Biodiversity and responsible sourcing for wind and solar developments

An overview and action agenda

Claire Fletcher, Leon Bennun, Ben Jobson, Laura Sonter,
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INTERNATIONAL UNION FOR CONSERVATION OF NATURE

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Acronyms

ARM	Alliance for Responsible Mining
ASI	Aluminium Stewardship Initiative
ASM	Artisanal and small-scale mining
BCG	Boston Consulting Group
BECS	Biodiversity extent, condition, significance
CBD	Convention on Biological Diversity
CEM	(IUCN) Commission on Ecosystem Management
CETM	Critical Energy Transition Minerals
CM	Copper Mark
CMMI	Critical Minerals Mapping Initiative
COP	Conference of the Parties
CRAFT	Code of Risk-mitigation for ASM Engaging in Formal Trade
CSDDD	(EU) Corporate Sustainability Due Diligence Directive
CSM	Climate Smart Mining
CSRD	(EU) Corporate Sustainability Reporting Directive
EBRD	European Bank for Reconstruction and Development
ESG	Environmental, Social and Governance
ETC	Energy Transitions Commission
ETTI	Extractive Industries Transparency Initiative
GHG	Greenhouse gas
GIIP	Good International Industry Practice
GRI	Global Reporting Initiative
GW	Gigawatt
IAI	International Aluminium Institute
ICA	International Copper Association
ICMM	International Council on Mining and Metals
IEA	International Energy Agency
IFC	International Finance Corporation
IIMA	International Iron Metallics Association
IMEC	(IUCN) Impact Mitigation and Ecological Compensation Thematic Group
IRENA	International Renewable Energy Agency
IRMA	Initiative for Responsible Mining Assurance
IUCN	International Union for Conservation of Nature
IZA	International Zinc Association
KMGBF	Kunming-Montreal Global Biodiversity Framework

LCA	Life cycle assessment
MW	Megawatt
NNL	No Net Loss
NPI	Net Positive Impact
OECD	Organisation for Economic Co-operation and Development
PDF	Potentially disappeared fraction of species metric
PV	Photovoltaic
RBI	Responsible Business Alliance
REE	Rare earth elements
RMAP	Responsible Mineral Assurance Process
RMI	Responsible Minerals Initiative
SBTN	Science-Based Targets for Nature
SDG	Sustainable Development Goal
SEIA	Solar Energy Industry Association
SSI	Solar Stewardship Initiative
STAR	(IUCN) Species Threat Abatement and Restoration (metric)
TBC	The Biodiversity Consultancy
TNC	The Nature Conservancy
TNFD	Taskforce on Nature-related Financial Disclosure
TSM	Towards Sustainable Mining
USGS	U.S. Geological Survey
WWF	World Wildlife Fund

Glossary

Alloy	Made by mixing two or more metallic elements to form a new, unique substance that has differing chemical and physical properties to its component parts. Over 90% of the metals in use today are alloys. The most common alloys are broadly classified as steels (ICMM, n.d.).
Beneficiation	The treatment of raw material (such as iron ore) to improve physical or chemical properties especially in preparation for smelting.
Decarbonisation	Both a method of climate change mitigation and the process of significantly reducing or eliminating carbon dioxide (CO_2) and other GHG emissions from the atmosphere.
Ecotoxicity	Ecotoxicity refers to the capability of a compound or any physical agent to have a harmful effect on the environment, organisms, or both.
Good International Industry Practice (GIIP)	Defined as the exercise of professional skill, diligence, prudence, and foresight that would reasonably be expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally or regionally (IFC, 2012a)
Life Cycle Assessment (LCA)	A standardised method tool for assessing the environmental footprint of a product, process, service, or corporation from 'cradle to grave'.
Mineral	Solid, naturally occurring inorganic substances found in the Earth's crust. They have a unique chemical composition and crystal structure (ICMM, n.d.).
Mitigation hierarchy	The sequence of actions to anticipate and avoid impacts on biodiversity and ecosystem services; and where avoidance is not possible, minimise; and, when impacts occur, rehabilitate or restore; and where significant residual impacts remain, offset (CSBI & TBC, 2015).
Metal	Elementary substances, such as gold, silver and copper. They are crystalline when solid and naturally occur in minerals. They are often good conductors of electricity and heat, shiny and malleable. The metals we use day-to-day are converted from metallic ores to their final form.* This usually requires the use of chemicals and special technology (ICMM, n.d.). *See ICMM for definitions of precious metals, base metals, ferrous, and non-ferrous metals.

Metalloid	An element whose properties are intermediate between those of metals and those of solid non-metals or semiconductors.
No Net Loss	The point at which project-related impacts on biodiversity are balanced by measures taken through the application of the mitigation hierarchy.
Net Positive Impact (or Net Gain)	The point at which project-related impacts on biodiversity are outweighed by measurable outcomes from actions taken through the application of the mitigation hierarchy to achieve sustainable biodiversity gains.
Potentially disappeared fraction (PDF)	The proportion of species going extinct locally (over a unit of area or volume) in response to external pressures (e.g. land use), usually over one year (unit: PDF.m^2.year or PDF.m^3.year).
Rare earth metals, or rare earth elements	These are not actually all that rare, but their extraction is complex and difficult. They include scandium, yttrium, lanthanum and the 14 elements (lanthanides) following lanthanum in the periodic table. They have widespread uses, though in small volume, in the manufacturing of glass, ceramics, glazes, magnets, lasers, and television tubes, as well as in refining petroleum (ICMM, n.d.).
Species.year	A variant of PDF in which the PDF result is multiplied by species density to enable comparison between impacts in different realms (albeit with some coarse assumptions about species distribution and sensitivity to impacts).

1 Introduction

1.1 Materials and the renewable energy transition

The need to transition to a lower carbon, nature-safe renewable energy-based economy is more urgent than ever (WWF & BCG, 2023; WWF & TBC, 2023). The Paris Agreement sets a stringent target of limiting global warming to 2°C above pre-industrial levels by 2050,[1] emphasising the necessity of urgent, rapid, and extensive renewable energy adoption to achieve this goal. Delays in implementing low carbon energy solutions as part of the transition from fossil fuels to renewable energy will severely hinder progress towards this goal.

In parallel, the more recently adopted Kunming-Montreal Global Biodiversity Framework (KMGBF) has the overall vision of achieving full recovery of nature by 2050, and by 2030 aims to halt and reverse biodiversity loss to sustain a healthy planet, whilst delivering benefits essential for human well-being and economic prosperity for all people (Box 1).

These global climate and nature goals highlight that the transition to low-carbon energy cannot occur in isolation, nor in a vacuum – achieving them both requires combining efforts to reduce greenhouse gas (GHG) emissions with biodiversity conservation and ensuring they are mutually beneficial (action on climate is not necessarily inherently good for biodiversity (Dunne, 2022). Further, lack of access to energy remains a critical challenge in many countries, subjecting many people to a life of poverty. Addressing this challenge through the rapid deployment of renewable energy is paramount – in 2023 at the halfway point for achieving the 2030 Sustainable Development Goals (SDGs) the world was currently not on track to achieve SDG 7 – ensuring access to affordable, reliable, sustainable and modern energy for all (IEA, 2023; IEA et al., 2023; Roser, 2020). All of these implies the need to transform the way societies are operating to address the current biodiversity and ecosystem collapse and work towards a just and nature-positive future (Box 1). However, whilst large-scale decarbonisation of global power infrastructure is essential to meeting climate goals, it must not happen at the expense of nature (Gasparatos et al., 2017; TNC, 2021) – especially as this would likely reduce the efficacy of decarbonisation efforts.

As wind and solar energy projects proliferate worldwide, policy makers, investors, and conservationists are recognising the need for enhanced responsible sourcing practices for biodiversity, including improved circularity, to ensure consistency of supply chains and to meet the increasing demand for scarce minerals and metals. The current production and processing of minerals and other materials will need to scale up substantially to meet this demand. There are concerns that this will exacerbate threats to biodiversity above and beyond those from traditional mining due to the greater overlap between mineral deposits for transition materials and areas of biodiversity importance (Sonter et al., 2020a). It is therefore crucial to ensure good practice and robust implementation of the mitigation hierarchy when identifying and operating new mining concessions, with the impetus and requirements flowing down from those corporates sourcing these materials through their supply chains. The issues are many and complex, often extending beyond the influence of a single developer (Section 4.2). Hence, identifying the ways in which developers can start taking action to engage in and improve responsible sourcing for biodiversity and wind and solar developments is key to a renewable energy transition that supports both climate and nature goals.

1 To achieve the Paris Agreement goal, greenhouse gas (GHG) emissions must peak before 2025 at the latest and decline 43% by 2030. However, global GHG emissions continue to increase, for various reasons (IPCC, 2023a).

Box 1

Global goals for biodiversity

In December 2022, global goals for biodiversity were adopted via the Kunming-Montreal Global Biodiversity Framework (KMGBF) (CBD, 2022). This historic intergovernmental agreement is also an explicit call to action for the private sector, requiring all sectors of society to contribute towards its delivery (Booth et al., 2023). The key elements of the KMGBF are four long-term goals to achieve the 2050 vision, that "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people", including 23 action-oriented global targets to achieve the 2030 mission – in short, "to take urgent action to halt and reverse biodiversity loss to put nature on a path to recovery" (CBD, 2022).

Goal A addresses biodiversity outcomes and includes elements to enhance ecosystem area and integrity, restore species populations and prevent extinctions, and safeguard genetic diversity.

Targets for 2030 address threat reduction and restoration, sustainably meeting people's needs, and means of implementation. Threat-reduction and restoration targets are especially relevant in the roll out and expansion of renewable energy development globally. These include targets related to: i) inclusive spatial planning and halting loss of high biodiversity importance areas (Target 1); ii) effective restoration of at least 30% of degraded areas of ecosystems (Target 2); iii) effective conservation and management of at least 30% of land and sea (Target 3); and iv) urgent action to halt extinctions and ensure conservation and recovery of species (Target 4).

Target 14 calls for governments to integrate biodiversity across all policies and plans, including strategic environmental assessments and environmental impact assessments, at all levels of government and across all sectors, "progressively aligning all relevant public and private activities, and fiscal and financial flows" (CBD, 2022, p. 11) with the KMGBF.

Target 15 requires government to take measures that ensure businesses assess and disclose their biodiversity-related risks, dependencies and impacts, along value chains and across portfolios, "in order to progressively reduce negative impacts on biodiversity, increase positive impacts, reduce biodiversity-related risks to business and financial institutions, and promote actions to ensure sustainable patterns of production" (CBD, 2022, p. 11).

The concept of 'nature positive': The 'nature positive' concept is emerging as an inclusive and ambitious rallying call that aligns with the KMGBF (Booth et al., 2023). 'Nature' is often used as shorthand for biodiversity, but it is a broader concept that also encompasses non-living components, such as climate, air, soil, and water. Conservation and business forums are increasingly converging on the nature-positive concept (zu Ermgassen et al., 2022) to achieve the 2030 and 2050 goals of the KMGBF and drive transformative change in the relationship between business and nature. There is no single agreed definition for the term 'nature positive', and several are in use. In line with the KMGBF, the Nature Positive Initiative defines it as to "halt and reverse nature loss by 2030 on a 2020 baseline and achieve full recovery by 2050". The UK Council for Sustainable Business says "a nature-positive approach puts nature and biodiversity gain at the heart of decision-making and design. It goes beyond reducing and mitigating negative impacts on nature as it is a proactive and restorative approach focused on conservation, regeneration, and growth" (zu Ermgassen et al., 2022, p. 3). Although debate continues on what 'nature positive' means for business (Milner-Gulland, 2022; zu Ermgassen et al., 2022), it is generally viewed as a broad societal goal to which businesses and civil society can contribute, rather than a specific project or organisational-level objective.

The idea of 'nature positive' emerges from the urgent need to conserve and restore nature, with widespread recognition of the pace at which species and ecosystems are disappearing and the scale of risk this poses to business and society (Dasgupta, 2021; IPBES, 2019; WWF, 2022). Nature positive moves beyond traditional corporate approaches, such as No Net Loss (NNL) or Net Positive Impact (NPI) of biodiversity, in three main ways (TBC, 2022): i) a broader scope, encompassing all of a company's value chain and integrating all of nature; ii) clearer alignment with global goals – requiring absolute improvements in the state of nature, not just slowing down its loss; and iii) emphasis on both mainstreaming nature in corporate structures and processes, and broader, transformational systems change that goes beyond any single company.

Box 1 (continued)

The KMGBF does not include the term 'nature positive', rather it embeds this purpose and clear direction for the journey towards collective action for biodiversity. It also signals increasing stakeholder expectations for the role of business in supporting efforts to halt and reverse biodiversity loss, including in the text of Target 15. The IUCN Commission on Ecosystem Management (CEM), through the Impact Mitigation and Ecological Compensation Thematic Group (IMEC), has developed a technical paper, Nature positive for business, Developing a common approach (Baggaley et al., 2023), to provide businesses with a better understanding of approaches that can contribute to the global goal of 'nature positive'. Application of the mitigation hierarchy is central to a 'nature positive' approach (Maron et al., 2023). This means strongly prioritising impact avoidance and minimisation, whether at project, landscape or systems levels. To meet the KMGBF and 'nature positive' goals for nature recovery, further conservation actions will also then be needed to obtain an overall net gain of biodiversity.

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1.2 Scope and aims

Figure 1 illustrates the renewables transition and the key issues related to materials sourcing, highlighting the scope of this document. It is aimed primarily at developers of wind and solar projects and transmission infrastructure, who primarily source composite goods (e.g. wind turbines and solar panels). The key aim of this document is **to outline how developers can start to act on supply chain biodiversity impacts**[2] by improving traceability and sourcing practices through, for example (Section 4):

- Mapping supply chains;
- Identifying mitigation opportunities, including adopting high-quality voluntary environmental standards, sourcing from suppliers that use sustainability-certified inputs (under existing schemes), and using trusted third-party auditors for verification;
- Industry-wide engagement and collaboration with key suppliers, using purchasing power to drive improvements;
- Implementing action plans to guide and monitor these actions.

Since the actions outlined are early and preparatory, there is also broader applicability to other technologies, as well as for manufacturers who are the direct suppliers of wind and solar developers, and who source processed minerals as inputs (Sections 4.2 and 4.3). This guidance also provides some of the key context for meaningful action by:

- Outlining the context for responsible sourcing (Section 2);
- Highlighting the most important minerals and metals (Box 2) needed for wind and solar development and summarising the potential impacts on biodiversity related to their sourcing and processing (Section 3);
- Outlining the challenges and opportunities associated with responsible sourcing (Sections 4.2 and 4.3);
- Summarising the major existing relevant initiatives, guidance and third-party verification schemes for metals and minerals (Annex I).

2 This document acknowledges the need for socially responsible sourcing. Ecosystem services impacts and impacts on human well-being and economy are not specifically addressed in this document. However, assessing such impacts is a fundamental part of robust strategic and project-level assessments aligned with global goals and targets, and for a just energy transition.

