcing of construction materials involves promoting and supporting the broader adoption of responsible practices throughout the entire materials supply chain. This process can stimulate demand for socially and environmentally preferable construction materials.

Many studies and frameworks have advocated for

local community participation in the reconstruction process.²⁷ For example, Chang et al advocate for a multistakeholder approach to facilitate training of artisanal and small-scale miners to improve resource availability for post-disaster rebuilding, while Junior, Franks and Arbelaez-Ruiz demonstrated the role that the quarry sector can provide as a refuge following human disasters, such as conflicts.²⁸ The Development Minerals sector is dominated by artisanal and small-scale mining (ASM) and quarrying enterprises that are staffed by local people. In the majority of cases, these employees are part of the affected communities. They work in and understand the sector better than most stakeholders and play an essential role in disaster recovery. For example, one of the 10 key propositions for building back better that were developed after the Indian Ocean tsunami disaster recovery process asks that governments, donors, and aid agencies must recognise that families and communities drive their own recovery.²⁹



Home destroyed by Typhoon Maysak in the Federated States of Micronesia in 2015.

27. See Elizabeth Maly, 'Building Back Better with People Centered Housing Recovery', *International Journal of Disaster Risk Reduction* 29 (August 2018): 84–93; Manoj Pardasani, 'Tsunami Reconstruction and Redevelopment in the Maldives: A Case Study of Community Participation and Social Action', ed. Rajib Shaw, *Disaster Prevention and Management: An International Journal* 15, no. 1 (January 2006): 79–91; Zabihullah Sadiqi, Bambang Trigunaryah, and Vaughan Coffey, 'A Framework for Community Participation in Post-Disaster Housing Reconstruction Projects: A Case of Afghanistan', *International Journal of Project Management* 35, no. 5 (July 2017): 900–912.

28. Yan Chang et al., 'Resourcing for Post-disaster Reconstruction: A Comparative Study of Indonesia and China', *Disaster Prevention and Management: An International Journal* 21, no. 1 (17 February 2012): 7–21; Patrick Junior, Daniel M. Franks, and Diana Arbeláez-Ruiz, 'Minerals as a Refuge from Conflict: Evidence from the Quarry Sector in Africa', *Journal of Rural Studies* 92 (May 2022): 206–13.

29. William J. Clinton, 'Key Propositions for Building Back Better: Lessons Learned from Tsunami Recovery' (Office of the UN Secretary-General's Special Envoy for Tsunami Recovery, December 2006), https://www.preventionweb.net/files/2054_VL108301.pdf.



Chapter 2

Climate change and Development Minerals

2.1 Development Minerals and climate adaptation

The fundamental components of climate-related climate risk are 'hazard', 'vulnerability', and 'exposure', as outlined in the diagram below. The IPCC states that "[t]here are options for risk reduction through adaptation. Adaptation can reduce risk by addressing one or more of the three risk factors: vulnerability, exposure, and/or hazard. The reduction of vulnerability, exposure, and/or hazard potential can be achieved through different

policy and action choices over time until limits to adaptation might be reached".³⁰ Development Minerals can play important roles across all three of these fundamental risk components to support climate adaptation, as discussed herein.

Low-lying coastal communities, especially those in small island developing states (SIDS), are particularly exposed to impacts of weather and climate events such as coastal flooding, sea level rise, and cyclones. In this context, communities have two primary options to reduce exposure, and Development Minerals play a critical role in both options.

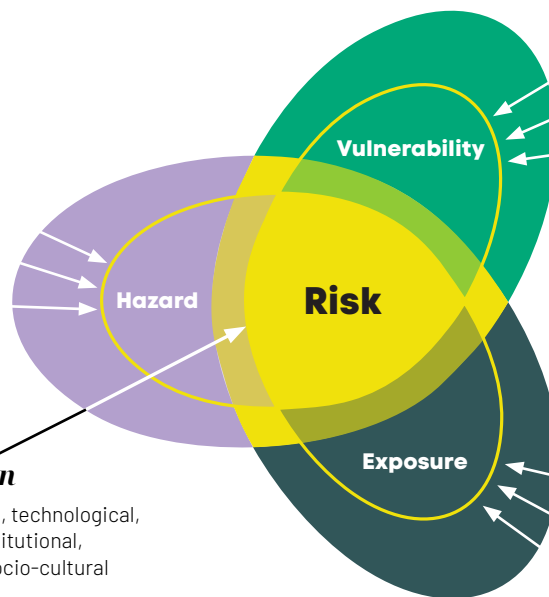
Actions to reduce Hazards

Examples include:

- Ecosystem-based measures to reduce coastal flooding
- Mangroves to alleviate coastal storm energy
- Water reservoirs to buffer low-flows and water scarcity

Limits to Adaptation

- E.g. physical, ecological, technological, economic, political, institutional, psychological, and/or socio-cultural



Actions to reduce Vulnerability

Examples include:

- Social protection
- Livelihood diversification
- Insurance solutions
- Hazard-proof housing and infrastructure

Actions to reduce Exposure

Examples include:

- Coastal retreat and settlement
- Risk sensitive land use planning
- Early warning systems and evacuations

FIGURE 1: The Intergovernmental Panel on Climate Change (IPCC) conceptual framework for risk and adaptation. (Source: IPCC Technical Summary, Figure TS.4 (2019))

30. Intergovernmental Panel On Climate Change (IPCC), 'Technical Summary', in *The Ocean and Cryosphere in a Changing Climate: Special Report of the Intergovernmental Panel on Climate Change*, 1st ed. (Cambridge University Press, 2019)

Firstly, communities can reduce **exposure** by retreating to higher land that has lower exposure or is not exposed at all to the impacts of coastal hazards. For example, Nauru is a country situated on a single uplifted limestone island in the Pacific with a land area of approximately 20 km². Although the island has an uplifted central plateau with an elevation up to approximately 71 m, almost all the country's infrastructure and population reside on a low-lying coastal plain which is highly exposed to coastal hazards.³¹ Subsequently, the nation has embarked on the Higher Ground Initiative, a massive, multi-generational project to develop the higher-elevation interior of the island for relocation of its population and infrastructure.³² This endeavour (and others like it around the world)

will require substantial quantities of Development Minerals to prepare the land for relocation and to construct the associated infrastructure.

Communities living in atoll nations such as Tuvalu, however, do not have any naturally occurring land at elevations with low exposure to coastal hazards, particularly when projected sea-level rise scenarios are taken into account.³³ Subsequently, in this context, the primary adaptation option to reduce exposure involves creating new elevated land which is less exposed to coastal hazards.³⁴ For example, the atoll nation of Tuvalu has set out a plan for the nation's long-term adaptation known as "Te Lafiga o Tuvalu" ("Tuvalu's refuge"). This bold vision seeks to create 3.6 km of raised safe land



Land reclamation on the lagoon foreshore of Funafuti Atoll in 2023 to create elevated land designed for 2100 sea-level rise scenarios, part of the Tuvalu Coastal Adaptation Project (Source: James Lewis, Intercoastal Consulting).

31. Moritz Wandres et al., 'Nauru Coastal Risk Assessment' (Suva, Fiji: Pacific Community, 2023).

32. Government of the Republic of Nauru, 'Nauru National Climate Change Policy', n.d.

33. Wandres et al., *A national-scale probabilistic coastal flood hazard assessment for the atoll nation of Tuvalu* (forthcoming)

34. Kate Walker and Patrina Dumar, 'Tuvalu Coastal Adaptation Project: Environmental and Social Impact Assessment, Funafuti' (Suva, Fiji: Pacific Community, 7 October 2020).

with staged relocation of people and infrastructure over time.³⁵ This pragmatic plan (and similar plans in other atoll nations, such as the Temaiku Land and Urban Development Project in Kiribati³⁶) requires vast quantities of Development Minerals to create the necessary elevated land. Implementation of Tuvalu's long-term plan will require more than 30,000,000 m³ of Development Minerals, which equates to approximately 2,500 m³ per capita, or in other words one Olympic-sized swimming pool of sand and gravel per Tuvaluan. This example vividly demonstrates the scale of Development Minerals required for atoll nations like Tuvalu to meet the mineral security needs of their people in the context of climate adaptation. Hence, it is abundantly clear that Development Minerals present the primary pathway for atoll nations to reduce exposure to and adapt to the impacts of climate change.

