Global Sustainability

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Mineral revolution for the wellbeing economy

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Non-technical summary. As we consider a transition to a low-carbon future, there is a need to examine the mineral needs for this transformation at a scale reminiscent of the Green Revolution. The efficiency gains of the agrarian transition came at ecological and social costs that should provide important lessons about future metal sourcing. We present three options for a Mineral Revolution: status quo, incremental adaption and revolutionary change. We argue that a sustainable Mineral Revolution requires a paradigm shift that considers wellbeing as a purpose and focuses on preserving natural capital.

Technical summary. As we consider a transition to a low-carbon future, there is a need to examine the mineral needs for this transformation at a scale reminiscent of the Green Revolution. The efficiency gains of the agrarian transition came at ecological and social costs that can also provide important lessons about the Mineral Revolution. We lay out some of the key ways in which such a mineral revolution can be delineated over temporal scales in a paradigm shift that considers wellbeing as a purpose and focuses on preserving natural capital. These prospects are conceptually presented as three pathways that consider the status quo, incremental adaption and revolutionary change as a means of planning more effectively for a low-carbon transition.

Social media summary. Sourcing metals sustainably will require to consider wellbeing as a purpose and to preserve natural capital.

Intelligence Briefing

Cite this article: Gloaguen R, Ali SH, Herrington R, Ajjabou L, Downey E, Stewart IS (2022). Mineral revolution for the wellbeing economy. *Global Sustainability* **5**, e15, 1–4. https://doi.org/10.1017/sus.2022.13

Received: 29 October 2021
Revised: 21 June 2022
Accepted: 31 July 2022

Key words:
industrial activities; natural resources (biological and non-biological); planning and design; social value

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Given firm political commitments to deliver net zero carbon by 2050, there is indisputable evidence regarding the need for minerals to construct and service climate neutral infrastructure. Technology commodities such as lithium, cobalt and graphite could face demand increases in mining of more than 500% (World Bank, 2020). To achieve the 2050 goal, new renewable energy networks such as wind, solar and geothermal power will require substantial amounts of minerals and base metals including copper, aluminium, steel and cementitious minerals, perhaps up to 3 billion tonnes (Vidal et al., 2016). Mining could directly influence 49.9 million km^2 of Earth's land area, assuming impacts extend 50 km from mine sites (Sonter et al., 2020) but indirect negative repercussions (e.g. pollution, downstream processing) have yet to be quantified. The sum of extracted materials (Baninla et al., 2019) is now of the same magnitude as the global land–ocean sediment flux (Mouyen et al., 2018). There are enormous challenges to reducing the carbon and environmental footprint of mining activities (Rötzer & Schmidt, 2020). With the increased mineralogical complexity of ores and increasing depths from which they are recovered and even with the introduction of new technologies, including metallurgical advances and extensive use of electricity from renewable energies, it will be difficult to ensure that human impacts on nature do not exceed the natural capital (Dasgupta, 2021).

The conundrum for society is that mining seems to be an essential but socially unpalatable part of our greener, low-carbon future. In a project recently funded by the Norwegian Research Council, this phenomenon was labelled 'the green curse' (Herrington, 2021). The acceptance of mining activities is particularly low because the negative impacts on land use, environment and health occur at the local level, but the positive income and employment effects is only measured at a national level (Mancini et al., 2018) or beyond borders. Where mining underpins national economies, such as in Australia, public support for the extractive industry remains broadly positive, but at the local level, even in many traditional mining heartlands, opportunities to establish new mines typically face critical public reactions and community opposition (Temper et al., 2018). Across the European Union, despite the mineral-rich future implicit in delivering its new 'Green Deal' (GD), the extractive sector has the lowest rates of public acceptance of all industrial sectors (Pellegrini, 2016). The apparent growing disenchantment with mining seems rooted in the wider socio-ecological unrest linked to the global climatic and ecological crises and the associated contention that an industry based on the extractive removal of a finite resource cannot be sustainable or environmentally benign, even if these minerals are needed to deliver the GD. For that reason, citizens of developed countries seem equally reluctant to embrace the sourcing of its raw materials locally or even