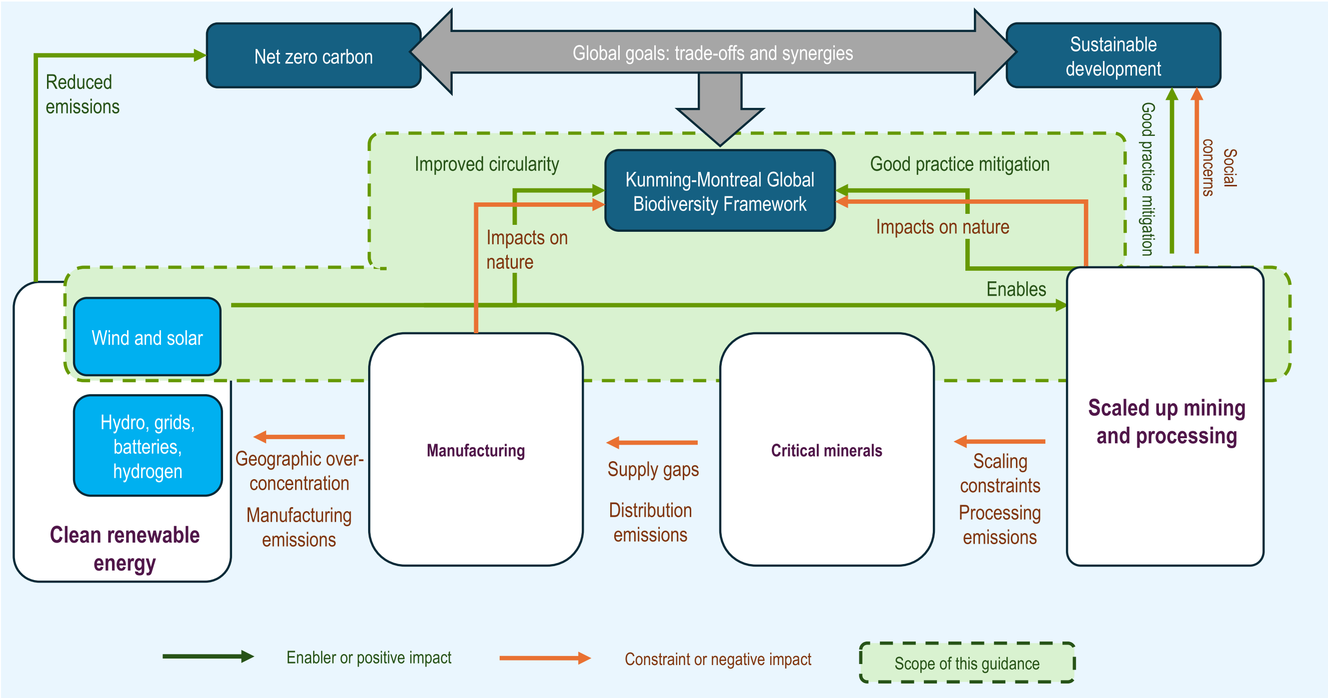

Figure 1 **The renewables transition: overview of the issues related to responsible sourcing, and the scope of this guidance**
Source: Authors.

Box 2

Clarifying the terms 'mineral' and 'metal'

Minerals are solid, naturally occurring inorganic substances found in the Earth's crust and have unique chemical composition and crystal structure (ICMM, 2024a). Metals are elementary substances that are crystalline when solid and naturally occur in minerals (ICMM, 2024a). All renewable energy technologies require metals (and alloys), which are produced by processing mineral-containing ores (IEA, 2021). Ores are raw, economically viable rocks that are mined and beneficiated to liberate and concentrate the minerals of interest. These minerals are further processed to extract the metals or alloys of interest, which are then used in end-use applications (IEA, 2021) (Figure 2 below).

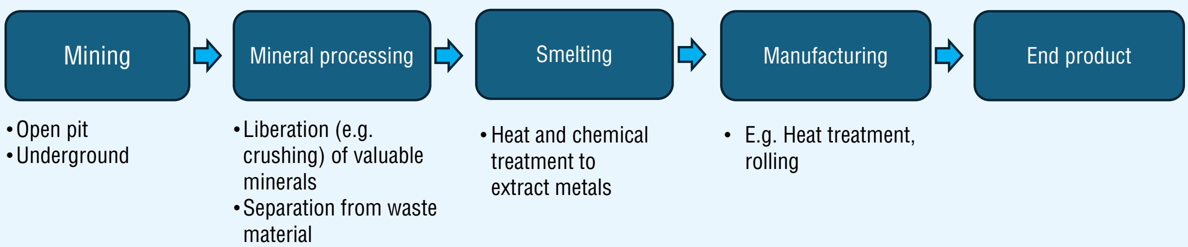

Figure 2 **Simplified flowchart of mineral ore processing, metal recovery, and manufacturing**
Source: Adapted from Pradip et al. (2019, p. 2160).

With respect to the specific materials essential to the renewable energy transition, there are several terms in use that are intended to denote both their strategic or economic importance as well as the risk of supply shortage or price volatility (Sovacool et al., 2020). These include 'critical raw materials', 'technologically critical elements', 'critical materials', 'critical minerals', and 'energy transition minerals.' There is no single definition for what constitutes a critical mineral or metal. In some instances, it may be defined in national policy or law and may change over time.

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2 The context for responsible sourcing

2.1 What is responsible sourcing?

Whilst there is no single global definition for the term 'responsible sourcing', it is generally used in the context of Environmental, Social and Governance (ESG) considerations, especially for organisations with complex and diversified supply chains. Broad definitions include "the management of social, environmental and/or economic sustainability in the supply chain through production data" (van den Brink et al., 2019, p. 389). Similar terms like 'responsible purchasing' (Leire & Mont, 2010; Mont & Leire, 2009) and 'sustainable supply chain management' (Sauer & Seuring, 2017) are also in use.

In the context of mining and minerals, the International Council on Mining & Metals (ICMM) Guide to Responsible Sourcing (ICMM, 2015) addresses two main activities in responsible sourcing:

- Internal: focusing on sustainable procurement. This relates to actions integrating environmental, social, and broader cost considerations into procurement processes. This is based on the significant leverage afforded to ICMM members to reduce impacts and optimise benefits through their combined purchasing power.
- External: focusing on the provision or responsible supply of minerals and metals that meet agreed-upon environmental and social performance standards or criteria. This is typically triggered by end-use markets in conjunction with other stakeholders (e.g. non-governmental organisations, or NGOs). For ICMM members, this involves understanding and meeting (as appropriate) expectations of downstream customers and other key stakeholders by responding to, or initiating, programmes to document environmental, social and governance performance along a minerals and metals supply chain.
- Fundamentally, sourcing the materials necessary to support the transition to renewable energy must not undermine the overarching objectives of the transition itself. However, the related expansion in extraction, processing and production of minerals and metals, and of renewable energy project component parts, could have significant negative impacts on biodiversity, if not properly managed (Section 3.3). This means that in the context of mining and metals, the external focus for responsible sourcing also extends to working with reliant industries to shift demand towards materials and practices that align with the transformative nature positive concept (Box 1). In early 2024, ICMM issued a position statement with a five-point plan for nature (Annex III) setting out ICMM members' approach to contributing to a nature positive future, which includes collaborating across value chains and catalysing wider change to create the conditions required to achieve systems transformation. Box 3 summarises some other international processes designed to guide the renewable energy transition and responsible sourcing.

Box 3

Ongoing international processes guiding the renewable energy transition and responsible materials sourcing

The Global Investor Commission on Mining 2030 is a collaborative investor-led initiative launched in 2022, with a mission "to develop a consensus about the role finance has in realising a vision of a socially and environmentally responsible mining sector overall by 2030 that: has a clear social license to operate, can meet the needs of society in a responsible manner without driving conflict or corruption, operates in a way that respects planetary boundaries, and positively contributes to social development and the environment, today and tomorrow" (Global Investor Commission on Mining 2030, n.d.). The initiative recognises the important role of the mining industry in society and the transition to a low carbon economy and aims to ensure that the sector leaves a positive legacy by addressing key systemic risks holistically. There are 10 focus areas, three of which are biodiversity, land, and protected areas. The end goal is a practical implementation plan for investors to see this vision realised by 2030 (Global Investor Commission on Mining 2030, n.d.).

The Energy Transitions Commission (ETC), created in 2015, is a global coalition of leaders from across the energy landscape who are committed to achieving net-zero emissions by mid-century, in line with the Paris climate objective of limiting global warming to well below 2°C and ideally to 1.5°C. ETC analysis has demonstrated that achieving this goal is technically and economically possible, requiring immediate, decisive, and collective action from policy makers, industry players, financial institutions and civil society organisations. The ETC currently comprises 58 commissioners from a range of organisations, including energy producers, energy-intensive industries, technology providers, finance players, and environmental NGOs. ETC work is focused on three types of programme: regional programmes, energy programmes, and sector decarbonisation programmes. In particular, energy programmes focus on driving the ramp-up of clean energy provision at scale and pace.

The Global Council for Responsible Transition Minerals was launched in 2023 on the sidelines of the 6th Edition Paris Peace Forum, as an independent high-level group working to further multistakeholder collaboration towards a sustainable supply of transition minerals. The Council was formed due to the projected steep increase in demand for minerals essential for the manufacturing of technologies associated with the transition towards net-zero. Council members aim to raise political awareness around the crucial importance of these minerals to reach the Paris Agreement goals and address the issues around their responsible supply by making global recommendations and proposing collaborative solutions. The Global Council for Responsible Transition Metals was formed by members of the Transition Minerals Initiative, which was itself launched during the 2022 5th Edition Paris Peace Forum as the 'Acting Together for a Responsible Transition Minerals Sector' initiative, along with a Call to Action around the sustainable sourcing of minerals necessary to the green transition.

The UN Secretary General's Panel on Critical Energy Transition Minerals, first proposed at COP28 in 2023, brings together governments, intergovernmental and international organisations, industry. and civil society, to develop a set of common and voluntary principles to build trust, guide the transition, and accelerate the race to renewables. It builds on existing standards and initiatives, particularly the Working Group on Transforming the Extractive Industries for Sustainable Development and its flagship initiative, 'Harnessing Critical Energy Transition Minerals for Sustainable Development,' to strengthen and consolidate existing efforts. The Panel released 'Resourcing the Energy Transition: Principles to Guide Critical Energy Transition Minerals Towards Equity and Justice' in September 2024, proposing the following seven voluntary Guiding Principles:

- **Principle 1**: Human rights must be at the core of all mineral value chains.
- **Principle 2**: The integrity of the planet, its environment and biodiversity must be safeguarded.
- **Principle 3**: Justice and equity must underpin mineral value chains.
- **Principle 4**: Development must be fostered through benefit sharing, value addition and economic diversification.
- **Principle 5**: Investments, finance, and trade must be responsible and fair.
- **Principle 6**: Transparency, accountability and anti-corruption measures are necessary to ensure good governance.
- **Principle 7**: Multilateral and international cooperation must underpin global action and promote peace and security.

A suite of other initiatives is summarised in Annex I-A.

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2.2 Drivers of responsible sourcing

Responsible sourcing has several legislative and social drivers, as well as a clear business case, for ensuring continuity of supply. Table 1 summarises the key drivers.

In terms of quantity and number of minerals required, offshore wind technology is the most mineral intensive technology per megawatt (MW) of energy generated – followed by onshore wind and solar PV (IEA, 2021). The following sections summarise the key minerals and metals required for wind and solar power, the demand for these (and other) minerals and metals, the associated supply risks, biodiversity impacts and mitigation measures, and sustainability challenges for renewable energy supply chains.

Table 1 Summary of key drivers for responsible sourcing

DRIVER	SUMMARY	EXAMPLES*
Regulatory and compliance-based	Regulatory and voluntary frameworks driving reporting and disclosure on company impacts, dependencies, risks, and opportunities across the whole value chain. These generally align with the Kunming-Montreal Global Biodiversity Framework (KMGBF).	– EU Corporate Sustainability Reporting Directive (CSRD) – EU Corporate Sustainability Due Diligence Directive (CSDDD)
Voluntary leading practice		– Taskforce on Nature-related Financial Disclosure (TNFD) – Science-Based Targets for Nature (SBTN) – Global Reporting Initiative (GRI)
Policy	Recognition of the risks of irresponsible and illegal mining, through policy, and the need to improve environmental practice alongside securing critical mineral supplies.	– EU Critical Raw Materials Act (CRM Act) – UK Critical Minerals Strategy – US Department of Energy Critical Minerals Strategy
Stakeholders and social license to operate	Responding to increased scrutiny and pressure from stakeholders, especially regarding potentially 'hidden' impacts of complex supply chains. Reducing the risks of stakeholder opposition to new projects, project disruptions, or financing challenges. Managing reputational risk.	Multistakeholder initiatives including: – Fair Cobalt Alliance – International Responsible Business Conduct Agreement – Beyond the Megawatt initiative from the Clean Energy Buyers Institute – Solar Stewardship Initiative ESG Standard – Equitable Origen EO100
Others	Transition risks: meeting future regulatory requirements, handling sourcing restrictions and ensuring continuity of supply, and navigating changing market conditions/consumer preferences. Systemic risks: large-scale disruption of supply chains due to changes/disruption to natural systems.	

* See also Annex I for links to websites of the examples cited.

Source: Authors.

3 Key minerals and metals for wind and solar development

3.1 Key minerals and metals

3.1.1 Wind power

The various components of wind turbines, including towers, nacelles, blades, foundations, panels and cabling, require a range of minerals, which are summarised in Figure 3 (below). Steel is key, used in the towers, nacelle structure, and the drivetrain, accounting for about 80% of the total weight (Giurco et al., 2019). Wind power also requires zinc,[3] used for protecting turbines from corrosion (IBRD/The World Bank, 2020; IEA, 2021). The proportions of other materials will depend on the design and whether they are sited onshore or offshore. Additionally, there are two main types of mechanical design determining materials required:

- **Geared**: These account for more than 70% of the global onshore wind market (IEA, 2021). Gearboxes convert low turbine rotation speeds into much higher speeds for generating electricity (at a ratio of around 1:100). This type of technology uses coil-driven generators that require significant amounts of copper.

- **Direct-drive permanent magnet generators (PMG)**: These account for more than 60% of the offshore wind market worldwide because they are lighter, more efficient, and have lower maintenance costs (IEA, 2021). They do not have a gearbox and instead use magnets containing rare earth elements (REE), such as neodymium-iron-boron (NdFeB), combined with additives – usually dysprosium, but also praseodymium and terbium, and chromium.

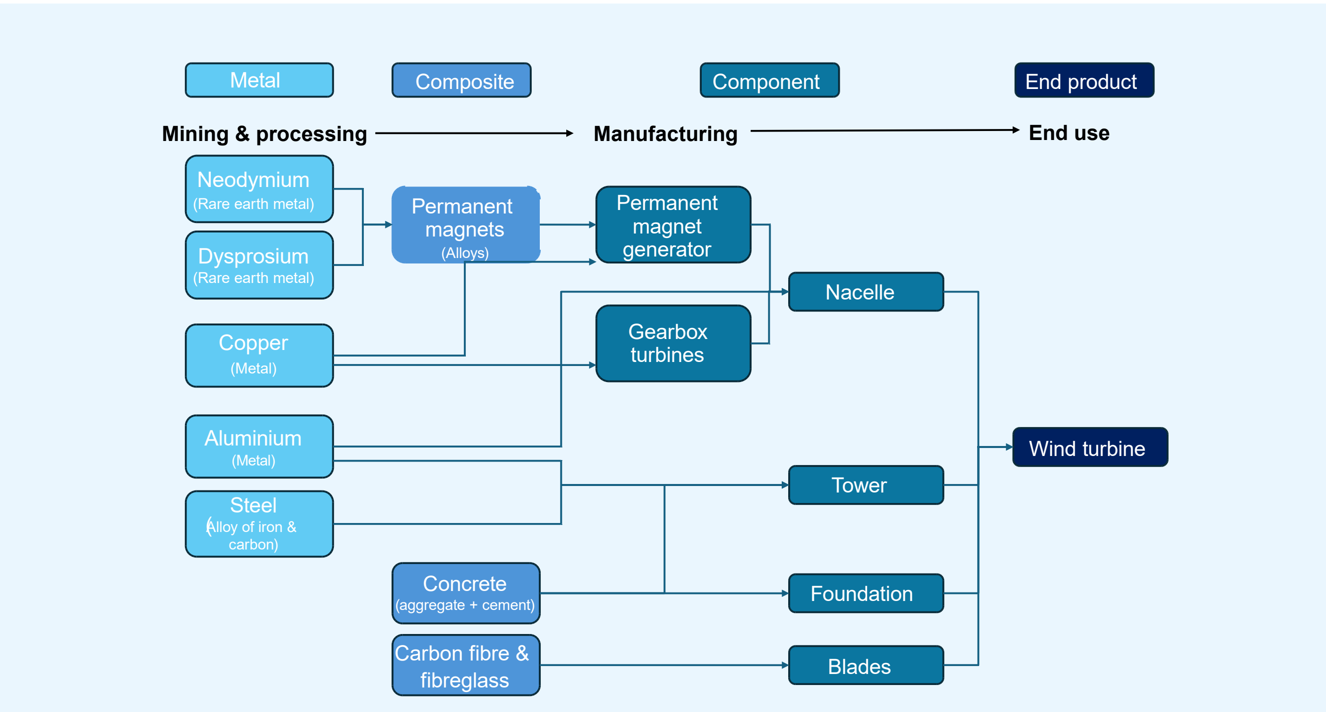

Figure 3 Overview of key metal requirements and supply chain for wind power
Source: Adapted from Giurco et al. (2019, Figure 11.2, p. 440).

3 More than 98% of zinc demand from energy technologies come from the wind industry (IBRD/The World Bank, 2020).

The increasing size of turbines is an important contributor to the increase in capacity factor (due to taller towers, larger rotors and lighter drivetrains), which in turn has helped to reduce material intensity for some materials in wind power (IEA, 2021).