Vulnerability refers to the propensity or predisposition to be adversely affected. In this context, Development Minerals play a critical role in creating resilient infrastructure with lower predisposition to be adversely affected by climate hazards. In many places around the world, particularly in developing countries, infrastructure and buildings are constructed from inferior materials and are highly vulnerable to damage during disasters. For example, in February 2016, Category 5 *Tropical Cyclone Winston* struck Fiji. The cyclone affected approximately 540,400 people (62% of the country's total population). Around 40,000 people required immediate assistance, with 44 fatalities confirmed. A total of 30,369 houses, 495 schools and 88 health clinics and medical facilities were damaged or destroyed.³⁷ Much of this damage was due to vulnerability associated with inferior construction. In the aftermath of the disaster, the Fiji Institution of Engineers conducted a damage assessment where they

concluded that "timber structures (damaged or not) are highly recommended to be demolished and re-built with concrete construction".³⁸ Currently, concrete structures account for around 40% of Fiji's housing stock, therefore if concrete upgrades are to be adopted to reduce vulnerability to future cyclones, vast quantities of Development Minerals will be required. The Blue Concrete Initiative case study highlighted in this report is an innovative example of a Development Minerals adaptation and mitigation action aimed at reducing the vulnerability of Fiji's infrastructure by improving the accessibility and affordability of concrete.

Development Minerals can also play an important role in terms of reducing the **hazards** posed by weather and climate events. Where Development Minerals are extracted from can either increase the hazard or reduce it. The previously discussed ESAT case study in Tarawa atoll, where Kiribati transitioned from beach mining to lagoon dredging, is an example of coastal hazard reduction through sustainable sourcing of Development Minerals. Another example where Development Minerals can support hazard reduction is related to flooding. Dredging of the lower reaches of rivers is a widespread method used to reduce flood hazards in estuaries, it is also a widespread method used to source sand and gravel resources. Therefore, there is an opportunity for an integrated river management circular economy approach whereby areas which require dredging for flood mitigation purposes are identified and the dredged materials are utilised as a source of sand and gravel (provided the material meets the necessary quality requirements). Effective planning and collaboration between stakeholders (particularly climate, disaster, land-use planning, and mineral governance departments) is essential for these hazard reduction opportunities to be realised.

35. *Te Lafiga o Tuvalu - Tuvalu's Long Term Adaptation Plan* (UNDP, 2022), <https://youtu.be/Gp14MhdaSTs>.

36. *Temaiku, Kiribati Land and Urban Development Presentation*, YouTube (Jacobs Official, 2018), <https://youtu.be/EnKlpEnDfCM>.

37. The World Bank, 'Fiji Post-Cyclone Winston Emergency Development Policy Operation (P159774)', 2016.

38. 'Cyclone Winston Damage Assessment Findings and Moving Forward' (Suva: Fiji Institute of Engineers, 2016).



House destroyed by Cyclone Winston in Fiji in 2016. Note the relatively resilient concrete building in the background which was used for refuge during the disaster.

2.2 Development Minerals and climate mitigation

The raw materials required for the energy transition is a topic of increasing discussion. However, discourse to date on the role of minerals in the energy transition has almost exclusively focused on energy transition metals. For example, a 2020 report by the World Bank titled *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition* focuses on 17 key minerals and steel, but explicitly excludes concrete.³⁹ The report states that “steel has been included because of the size of demand for the alloy from energy technologies”. Following this logic, it could be assumed that concrete is therefore excluded because it is not a significant material required for the energy transition.

In reality, Development Minerals play a significant role in the construction of energy technologies.

Almost all forms of renewable energy require the use Development Minerals in their construction. However, due to their absence in current discourse, there are no estimates on the volume of Development Minerals required for the energy transition. Nevertheless, the volume of Development Minerals required is undoubtedly several orders of magnitude higher than any other energy transition metal.

Hydroelectricity (hydro) accounts for the largest share of global renewable electricity generation at 61%.⁴⁰ Development Minerals are the primary materials used to construct hydro technology. For example, 28 million m³ of concrete were used during the construction of the Three Gorges Dam in China, the world’s largest hydroelectric dam. Wind accounts for the second largest contribution to renewable electricity generation at 20%. Concrete is also the primary material used to construct wind turbines, ranging between 243,500 to 413,000 t/GW depending on the type of turbine, compared to 18,000 to 20,000 t/GW for iron.⁴¹ Other renewable

39. Kirsten Hund et al., ‘Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition’ (Washington, DC: The World Bank Group, 2020).

40. IRENA, ‘Renewable Energy Statistics 2021’ (Abu Dhabi: The International Renewable Energy Agency, 2021).

41. Dolf Gielen, ‘Critical Minerals for the Energy Transition’ (Abu Dhabi: The International Renewable Energy Agency, 2021).

energy technologies including solar, bioenergy and geothermal all use Development Minerals in their foundations, buildings, and supporting infrastructure such as roads.

Aside from the significant role that Development Minerals play in terms of their use in energy transition technologies, there is also potential for mitigation actions directly associated with the extraction, processing, manufacturing, and transportation of Development Minerals. Development Minerals are the second most consumed natural resources in the world after water. Globally, UNEP estimates that approximately 50 billion metric tons of sand, gravel, crushed stone, and aggregates are consumed annually.⁴² Given this enormous scale it is somewhat inevitable that Development Minerals account for a notable contribution to global greenhouse gas (GHG) emissions. The Blue

Concrete case study highlighted in this paper is an excellent example of a mitigation action led by the Government of Fiji aimed at reducing cement emissions.

However, currently there are no estimates on the collective emissions profile for Development Minerals. Due to the cross-cutting nature of Development Minerals, IPCC reports associated GHG emissions in other sectors such as building, transport, industry and energy. Even for the cement sector (which has relatively robust data compared to other facets of Development Minerals), the IPCC notes that a lack of data prevents the full analysis of emissions to this sector. Therefore, the relative contribution of the cement sector to total GHG emissions is underestimated due to this data gap.

The cross-cutting nature of Development Minerals



Concrete foundations of a solar farm in Tonga, designed to withstand Cyclone winds.

42. UNEP, 'Sand and Sustainability: 10 Strategic Recommendations to Avert a Crisis' (Geneva: United Nations Environment Programme, 2022).

means that ongoing mitigation actions targeting sectors such as buildings, transport, industry, and energy will inevitably reduce emissions associated with Development Minerals. However, there is additional value in viewing emissions through the lens of Development Minerals to inform nuanced mitigation strategies. For example, ongoing mitigation actions in relation to the electrification of transport will directly reduce emissions associated with Development Minerals transportation. However, when viewed through the lens of Development Minerals an additional approach to reducing transportation emissions becomes apparent. In many places throughout the world Development Mineral resources are not given sufficient priority in planning processes and competing land-uses are given precedence. This has prevented the establishment of extraction sites close to urban centres, which are the primary locations of demand for Development Minerals. As

a result, Development Minerals are currently being transported unnecessarily large distances with unnecessarily excessive transportation emissions, such as in New Zealand’s largest urban centre of Auckland where one-third of the aggregates are transported further than 100 km.⁴³ Subsequently, an apparent mitigation action is to prioritise the establishment of extraction sites close to urban centres in order to reduce the distances Development Minerals are transported.

The lack of data on the emissions profile of Development Minerals inhibits the potential for the design and implementation of informed mitigation actions. Therefore, we recommend further research is conducted to better understand the emissions profile for Development Minerals. Such research should focus on identifying priority areas for targeted mitigation actions such as the Blue Concrete Initiative (see Box 2).



Concrete Seabees constructed in Fiji, destined for a coastal adaptation on Nanumea Island in Tuvalu.

43. Aggregate & Quarry Association of New Zealand, 'The Tyranny of Distance: Counting the Cost of Transporting Aggregates' (Wellington: Aggregate & Quarry Association of New Zealand, n.d.).

Box 2: The Blue Concrete Initiative

Cement is the most widely used building material in the world and is a major contributor to global climate change, accounting for an estimated 7–8 percent of all anthropogenic CO₂ emissions. Pacific Small Island Developing States (PSIDS) like Fiji are reliant on imports of high-carbon, high-cost clinker to produce cement, concrete and the construction of infrastructure, with Fiji the main distribution point for PSIDS.