from the backyards of other jurisdictions, particularly developing nations. Addressing these legitimate societal concerns will require the extractive sector to meaningfully align with the emergent global sustainability mission of long-term wellbeing for all (O'Neill et al., 2018). It also requires concerted policy changes from appropriate governments to ensure that the mineral demands of delivering the GD are sourced in net positive ways for people and the planet. This ambition should be shared by industry if the successful financing, permitting and development of profitable mining operations is obliged to comply with internationally respected policies that will deliver net positive outcomes for all stakeholders. To grapple with this perplexing challenge, geoscientists and policymakers need to couch discussions of the Anthropocene in the context of a new Mineral Revolution (MR), in many ways like how the 'Green Revolution' (GR) in the 1960s was characterised for agriculture. Whilst the benefits of the GR may have outweighed the costs in terms of its overall value for meeting food security challenges of the planet (Evenson & Gollin, 2003), it is clear that the MR should avoid some of the negative aspects that the GR brought and develop strong positive environmental, social and governance (ESG) credentials (Benton & Bailey, 2019).

In recent years, the prevailing Anthropocene economic logic of profit maximisation as the key way for business to generate wealth and deliver wellbeing for wider society has been challenged as the socio-ecological costs of accelerating economic growth and material consumption become ever more apparent (Wiedmann et al., 2020). Concerns about the sustainability and social responsibility of businesses have become an increasingly high-profile issue, none more so than in the mining sector (Jenkins & Yakovleva, 2006). An alternative economic paradigm characterised by the pursuit of human and ecological wellbeing rather than material growth has recently emerged: a wellbeing economy (WE) (Llena-Nozal et al., 2019). At the vanguard is a small but influential group of governments (Finland, New Zealand, Iceland, Wales and Scotland) who are declaring that their countries are to be governed with wellbeing and economic outcomes as priorities (Wellbeing Alliance, 2021). The economic logic of the wellbeing framework is building momentum, offering a powerful and adaptable cultural and socio-economic narrative that can be extended globally (Fioramonti et al., 2022).

How that narrative is framed in terms of the mining sector is critical, and different potential development pathways are shown in Figure 1 using the Three Horizons illustrating this framework (Sharpe et al., 2016). In the first pathway, business as usual, external forces (financial and regulatory) accelerate the decline and demise of the current sector behaviours, norms and drivers (grey). In response, the second 'innovation' pathway impels the mining industry towards a profound change of business model and leads the transition to a circular economy (blue), but falls short of the broader demands of a genuine wellbeing-based economy. But 'in the wings' lurks a third 'visionary' pathway, in which the extractive industry is part of a paradigm shift in our society, and a pillar of well-being and environment (green). A fundamental pillar of this more radical approach is a sector-wide focus on ensuring the wellbeing of the natural capital resource – reducing the environmental footprint of mining activities, greening extractive operations and making efficiency gains, and practices that pursue 'no net loss' (Sonter et al., 2014) or 'net positive impact' (Teck, 2017).

Although there is little evidence that the mining sector is setting course for a radical well-being oriented development pathway, there are clearer signs of an impetus towards innovation-led change. There is general consensus that we need to decrease our environmental footprint by wasting less, reusing and recycling more and perhaps more controversially lower developed societies 'mineral metabolism' (e.g. Marín-Beltrán et al., 2022). But achieving the ambition of a truly circular economy by 2050 is challenging even though there are key efforts in that regard (e.g. Korhonen et al., 2018). Better tracking of stocks and flows and shifts towards producer ownership models might help to increase this circularity. Currently the levels of recycling for a range of minor metals are low (e.g. rare-earth elements) largely because the cost of recycled product is higher than mined raw materials (e.g. Babbitt et al., 2021). Increasing costs for raw materials could perhaps act as a financial stimulus for change. For other metals there is an insufficient mined stock in the system that can be recycled (e.g. lithium, cobalt). In fact, for many metals even increased recycling rates will not be enough to satisfy demand (World Bank, 2020) and future technologies may demand the use of metals not currently recovered (e.g. scandium). An audit and complete inventory of mining wastes and stocks may help, particularly for companion metals (e.g. Co, Re, Ga, Ge), as well as a requirement for this to be a mandatory, ongoing venture. In many cases, cleaning up mine wastes can have the benefit of yielding useful metals (Hudson-Edwards et al., 2011) and construction materials. Designing the global infrastructure for its reuse potential (the urban mine) should also be an integral part of that plan (Heisel & Hebel, 2021). In the aftermath of the COVID-19 pandemic, the transition for a 'green reset' towards a low-carbon energy future is gathering momentum. On 24th February 2021, President Biden issued a new Executive Order on securing responsibly sourced supply chains of critical materials, including metals (White House, 2021). Coordinating mineral supply to build the infrastructure required for wind, solar and hydrogen energy delivery as well as storage is more urgent if we are to meet the renewed ambitions for meeting the Paris Agreement targets (Ali et al., 2017). Criticality of the supply chain also affects construction raw materials and base metals. The United Nations Environment Assembly commissioned an international consultative process towards improved mineral governance in 2019 and the findings are now being assembled. Among the suggestions that have emerged from the consultations is the creation of an International Minerals Agency which would be able to monitor prices, look at material stocks and flows, streamline the environmental and social performance of the mining sector, while also eventually aspiring for a circular economy (International Resource Panel, 2020).