Turbine foundations (for onshore wind, fixed offshore wind power, and gravity base anchors for floating wind) also require substantial amounts of concrete, using cement, sand, and gravel, as well as large amounts of freshwater during the construction process. Turbine blades are made up of a composite of fibreglass (or carbon fibre), resins, balsa wood, and adhesives (IBRD/The World Bank, 2020).

3.1.2 Solar power

Solar photovoltaics (PV) are designed to enable the conversion of sunlight to electricity as efficiently as possible via the photovoltaic effect. There are three main types of design for solar PV with variable mineral content, as summarised in Figure 4 (below).

- Most commercially available solar PV cells are crystalline silicon (C-Si) – either **monocrystalline silicon solar cells** or **polycrystalline silicon solar cells**. A typical C-Si PV panel contains about 76% glass (Giurco et al., 2019), about 8% aluminium (frame), 5% silicon (solar cells), 1% copper (interconnectors), and less than 0.1% silver (contact lines) and other metals (steel, lead, and nickel) (Giurco et al., 2019; IEA, 2021). Other materials include ethylene vinyl acetate (EVA) and fluorinated polymers (used for encapsulation and backing) (Giurco et al., 2019).

- **Thin-film solar cells** require more glass but less material overall than crystalline silicon (Giurco et al., 2019; IEA, 2021). They include cadmium telluride (CdTe) panels and copper indium gallium diselenide (CIGS) panels. They are also predominantly glass, with amorphous thin-film silicon (a-Si, TF-Si), copper, zinc, indium, and gallium (Giurco et al., 2019).

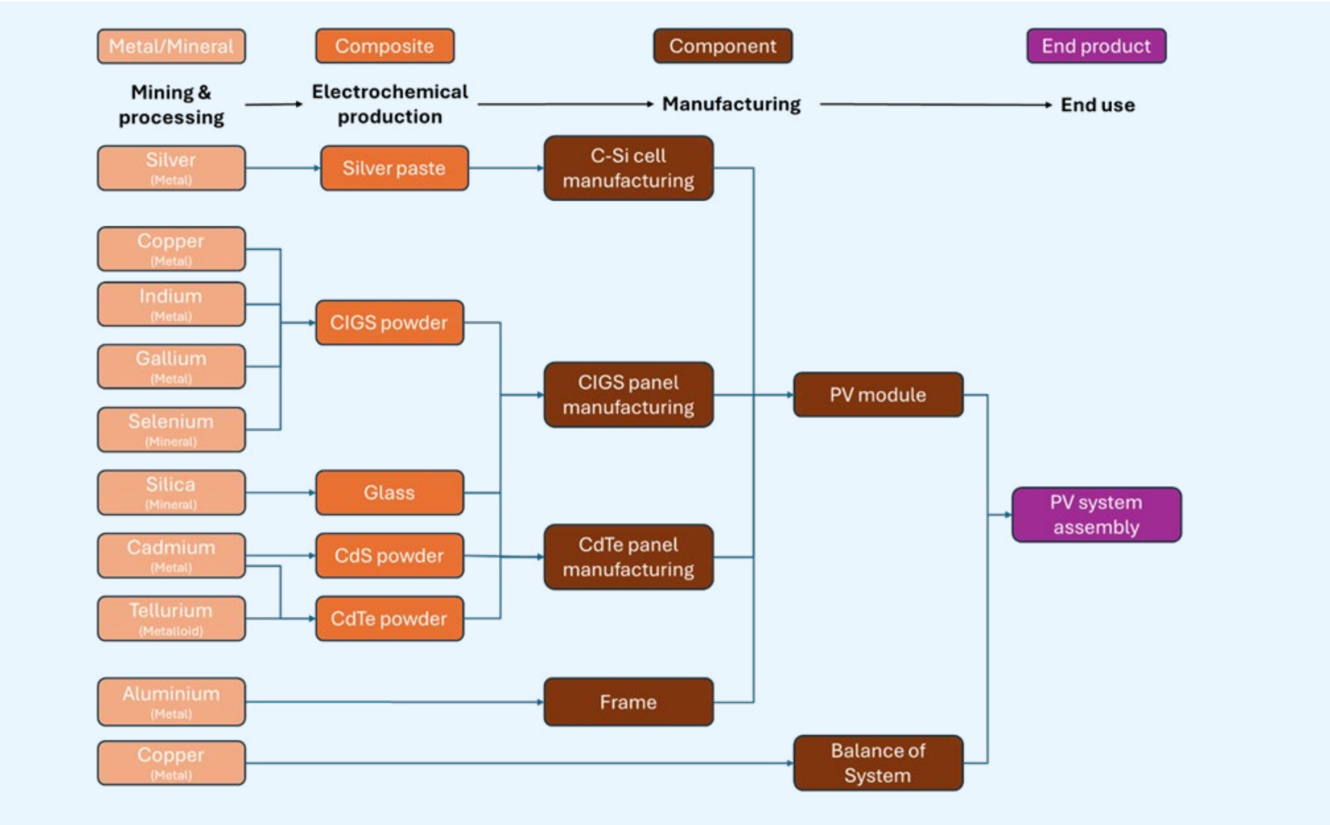

Figure 4 Overview of key metal requirements and supply chain for solar PV
Source: Adapted from Giurco et al. (2019, Figure 11.1, p. 439).

3.2 Demand and supply risks

Renewable energy production is material intensive (IEA, 2021). A renewable energy transition in line with any predicted climate scenario will substantially raise demand for certain minerals, depending on the clean energy technology type (IBRD/The World Bank, 2020). Clean energy technologies[4] are set to emerge as a major force in driving demand growth for critical minerals (IEA, 2021). A recent study by Wang et al. (2023) found that the magnitude of material needs for future power generation scales directly with wind and solar deployment. COP28 resulted in a pledge to triple the world's renewable energy capacity by 2030, and the IEA predicts mineral demand from low-carbon power generation will double or almost triple over the period from now to 2040, depending on the modelled climate scenario (IEA, 2021). This is driven by wind power due to a combination of large-scale capacity additions and higher mineral intensity, followed by solar PV because of the scale of capacity additions among the low-carbon power technologies (IEA, 2021).

It is clear then that the scale and intensity of the predicted increase in demand should be sufficient to catalyse action, which will necessarily initially involve developing a better understanding of supply chains and supply chain actors (Section 4). It is less straightforward to determine broadly whether the wind and solar sectors might have more influence or less influence for specific minerals and metals compared to other sectors where there is demand.

For some minerals, like lithium, the energy transition is already the major driver of global demand – electric vehicles and battery storage count for around half of the mineral demand from clean energy technologies over the next two decades (IEA, 2021). Figure 5 shows projected annual mineral and metal demand in 2050 from solar, wind, hydropower, geothermal, nuclear, battery technologies, and conventional electricity generation from coal and gas, as modelled by IBRD and The World Bank (2020) under a 2°C warming scenario.[5] The minerals with the projected highest percentage increase in demand between 2018 and 2050, as shown in Figure 5, are graphite and lithium, linked only to energy storage in lithium-ion batteries. Since these two materials are not used in other energy technologies, their overall demand cannot be compared to other technologies (IBRD/The World Bank, 2020).

When focusing on electricity generation technologies (and not including battery mineral demand), iron and aluminium show the highest absolute increases, followed by copper and zinc (IBRD/The World Bank, 2020). Figure 6 shows the cumulative requirement for minerals and metals through to 2050 for wind and solar electricity generation under different climate and demand scenarios. Annex II provides a list of summary factsheets for seven of the most in-demand minerals and metals across wind and solar.

For metals like iron, renewable energy is only part of global consumption. Almost all iron ore is used in steelmaking (National Minerals Information Center, n.d.a), and most steel is used in the building and infrastructure sector which, alongside energy (electricity and gas transmission networks), also includes transport, telecommunications networks, and water supply and distribution networks. Other minerals and metals are closely associated with these, like zinc and chromium, which are mostly used to galvanise and harden steel and iron, preventing corrosion.

Aluminium is the single most widely used material in solar power applications (e.g. in solar frames, wires, support structures) (European Aluminium, n.d.), accounting for more than 85% of most solar PV components (IBRD/The World Bank, 2020). However, the transportation sector had the largest share of the aluminium market in 2023.[6] The French Committee of the IUCN (Comité français de l'UICN) has published a factsheet on aluminium, as part of a study on the upstream value chain of companies, to identify their impacts

4 Clean energy technologies are: solar PV, wind, hydro, concentrated solar power (CSP), bioenergy, geothermal, nuclear, electricity networks, electric vehicles and battery storage, and hydrogen – as modelled in IEA (2021).

5 See Table 1.1 in IBRD/World Bank (2020).

6 For more information, please see: Fortune Business Insights

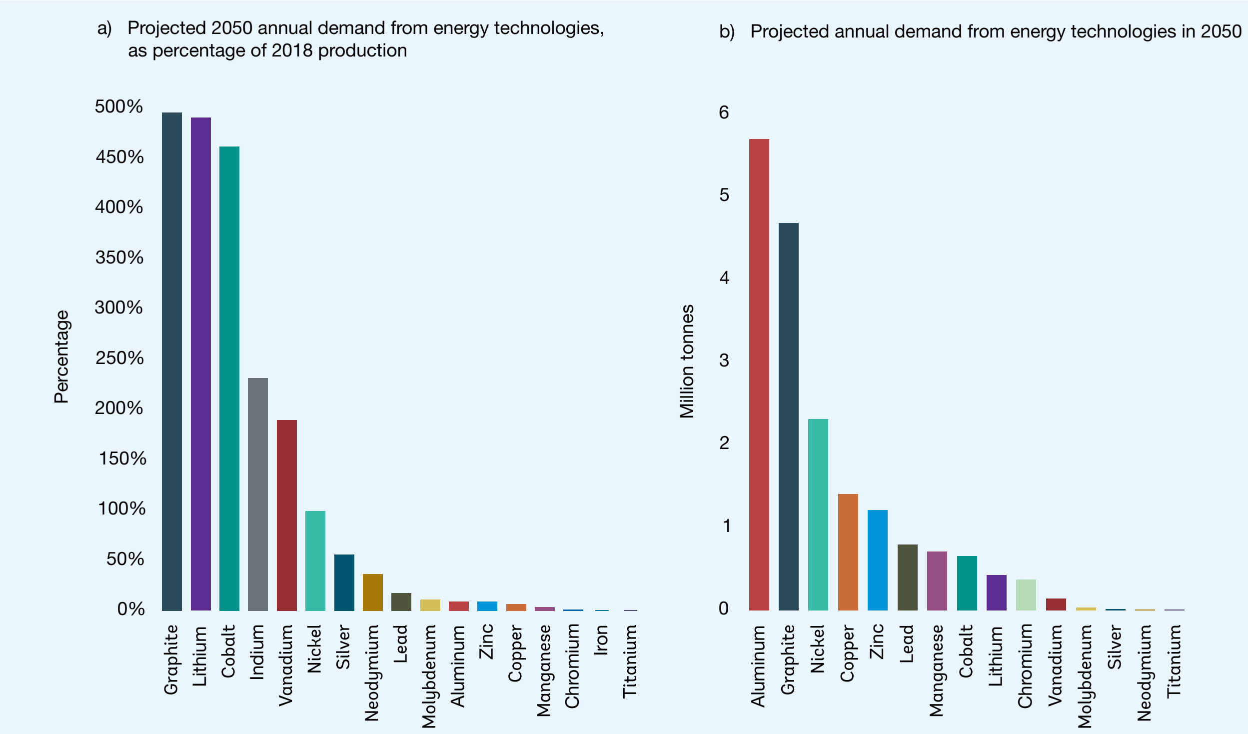

Figure 5 Projected annual mineral and metal demand under a 2°C warming scenario from energy technologies in 2050, compared to 2018 production levels

Source: Adapted from IBRD/The World Bank (2020, Figure 4.3, p. 73).

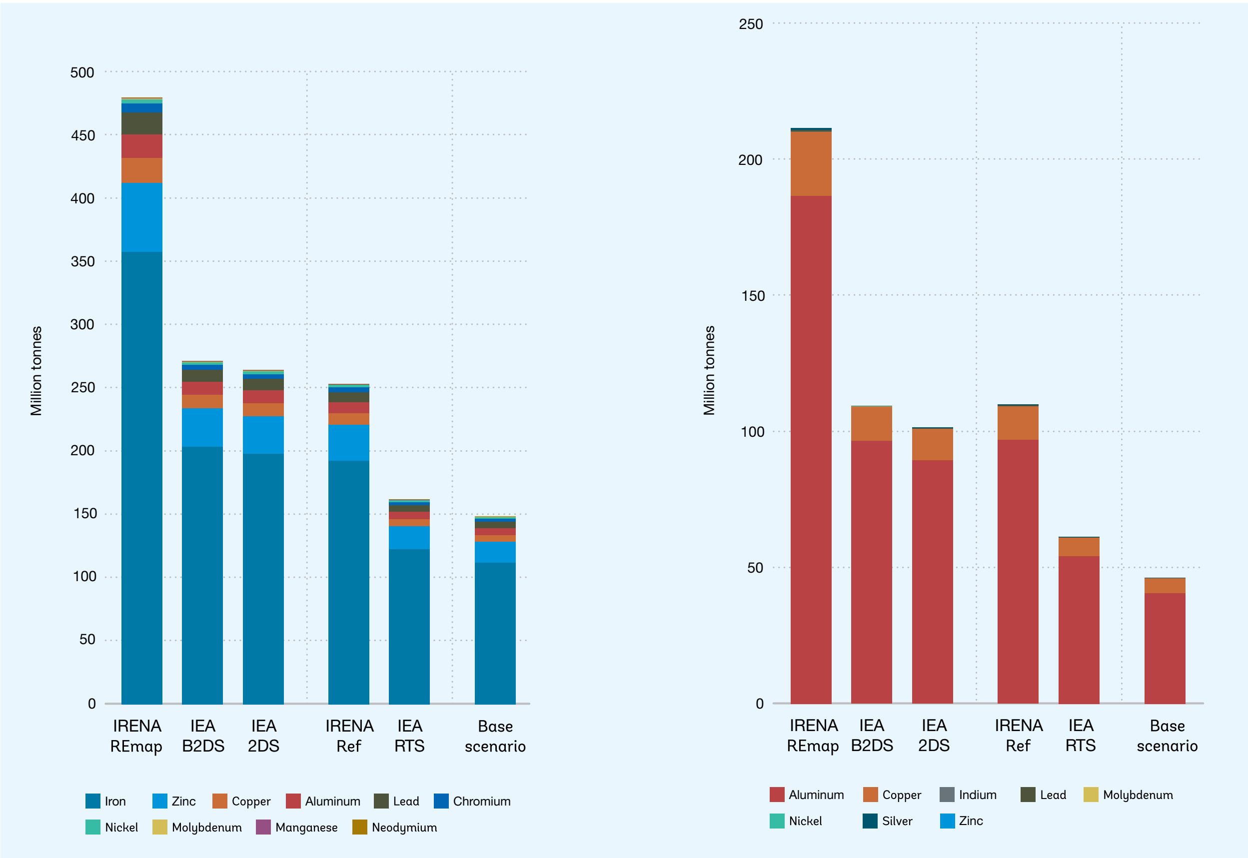

Figure 6 Cumulative requirement for minerals and metals through to 2050 for wind (left, in blue) and solar (right, in red) under different climate and demand scenarios*

Source: Adapted from IBRD/The World Bank (2020, Figure 3.2, p. 40 and Figure 3.9, p. 47).

* For more information on climate scenarios: IRENA REmap and Ref cases (IRENA, 2019); IEA 2DS (2°C scenario), IEA B2DS (beyond 2°C scenario), and IEA RTS (reference technology scenario) (IEA, 2017); Base scenario is defined as "the state of affairs where there is marginal progress toward a low-carbon transition" (IBRD/The World Bank, 2020).

and dependencies on biodiversity and ecosystem services (UICN, 2024).[7]

Copper is key to the energy transition. It is the best conductor of electricity after silver (EuRIC, n.d.). The National Minerals Information Center of U.S. Geological Survey (USGS) estimates that about three quarters of total copper use is for electrical purposes, including power transmission and generation (National Minerals Information Center, n.d.b).[8] Demand for copper is predicted to increase by 56% on 2018 levels due to wind and solar energy (ICA 2019). Månberger and Stenqvist (2018) estimate the societal stock of wind power and solar PV technologies could increase 1,000% and 3,000%, respectively, between 2015 and 2060 (based on various climate mitigation scenarios).