Clinker imported to Fiji is among the most expensive in the world, inhibiting development, as well as the ability to adapt to the effects of climate change due to a lack of affordable and reliable supply of materials to construct resilient coastal infrastructure and housing. Furthermore, key materials added to cement to make concrete, such as aggregate, are currently extracted with significant environmental damage to waterways and coasts, including rivers, beaches, and reefs.

The potential introduction of ground-breaking low-carbon cement technology, known as limestone calcined clay cement (LC3), to Fiji presents an opportunity to both significantly reduce carbon emissions from the production of cement and ensure a reliable and sustainable supply of construction materials. LC3 uses local resources, is less energy intensive, and produces up to 40% less CO₂ emissions compared to ordinary Portland cement (OPC). Successful transition to a local cement industry based on LC3 has the potential to reduce Fiji's carbon emissions by around 80 kt per year, or approximately 4% of the country's annual emissions, and deliver significant cost savings for local industry. Coupled with the creation of a regional knowledge base of aggregate resources, as well as new safeguards for their extraction, adoption of LC3 could ensure Fiji and neighbouring states have a reliable and sustainable supply of concrete, that is essential to mitigate and adapt to the impacts of climate change.

The Blue Concrete Initiative will ensure that the Pacific's leadership on climate change advocacy is complemented by leadership in climate change mitigation, while also improving access to concrete for climate adaptation actions and resilient development. The initiative will therefore support the adoption of concrete that embodies the values of the Blue Pacific. The project has three primary objectives: 1) Determine the best configurations for producing low-carbon cement in Fiji and support the government and private sector through technology transfer to adopt low-carbon cement in Fiji's cement industry; 2) Build resilience in regional supply chains to ensure PSIDS have reliable sources of affordable materials to produce concrete (cement and aggregate) for infrastructure development and climate change adaptation actions such as coastal protection and climate resilient housing; 3) Ensure that key concrete inputs such as aggregate, limestone, clay and gypsum are sourced in a way which optimises environmental, social, and economic outcomes for the Blue Pacific.

The Blue Concrete Initiative is the result of a partnership between the Government of Fiji and The University of Queensland's Sustainable Minerals Institute, Technology and Action for Rural Advancement in Delhi, the Pacific Community, the ACP-EU Development Minerals Programme implemented by UNDP, and the Indian Institute for Technology Delhi.

2.3 Climate impacts on the quarry sector

In recent years, the global mining industry has engaged more meaningfully with the climate change agenda, in part motivated by their exposure to extreme weather events such as droughts, cyclones, flooding, and heat waves impacting operations, assets, infrastructure, and supply chains.⁴⁴ Given the potential to significantly impact financial bottom lines, some mining companies have now put in place policies and risk management measures to minimise such risks.⁴⁵ In some cases, oversight of climate risks is even held at the Board level, indicating the seriousness with which some companies now take climate change.

By contrast, the impact of climate change on the quarry industry has not received anywhere near the same amount of attention, either by government, those planning for disasters, or even companies themselves. This is especially the case in developing countries when operations are often run by small- and medium-sized enterprises. Quarry materials such as sand, gravel, and crushed stone ('aggregate'), clay, limestone, and granite are essential raw ingredients for cement and the construction of houses, buildings, and infrastructure, and are therefore crucial in the response to and recovery from, disasters. Despite this, pre- and post-disaster planning does not usually include analysis of how prepared the sector is to respond to the disruption to operations and the greater need for construction materials once a disaster occurs.



Gravel stockpiled on a river bank in Fiji, exposed to flood risk.

44. Vigya Sharma et al., 'Extractive Resource Development in a Changing Climate: Learning the Lessons from Extreme Weather Events in Queensland, Australia' (Gold Coast: National Climate Change Adaptation Research Facility, 2013); Vigya Sharma and Daniel M. Franks, 'In Situ Adaptation to Climatic Change: Mineral Industry Responses to Extreme Flooding Events in Queensland, Australia', *Society & Natural Resources* 26, no. 11 (November 2013): 1252-67.

45. See for example Rio Tinto, 'Our Approach to Climate Change 2021' (London: Rio Tinto plc, 2021).

The quarry industry itself is vulnerable to disasters and climate change, especially for river-based extraction of sand and gravel, which is the primary source of these materials in Small Island Developing States (SIDS) such as Jamaica and Fiji.⁴⁶ Flooding of quarry sites and damage to quarry infrastructure and machinery are some of the common ways in which quarry operations can be disrupted. Even under optimal circumstances, the quarry sector in many countries in Africa, the Caribbean and the Pacific is unable to meet local demand for minerals and, in the event of a disaster, capacity constraints may become critical. Such as the previously discussed example of *Cyclone Winston* in Fiji. A similar situation occurred in Mozambique, following *Tropical Cyclone Idai* in 2019, with the PDNA overlooking the minerals sector and the necessary steps that were needed to integrate it into the reconstruction effort. To our knowledge, no PDNA has undertaken an analysis of this crucial sector, even while they have commonly analysed the export metals sectors, and no guidance exists on how quarrying of the necessary materials for reconstruction can be integrated into PDNAs.

2.4 Climate and Impacts on Mining (CLAIM) framework

The impacts of climate change-related hazards on the availability of and access to Development Minerals are diverse and not fully understood. If policy makers, development partners, and industry organisations have a clear and comprehensive understanding of these impacts, they can help guide Pacific nations towards a sustainable and prosperous future. If not, then unforeseen risks



This limestone quarry in Tonga is not exposed to river flood hazards.

are likely to cause significant disruptions to the supply of Development Minerals, with subsequent effects on key economic sectors and communities in Pacific SIDS, including their ability to recover following climate change-related disasters.

Until now, research on the impacts of climate change on the quarry sector, a key source Development Minerals in most countries, has been mostly narrow in scope and disconnected. Because of this, important policy and assessment frameworks routinely overlook critical issues. This section introduces the *Climate and Impacts on Mining (CLAIM)* framework, which provides a more comprehensive approach to understanding diverse climate-related impacts across the quarry sector in the Pacific.⁴⁷ While originally developed for understanding the full range of climate change impacts in the Australian large-scale mining context, here it has been tailored to climate-related hazards in the quarry sector and to the context of Pacific Island nations.

46. UNDP, 'Disaster Reconstruction and Quarry Materials: Promoting Resilience in a Neglected Sector' (United Nations Development Programme, 2017).

47. R. Maher et al., 'Mining Transitions and Climate Change: A Research Synthesis to Inform CRC TIME Strategy' (Perth, Australia: Cooperative Research Centre for Transformations in Mining Economies Ltd, 2022).

2.4.1 Application of CLAIM framework

The CLAIM framework can help policy makers, development partners, and industry organisations to assess the impacts of climate change-related hazards on Development Minerals to better support resilience in the sector, and in turn, the resilience of communities which depend on it. Specifically, the CLAIM framework helps to:

- understand the impacts of climate change-related hazards on the quarry sector in a more comprehensive way based on leading research;
- inform and provide a rationale for policy and regulatory decisions;
- provide a foundation for more effective assessment frameworks and risk analyses which align with leading international frameworks; and,
- inform sector development and business strategies.

The most visible, and impacted, parts of the quarry sector following disasters are the sites of extraction, their equipment, processing facilities, and transportation networks. The CLAIM framework groups the quarrying sector into three main areas, which can allow policy makers and industry to identify all areas that may be potentially impacted by hazards (Figure 2):

- Social-economic-environmental context: finance (demand, markets, and insurance), permissions (policy, approvals, and social license), people (workforce and community), environment (biodiversity, water, ecosystem services).

- Industry operations: technology (used throughout the sector), exploration, operation (development and extraction), processing, transport.
- Post-mine futures: closure (rehabilitation and relinquishment).

While not all these areas of the quarry sector are immediately affected by climate-related hazards, the framework nevertheless provides a more systematic approach to understanding what these impacts may be and how to build resilience. For example, in terms of the social-economic-environmental context, disasters will require operators to have appropriate insurance and access to finance for recovery if equipment or site infrastructure is damaged. Government may also need to have special contingencies in the approvals/permitting processes to open new quarries in areas not affected by a hazard to provide essential materials for rebuilding. Preparations must also be made to ensure key workforce are available and can access sites to resume operations. Examples of these impacts on the quarry sector are provided in Figure 2 below. The arrows above each component of the quarry sector represented by the CLAIM framework indicate the most vulnerable areas and types of impacts that may occur. In some cases, such as technology, there may be opportunities to build resilience such as adopting renewable sources of energy produced locally, which can mitigate the risks of power disruptions caused by extreme weather events.