Such efforts are important to transcend parochialism and need global coordination, but such resource governance changes ought to be seen as part of a more holistic and purposeful approach to extractives. To date, the social purpose of mining companies has been largely restricted to corporate social responsibility initiatives which – like many other parts of the corporate world – has generally been seen as a bolt-on activity rather than core business. But in the WE, 'the purpose of business is to solve the problems of people and planet profitably, and not profit from causing problems' (British Academy, 2021). The concepts of WE can be adapted to different social and economic situations, allowing an easier implementation in policy processes and encompassing cultural idiosyncrasies, suitable to advanced economies and less industrialised societies. In that context – reflecting a growing purpose-led shift within the wider business culture (Hurth & Vrettos, 2021) – mining companies ought to re-define themselves as 'purpose-driven organisations', reframing mining as an endeavour in which profit becomes a vital means to achieving a more

https://doi.org/10.1017/sus.2022.13 Published online by Cambridge University Press

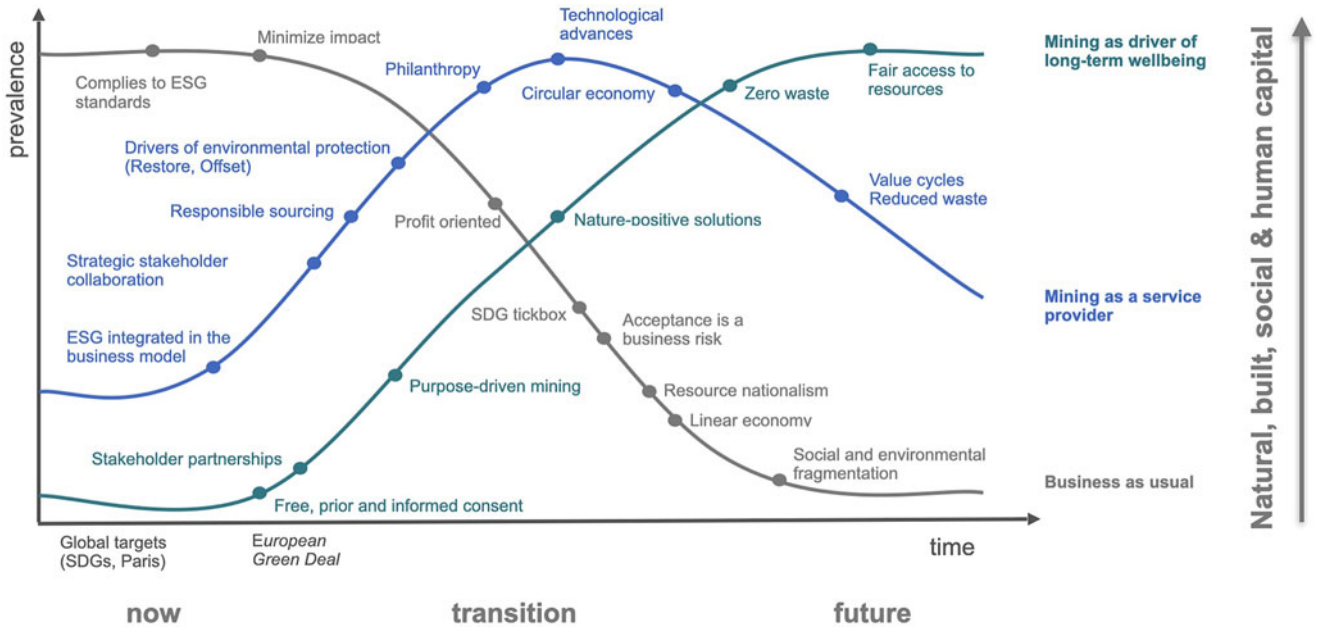

Figure 1. Future of mining as viewed through the 'Three Horizons' foresight tool of Sharpe et al. (2016). The first horizon (black line) is the current 'business as usual' pathway of behaviours, norms and drivers, which are expected to decline in influence as the wider landscape changes (e.g. due to climate change, shifting markets or changes in digital technology). The third horizon (green line) represents a radical visionary pathway that would deliver outcomes viable in the future. The second horizon (blue line) is the intermediary transition space where disruptive innovations and actions help create space for the third horizon pattern to grow. In this heuristic approach, all Three Horizons exist simultaneously – in the present, medium and longer term – albeit to greater or lesser extent. Each path is described by key features (circles) that illustrate the choices, goals or consequences that define a given alternative. ESG, environmental, social, governance, SDG, sustainability development goals.

ambitious, enduring, motivating and meaningful contribution to global society. Also, instead of focusing on stakeholder engagement, the extractive sector should favour collaborative approaches (Fraser, 2018) and go beyond simply complying with ESG criteria and standards. The life of any mine is finite, and community participation is vital in designing post-mining legacies and compensatory actions for repurposing the land for next use (e.g. natural capital compensation schemes or nature-based solutions). Mining companies should move from being 'socially-engaged' to being 'socially-embedded' organisations that, before any venture is sanctioned, fully recognise and account for the value of not just the 'mineral play' but the 'community play' they operate in and the wider environment they impact (Braungart & McDonough, 2002; Rötzer & Schmidt, 2020).