For most materials, clean energy technologies are expected to become the fastest growing segment of demand, with total share of demand approaching 40% for copper and rare earth elements, 60–70% for nickel and cobalt (and almost 90% for lithium) (IEA, 2021). Even where projections are lower, demand could still result in enormous increases in absolute production globally (Sovacool et al., 2020). However, uncertainty in demand projections varies among these commodities, for example depending on the renewable energy technology mix ultimately utilised, and whether minerals are required for many energy technologies or for only a few (e.g. copper is required for all types of clean and conventional energy generation and for battery storage, while indium is only required for solar PV and nuclear power (IBRD/The World Bank, 2020).

Notwithstanding which sector or activity drives demand for a mineral or metal, some are already considered endangered – meaning they face critical supply risks and limitations. Of the 188 elements that make up everything, supply limitations are anticipated for 44 of these elements in the coming years,[9] including nine for which there is a serious threat in the next 100 years, among which are silver, zinc, and indium. For endangered and critical elements especially, responsible management of their extraction, use and reuse is essential. These might be included on national critical minerals lists, denoting vulnerabilities in their long-term supply (Ali et al., 2017), particularly in meeting accelerated (rather than gradual) demand trajectories. Some of these risks include:

- Higher geographical concentration of production (e.g. cobalt is mostly extracted in the Democratic Republic of the Congo, whereas rare earth elements are mostly sourced from China (IEA, 2022, p. 121);
- A mismatch between the pace of change in demand and typical project development timelines (e.g. the very long lead time from discovery to production for nickel, which is 15+ years in some places (IEA, 2022, p. 122);
- The effects of declining resource quality (e.g. copper; Rötzer & Schmidt, 2020);
- The growing costs of poor environmental and social performance (Lawley et al., 2024; Lèbre et al., 2020; Valenta et al., 2019);
- Higher exposure of mine sites to climate risks such as water stress (Northey et al., 2017) (e.g. half of global copper and lithium production currently occurs in areas of high water stress; IEA, 2022, p. 128).

3.3 Mining impacts on biodiversity

The building and operation of mines and mineral processing facilities creates significant pressure on species and ecosystems (Sonter et al., 2018), and these are not less so for energy transition minerals (Sonter et al., 2022). For example, 8% of all vertebrate species are listed by the IUCN Red List as threatened by mining (Lamb et al., 2024), and 42 threatened mammal species have

7 Three strategic raw materials were selected for the first phase of the French Committee's work – aluminium, lumber and industrial timber, and steel. Aluminium is the first factsheet to be published.
8 The requirement for copper is expected to increase yet further, with the need to upgrade aging infrastructure and power data centres with renewable energy (Bloomberg Intelligence, 2024), which is linked to the build out of data centres as artificial intelligence (AI) demands increase,
9 For further information, please see: https://www.acs.org/green-chemistry-sustainability/research-innovation/endangered-elements.html

more than 30% of habitat within 10 km of an operational mine (Sonter et al., 2022). Further, considerable metal production occurs within species-rich biomes and ecosystems under water stress (Luckeneder et al., 2021), and 30% of the world's permanent waste storage facilities are built either within or nearby areas protected for their biodiversity value (Aska et al., 2024). Establishing mining-related infrastructure can also cause biodiversity loss through habitat removal and landscape fragmentation (Siqueira-Gay et al., 2022). Mine operation can also degrade ecosystem condition and function through noise, dust, and light pollution (Cross et al., 2021), introduction of invasive species (Cristescu et al., 2012), and by causing declines in water quality and quantity (Lakshman, 2024). Biodiversity losses can occur at the site level, and also permeate indirectly for tens of kilometres from mine site boundaries, because of the tendency for mines to enable further development (Giljum et al., 2022; Sonter et al., 2017) and provide access enabling other pressures such as bushmeat hunting (Edwards et al., 2014). In the same manner, biodiversity losses can affect ecosystem services and risk human rights (Bebbington et al., 2018; Tost et al., 2020).

Meeting the growing demand for energy transition minerals without adequate mitigation of biodiversity losses will cause significant biodiversity loss (Sonter et al., 2023). Following current trajectories, biodiversity loss per tonne of mined material in the future will likely increase. For example, declining ore grades will lead to larger mine pits and more habitat loss, more waste material, and a greater risk of pollution (Owen et al., 2024), and minerals being increasingly sourced from ecologically vulnerable areas (Luckeneder et al., 2021), with less stringent environmental regulation (Watari et al., 2021). However, the amount and location of these biodiversity losses will depend on which minerals are mined from where (Cabernard & Pfister, 2022) and the implementation and outcomes of mitigation actions taken by mining operations (Sonter et al., 2023), which are dependent on regulatory requirements, voluntary efforts by the mining sector, and pressure from consumers. Figure 7 shows proportion of global mining area for different materials per country, and related biodiversity loss. Rising demand, combined with depleting terrestrial deposits, also mean that obtaining energy transition minerals via deep sea mining may begin soon (Box 4).

Beyond the extraction site, the processing, transport, and manufacturing of minerals can have significant impacts on biodiversity as well, arising from pressures, including (but not limited to) land use change to accommodate new and expanding facilities, emissions, water use, and water and soil pollution. Energy consumption and GHG emissions are a major impact of mineral processing. The environmental impacts of most metals are dominated by the purification (i.e. smelting) and refining stages, due to the energy-intensive melting stages, which often use fossil-fuel either directly or indirectly (Nuss & Eckelman, 2014). About half of global power plants owned by metal and mining companies burn coal (Schenker et al., 2022). In 2007, iron and steel production accounted for 30% of global industrial CO_2 emissions. GHG emissions and energy consumption are also issues during distribution of minerals and manufacturing of components for wind and solar technologies.

Mineral processing operations all consume substantial amounts of water, and many processing facilities are located in areas already under water stress (e.g. iron production in Australia) (Norgate & Lovel, 2004). Mineral processing, such as smelting, can also lead to metals polluting water and causing ecotoxicity. Heavy metals like lead, cadmium, and chromium can be toxic to organisms even at low concentrations and have been linked to reduced growth of phytoplankton and zooplankton. These toxic metals can also enter the air in the form of metal fumes or suspended particulates. They can be biomagnified through food chains and can have a destructive impact on terrestrial, freshwater and marine species (Izah & Ogwu, 2023; Raj & Das, 2023). Other environmental pollutants released during processing include arsenic emissions and sulphuric acid from copper processing, and red mud resulting from the production of aluminium from bauxite (Schenker et al., 2022). Country-specific legislation and policy around sustainability and responsible business practices are also variable and influential.

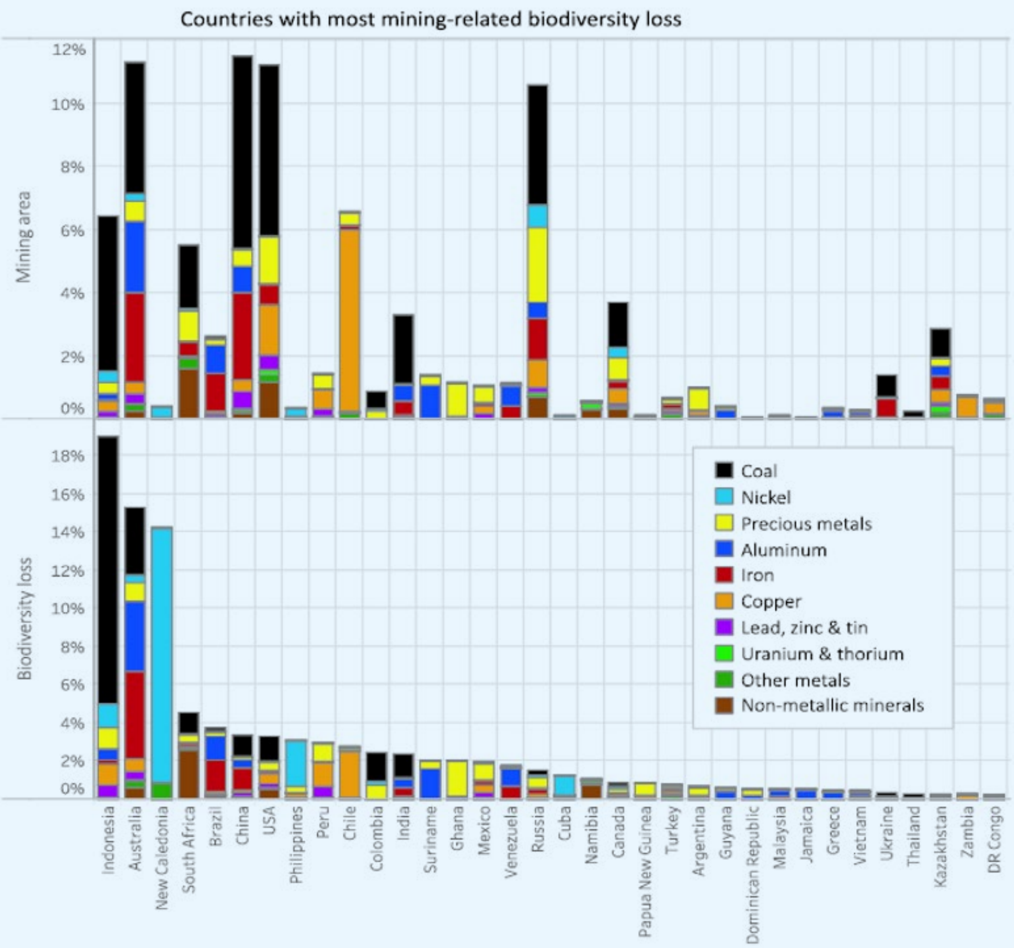

Figure 7 Global mining area and related biodiversity loss
Source: Adapted from Cabernard & Pfister (2022, Figure 2, p. 8).

Box 4

Deep-sea mining of critical metals and minerals

The deep sea (below 200 m in depth) contains large quantities of minerals and metals needed to support an energy transition (Teske et al., 2016). These include potato-sized polymetallic nodules (comprising copper, nickel, cobalt, iron, manganese, and rare earth elements) on the seabed surface of abyssal plains (4,000–6,000 m), sulphide deposits within hydrothermal vents (200–4,000 m depth), and cobalt crusts located on seamounts (700–7,000 m) (UNECE, 2024). While these resources are not yet being extracted commercially, there is growing and significant interest in mining polymetallic nodules in the Pacific Ocean's Clarion-Clipperton Zone (CCZ). Exploration licences have been granted to 16 deep-sea mining contractors across one million km^2 of the CCZ, and the International Seabed Authority (ISA).* However, despite economic potential, many social and environmental challenges remain with respect to deep sea mining (Levin et al., 2020). Stakeholders are particularly concerned about potential risks to marine ecosystems, a lack of governance of costs and benefits of deep-sea mining, and how risks and impacts compare to alternative terrestrial sources of these minerals. In 2020, the IUCN supported a moratorium on deep sea mining in international waters, and highlighted the need for rigorous impact assessments, alignment with the precautionary principle, and clear mechanisms to mitigate environmental impacts (IUCN Members' Assembly, 2020) – all of which would contribute towards responsible sourcing approach.

* ISA, the regulator of extractive activities in international waters, is currently drafting rules and regulations to enable this industry

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3.4 Mitigating biodiversity impacts of mineral and metal supply

The implementation of the mitigation hierarchy is central to mitigating impacts of mining and mineral processing - to first avoid, then minimise, restore and finally offset impacts to achieve at least NNL of biodiversity (Glossary). Guidance, tools, and technical support exist to facilitate implementation of mitigation hierarchy good international industry practices (GIIP) in the mining sector and more broadly (for example: CSBI, 2015; ICMM, 2006; IFC, 2012b & 2019). Impact avoidance is the primary focus, primarily via site selection (e.g. no-go commitments with respect to World Heritage Areas), project design (e.g. selecting lower impact infrastructure options) and scheduling (e.g. avoiding operations during sensitive periods for biodiversity). Impact minimisation involves use of physical controls (e.g. fencing to reduce wildlife mortality), operational controls (e.g. discharging only during certain times of year) and abatement controls (e.g. using dust control to reduce impacts on nearby habitat). Restoration is then used to repair degradation and damage to biodiversity post-mining and should include progressive approaches where possible to reduce lag times between losses and gains (Young et al., 2022). Finally, offsets are used as a measure of last resort to mitigate residual losses through securing and increasing the extent and condition of biodiversity elsewhere (Bull et al., 2013).

Numerous regulatory, financial and voluntary initiatives support mining sector application of the mitigation hierarchy and an ambition for the mining sector to achieve NNL of biodiversity (Annex I-A). More than 100 countries have, or are developing, legal requirements to mitigate biodiversity impacts, including 37 countries in which demonstrating potential for NNL is a prerequisite for project permitting (GIBOP, 2019). While the majority of offset implementation is driven by a regulatory requirement (Bull & Strange, 2018), when these do not exist, financial safeguards, such as IFC Performance Standard 6 (IFC, 2012b), often drive implementation and can result in much larger and transparent mitigation. More recently, businesses are increasingly making voluntary commitments to apply the mitigation hierarchy, although the specifics of these commitments and how they are implemented varies widely (Rainey et al., 2014; zu Ermgassen et al., 2022). Voluntary commitments include those of relevant industry membership groups (e.g. ICMM and the Initiative for Responsible Mining Assurance (IRMA); see Annex I-A), corporate interest in alignment with emerging risk reporting and disclosure frameworks (e.g. GRI, 2024; SBTN, 2020; TNFD, 2023), and requirements for certification, including schemes that certify mines (e.g. IRMA, 2024) and commodities (e.g. the Copper Mark, or CM, and the Aluminium Stewardship Initiative, ASI; see Annex I-A) at various locations along the value chain.

Despite all these, there remains limited evidence that mining sector actions add up to achieve NNL of biodiversity (zu Ermgassen et al., 2019), beyond several well-cited case studies (e.g. Devenish et al., 2022). There are reasons for this, including confusion around key concepts (Maron et al., 2018), poor design in offset policy, failure to recognise limits to achieving NNL outcomes (Simmonds et al., 2022; Sonter et al., 2020b), underestimation of project costs, and a failure to monitor outcomes and adapt to changing conditions throughout and beyond the mining project life. Companies still commonly fail to internalise the cost of addressing biodiversity impacts as a core cost of doing business.[10] Additionally, another emerging risk relates to the broadening scale and ambition of biodiversity commitments towards the concept of a nature positive contribution (Box 1) (e.g. ICMM, 2024b) and the potential for these efforts to dilute the basic principles of strict adherence to applying the mitigation hierarchy and achieving NNL (Maron et al., 2024). Hence, implementation of the basic first principles of mitigation by mining companies at mine sites (CSBI, 2015) – mitigating impacts of direct operations before allocating effort to broader commitments – is fundamental to responsible sourcing of minerals and metals.

10 This is exacerbated by government failures to internalise externalities fully, through fiscal measures, standards, regulations and market mechanisms (Dasgupta, 2021, p. 467).

4 Initial action on responsible sourcing and biodiversity for wind and solar developers

4.1 Overview

The scale of the responsible sourcing challenge is vast and complex with numerous challenges to navigate (Section 4.2). There are, consequently, limits to what can be achieved by individual developers to address biodiversity impacts linked to supply chains. Collaborative action and innovation and social signalling are essential – within the renewable energy sector, between the renewables sector and other sectors with similar challenges and opportunities, and between renewable energy developers and organisations throughout their supply chains.

This section outlines some of the ways in which wind and solar developers can approach initial action on responsible sourcing and biodiversity, and their role in driving responsible sourcing in line with the mitigation hierarchy (Section 3.4). This includes mapping supply chains as far as possible to identify and collate the information available to the developer (and highlight key data gaps), which will in turn inform prioritised initial actions including: adopting high-quality voluntary environmental standards; improving circularity and recovery of materials from operations; sourcing from suppliers who use sustainability-certified inputs (under existing schemes); establishing effective collaborations across and between industries and key suppliers to share information and experience; and working with industry partners and suppliers to exert positive influence and improve practices.

Such actions will develop the foundation for meaningful action on responsible sourcing and biodiversity – still it is recognised that there is a long way to go. Seeding and setting expectations for good practices for biodiversity all the way through supply chains is a first step towards halting and reversing biodiversity loss, and ultimately transforming the way business is conducted to contribute to the societal nature positive goal.