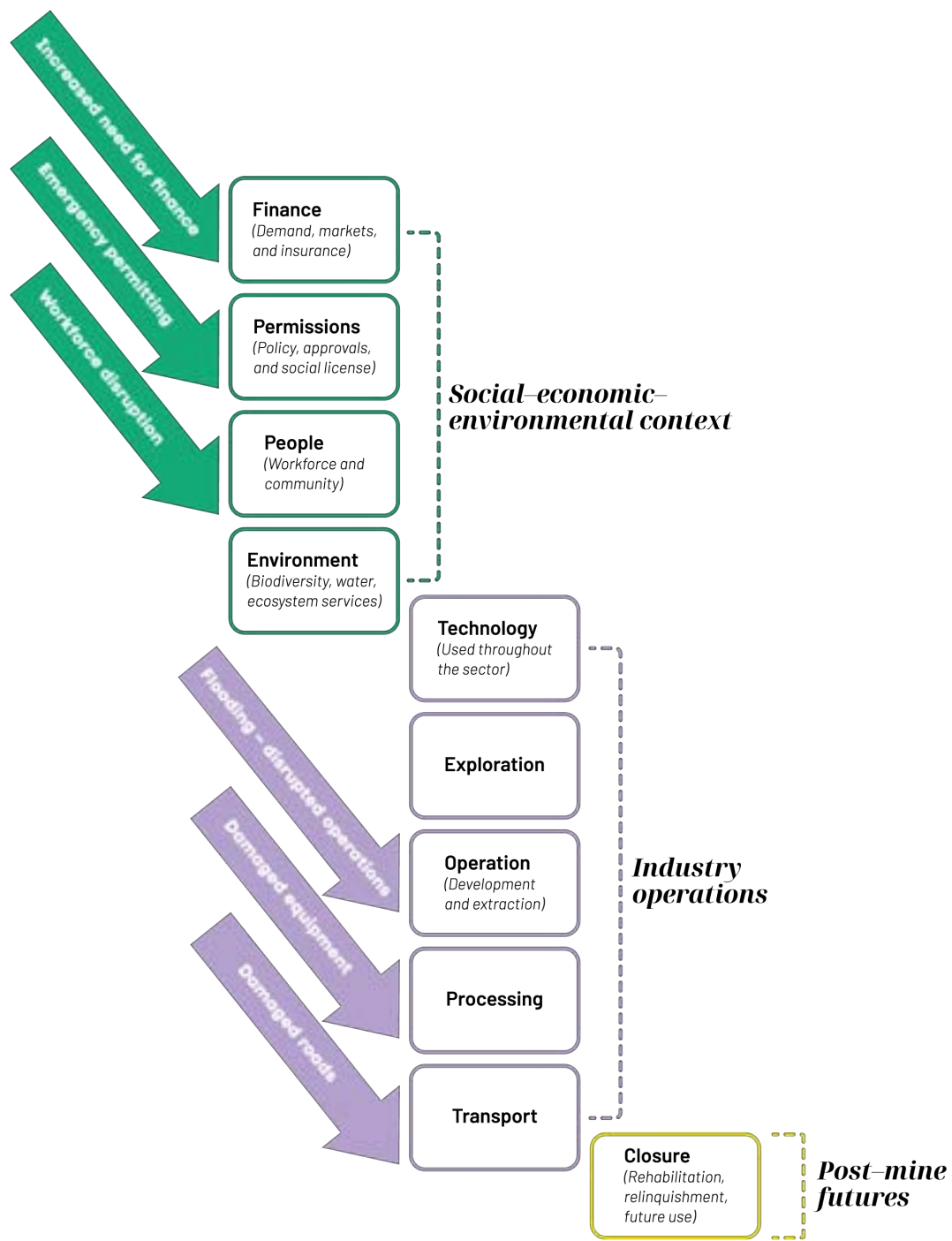


FIGURE 2: Components of the quarry sector system in the CLAIM framework and climate-related disaster/hazards impacts



Chapter 3

Analysis of policy and frameworks

This chapter examines three key disaster risk frameworks established in recent decades and assesses the extent to which construction materials and other Development Minerals are considered.

3.1 Sendai Framework

The Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework) was agreed by UN Member States and endorsed by the UN General Assembly following the 2015 Third UN World Conference on Disaster Risk Reduction (WCDRR).⁴⁸ It succeeds the Hyogo Framework for Action (HFA) 2005–2015 and builds on elements in this framework to ensure continuity of work, as well as to introduce a number of new innovations.⁴⁹ The Sendai Framework advocates for “[t]he substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.” Sendai is intended to “work hand in hand” with other Agenda 2030 agreements – such as the Paris Agreement on climate change – and is considered essential to the achievement of the SDGs, which were established shortly afterwards. While the state is expected to play the primary role in reducing disaster risk, other stakeholders, such as local government, industry and local communities are also expected to share responsibility.

Sendai encompasses seven targets and four priorities for action, which aim to prevent the

creation of new disaster risks, reduce existing risks, and increase resilience by 2030.⁵⁰ The targets are intended to guide and assess performance against these aims. They include such things as: substantially reducing global disaster mortality; reducing economic loss due to disasters; increasing the number of countries with national and local disaster risk reduction strategies; increasing international cooperation in developing countries and others. These global targets are measured through 38 global indicators. Meanwhile, priorities include understanding disaster risk; strengthening governance to manage risk; investment in disaster risk reduction for resilience; and enhancing preparedness for effective response and “building back better”. In addition, there are nationally defined custom targets and indicators which measure a nation’s progress against the four priorities.⁵¹

3.2 Framework for Resilient Development in the Pacific

The Framework for Resilient Development in the Pacific (FRDP): An Integrated Approach to Address Climate Change and Disaster Risk Management 2017–2030, is a high-level framework tailored to the context of the Pacific region. The FRDP was established in 2016 by the Pacific Islands Forum, SPC, the Secretariat of the Pacific Regional Environment Programme (SPREP), UNDP, United

48. UNDRR, ‘What Is the Sendai Framework for Disaster Risk Reduction?’ (United Nations Office for Disaster Risk Reduction, 2015).

49. United Nations, ‘Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030: Report of the Secretary-General’ (New York: United Nations, 27 July 2021).

50. UNDRR, ‘What is the Sendai Framework’.

51. UNDRR, ‘What is the Sendai Framework’. The COVID-19 pandemic and intensification of the climate crisis has adversely impacted performance in achieving some of these global targets. A July 2021 assessment of Sendai implementation revealed a picture of mixed success in achieving some of the global targets.

Nations Office for Disaster Risk Reduction (UNDRR) and the University of the South Pacific (USP). The regional framework outlines an integrated approach to climate and disaster risk management to create a more resilient Pacific.⁵² It supports coordination and action on important issues related to climate change and disaster risk management.⁵³

There are three strategic goals of the FRDP: i) strengthened integrated adaptation and risk reduction to enhance resilience to climate change and disasters; ii) low-carbon development; and iii) strengthened disaster preparedness, response, and recovery. The FRDP provides high-level voluntary guidance that can be used by a diverse range of stakeholders who have a role to play in achieving the strategic goals, ranging from governments and civil society groups to regional development partners and donors.

The guidance is provided in the form of a non-exhaustive list of priority actions to be taken by each of the stakeholder groups for each strategic goal. For example, for Goal 1 – strengthened integrated adaptation and risk reduction to enhance resilience to climate change and disasters, a set of priority actions is listed for national and subnational governments and administrations, civil society, communities, and so on. While some of the actions are to be implemented at the national level, others are to be implemented at the regional level. There is also a strong focus on sectoral aspects of resilient development, for example actions that should be taken in the energy sector, such as government ensuring that energy infrastructure is designed and located in ways that minimise the risks of extreme weather events and climate change. The FRDP also emphasises the link between climate and disaster risks and sustainable development, as well as inclusive engagement so that all voices,



Hanoabada, a vulnerable coastal community outside Port Moresby in Papua New Guinea.