This cultural shift will require adaptive change in mindsets and skillsets within the industry. Delivering against a people-centred, wellbeing-aligned 'purpose' will demand a greater integration of geoscientists and engineers involved in mineral production with experts in, social sciences, biodiversity and economics. With exploration being the first step of any mining project, geoscientists are generally the first 'boots on the ground' and so need to be better skilled in a strong and authentic approach to ESG from the outset. Communication will become a critical skillset as society at large needs to understand the entire value chain of minerals, the stocks and flows, their impact on society (including on indigenous cultures), and the potential for application of more sustainable practices in their recovery and use.

The scale of the challenge ahead should not be underestimated. Mining is a truly global venture. Minerals are often sourced and mined in countries that are not the main consumers of the mineral product. Consuming countries benefit from the greater financial opportunities at the service and product levels, versus the raw material itself. The financial sector has already started to include sustainability indicators to assess investments and rating agencies could assign ESG grades to the performance indicators of companies (Renn et al., 2022). Europe for example, has a challenge with respect to sustaining its needs for raw materials, producing far less than it needs to sustain greener technologies (Smol et al., 2020). Some in the mining sector favour a renewed local mineral extraction in Europe, given the good mineral exploration potential on the continent (Vidal et al., 2016) and already substantial ESG standards. In this context, the European mining sector could be a driver of a truly transformative agenda for positive change, especially for standards in responsibly sourced raw minerals and zero waste production. At the same time, mining is a key industry in many emerging economies and benefit-sharing instruments should be developed to generate a more inclusive development. Small-scale mining can play a pivotal role in alleviating poverty in the developing world and contributes significantly to national revenues and foreign exchange earnings. In any case, regional and national regulations should be harmonised at a global scale to bind extractive operations to the same sustainability criteria and rules regardless of where they operate (Renn et al., 2022). Attention should also be directed on the disproportionately negative impacts on women, women's changing roles and identities in communities affected by mining, gendered inequalities in relation to the benefits of mining (Jenkins, 2014) but also on minorities such as indigenous communities. The 21st century mining needs a 'moonshot' mission and delivering genuine wellbeing improvement across society would seem to be a purpose that the extractive sector could meaningfully rise to.

Acknowledgements. This paper resulted from discussion at the 2-day virtual debate event 'Can Mining Make the World a Greener Place?' (https://

https://doi.org/10.1017/sus.2022.13 Published online by Cambridge University Press

bit.ly/3mqF1Fu) co-convened by the Natural History Museum and the INFACT and PACIFIC Horizon 2020 projects in December 2020. Figure inspired by John Elkington with our many thanks. Part of this research has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 776487 (INFACT).

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