4.2 Sustainability challenges in renewables' supply chains

Responsible sourcing has multiple challenges and involves a wide array of different actors. Key sustainability challenges are highlighted in this section, providing some indication of the complexity and scale of the issues wind and solar developers must consider, and which will inform initial action. Challenges outlined here are:

- The developer's sphere of influence;
- Geographical separation and concentration at key stages of the supply chain and geopolitics;
- Minerals and metals are considered; undifferentiated goods;
- The large number of existing standards and certification schemes;
- The scale of renewables supply chains.

Sphere of influence: For developers, assessing and acting on biodiversity issues in supply chains is more complex than for direct operations. This is generally because developers have complete operational and/or financial control as well as reliable, spatially explicit data for their direct operations. Beyond these, developers have varying degrees of understanding, influence, and ability to affect practices and outcomes, which have implications for setting corporate and project-level targets for biodiversity (for example, in line with Science Based Targets for Nature, or SBTN) (Box 5).

Box 5

Spheres of company influence and biodiversity target setting

IUCN defines the corporate scope of biodiversity influence as "activities such as operations, processes and services managed by the company, all the supply chains and the services feedback and supporting the company's activities" (Stephenson & Carbone, 2021, p. ix). The strength of this influence varies across the corporate scope. Science Based Targets Network (2020, p. 18) offers another definition of 'spheres of company influence', as follows and represented in Figure 8 (below):

- **Value chain**: The series of activities, sites, and entities starting with raw materials and extending through to end-of-life management.
- **Upstream**: All the activities associated with suppliers, as well as transportation of commodities to manufacturing sites.
- **Downstream**: All the activities linked to the sale of products and services produced by the company, including use and reuse of products and their end of life (recovery, recycling, and final disposal).
- **Value chain-adjacent areas**: The landscapes, seascapes, and watersheds geographically adjacent to value chain sites. To adequately address impacts and dependencies on biodiversity and nature, it is necessary to act at these scales, as relevant.
- **Systems**: The broadest extent of corporate influence on socio-economic and socio-ecological systems. It will be necessary to act at this scale to bring about the transformative change in the relationship between business and nature required to achieve the goals of the Kunming-Montreal Global Biodiversity Framework (Box 1).

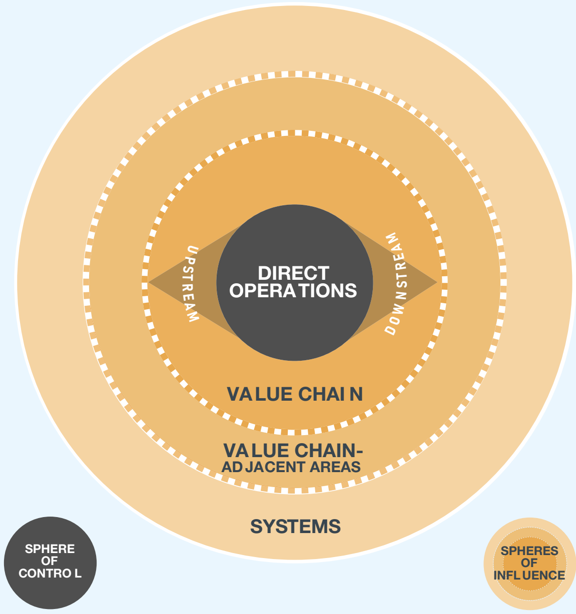

Figure 8 Spheres of control and influence relevant for companies acting on biodiversity
Source: SBTN (2020, Figure 6, pp. 18–19).

Where companies have subnational (or finer) spatial resolution data for activities in their direct operations and the upstream value chain, detailed guidance is available for setting precise science-based targets for nature (SBTN, 2023b). However, where the available data are national or less granular, companies are directed to improve traceability and transparency to enable science-based target setting (SBTN, 2024).

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Geographic separation and concentration, and geopolitics: There is geographical separation of the metal reserves, extraction facilities and processing plants (Schöneich et al., 2023), component manufacturing facilities, and end-use locations of wind and solar project sites. There is also geographic concentration at key stages of the supply chain, with a select group of countries playing a dominant role in mining and processing (e.g. Chile for copper, and China for rare earth metals) (IRENA, 2023). The mining industry is dominated by a few major companies with the resources and skills needed to develop complex mines, operating across multiple countries, and thereby controlling a significant proportion of global production and trade (IRENA, 2023). In particular, supply chains for solar PV (and battery manufacturing) are highly concentrated geographically at several stages, which could lead to frictions for supply (ETC, 2023a). Extraction and processing of some minerals, and manufacturing of some components, are also currently concentrated in countries with limited regulatory focus or investor pressure on sustainability (e.g. solar panels and solar panel components in China[11] (USDE, 2022; ETC, 2023a). Reducing reliance on individual countries for component parts, diversifying the supply chain and investing in renewable energy manufacturing could increase energy independence for many countries.

Each critical material has a unique geography of trade, varying across countries, sectors, and technologies, and making countries interdependent in terms of mineral and metal supply and demand (IRENA 2023). Disruptions and volatility in the supply of critical minerals have created instability in the global economy (Dou et al., 2023). However, in the medium to long term, trade flows for critical materials are thought unlikely to be as susceptible to geopolitical influence as oil and gas because of the abundance and geographic spread of minerals and metals, and processing locations (IRENA, 2023).

Undifferentiated goods: Another major challenge in all mineral and metal supply chains is that these materials are undifferentiated goods,[12] with inputs collected from numerous sources by traders and mixed at smelters or refineries. This often makes it extremely hard to trace the raw material back to individual mines. For metals like copper and gold, unformalised small-scale and artisanal mining, as well as illicit material flows, hinder traceability, and present challenges for certification and due diligence (Laing & Pinto, 2023). In these cases, cooperation between governments, corporates, and certification schemes to ensure sustainability and human rights is particularly necessary. The Fairmined Standard for Gold and Associated Precious Metals (ARM, 2014) and the more accessible Code of Risk Management for ASM engaging in Formal Trade (CRAFT) (ARM, 2020) are standards for good practice in artisanal mining, which include requirements around biodiversity that aim to improve incomes for artisanal mining based on a continual improvement model. However, few artisanal-scale mines are able to meet these standards, and the continuous improvement model mean that biodiversity impact management is not necessarily guaranteed at any given point in time through its implementation.

Number of existing standards and certification schemes: There is an overwhelming number of initiatives, industry associations, certification bodies, standards, and guidance related to responsible and sustainable sourcing of raw materials (Annex I for a summary). This can lead to frustration and overload for businesses – especially for users of multiple minerals and metals. Further, not all minerals and metals needed for wind and solar development are included in schemes requiring good standards of practice. Ideally, existing standards will be expanded to be more inclusive and comprehensive, rather than be at risk of compounding the issue with the creation of new responsible sourcing or material standards. Renewable energy companies could use their collective leverage to call for this (Section 4.4.3). Developers will need to conduct due diligence to ensure they require only high-quality and auditable good practice standards and schemes from their suppliers. While an assessment of the credibility and efficacy of initiatives and other resources has not been conducted as part of this guidance, some organisations lead and influence

11 China has the dominant global share of manufacturing capacity for several key solar panel components including polysilicon (72%), ingots (98%), wafers (97%), cells (81%), modules (77%), and inverters (66%) (Basore & Feldman, 2022)

12 Undifferentiated goods are products that are suitable for many different types of consumers.

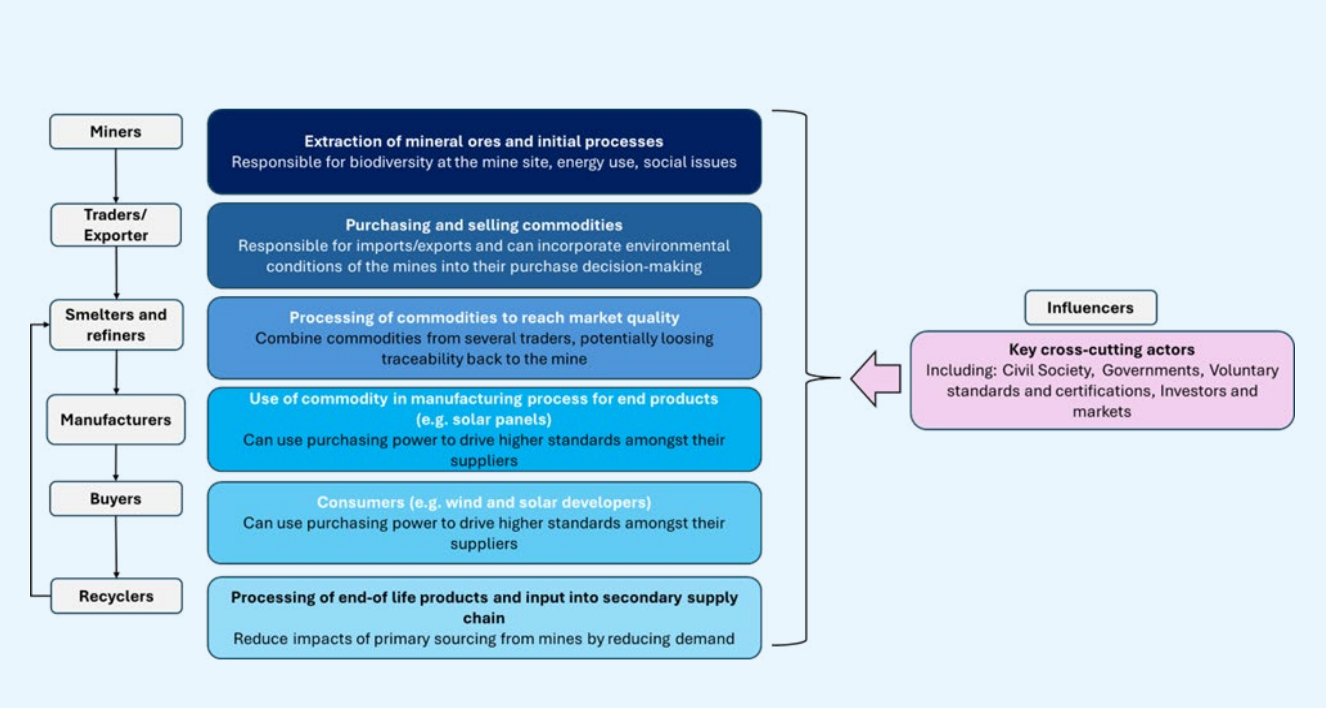

Figure 9 A simplified overview of key actors across mineral supply chains
Source: Adapted from ETC (2023b, Exhibit 4.8, p. 103).

good practice in the mining and metals industry (Annex I-A provides a few examples).

Scale of renewables supply chains: The scale of supply chains for renewable energy companies operating across the world is vast[13]. Mineral and metal supply chains for wind and solar energy are complex and include numerous stages and actors between the mine, the final technology construction, and the end use (Figure 9). Developers are not usually involved in the direct purchase of raw mineral and metal commodities – instead procuring composite products (e.g. solar panels or wind turbines) from primary (or tier 1) suppliers (Figure 10). This means that responsible sourcing for developers of wind and solar projects and transmission infrastructure is most likely to be related to leveraging their purchasing power to drive responsible sourcing practices throughout their upstream supply chains. However, various sustainability challenges exist linked to low traceability and the relatively low influence developers and their primary suppliers have over geographically restricted minerals and metals. Consequently, it is difficult for developers to demonstrate sufficient traceability to establish confidence in the original sourcing of the materials in their supply chain, the associated appropriate management of biodiversity impacts, and therefore set corporate or project-level sustainability goals and targets for supply chains in the same way as for direct operations.

4.3 Responsible sourcing and the project cycle

Responsible sourcing considerations are relevant and have implications throughout the project cycle, with opportunities to manage major 'one-off' purchases made in the pre-construction and construction phases (for example, the wind turbines and solar panels), and ongoing maintenance and repeat purchases associated with the operational phase.

Decisions taken during the pre-construction technical planning and design phase can influence supply chain-related biodiversity impacts and opportunities for mitigation throughout the project cycle. Impacts can be avoided and minimised by opting for component parts with lower requirements

13 For example, at the time of writing, companies, such as Iberdrola and Vestas, work with 20,000 with 12,000 suppliers, respectively.

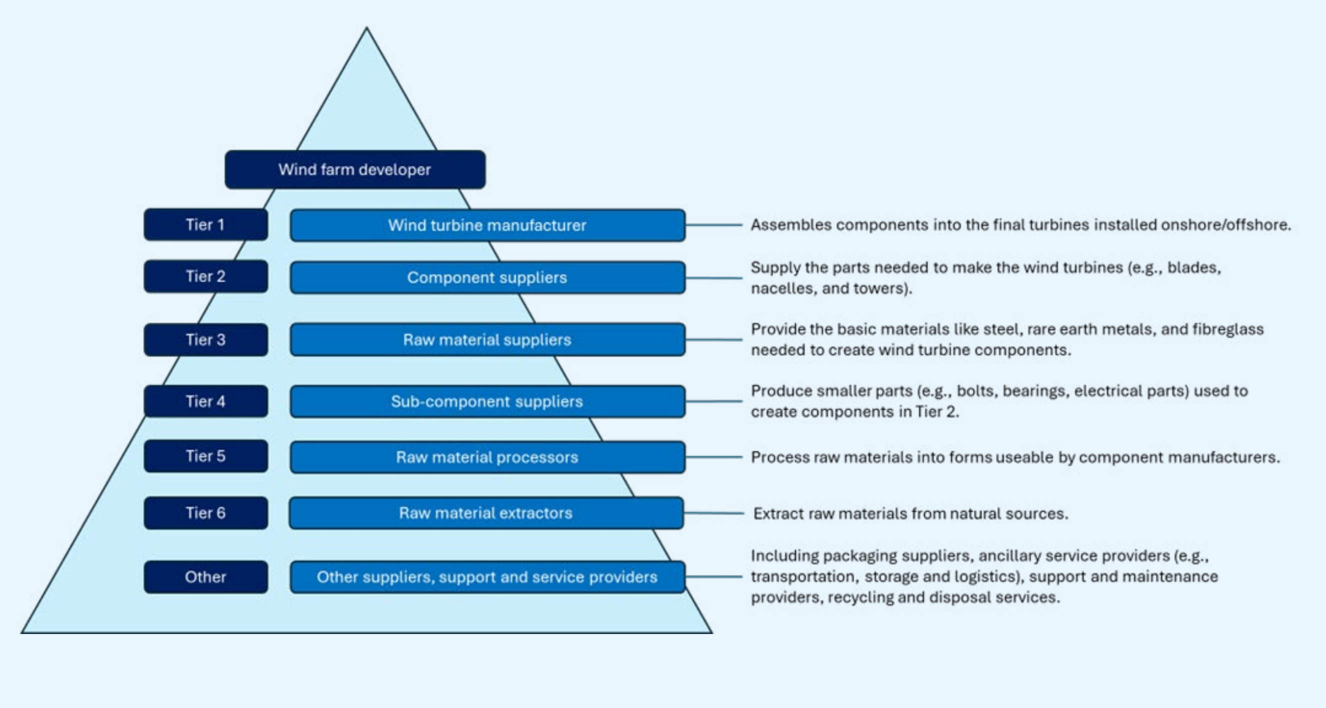

Figure 10 **Example of simple supply chain tiers for a wind farm development**
Source: Authors (adapted from Moore (2024).

for impactful minerals and metals, increasing the use of alternative, recycled and recyclable materials, minimising infrastructure material use, and re-using and recovering as much redundant material as possible (NatureScot/NàdarAlba, 2024). For example, up to 94% of the mass of a wind turbine is recyclable with improvements in recyclable blades increasing this still further (Woo & Whale, 2022).[14] Modular design of floating offshore wind farms could be used to enable serial production and assembly at ports before being towed into position and anchored with minimal use of additional materials like concrete and steel (Edwards et al., 2023). For solar farms, construction designs could aim to optimise mounting structures to use less steel[15] without compromising stability. Such design and procurement decisions like these will also influence the opportunities for effectively managing waste throughout the project cycle (Figure 11).

As the wind and solar sectors mature, increasing opportunities available for managing and mitigating biodiversity impacts linked to responsible sourcing, decommissioning and end of life are likely to emerge.[16] Components designed with recyclability or refurbishment in mind should enable developers to reduce purchases of primary materials and instead retain and reinvest the value of existing materials into new projects or repowering existing projects. Opportunities to refurbish components can reduce material requirements,[17] and for some materials it can be more environmentally efficient to modernise key components than to decommission and repower facilities (for example, steel, aluminium, copper, cast iron, and concrete associated with wind farm rotors and nacelles) – which is consistent with the concept of a circular economy (Kasner, 2022). Some materials may not have been designed for recyclability but there are still opportunities to reduce waste.[18] Box 6 summarises the importance of moving towards a circular economy to reduce overall resource demand and enable responsible sourcing and a sustainable renewable energy transition.