52. Pacific Resilience Partnership, *Framework for Resilient Development in the Pacific: An Integrated Approach to Address Climate Change and Disaster Risk Management 2017-2030* (Suva, Fiji, 2016).

53. SPC, 'The Framework for Resilient Development in the Pacific' (Suva, Fiji, 2016).

including vulnerable groups, are heard to ensure there is disaster resilience in all sectors, from health to infrastructure.

Success in achieving the three goals is premised on a “sound enabling environment” which includes the availability of resources, good governance arrangements, and effective communication and partnerships.⁵⁴ To provide such an enabling environment, the Pacific Islands Forum foreign ministers established the Pacific Resilience Partnership (PRP) in Sydney in July 2015. The PRP brings together various stakeholder groups working on climate change and disaster risk management and sustainable development to share lessons and collaborate more closely to build resilience in the Pacific. The PRP meets every two years or as decided by the PRP itself.

3.3 Post Disaster Needs Assessments

Unlike Sendai and the FRDP, Post Disaster Needs Assessments (PDNAs) are a tool to be used when responding to the needs of communities once a disaster has already happened, as opposed to preparing before a disaster occurs. PDNAs were developed by the UN Development Group (UNDG), the World Bank (WB) and the European Union (EU) in 2013 to standardise the disaster needs assessment processes in the post-disaster period.⁵⁵ Historically, assessments involved a large number of agencies using different methodologies which, it was believed, risked causing confusion among stakeholders. The introduction of PDNA was therefore aimed at providing guidance so that government could take a harmonised and coordinated approach to comprehensively assess

damage, losses, and recovery needs.

The main goal of conducting a PDNA is to help governments to assess the full impacts of a disaster on the country and on the basis of this, develop a strategy to mobilise financial and technical resources to enable recovery.⁵⁶ In addition to government as the lead actor, implementation of a PDNA may involve a wide range of other stakeholders, such as NGOs, CSOs, the private sector, and bilateral and multilateral donors.

A key organisation in the implementation of PDNAs is The World Bank administered GFDRR. The facility describes itself as “a global partnership that helps developing countries better understand and reduce their vulnerability to natural hazards and climate change.” After each disaster the GFDRR works with the host government to send a team of analysts to the disaster location, and with the host country, compiles a report on losses and reconstruction needs in the form of a PDNA⁵⁷ or Rapid Damage and Loss Assessment (RDLA). These reports are extremely detailed including impacts on water, agriculture, sanitation, housing macroeconomy, health, education, transport, energy, environment, displacement, and many other topics.⁵⁸

3.4 Gaps in disaster planning and response frameworks

One of the most significant limitations of the above frameworks is that they do not adequately consider how the construction materials that are essential for reconstruction will be sourced following disasters. This is a glaring gap given

54. PRP, ‘About the PRP’ (Pacific Resilience Partnership), accessed 1 November 2022. <https://www.resilientpacific.org/en/about-prp>.

55. GFDRR, ‘Post-Disaster Needs Assessments: Guidelines’ (Global Facility for Disaster Reduction and Recovery, 2013).

56. GFDRR, ‘Post-Disaster Needs Assessments: Guidelines’ (Global Facility for Disaster Reduction and Recovery, 2013).

57. This includes elements of the Damage and Loss Assessment (DaLA) method and the Human Recovery Needs Assessment (HRNA) approach.

58. GFDRR, ‘Post-Disaster Needs Assessments: Guidelines’ (Global Facility for Disaster Reduction and Recovery, 2013).



Homes destroyed by Typhoon Maysak in the Federated States of Micronesia. Note: people sheltering in the relatively resilient concrete structure in the background.

that post-disaster recovery and reconstruction of infrastructure, housing and other buildings is such a high priority. For instance – and bearing in mind that it is a high-level framework – there is only a brief mention in the Sendai Framework of the construction materials needed to rebuild following disasters. This includes mention under Priority 3 – Investing in disaster risk reduction for resilience of the need for “standardization of building materials”, in order to build back better to withstand natural hazards. There are instructions in Sendai’s Technical Guidance for calculating costs of rebuilding damaged structures (Table 1) but no discussion of what this might mean in terms of ensuring the necessary construction materials are available to enable recovery following a disaster, for example, in terms of planning for stockpiling construction materials like cement, timber or aggregate. And there are no recommendations for governments to put in place policies or management plans on how to best utilise the often mountains of debris created by earthquakes, cyclones, and floods, comprised of concrete, rock and other material. As some researchers have shown, such strategies can cover measures such

as waste collection, transportation, processing, and disposal.⁵⁹

As with the Sendai Framework, the FRDP does not mention the importance of ensuring that minerals and construction materials are available in adequate quantities to rebuild communities in the event of a disaster. The quarrying sector is not mentioned. The mining sector is mentioned, but no specific guidance is provided on what role the sector can play towards strengthening disaster and climate resilience in the Pacific. However, the FRDP does provide some promising high-level statements which, with concerted effort, could be applied to the Development Minerals sector. Such as “facilitate sector needs and capacity mapping, including an inventory of private sector resources and services that can be made available before and after a disaster event in ways that assist response and recovery efforts” and “establish a contingency stockpile of emergency relief items”.

Likewise, the GFDRR’s PDNA tool does not provide guidance for assessment of damage to the quarry sector or on the sourcing of construction

59. Karunasena, G., Amaratunga, Dilanthi, Haigh, Richard, Lill, Irene. (2009). Post Disaster Waste Management Strategies in Developing Countries: Case of Sri Lanka. *International Journal of Strategic Property Management*, 13(2), 171-190.

materials following disasters, even though sector level guidance does raise the issue of the local availability of materials and other possible constraints for reconstruction. This might explain why of the reviewed PDNAs undertaken since 2015, none contain any information or recommendations about where and how the essential raw materials needed for post-disaster reconstruction will be obtained. The PDNAs assess the damage, losses, and financial cost of reconstruction for houses, bridges, and kilometres of roads, but contain nothing about the raw materials needed to build them. Infrastructure requires massive amounts of construction materials, including sand, gravel, and cement for the production of concrete.

Other materials left out of these PDNAs include wood, steel, aluminium, silica/glass for houses and buildings, and bitumen and tar for roads and other infrastructure. The result of overlooking these construction materials is that countries are often not adequately prepared to respond when a disaster strikes, and material shortages result. And finally, while damage to the quarry sector is consistently overlooked, many PDNAs do include damage assessments of the (export) metal mining sector, as was the case for the PDNA undertaken following Tropical Cyclone Winston.

A summary of this analysis is presented in Table 1 below.

TABLE 1: Analysis summary of the three key disaster planning and response frameworks.

Name	Organisation(s)	Responsibility for implementation	Key objectives	Scale	Scope	Guidance on sourcing construction materials?
Sendai Framework (2015)	UNDRR	National government (primary role) plus other actors: local government., industry, communities	Outlines targets and priorities to prevent new risks, reduce existing risks and increase resilience	Global with nationally defined targets High-level guidance	All disasters Sectoral guidelines provided in technical guidance	No – coverage limited to statements such as “standardization of building materials” in order to build back better to withstand natural hazards”. Technical guidance for data collection provides instructions for calculating costs of rebuilding damaged structures but not the sourcing of construction materials. ⁶⁰
Framework for Resilient Development in the Pacific (2016)	PIFS, SPC, SPREP, UNDP, UNDRR and USP	Pacific Resilience Partnership plus national and subnational governments and other stakeholders (e.g., communities, civil society)	Strengthened integrated adaptation and risk reduction to enhance resilience to climate change and disasters, low-carbon development, strengthened disaster preparedness response, and recovery.	Pacific region High-level voluntary guidance	Climate change and disasters	No specific mention, brief reference to building codes, reconstruction of housing, highways, bridges, building back better. Some high-level text which could be applied to Development Minerals, such as “facilitate sector needs and capacity mapping including an inventory of private sector resources and services that can be made available before and after a disaster event in ways that assist response and recovery efforts, and establish contingency stockpiles.”
Post Disaster Needs Assessment (2015)	GFDRR/World Bank	National governments and potentially other actors e.g., NGOs, CSOs, the private sector, and donors (including World Bank/GFDRR)	Provide a tool to comprehensively assess damages, losses, and recovery needs.	Global with detailed specific guidance for undertaking PDNAs at local level.	All disasters Separate detailed guidance covering various sectors, including housing and transport	Construction materials only briefly mentioned in sectoral guidance, e.g., requirements in Housing Sector guidance to document type of housing construction materials, as well as local availability and other possible constraints for reconstruction. However, no further detailed guidelines given on things like sourcing or assessment of quarry impacts. ⁶¹

60. UNISDR, ‘Technical Guidance for Monitoring and Reporting on Progress in Achieving the Global Targets of the Sendai Framework for Disaster Risk Reduction: Collection of Technical Notes on Data and Methodology’ (United Nations Office for Disaster Risk Reduction, December 2017).