14 For example, wooden and recycled turbine blades are being tested, to avoid the difficulties (e.g. see La Rosa, 2023) and costs (e.g. see Gonçalves et al., 2022) associated with recycling traditional wind turbine blades made from glass fibre reinforced polymer (GFRP).
15 See, for example: https://www.hdrinc.com/au/node/4328#:~:text=Our%20idea%20is%20pretty%20simple,steel%20piles%20aren't%20uncommon
16 For example, it is estimated that more than 50,000 wind turbines will be decommissioned by 2030. For more information, see: https://renercycle.com/en/more-than-50000-wind-turbines-shall-be-decommissioned-by-2030/
17 See, for example: https://orsted-innovationreport.com/#offshore-excellence/operations/component-refurbishment
18 For example, Ørsted have piloted shredding GFRP blades from onshore wind farms for reuse in construction materials.

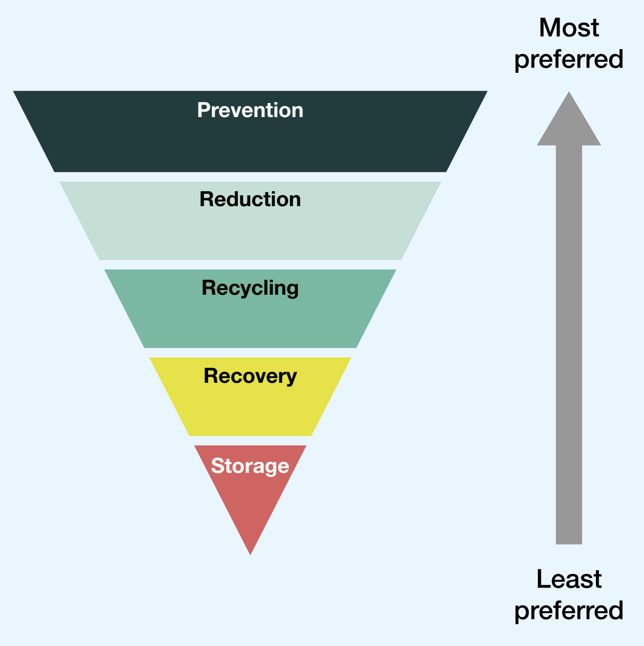

Figure 11 The waste management hierarchy
Source: ICMM (2022, Figure 2, p. 18).

Technical innovations[19] and increased recycling have huge potential to reduce long-term demand for primary materials (ETC, 2023a; 2023b). There are also potential opportunities to source recycled materials from other sectors, such as electronic waste (e-waste) from electrical and electronic equipment which contains valuable materials that could be used in renewable energy technologies (Seif et al., 2024). As elements, most metals[20] can theoretically be recycled indefinitely, provided their purity is maintained and there are systems are in place for recovering them. Among the most recyclable metals are (EuRIC, n.d.):

- **Steel**: 70% of the steel produced to date is still in use. In Europe, more than 90% of end-of-life stainless steel is collected and recycled into new products and in 2017, 35.5% of global crude steel was produced from secondary raw materials.
- **Aluminium** is also one of the most recycled materials in the world. Almost 75% of all the aluminium ever produced is still in use today.[21]
- **Copper**: In the EU, 44% of copper comes from recycled sources and 70% of copper in end-of-life products are recycled.

However, recycling rates vary greatly for all minerals and metals due to costs and technical issues (IBRD/The World Bank, 2020). It will take time for large volumes of materials to reach end-of-life, hence the short to medium term potential for recycling to reduce demand is limited (ETC, 2023b & 2023a; Gielen 2021). Recycling is limited by a lack of basic recycling infrastructure and technology in many developing countries, new and complex applications of metals at mass production scales, and the undue loss of too much valuable metal due to imperfect collection of end-of-life products (UNEP, n.d.).

4.4 Actions for developers

While wind and solar developers generally lack direct operational or financial control over the sourcing of the primary minerals and metals in their upstream supply chains, there are several important actions developers can take to improve understanding of the issues, take direct action in their own sourcing and decommissioning, improve traceability, and influence good practices for biodiversity along their supply chains - most powerfully related to leveraging purchasing power and industry influence. These actions are:

- Mapping the supply chain using footprinting approaches;
- Identifying company commitments, targets, and opportunities to act in line with the mitigation hierarchy;
- Collaborating with industry partners and suppliers to exert a positive influence for transformative change;
- Implementing action plans to guide and monitor these actions.

19 For example, design innovations in offshore wind include the use of geopolymer concrete, replacing steel rebar with basalt and reducing the weight requirements of monopiles through slip-forming. For more information, see: https://www.windsystemsmag.com/the-greening-of-offshore-wind-farm-construction/
20 Except for radioactive metals such as uranium and plutonium.
21 For more information, see: https://international-aluminium.org/work_areas/recycling/

Box 6

The importance of moving towards a circular economy

Circular economy practices are one of the most important pillars for achieving emission reduction targets and accelerating the energy transition (IRENA, n.d.). Energy conservation and efficiency, including circular economy practices, is a key technological avenue towards the 1.5°C scenario (IRENA, 2022). There are various definitions for the circular economy concept. A study of 114 such definitions found the concept to be most frequently depicted as a combination of reduce, reuse, and recycle activities with the aim of economic prosperity, but generally without including a waste hierarchy or highlighting that the circular economy necessitates a systemic shift (Kirchherr et al., 2017).

As the concept gains traction, definitions are becoming more inclusive, bringing biodiversity and the need for transformative change to the fore. The Australian Circular Economy Hub acknowledges the primary aim of the circular economy is to redefine what is meant by growth, focusing on positive society-wide benefits rather than narrower and purely economic metrics (Taylor, 2020). The Ellen MacArthur Foundation, devoted to creating a circular economy, defines it as a system where materials never become waste and nature is regenerated (Ellen MacArthur Foundation, n.d.).

There are three primary principles driven by design: i) eliminate waste and production to reduce threats to biodiversity; ii) circulate products and materials (at their highest value) to leave room for biodiversity; and iii) regenerate nature to enable biodiversity to thrive (Ellen MacArthur Foundation, 2021).

A study of low-carbon technologies, including wind and solar energies identified three main strategies for circularity: reduction in demand; lifetime extension; and recycling (Simas et al., 2022).* The concurrent effect of these strategies can be to reduce annual mineral and metal demand, increase the lifetime of infrastructure and services (extracted minerals and metals stay in society for longer), and determine when and how much material can be recovered and re-enter the manufacturing process as a substitute for primary raw materials (Simas et al., 2022). The transformative change necessary to achieve the goals of the KMGBF (Box 1) requires all three strategies because, for example, even if end-of-life recycling rates reached 100% (i.e. if all possible scrap was captured, recycled and could be reused), the use of recycled content is unlikely to reach 100%, unless there are significant reductions in the overall demand for raw minerals and metals (IBRD/The World Bank, 2020). Approximately 40% of copper and 40% of steel are produced from recycled materials, and over 30% of aluminium, lead, and zinc production use recovered inputs, but export taxes remain high on all these materials (Korinek, 2018). Trade restrictions on metallic waste and scrap are a particular challenge for the decoupling of industrial production from resource use, which is necessary to achieve the SDGs (CEPAL, 2016; Korinek, 2018).

Transformative, systems-level change requires the involvement of all actors and stakeholders involved in the mineral and metals supply chain (Figures 9 and 10), and it takes time. Beyond the responsibility of developers to manage material recycling after decommissioning, there is a broader responsibility of mining companies to align with the basic principles of the mitigation hierarchy, providing an opportunity to develop circular 'metals-as-a-service' business models and become 'resource managers'. Concretely, it could mean going beyond simply mining primary materials to the provision of secondary recycled supply, providing tracing and monitoring capabilities throughout material life-cycles, or becoming effective managers of disused mining sites and waste (ETC, 2023b).

A survey of the readiness of three global wind turbine manufacturers (Tier 1 suppliers; Figure 10) for a transition to a circular economy showed that while they were more prepared than other non-renewable energy industries, major innovations are required in at least six areas: (i) implementation of a circular criteria and indicators in product design and public tender processes; (ii) ensuring components are tracked and monitored over their life cycle; (iii) implementation of efficient reverse logistics; (iv) exploration of alternative business model concepts; (v) improvement of recycling technologies for higher material quality outcomes; and (vi) development of circular wind hubs for information and data sharing (Mendoza & Pigosso, 2023). For solar energy, reviews have shown that the industry is on a path towards increased circularity, but that priorities need to expand beyond recycling to a broader set of environmental policies and activities to fully realise the benefits of circular production (Heath et al., 2022; Schichtel et al., 2022).

Whilst some policies are starting to encourage movement towards a circular economy, such as the European Commission's Circular Economy Action Plan, more ambitious frameworks for renewable energy are required: defining responsibilities, standardisation and certification; data collection and reporting systems; financial and fiscal policies; research, development and demonstration of recycling technologies; and public awareness-raising (IRENA, 2022).

* See also a separate systematic review for offshore wind developing a framework to embed a circular economy throughout the lifecycle of offshore wind energy infrastructure, resulting in 18 strategies, in Circular Wind Hub (2024) and Velenturf (2021).

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The following sections address each of these key actions.

4.4.1 Map supply chain

Mapping the supply chain is a powerful first step towards improving developers' understanding of their supply chains, including identifying key issues, the nature of the associated biodiversity impacts, the scale and importance of specific minerals and metals in the supply chain, the available data and the major data gaps, and where there are opportunities to apply the mitigation hierarchy. Frameworks, such as the Taskforce for Nature-related Financial Disclosures Locate, Evaluate, Assess, Prioritise approach (TNFD, 2023b), for which guidance on value chains is also available (TNFD, 2024), provide a useful structure that companies may already have implemented for their direct operations.

Mapping the supply chain can be achieved using two main approaches:

- The collection of any primary data available to the developer, including details of key suppliers and potential suppliers of suppliers (Figure 10 for an indication of the possible number of tiers in the supply chain). Developers who have already undertaken a carbon footprinting process are likely to have already collated much of the relevant data. It might also be possible to begin to identify mining companies and suppliers who have committed to contributing to a nature positive future (Box 1). This review of suppliers can also include an analysis of whether suppliers already align with existing standards of good practice (Annex I-B).

- Supply chain footprinting to identify priority minerals and metals in the wind or solar supply chain that require most urgent action. This will be informed, at least in part, by the primary supply chain data collated. A key tool for supply chain footprinting is the Life Cycle Assessment (LCA), a standardised method for assessing the environmental footprint of a product, process, service, or corporation from 'cradle to grave', which can be done with both primary and secondary data (Box 7).

  Biodiversity 'extent x condition' frameworks for estimating the state of biodiversity in an ecosystem can also be used for supply chain footprinting (Box 7). Footprinting approaches are likely to be one of the most accessible ways developers can begin to establish a better view of their supply chains and associated biodiversity impacts, because they can be carried out with different levels of data availability and resolution.

Mapping and footprinting the supply chain helps developers to scope targets for responsible sourcing and prioritise minerals and metals that require further investigation and action most urgently. For example, depending on the information available, mapping can help identify:

- Minerals and metals used in largest quantities;

- Minerals and metals (and sourcing locations) with comparatively high impacts on biodiversity (noting that this may not equate to the materials used in the largest quantities), such as copper which is shown to have disproportionately large pressures on biodiversity, according to one non-dimensional index based on data on land cover, protected areas, and mining operations (Kobayashi et al., 2014);

- Parts of the sourcing, processing, and production processes with comparatively high impacts and dependencies on biodiversity;

- The range of suppliers and partners, and understand their procurement practices and level of commitment to responsible sourcing and traceability;

- Major data gaps in supply chain knowledge and at what tier (helping to prioritise where to focus efforts to collaborate and improve data availability and awareness).

Further investigation could include biodiversity risk screening of sourcing locations for priority minerals and metals, for example, assessing species extinction risk using the IUCN Species Threat Abatement and Restoration (STAR) metric.

4.4.2 Identify company commitments, targets, and mitigation opportunities

Developers may already have established biodiversity strategies and made commitments setting out overarching ambitions for biodiversity.[22] These may include supply chains or their need to be revised to incorporate robust and clear commitments scoped to include them. Where appropriate for the business, these may be linked to specific high-quality voluntary environmental standards. Commitments associated with responsible sourcing should include broad 'no regrets' actions, such as:

- No Go commitments, avoiding sourcing minerals and metals extracted at mines within protected areas and at-risk ecosystems. One of the means to implement this is through adopting a supplier code of conduct and ensuring independent audit of suppliers.[23]
- Zero conversion and zero deforestation commitments, reducing land conversion for mineral and metal extraction, again through an independently audited supplier code of conduct.

Given the complexity of wind and solar supply chains (Section 4.2), overarching goals for responsible sourcing are initially likely to be qualitative (or semi-quantitative), informed by the outcome of supply chain mapping and footprinting. Goals could include commitments to:

- Avoid and reduce biodiversity impacts in wind and solar upstream supply chains through:
  - Changing direct business operations within the company sphere of control (Box 5);
  - Improving 'in house' circularity and sustainability (Section 4.3 and Box 6);
  - Optimising longevity of components and parts and championing reuse.
- Influence as far as possible the actions and decisions of suppliers within the upstream supply chain, primarily through biodiversity-sensitive sourcing and supplier engagement (Section 4.4.3), and identification of the most appropriate and credible initiatives and certification schemes etc. (Annex I-A). Along with public-facing biodiversity strategies and commitments, these are social signalling actions that publicly express a company's opinions and position on biodiversity loss and contribute to spreading norms and practices aligned with societal goals for nature (Booth et al., 2024).
- Making proportional contributions to restoring and regenerating biodiversity in landscapes impacted by wind and solar supply chains by investing in conservation initiatives in countries where the company operates and where raw minerals and metals are sourced from.
- Contributing to transformative change by investing in research, development, and innovation to drive advances in technology and practices that can accelerate the transition towards a circular economy and achieving global goals for biodiversity (Box 1).

Table 2 summarises key opportunities for action on responsible sourcing, which address biodiversity impacts in line with the mitigation and waste management hierarchies.

4.4.3 Engage collaboratively for transformative change

Achieving transformative change throughout supply chains requires engagement and collaboration across the board, from all actors at all tiers of the supply chain, as well as indirect stakeholders such as local communities and indigenous peoples in sourcing landscapes. Collective and collaborative action can influence the individual behaviours of many other companies up and down the supply chains (Booth et al., 2024). For wind and solar developers, supplier engagement will be key to improving traceability and driving responsible sourcing practice, especially because suppliers are likely to be facing similar challenges, drivers, and incentives for doing the same (Sections 2.2 and 4.2).

22 Strategies and commitments of developers may, or may not, be public.
23 Voluntary no-go commitments can also send a strong signal to legislators to pursue supply chain legislation that prevents the import of products associated with conversion of important habitat, such as in the European Union's deforestation legislation.

Box 7

Key tools for supply chain footprinting

Footprinting approaches are essential for businesses to understand their interactions with and impacts on nature across the value chain, and to align with a suite of reporting frameworks, including the Taskforce for Nature-related Financial Disclosures, SBTN, and the European Union's Corporate Sustainability Reporting Directive. These frameworks enable companies to set targets and identify key actions that can contribute to achieving global biodiversity goals (Box 1). Two key tools for footprinting are Life Cycle Assessment (LCA), and the biodiversity extent, condition, and significance (BECS) approach.

Life cycle assessment

LCA is an assessment of the total environmental impact of a product (or service) throughout its entire life, based on the resources and energy inputs required and the emissions produced from production to end of life. It is carried out using either specialist modelling software which can be purchased (e.g. SimaPro or GaBi) or open source (e.g. OpenLCA or Brightway). Both paid-for and open-source options require the use of an LCA database which may need to be purchased separately. The most commonly used databases include EcoInvent, Sphera, and EXIOBASE. These databases, built with primary or secondary data, are becoming more comprehensive as organisations increasingly produce and share data. Primary data is specific to the company (e.g. quantity of a specific emission, volume, and source of a mineral withdrawal). Secondary or proxy data (e.g. data modelled for similar activities, based on regional or global averages) can also be used for LCA, but results have a high level of uncertainty and may not reflect the specifics of a company's supply chain. LCA can also be carried out using procurement data in spend or volume per sector of activity and country in place of primary or secondary data.

LCA measures impacts on ecosystems using methods, such as ReCiPe, LC-Impact, Impact World+ or Environmental Footprint, which are most commonly applied through LCA software, but can also be used independently. Multiple impacts can be assessed at the same time, enabling exploration and comparison of different scenarios and trade-offs or synergies between different impacts. Two main well-established metrics are used to quantify impacts:

- **Potentially disappeared fraction** (PDF) of species, which quantifies the proportion of species going extinct locally (over a unit of area or volume) in response to external pressures (e.g. land use), usually over one year (unit: PDF.m^2.year or PDF.m^3.year).
- **Species.year** – a variant of PDF, where its result is multiplied by species density to enable comparison between impacts in different realms (albeit with some coarse assumptions about species distribution and sensitivity to impacts).

LCA is currently the best available method for assessing the impacts of downstream activities such as transport, use, and end-of-life phases. For wind and solar, LCA could be carried out for a model of wind turbine or solar PV panel, and results extrapolated. Initial results might be spatially coarse, for example indicating most likely source countries for minerals and metals, but nonetheless a useful starting point for understanding supply chain-related issues. It is important to note that LCA results are typically not comparable between companies because models are very sensitive to different data and assumptions.

Biodiversity extent, condition, significance

The biodiversity 'extent x condition' framework is a standard and well-tested measurement framework for estimating the state of biodiversity in an ecosystem. It has been extended to include a measure of biodiversity significance, such as the biodiversity, extent, condition, significance (BECS) approach developed by The Biodiversity Consultancy. BECS estimates the potential area of land used to produce the raw materials used in a company's value chain, the biodiversity impact associated with occupying this land area, alongside the state of nature and biodiversity in this location. Land use change is the main global driver of biodiversity loss (IPBES, 2019), primarily driven by economic activity in three main sectors: agriculture; forestry; and mining. The BECS approach can be used with primary data on raw material production locations, or with secondary data based on global production and trade information. As for LCA, results produced using secondary data contain a high degree of uncertainty, which can be addressed using improved sourcing and traceability data when it becomes available.

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Table 2 Summary of key responsible sourcing actions to address biodiversity impacts

MITIGATION HIERARCHY	WASTE MANAGEMENT HIERARCHY	EXAMPLE ACTION OR OPPORTUNITY
Avoid	Prevent	Avoid sourcing minerals and metals from high-risk locations to prevent biodiversity impacts (source from lower risk locations).
		Avoid using high-impact and high-waste minerals and metals to prevent biodiversity impacts (choose alternative materials).
Avoid/minimise	Prevent/Reduce	Adopt high-quality voluntary environmental standards covering supply chains (Annex I-B) and require the same from upstream suppliers.
		Source only from suppliers that use sustainably certified inputs and/or have effective supply chain due diligence. The actions in these standards relating to biodiversity often include commitments to avoid areas of biodiversity importance, adherence to the mitigation hierarchy, targets like NNL or Net Gain, and zero deforestation.
		Review alternative sourcing options from suppliers that use sustainably certified inputs under existing schemes or supply chain due diligence
Avoid	Storage	Support avoidance of biodiversity impacts by engaging with mining companies, certification schemes, and industry bodies to drive responsible tailing storage practices aligned with good practice for biodiversity such as not storing tailings in or near biodiversity sensitive areas (Aska et al., 2024).
Minimise	Reduce	Invest in technical design and innovation to reduce overall demand for extraction of primary materials through: – Reducing overall use of minerals and metals (prioritising the most impactful ones). – Increasing the use of minerals and metals extracted from repurposed mining waste, such as from the Regeneration initiative which reinvests earnings in habitat restoration and transformation of former mine sites into ecological and community assets.
Minimise	Recycle/recover	Circular economy: Increase use of alternative materials and recycled content, and alternative sources.
		Circular economy: Identify opportunities for refurbishment and repowering to maximise re-use of existing materials (especially hard-to-recycle materials) and reduce requirement for extraction of primary materials.
		Circular economy: Identify opportunities to recycle and re-purpose existing materials. For example, GE Renewable Energy and Veolia have developed an approach to reincorporate blades into cement mixes in place of sand and gravel, minimising overall aggregate requirements and reducing manufacturing emissions by 27%. Fibres can be recovered from wind turbine composite materials through a chemical recovery (solvolysis) method and metals can be extracted from solar panels via leaching methods (Chen et al., 2020).
Restore and offset	n/a	While restoration and offsetting actions to achieve NNL or NPI of biodiversity at mine sites are the responsibility of the mining company, wind and solar developers can seek opportunities to support restoration initiatives and compensation actions to address unavoidable residual impacts on biodiversity. Collaborating on such action could improve and enhance biodiversity outcomes in line with global goals for biodiversity.

Source: Authors.

Developers can explore ways to engage with:

- **Suppliers of major project components** (existing or new), to use purchasing power and shared incentives to encourage and drive improvements. One leading example for offshore wind energy is the collaboration between the developer Ørsted, the manufacturer and service providers Siemens Gamesa and Siemens Energy Grid Technologies, and the supply chain traceability platform Circulor, where full copper traceability has been achieved for the offshore wind farm Hornsea Two down to the mine site-level in Chile and Indonesia (a world-first for wind energy). This represents a good example of a collaborative solution resulting from workshops and technological blockchain-based approaches.

- **Other developers**, to drive and effectuate responsible sourcing at scale, and to improve biodiversity outcomes. Collaboration at the sector level is crucial to delivering Target 15 of the KMGBF (Box 1), which requires companies to promote actions to ensure sustainable patterns of production. Sharing practices and experiences and combining efforts should accelerate positive change.

- **Other industries with comparable supply chains**, to share lessons and learn from existing approaches, for example:

  - The Drive Sustainability initiative is a partnership between 16 automotive manufacturers with a mission to improve the social, ethical, and environmental performance of automotive supply chains, which has thus far assessed 37 raw materials based on their importance for the industry and the associated environmental, social, and governance risks.
  - The Watch & Jewellery Initiative 2030 (WJI), with a mission to champion best practice and develop joint solutions that create positive outcomes for people and planet as part of a just transition. The WJI has produced a Nature Roadmap focusing on one of their three pillars, 'Preserving Resources', to provide a practical common framework for the sector as a whole.

- **Governments**, to leverage sector level influence to lobby for and support strategic long-term planning for sustainable mining and biodiversity conservation (Sonter et al., 2018). For example, Brazil a country with over 90% of the world's niobium deposits, faces increasing biodiversity loss from mining-linked deforestation and pressure to downgrade protected areas for new mining concessions (Sonter et al., 2017; European Commission, 2020). Likewise, across Africa, mining poses a serious threat to high biodiversity areas and requires careful management and strategic planning (Edwards et al., 2014). Supporting governments to identify and address potential cumulative impacts of extraction on a landscape scale can also contribute to avoiding and minimising biodiversity loss, and in turn to achieving biodiversity goals. More broadly, engaging with governments can support the development of a level playing field to harmonise requirements for companies with supply chains depending on transition materials. Round table collaborations (for example, organised by landscape or region of significance, or by key mineral/metal) can be an effective means of initiating dialogue and collaborative action by bringing major stakeholders together in an open and transparent way (Annex III-B, Case study on the RE-SOURCING project).

- **Existing industry associations, initiatives and certification schemes**: As noted in Section 4.2, a challenge for responsible sourcing is the sheer number of existing bodies, standards and schemes. Likewise, a risk is that new ones are created to address minerals and metals not already covered by existing schemes.

- Since the demand for minerals and metals associated with wind and solar expansion is so clear and strong (Section 3.2), developers are very well placed to leverage collective influence to call for and support the development and expansion of existing high-quality schemes. This would be further strengthened through wind and solar engagement with influential industry associations, like ICMM, who could facilitate.

The potential reach of such engagement could be substantial, considering the existing membership of some of the most prominent minerals and metals initiatives (for example, ICMM membership includes one third of the global metals and mining industry, while the Extractive Industries Transparency Initiative Standard has a commitment from more than 50 countries to strengthen transparency and accountability of their extractive sector management).

- Additionally, research, development, and innovation collaborations with scientific institutes, industry partners, and academia can advance possibilities for re-use and recycling and technical developments in efficiency and lifespan of renewable energy technologies (Section 4.3). Furthermore, applied research solutions can help reduce the impacts of mining through novel approaches, such as using microbial communities to remediate the toxicity of the mine waste for transition materials (Newsome & Falagán, 2021), or modelling approaches to reduce the water consumption of mines (Gunson et al., 2012; Gunson, 2013).

4.4.4 Implement action plans for responsible sourcing

The initial focus of developer action plans for wind and solar responsible sourcing will be on improving traceability, transparency, and procurement practices. This may require a phased approach with near-term, medium-term and long-term targets, regular progress review, and an adaptive management philosophy based on new incoming data and implementation experience. For example:

- **Year 1**, identification of priority minerals, metals, components, and geographies;
- **Year 2**, implementation of no regret actions, thus improving supply chain data and traceability, and setting specific, measurable, actionable, and time-bound targets for priority minerals and metals;
- **Year 5**, demonstration of meaningful progress towards reducing and counterbalancing biodiversity impacts associated with the upstream supply chain;
- **Year 15**, establishment of an overall positive impact on biodiversity.

Action plans to guide and demonstrate progress towards these types of goals should aim to consolidate the approach into a single document for clarity and easy tracking. Ideally, the action plan will contain a clear statement of purpose, reflecting the company risks to biodiversity associated with inappropriate sourcing practices and identifying the opportunities available to improve and enhance traceability, transparency, and procurement practices.

For complex supply chains (Section 4.2), it is likely to be challenging to set quantitative science-based targets (Box 5) for the upstream wind and solar supply chain. Thus, action plans for responsible sourcing will likely benefit from outcomes-based approaches, rather than risk-based approaches. Developers can still aim to set specific, time-bound, and actionable targets with clear expected outcomes, and track these using a performance measurement framework. This may involve periodic re-assessment or re-evaluation of the supply chain mapping and biodiversity footprint, where possible disaggregated by pressure (type of impact).

Tracking and monitoring performance against commitments and targets enables an adaptive approach, responding to new and emerging information, ensuring key risks and materials are always prioritised for action, and allowing opportunities emerging from collaboration, research, development, and innovation to inform the action plan. It is important to be clear about what will be monitored, and take into consideration the following (Proforest, 2015):

- What information is needed, how it will be collected or collated, and how often;
- Where the information will come from (e.g. can the company collect it, or does it need to be requested from suppliers?);

- How the information will be used (avoid the collection of data unnecessarily);

- What the information can inform, and what it cannot.

Commitments and mitigation actions like those outlined in Table 2 could be verified through, for example:

- Updated in-house policies, standards and key performance indicators on responsible sourcing;

- Updated procurement standards and environmental supplier codes covering supply chains;

- Risk screening of all suppliers and partners;

- Implementing third party certification (Annex I-B) and/or audits of suppliers;

- Spatially explicit global maps of suppliers and source materials to country level (or finer scale, if possible), focusing on minerals and metals identified as priorities;

- Bills of materials for major project components (e.g. wind turbines and solar panels);

- LCA for new components;

- Certifications for recycled content, and verification of suppliers' recycled content certification;.

- Updated or new conservation investment budgets and programmes, with associated targets and action plans;

- Updated or new research, development and innovation programmes and collaborations, with associated targets and action plans.

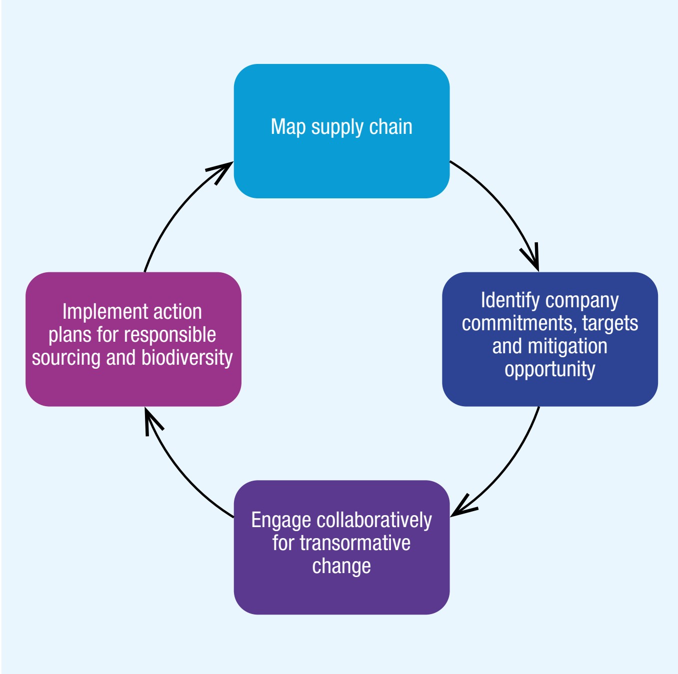

Figure 12 Summary of initial actions for wind and solar developers on responsible sourcing and biodiversity

Source: Authors.

4.4.5 Summary of actions for developers

Figure 12 (above) summarises the initial actions wind and solar developers can take on responsible sourcing and biodiversity, as outlined above. There is strong feedback between these, based on the premise that initial action will identify and generate new information, provide lessons, and continue to build the community of practice, subsequently enabling more and deeper action.

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Annex I Summary of existing initiatives, guidance, and certification and verification schemes relevant to minerals and metals

This section provides an overview of existing industry associations and initiatives, certification bodies and standards, and guidance relevant for minerals and metals.

In conducting supply chain due diligence, renewable energy companies can in the first instance look for alignment with leading initiatives that are well established and mature, have broad geographic scope, wide membership, and clear principles and commitments on sustainability. Government involvement and third party/external audit or assurance are also good indicators of credibility. Good examples of organisations leading and influencing good practice in the mining and metals industry include:

- The ICMM: Established in 2002, membership now includes a third of the global mining and metals industry. ICMM has 10 Principles for sustainable development to set a standard for the ethical performance of members. There is a comprehensive set of 39 performance expectations and nine related position statements, including a Nature Position Statement (Annex III-A).
- The Initiative for Responsible Mining Assurance (IRMA) was founded in 2006 by NGOs, businesses purchasing minerals and metals for resale in other products, affected communities, mining companies, and labour unions. IRMA independently assesses social and environmental performance at mine sites globally using an internationally recognised standard developed in consultation with a wide range of stakeholders. The audit results are publicly available. The Standard for Responsible Mining and Mineral Processing 2.0 is expected to be released by early 2025.
- More recently (in 2023), the International Responsible Business Council (RBC) Agreement for the Renewable Energy Sector has emerged specifically to generate more transparency in the renewable energy supply chain, aimed at any organisation active in the wind and/or solar industry. The Agreement is facilitated by the Dutch Social and Economic Council.

Annex I-A Industry associations and initiatives

INITIATIVE	SUMMARY	REFERENCE TO BIODIVERSITY
Climate Smart Mining (CSM) Initiative	CSM is a public-private partnership led by the World Bank and IFC. CSM aims to support resource-rich developing countries to decarbonise and reduce the material footprint of critical mineral supply chains required for the clean energy transition. CSM achieves this objective by focusing its activities on a framework developed in consultation with key stakeholders in government, industry, and civil society, serving as guidance to help developing countries integrate climate-smart approaches through four pillars: (i) decarbonisation, (ii) resilience, (iii) circular economy, and (iv) market opportunities.	CSM Pillar 2 on Resilience focuses on the topic of nature-based solutions and how the mining sector can support them though various practices. These practices can include maintaining wetlands and urban green spaces, managing watersheds and reservoirs, practicing community-based natural resource management, conserving soil, and planting trees, among others.
Critical Minerals Mapping Initiative (CMMI)	CMMI recognises that there is increased demand for critical minerals from emerging technologies like solar photovoltaics. The initiative aims to develop better understanding of the distribution of critical mineral resources in known deposits.	With better information on the spatial distribution of critical minerals, biodiversity can be considered in the sourcing process including through use of the spatial web tool where custom data layers can be uploaded.
Extractive Industries Transparency Initiative (EITI) Standard	The EITI standard is the global benchmark for transparency and accountability in the mining sector, and is designed to empower governments, industry and civil society to promote understanding of natural resource management; strengthen public and corporate governance and accountability; and provide the data to inform policymaking and debate.	Environmental monitoring and disclosure is mentioned in the standard, but not biodiversity specifically. However, implementing countries must disclose information on environmental impact assessments which include biodiversity impacts.
Initiative for Responsible Mining Assurance (IRMA)	IRMA provides a framework for certification of mining operations and chain of custody based on responsible practices.	Standard includes detailed requirements on biodiversity, ecosystem services and protected areas.
International Aluminium Institute (IAI)	The IAI seeks to contribute to standards and regulation that encourage wise use of aluminium and foster improved performance in the industry by:	Explicit sections of Sustainable Bauxite Mining Guidelines (SBMG) documenting biodiversity principles.
International Copper Association (ICA)	The ICA advocates for the copper industry, promoting sustainable development and advancing the use of copper as a material of choice.	Explicit mentions of biodiversity principles in policy.
International Council on Mining and Metals (ICMM)	ICMM is an association of mining and metals companies that enables collaboration, development of good practice standards and guidance and knowledge-sharing on responsible production practices.	ICMM's Nature Position Statement sets out ICMM members' approach to contributing to a nature positive future guided by the Kunming-Montreal Global Biodiversity Framework (KMGBF) 2030 targets and ICMM's existing commitments. Commitments include assessing and addressing impacts to biodiversity by implementing the mitigation hierarchy to achieve a minimum of no net loss (NNL) or net gain of biodiversity.
International Iron Metallics Association (IIMA)	The IIMA advocates for the iron industry, promoting sustainable development and advancing the use of iron as a material of choice.	Explicit mentions of biodiversity principles in policy.