61. GFDRR, ‘Post-Disaster Needs Assessments: Guidelines’ (Washington, DC: Global Facility for Disaster Reduction and Recovery, 2013).



Chapter 4

Circular economy and Development Minerals

This chapter presents the value of the circular economy (CE) concept to building disaster and climate resilience through Development Minerals.

Large quantities of materials are damaged in a disaster event, and even more materials are needed to build back in a more resilient way. Disposing of waste materials and replacing them places a huge burden on strained economies. It also degrades the natural environment, already harmed by the disaster. A circular economy (CE) approach can help to reduce these impacts and support long-term resilience. The circular economy is an alternative to the traditional linear “take-make-dispose” economy. It reduces the pressure on the ecosystem of producing goods, services, and waste by keeping the value of materials, products, and components for a more extended period in a system.⁶² The circular

economy goes beyond waste management and recycling to alleviate the limited supply of resources and fulfil increased demand for resources such as Development Minerals after a disaster. This can help nations prone to disasters to escape the trap of sinking more and more resources into vulnerable infrastructure.

The figure below distinguishes between a linear economy, a recycling economy, and a circular economy. It emphasises that the circular economy facilitates several alternative ways of recovering used materials, in addition to recycling, and reconnecting them back to conventional processes. The circular economy is built upon three principles: eliminating waste pollution, circulating products and materials, and regenerating nature, as outlined in Figure 4.

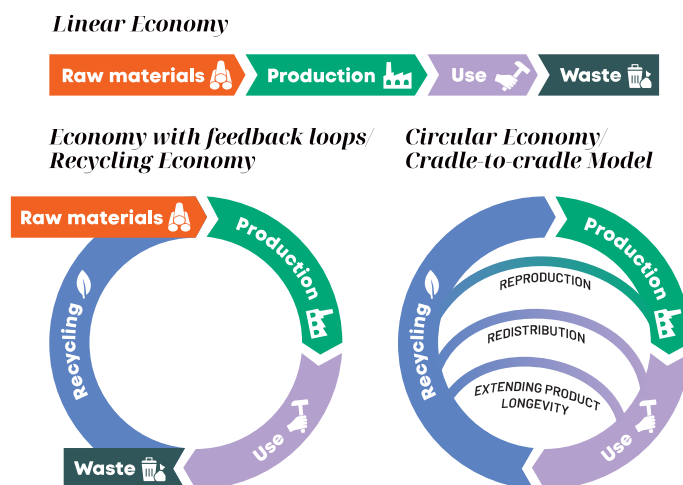


FIGURE 3: The difference between a linear economy, recycling economy, and circular economy.⁶³

62. Ellen MacArthur Foundation, 'Towards the Circular Economy Vol 1: Economic and Business Rational for an Accelerated Transition' (Isle of Wight, UK: Ellen MacArthur Foundation, 2013).

63. Niamh Pearce, *Bring on the Circular Economy*, 22 July 2017, <https://www.niamhpearce.com/blog/bring-on-the-circular-economy2203348>.

Eliminating waste pollution: As opposed to a linear economy where products end up in landfills or incineration, a circular economy encourages reducing and eliminating waste in the system. How products and infrastructure are designed can eliminate waste pollution. For example, post-disaster reconstruction can reuse debris from demolished/damaged structures. This can reduce waste going to landfills after a disaster, hence protecting the already damaged environment.

where CE encourages a shift of focus from extracting resources to building natural capital. These CE practices give natural ecosystems time to recover from the impacts of mining and disaster events. This benefits both native species and supports ecosystem services for communities, such as water filtration, flood mitigation, and food production. For example, reusing construction materials for reconstruction reduces the consumption of virgin Development Minerals resulting in fewer quarrying activities.



FIGURE 4: *Three principles of circular economy.*⁶⁴

The second principle, **circulating products and materials**, aims to keep products and materials in use for as long as possible at their highest value. This is similar to natural ecosystems, where the outputs of one species are used by another. Then, products and components will be utilised as raw materials when they cannot be used as products any longer. There are two main ways to cycle materials. **Technical cycling** keeps materials in use through reuse, maintenance, repair, and finally recycling. **Biological cycling** supports reusing biological materials such as timber and fabric by composting or anaerobically digesting them. These two processes can help to keep materials in use following a disaster event.

The third principle of CE is **regenerating nature**,

4.1 Circular economy, Development Minerals, and resilience

This section summarises the current literature on how circular economy can be applied to a) the mining/quarrying sector, and b) disaster resilience. Currently, there is a dearth of literature showing how all three concepts (Development Minerals, disaster resilience, and CE) can be integrated, implying this approach is still novel (Figure 5).

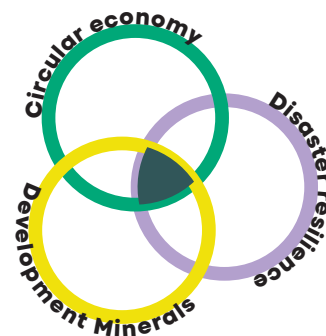


FIGURE 5: *The interconnection of themes: Circular economy, Disaster resilience, and Development Minerals.*

⁶⁴ Ellen MacArthur Foundation, 'Circular Economy Introduction: Key Ideas' (Ellen MacArthur Foundation, n.d.), <https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/key-ideas>.



The extraction of Development Minerals can cause unnecessary harm to the environment.

Quarrying and mineral extraction provide essential minerals for human development, but their extraction may also harm the environment and people. There is a growing body of research examining the feasibility of applying circular economy strategies to the minerals/mining industry to improve social, economic, and environmental outcomes, and provide opportunities for building resilience in Development Minerals supply chains. One model to assess the CE potential of the quarrying and Development Minerals sectors is the ReX concept, which, as Cisternas et al. explain, provide options for retaining the value of resources for the mining sector through “Rs strategies”. The Rs strategies encompass, in order of importance, 10 ways to retain the value of resources for the mining sector. In order of priority, they are: refuse, reduce, resell/reuse, repair, refurbish, remanufacture, repurpose, recycle, recovery (of energy), and remine.⁶⁵

For example, Lederer et al.⁶⁶ analysed the potential for using demolition waste in place of mineral construction materials with a case study from Vienna. The case study examined several available CE options, including avoiding demolition to reduce construction and demolition waste (refuse); reusing bricks from debris (reuse); recycling waste asphalt as new materials in asphalt hot-mix, using concrete waste as aggregates, using waste debris in raw-mix of cement raw material, and using gravel debris in road reconstructions (recycle).

Kaźmierczak et al.,⁶⁷ analysed the economical use of rock raw materials in waste plants which underpin Rs strategies of reduce, recycle, and reuse. Preferably, such waste can be used for road and railroad construction, agriculture, and reclamation or rehabilitation of mined areas. Similar approaches can be used to build resilience

65. Luis A. Cisternas et al., 'Toward the Implementation of Circular Economy Strategies: An Overview of the Current Situation in Mineral Processing', *Mineral Processing and Extractive Metallurgy Review* 43, no. 6 (18 August 2022): 775-97.

66. Jakob Lederer et al., 'Potentials for a Circular Economy of Mineral Construction Materials and Demolition Waste in Urban Areas: A Case Study from Vienna', *Resources, Conservation and Recycling* 161 (October 2020): 104942.

67. Urszula Kaźmierczak, Jan Błachowski, and Justyna Górniak-Zimroz, 'Multi-Criteria Analysis of Potential Applications of Waste from Rock Minerals Mining', *Applied Sciences* 9, no. 3 (28 January 2019): 441.

to disasters and reduce demand for raw materials for reconstruction.

Disasters create different types of waste, including green waste, soil, rock, hazardous waste, debris from buildings and infrastructure, chemicals, plastics, and electronics waste. In the urban context, a large proportion of disaster waste is much like construction and demolition waste.⁶⁸ Handling disaster waste effectively is essential to responding to the emergency, recovering, and rebuilding efficiently.⁶⁹

To retain its value, disaster waste can be treated differently through temporary storage, recycling, landfilling, and waste-to-energy.⁷⁰ Products of Development Minerals like concrete, bricks, stone, and sand can be recycled and utilised in the place

of new materials/minerals. This can recover value from materials, reduce the consumption of raw materials, and reduce costs. Waste management policies and capacities⁷¹ can help retain value from materials for longer through various cycling options.⁷²

The effectiveness and feasibility of recycling disaster waste is influenced by the volume of waste and how mixed it is, human and environmental health hazards, the geographical spread of the damage and waste, community priorities and beliefs, available financial support, time constraints and regulations.⁷³

Lauritzen identifies two approaches in disaster waste management: micro-recycling and macro-recycling. In micro-recycling, owners and the



Debris on Vanuabalavu Island in Fiji following Cyclone Winston in 2016.

68. Charlotte Brown, Mark Milke, and Erica Seville, 'Disaster Waste Management: A Review Article', *Waste Management* 31, no. 6 (June 2011): 1085–98.

69. Raju Poudel et al., 'Field Study of Disaster Waste Management and Disposal Status of Debris after Gorkha Earthquake in Kathmandu, Nepal', *Journal of Material Cycles and Waste Management* 21, no. 4 (July 2019): 753–65.

70. Fanshun Zhang et al., 'A Systematic Review of Recent Developments in Disaster Waste Management', *Journal of Cleaner Production* 235 (October 2019): 822–40.

71. Giacomo Di Foggia and Massimo Beccarelli, 'Designing Waste Management Systems to Meet Circular Economy Goals: The Italian Case', *Sustainable Production and Consumption* 26 (April 2021): 1074–83.

72. Hanna Salmenperä et al., 'Critical Factors for Enhancing the Circular Economy in Waste Management', *Journal of Cleaner Production* 280 (January 2021): 124339.

73. Charlotte Brown and Mark Milke, 'Recycling Disaster Waste: Feasibility, Method and Effectiveness', *Resources, Conservation and Recycling* 106 (January 2016): 21–32, 25.

local community manually demolish, sort, crush, and reuse debris on-site by hand or using small machinery.⁷⁴ Macro-recycling is larger scale and led by companies or the government using mechanical demolition with transportation of materials to the nearest recycling facility where they can be crushed by a mobile/semi-mobile crusher. Lauritzen⁷⁵ identifies different options for reusing debris such as reusing stones for the reconstruction of buildings, coastal land reclamation, finishing façades, decoration, landscaping, backfill, sub-base for roads, concrete blocks, aggregates in new concrete, gabion walls, covering of municipal landfills, and preparation of new landfills.

After the Christchurch earthquake in New Zealand in 2010, debris recovery began with demolition and on-site separation, and a recovery site was established to sort mixed waste. Crushed concrete was used for road construction, and concrete and brick were used for engineering fill-in land remediation and reclamation, reducing the consumption of new Development Minerals.⁷⁶

Following the Rs hierarchy, the value of salvaging concrete can be prioritised as:

1. Reduce demand for concrete;
2. Reuse concrete structures;
3. Reuse concrete construction elements;
4. Recycle aggregate concrete in new concrete;
5. Recycle concrete aggregates as unbounded road materials; and
6. Recover crushed concrete as backfill.⁷⁷

The designing and planning stage of current and new buildings can make it much easier to reuse materials after a disaster. Lauritzen⁷⁸ highlighted the importance of 'design for disassembly' relevant

to the reuse of waste materials and discussed five principles that should be considered: i) use of materials with required properties to ensure that used materials can be reused further (materials); ii) designing buildings with a consideration for the entire building lifetime (service life); iii) designing a simple building that can be adapted to other uses (standards); iv) use of reversible connections which enable repeated assembly and disassembly (connections); and, v) planning for deconstruction (deconstruction). Applying these principles in disaster-prone areas can improve resilience and enable faster and cheaper recovery.

Golev et al.,⁷⁹ and Segura-Salazar et al.⁸⁰ introduce ore-sand as a circular economy solution to reduce waste associated with large-scale metal mining and to co-produce sand as an alternative to extraction from natural environments. Historically the large-scale metal mining industry has produced huge volumes of tailings and waste rock, which has presented challenges for management, including disasters associated with the catastrophic failure of tailings storage facilities, such as the Brumadinho and Mariana disasters in Brazil. Attempts have been made by mining companies to repurpose tailings, without widespread success (see Box 3: Ore-sand). Ore-sand takes a different approach that emphasises the addition of mineral processing circuits to extract sand as a secondary product, with desired properties and specifications, and thus reduce the production of waste.

74. Erik K. Lauritzen, *Construction, Demolition and Disaster Waste Management: An Integrated and Sustainable Approach*, 1st ed. (Boca Raton: CRC Press, 2018), 224.

75. Lauritzen, *Construction, Demolition*

76. Brown and Milke, 'Recycling Disaster Waste'

77. Lauritzen, *Construction, Demolition*, 113.

78. Lauritzen, *Construction, Demolition*

79. Artem Golev et al., 'Ore-Sand: A Potential New Solution to the Mine Tailings and Global Sand Sustainability Crises: Final Report' (Brisbane, Australia; Geneva, Switzerland: The University of Queensland; The University of Geneva, 1 March 2022).

80. Juliana Segura-Salazar and Daniel M. Franks, 'Ore-Sand Co-Production from Newcrest's Cadia East HydroFloat Reject: An Exploratory Study' (Brisbane, Qld, Australia: The University of Queensland, 12 January 2023).

Box 3: Ore-sand

Awareness of sand sustainability is generating clear calls for alternatives at scale. Among secondary sources, one stands out globally – mineral ores. Currently large volumes of sand- and aggregate-like materials are produced by crushing mineral ores for the extraction of metals (and other commodities), which are then discarded as part of mine waste rock and tailings.⁸¹ The global mining industry thereby generates billions of tonnes of waste that could potentially be recovered every year.⁸²

Attempts to give mining residues a second life have been made in the past, and suitability for certain applications has been proven. However, serious uptake has been impeded because: i) these residues must be technically and economically competitive with conventional materials, and ii) they were residues, rather than by-products or co-products that required their own optimisation to achieve specific properties during mineral processing.⁸³ Thus, a step-change in mineral processing towards alternative aggregate recovery could help the world address the sustainability challenges of both mine tailings production and sand extraction.

Ore-sand is a type of processed sand sourced as a co-product and/or by-product of mineral ores. Typically, it is a result of mechanical crushing and grinding, different physical and physicochemical beneficiation processes for mineral concentrates recovery, including optimisation of these processes and additional processing stages to achieve the required properties. Importantly, ore-sand is a deliberate product produced by design, rather than repurposing of existing waste materials. Given that certain ore bodies are associated with minerals and potentially harmful and hard to remove trace elements, a thorough evaluation of the mineral ores is required to guarantee the production of ore-sand which is safe to use.

An example of one of the first dedicated ore-sand recovery projects at scale is Vale Sand. Vale is a Brazilian multinational corporation and one of the world's largest producers of iron ore. In 2013, Vale initiated the Quartz Project to investigate whether sand by-products could drastically reduce the amount of tailings requiring storage at its mine sites.⁸⁴ After two high profile tailings storage facility failures, Vale accelerated the innovation and development of ore-sand in its motivation to find an alternative waste management solution.

In 2021, Vale received its first environmental licence for sand by-product, and launched several large-scale initiatives for the reuse of ore-sand for road construction, concreting, and bricks manufacturing.⁸⁵ The University of Queensland and The University of Geneva, in collaboration with the Federal University of Minas Gerais, sampled, tested and evaluated sandy co-products of a Vale iron ore operation in Brucutu (Minas Gerais, Brazil), developed potential resource substitution strategies, and interviewed stakeholders in the mining and construction sectors to understand the uptake and scalability of the innovation.⁸⁶ The project, mapped and matched mine tailings generation sites with sand consumption markets around the world. Furthermore, the potential environmental benefits of co-producing this

81. Golev et al., 'Ore-Sand'

82. Daniel M. Franks et al., 'Tailings Facility Disclosures Reveal Stability Risks', *Scientific Reports* 11, no. 1 (5 March 2021): 5353.

83. Golev et al., 'Ore-Sand'

84. Vale S.A., 'Sustainability Report 2016' (Rio de Janeiro: Vale S.A., 2016).

85. Vale S.A., 'Vale Opens Factory That Transforms Mining Waste into Products for Civil Construction', *Vale News*, 17 November 2020, <https://www.vale.com/w/vale-opens-factory-that-transforms-mining-waste-into-products-for-civil-construction/-/categories/64919>.

86. Golev et al., 'Ore-Sand'

alternative sand in mineral processing circuits was compared to conventional sands from a holistic life cycle assessment perspective. The research revealed that the Brucutu operation is already producing more than 2 million tonnes of ore-sand per year, and that countries like Fiji have the potential to supplement more than 80% of their aggregate demand with locally produced ore-sand, that would otherwise be extracted from Fiji's rivers.

In 2022, The University of Queensland extended its research on ore-sand to copper-gold ore bodies, working with Newcrest Mining Limited associated with the Collaborative Consortium for Coarse Particle Processing Research. The research evaluated the potential for ore-sand production at the Cadia operation. Newcrest has been pioneering work on installing and testing the HydroFloat technology for coarse particle flotation, which has the effect of allowing coarser ore-sand production. Comprehensive characterisation of the sandy material from the HydroFloat equipment was performed, involving a suite of physical, chemical, mineralogical, environmental and geotechnical tests, finding that the material is potentially suitable as a fine aggregate in construction applications.

[This case was adapted from Golev et al., (2022); UNEP (2022); and Segura-Salazar and Franks (2023).]

Box 4: Nepal earthquakes, 2015

Nepal, a country vulnerable to earthquakes, faced powerful earthquakes measuring 7.6 and 6.8 magnitude on the Richter scale in April and May 2015 in Barpak, Gorkha and later in the Sindhupalchok–Dolakaha borders. Of the 75 districts in Nepal, 67 were affected by these earthquakes. They destroyed private and public properties and historical and archaeological structures, in addition to the more than 8,841 lives lost. Memon (2016) claims that earthquakes damaged historic buildings developed during the Malla and Rana dynasties and many newly built reinforced concrete edifices in Balaju, Gongabu, Dhapasi, and Sitapaila areas in Kathmandu Valley. A vast amount of debris, estimated at around 14 million tons, presented a significant management challenge to Nepal. Almost 85% of destroyed buildings were mud and mortar-jointed masonry. With the support of UNDP and NGOs, the Nepalese people demolished over 3,000 damaged structures and cleared over 170,000 m³ of debris. Reuse, recycling, and recovery was pre-planned under the Kathmandu Valley Post-Earthquake Debris Management Strategic Plan. Concrete and masonry debris were used in road repair in Kathmandu. However, although usable housing materials and bricks were collected, they were not sufficiently reused or recycled.⁸⁷ One reason was due to the lack of access to relevant facilities such as crushers.

[This case was adapted from Poudel et al. (2019); Lauritzen (2018, 269–270); Memon, (2016)]

87. Lauritzen, *Construction, Demolition*



Chapter 5

Recommendations for strengthening climate and disaster resilience through Development Minerals

- **Governments** should ensure the presence of a legal and policy framework to regulate the extraction of Development Minerals and appropriate agency responsibility and oversight.
- **Governments** should build the capacity of the private quarry sector to sustainably extract Development Minerals, strengthen their resilience to disaster events and their preparedness to support recovery efforts after disasters. The **private sector** should form representative associations to provide support in this transformation.
- **Governments** should advocate for, and **multilateral institutions** should dedicate, international development programming on the topic of mineral security and reform existing disaster and climate frameworks and guidance to appropriately include the role of Development Minerals. For example, key international frameworks and tools, such as United Nations Framework Convention on Climate Change and the GFDRR Post Disaster Needs Assessment (PDNA) guidance.
- **Governments** should prioritise the involvement of the small-scale private quarry sector in post-disaster recovery efforts, to stimulate employment in quarrying, stone masonry, road-building and clay-brick manufacture and construction.
- **Governments**, through respective ministries should consider maintaining an updated database of quarries that holds information on location, size, production capacity, and ownership. Alternative quarry sites that are not yet operational should also be included in the event that quarries are damaged or are inaccessible following a disaster. This initiative will ensure that government and the disaster aid sector have adequate information about the availability of the materials to ensure timely reconstruction of damaged facilities and can conduct necessary post-disaster damage and capacity assessments.
- **Governments** and the **international development sector** should strengthen pre-disaster planning to include measures such as construction material stockpiles; sector mobilisation plans; the identification of emergency sources of construction materials and mapping of contingency reserves; emergency licensing procedures; and quality control of minerals and materials in post-disaster settings (including, preparedness to meet the range of international quality standards for foreign financed infrastructure projects). Special contingencies should also be made in the approvals/permitting processes to temporarily open new quarries in areas not affected by a disaster in order to provide essential materials for rebuilding.
- **Governments** in partnership with **research institutions**, and with the support of **international development partners** should invest in research and development on mineral security, sustainable construction materials, and the role of Development Minerals in climate and disaster resilience as well as renewable energy transitions. One key initiative is research on the feasibility and potential for the manufacture of low-carbon cement such the limestone calcined clay cement (LC3) to enable the construction of resilient housing and infrastructure.



Seawall constructed with coral on Arno Island, Republic of the Marshall Islands.

- Where the geological diversity of construction materials is limited, **governments**, **multilateral institutions**, and **international development partners** should explore the feasibility of regional approaches to the sourcing of construction materials for climate adaptation and post-disaster recovery.
- **International development partners** financing infrastructure should ensure the presence of safeguards around the sustainable sourcing of construction materials, and **the public** should consider sustainability in any purchasing decisions.
- **Governments** and **international development partners** should advocate within the United Nations Framework Convention on Climate Change for greater visibility and engagement on the issue of mineral security, including a dedicated pavilion at the Conference of the Parties as a focal point for capacity building and collective knowledge exchange.
- **The private sector** should embrace sustainability and circular economy principles in consumption and production. Such initiative has two major advantages. First, on the sustainability aspect, the use of recycled materials will help preserve natural resources which would otherwise be exploited. Second, the use of circular economy approaches reduces the costs and impacts of waste management.



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Appendix

Appendix 1: Quarry Sector Post-disaster Damage and Capacity Assessment Questionnaire

Assessment Details

Name of site representative providing information:

Please describe the activity on the site (please be specific): [e.g. river gravel extraction]

Contact details of site representative providing information:

Please tick the different products you sell? (including the volume of sold produced annually; please indicate the units)

If relevant, name of assessor conducting questionnaire:

Extraction

- Sand _____
- Large rock (boulders) _____
- Dust _____
- Gravel _____
- Other? _____

Name of disaster event:

Beneficiation

- Construction aggregate _____
- Silica sand _____
- Limestone _____
- Cement _____
- Concrete blocks _____
- Custom form work blocks _____
- Ready-mixed concrete _____
- Glass _____
- Paving stones _____
- Prefabricated culverts _____
- Lime for soil conditioning _____
- Marble _____
- Sealing chips _____
- Other

Date of disaster event:

Date of assessment:

Site Details

Company Name:

Site Name:

Site Address/Location:

Name of Site Manager:

Contact Details of Site Manager:

Latitude:

Longitude:

Please indicate your Business Sector (s)

- River gravel/sand extraction
- Hard rock quarrying
- Cartage hire
- Batch Plant/Precast
- Crushing

What is your monthly cement consumption?

Employment Details

Number of employees at the site:

Fulltime

Male:

Female:

If others, please state:

Part-time

Male:

Female:

Please describe the availability of each product for new clients (by unit of product):

Please list any unutilised or underutilised equipment on-site that might be available for offsite deployment (please note the mobility of such equipment)

Transportation

Please describe how your products are transported to the market (e.g. by what sized trucks & via which roads, by what sized barge & which jetty etc):

Are any of these transport links damaged/non-operational due to TC Yasa? Yes/No
If yes, please describe:

Do you have current capacity/systems in place to barge/ship your products to outer islands? Yes/No
If yes, please describe, including available shipment size:

Site/Business Needs

Please note any immediate site/business needs:

Please note any expected future site/business needs:

Any other notes:







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