Annex I-A (continued)

INITIATIVE	SUMMARY	REFERENCE TO BIODIVERSITY
International Responsible Business Conduct (RBC) Agreement for the renewable energy sector	A broad coalition of solar and wind energy companies, industry associations, the Dutch government, knowledge institutions, NGOs and trade unions jointly committed themselves to making international value chains more sustainable. Key focus areas for the agreement are: • Supporting and monitoring individual companies' efforts to identify, understand and address risks of violation of human rights and environmental standards in their value chains; • Initiating projects to jointly address prevalent risks in the sector; • Increasing the collective influence (leverage) of the agreement participants by broadening membership, and by encouraging relevant actors in the renewable energy supply chains to adopt and implement the OECD Guidelines and UNGPs; • Encouraging embedment of international responsible business conduct criteria in tender and procurement processes regarding renewable energy technologies.	Through the Agreement, companies commit to implementing the OECD Guidelines for Multinational Enterprises and the United Nations Guiding Principles on Business and Human Rights in their operations and throughout their supply chains. The former includes guidance and recommendations on the topic of Environment.
International Renewable Energy Agency (IRENA) Collaborative Framework on Critical Materials for the Energy Transition	A platform provided by IRENA to exchange knowledge, best practices, and coordinate actions to ensure that the scarcity of minerals and metals does not threaten the accelerated deployment of renewable energy.	Not explicitly mentioned within the framework. However, as part of a sustainable future this should be integrated as mentions in the technical report "respect for cultural and natural heritage" as a key pillar of this sustainable transition.
International Tin Association	Organisation dedicated to supporting the tin industry and expanding tin use. Has several guidelines for the tin industry and includes a due diligence programme designed for Artisanal and Small-Scale Mining.	Biodiversity is mentioned under principle 2 of the Tin Code.
International Zinc Association (IZA)	The IZA advocates for the zinc industry, promoting sustainable development and advancing the use of zinc as a material of choice.	Explicit mentions of biodiversity principles in policy.
Nickel Institute	The Nickel Institute advocates for the nickel industry, promoting sustainable development and advancing the use of nickel as a material of choice.	Explicit mentions of biodiversity principles in policy.
Renewable Energy & Human Rights Benchmark (REHRB)	The REHR Initiative focuses on the human rights impacts associated with renewable energy projects, including wind energy. It encourages responsible practices throughout the supply chain, addressing issues such as labour rights and community engagement.	Company must comply with the Convention on Biological Diversity (CBD) guidelines. The impact assessment must include impacts on biodiversity, flora and forestry, and natural habitats (in compliance with CBD and other relevant instruments), as well as plans for restoring the impacted environment.
RE-SOURCING	Global stakeholder platform started in 2020. RE-SOURCING is funded under the European Union's (EU) Horizon 2020 programme.	Biodiversity is embedded within Re-sourcing guidelines. Target 2 – Paris Agreement & Environmental Sustainability – highlights the need to integrate and harmonise rules and objective for environmental sustainability, pollution prevention, biodiversity conservation, and water use.
Responsible Business Alliance (RBA)	The RBA provides tools and resources for companies to implement good practices with a particular focus on manufacturing suppliers.	Code of conduct includes environmental standards which include resource conservation but not explicitly linked to biodiversity.

Annex I-A (continued)

INITIATIVE	SUMMARY	REFERENCE TO BIODIVERSITY
Responsible Minerals Initiative (RMI)	The RMI is part of the RBA and provides resources for companies to implement responsible sourcing practices. Aim is to Improve business practices to support responsible mineral production and sourcing.	Within the Risk Readiness Assessment tool there are criteria linking directly to biodiversity issues. These are:
Solar Energy Industry Association (SEIA)	Avoid, minimise, restore or replace, and compensate for adverse impacts on biodiversity, soil and productive land, commit to a no net loss and consider a net gain of biodiversity.	No explicit mentions of biodiversity within the documentation.
Solar Energy UK	No explicit mentions of biodiversity within the documentation.	Best practice is promoted through Solar Power Europe which includes detailed information on biodiversity issues in solar PV plants. Less information for the supply chain biodiversity impacts.
Solar Stewardship Initiative (SSI)	Launched by SolarPower Europe and Solar Energy UK, setting out the solar industry's plan for a responsible, transparent, and sustainable solar value chain.	The SSI has an ESG standard and includes commitments for the manufacturing parts of the supply-chain such as: no net-loss of biodiversity; zero deforestation; not operating in natural World Heritage sites or their buffer zones; and respecting the management objectives of protected areas.
The London Metals Exchange (LME)	A centre for the trading of industrial metals.	Biodiversity not explicitly mentioned but requires producers accredited under LME to have ISO14001 or equivalent certification. This would include elements of biodiversity.
Towards Sustainable Mining (TSM) of Mining Association of Canada	The Mining Association of Canada's TSM standard is a globally recognized sustainability programme that supports mining companies in managing key environmental and social risks.	There is a Biodiversity Conservation Management protocol with three indicators: corporate biodiversity conservation commitment, accountability and communications; facility-level biodiversity conservation planning and implementation; and biodiversity conservation reporting.
WindEurope	Industry group bringing together all large developers and original equipment manufacturers for wind energy in Europe. WindEurope engages in various activities to support the wind energy industry, including advocacy efforts to shape favourable legislative and regulatory environments, promoting research and development, and facilitating networking and collaboration among its members.	There is explicit mention of biodiversity within impacts of wind energy but is mainly focused on the generation rather than impacts within supply chains.
World Gold Council	A membership organisation that champions the role of gold as a strategic asset, shaping the future of a responsible and accessible gold supply chain. Developed industry standards for mining, including third party verification to provide assurance to stakeholders including investor and buyers. The Responsible Gold Mining Principles are assured by Bureau Veritas.	Principle 9 of the Responsible Gold Mining Principles is related to biodiversity management and should ensure at least a no-net-loss of critical habitat and goal for a net gain for biodiversity.
World Steel	Goal of the organisation is to leadership on all major strategic issues impacting the industry, particularly focusing on economic, environmental and social sustainability. They have developed standards for mining, including third party verification to provide assurance to stakeholders including investor and buyers.	No explicit mention of biodiversity within the principles.
Additional country-level initiatives	Most countries with established mining and minerals sector will have industry groups or initiatives. These range in size and activity. Some notable ones are the Mining Association of Canada and the Mining Association of Australia. These groups represent the respective Canadian or Australian mining industries and have initiatives focused on sustainable development, responsible mining, and community engagement.	Dependant on the exact country initiative. However, as with responsible sourcing commitments, there is an alignment with international initiatives which do explicitly include biodiversity principles.

Source: Authors.

Annex I-B Certification bodies and standards

INITIATIVE	SUMMARY	REFERENCE TO BIODIVERSITY
Aluminium Stewardship Initiative (ASI)	ASI works together with producers, users and stakeholders in the aluminium value chain to collaboratively foster responsible production, sourcing and stewardship of aluminium. Aim to promote and maximise the contribution of aluminium to a sustainable society. Bureau Veritas offsets accredited certification to ASI.	Biodiversity and Ecosystem Services is Principle 8 of ASI Performance Standard.
Copper Mark (CM)	Also an industry initiative, the Copper Mark reviews the sustainability standards at copper production sites including mines, smelters, and refineries. They promote responsible practices across the copper, molybdenum, nickel and zinc value chains via the Joint Due Diligence Standard for Copper, Lead, Nickel and Zinc.	There is a 'Land Use and Biodiversity' section in the guidelines which includes recommendations.
CRAFT	CRAFT is the Code of Risk-mitigation for ASM engaging in Formal Trade – CRAFT. CRAFT was developed by Resolve and the Alliance for Responsible Mining (ARM). CRAFT is a code or standard aiming to serve as an instrument for ASM and the downstream industry to validate its eligibility to sell and source minerals and metals originating from ASM.	CRAFT 2.0 refers to land use and biodiversity in the context of aligning with conservation goals of protected areas, as well as sustainable water use and appropriate use of land that local inhabitants also require for activities including ecotourism.
Fairmined Standard for Gold from Artisanal and Small-scale Mining	The Fairmined Standard developed by the Alliance for Responsible Mining (ARM) drives improved environmental management, especially mitigating the effects of use of mercury and other toxic chemicals, enhancing ecological restoration, and responsible water management.	Exclusion for protected areas and Critical Ecosystems (adapted from IFC PS6) protected under national legislation and does not encourage newcomer-operators in these areas. Mentions a pro-active responsibility of ASMOs over issues including biodiversity/forest conservation and water stewardship in their area of influence. Responsible ASM cares for water, respects protected areas, avoids damaging important biodiversity, minimises the ecological footprint of mining, and, where possible restores or replaces biodiversity, and where this is not possible, compensates for that residual loss.

Source: Authors.

Annex I-C Guidance

INITIATIVE	SUMMARY	REFERENCE TO BIODIVERSITY
EBRD Environmental and Social Policy	Policy document which: outlines how the EBRD will assess and monitor the environmental and social risks and impacts of its projects; sets minimum requirements for managing environmental and social impacts and risks caused by EBRD financed projects; and defines the respective roles and responsibilities of both EBRD and its clients in designing, implementing and operating projects in accordance with this policy.	There is a 'Biodiversity Conservation and Sustainable Management of Living Natural Resources' Performance Requirement, which includes a section on biodiversity impacts in the supply chain.
IFC Environmental, Health and Safety Guidelines for Mining	Guidelines from the IFC which serve as reference documents with general and mining-specific examples of Good International Industry Practice (GIIP). When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards.	There is a 'Land Use and Biodiversity' section in the guidelines which includes recommendations.
Natural Resource Charter	A global initiative to assist governments, societies and the international community to effectively govern non-renewable natural resources in a way that generates economic growth, promotes the welfare of the population and is environmentally sustainable. The Charter is made up of 12 best practice principles.	Although Precept 5 includes the mitigation and offsetting of environmental costs of resource extraction, biodiversity is not explicitly mentioned.
OECD Handbook on Environmental Due Diligence in Mineral Supply Chains	Developed to help companies embed environmental considerations into their mineral supply chain due diligence procedures. The handbook builds on the OECD Guidelines for Multinational Enterprises on Responsible Business Conduct, the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas, and the OECD Due Diligence Guidance for Responsible Business Conduct. This handbook demonstrates how OECD instruments on due diligence can be applied to address environmental risks and impacts in mineral supply chains by contextualising existing recommendations and directing users towards useful resources.	Covers biodiversity loss and degradation, species, terrestrial, marine and other aquatic ecosystems (for example, deforestation, damage to protected areas and soil erosion)
Responsible Mineral Assurance Process (RMAP)	RMAP is the flagship programme of the RMI and takes a unique approach to helping companies make informed choices about responsibly sourced minerals in their supply chains. Focusing on a 'pinch point' in the global metals supply chain, the RMAP uses an independent third-party assessment of smelter/refiner management systems and sourcing practices to validate conformance with RMAP standards.	Explicit sections of Sustainable Bauxite Mining Guidelines (SBMG) documenting biodiversity principles.
Sustainable Bauxite Mining Guidelines	Guidelines from the IAI (edition 2022) which provide a practical, attainable guide to improve sustainability. It is bauxite specific and has theory and examples developed at some mines for over 50 years. Downloadable material includes the Guidelines Report and PowerPoint Overview.	The IAI Sustainable Bauxite Mining Guidelines have an explicit biodiversity section.

Annex I-C (continued)

INITIATIVE	SUMMARY	REFERENCE TO BIODIVERSITY
TNFD Sector Guidance – Metals and mining	The Taskforce on Nature-related Financial Disclosures (TNFD) has developed a set of disclosure recommendations and guidance that encourage and enable business and finance to assess, report and act on their nature-related dependencies, impacts, risks and opportunities. Additional sector guidance, such as for metals and mining, supplements the TNFD's Guidance on assessment of nature-related issues — the LEAP approach.	ICMM's Nature Position Statement sets out ICMM members' approach to contributing to a nature positive future guided by the Kunming-Montreal Global Biodiversity Framework (KMGBF) 2030 targets and ICMM's existing commitments. Commitments include assessing and addressing impacts to biodiversity by implementing the mitigation hierarchy to achieve a minimum of no net loss (NNL) or net gain of biodiversity.
UNECE Critical Minerals for the Sustainable Energy Transition: A Guidebook to Support Intergenerational Action	A guidebook which intends to elevate the importance of discussions around critical energy transition minerals (CETMs) and aims to serve as a hub of accessible information that can facilitate knowledge exchange and encourage further intergenerational action on this topic.	No explicit mentions of biodiversity within the guidebook.

Source: Authors.

Annex II Factsheets for key minerals

This annex contains summary factsheets for key minerals and metals in wind and solar energy, based on the top five for each technology shown in Figure 6.

Annex II-A Iron

Biodiversity impacts

- Iron ore is generally mined through open pit methods which require large surface areas and necessitates the removal of vegetation, so existing habitats will be destroyed. Associated infrastructure, such as roads, can further increase habitat fragmentation.
- Iron ore mining and processing require large quantities of freshwater, and many mines are in areas of water stress which exacerbates local scarcity further.
- Regarding pollution, large quantities of water can become contaminated with environmentally harmful tailings if tailing dams fail.
- Dust from mining activities can adversely affect nearby wildlife (UKGBC, 2024).
- In a life cycle assessment (LCA) of metals, iron production was shown to have the highest global warming potential out of 63 metals assessed. The iron and steel sector alone was calculated to be responsible for ~71% of the global CO_2 emissions and ~74% of primary energy demand within the mining and metals sector (Nuss & Eckelman, 2014).

Geographic sources (based on 2023 mine production of usable ore)

Australia (944,000 metric tonnes = 37% of global production); Brazil (440,000 metric tonnes = 18% of global production); China (280,000 metric = 11% of global production) (USGS, 2024)

Alternatives

The only source of primary iron is iron ore. DRI, iron nuggets, and scrap are used for steelmaking in electric arc furnaces and in iron and steel foundries. Technological advancements now allow hematite to be recovered from tailings basins and pelletised (USGS, 2024)

Distribution of impacts across production process steps

According to an LCA, ecosystem damage (species.yr/kg) is higher in the refining stage (75%) than the mining stage (25%). The refining stage also has higher global warming potential and energy demand (Nuss & Eckelman, 2014).

Major producing companies (based on 2021 iron ore production)

Vale (319.6 million tonnes); Rio Tinto (276.6 million tonnes); BHP (245.4 million tonnes) (Mining Intelligence, 2022)

Metal to rock ratio

9 tonnes of rock needed to produce 1 tonne of iron (Nassar et al., 2022).

Annex II-B Zinc

Biodiversity impacts

- ~80% of zinc ore comes from underground mines and 20% from open pit mines. Both methods can pose risks to biodiversity through habitat loss, degradation and fragmentation.
- Production of zinc can lead to zinc being discharged into waterways, posing a risk to fish.
- Zinc levels in soil can increase from disposal of zinc wastes, and zinc may reach groundwater and lead to contamination.
- Zinc may also be taken up by animals eating soil or drinking water containing zinc (ATSDR, 2014).
- Production for sulfidic zinc ores produces large amounts of sulphur dioxide (which can form acid rain) and cadmium vapour.
- Zinc production also produces carbon monoxide and carbon dioxide. The production of zinc produces around 3 tonnes of CO_2 per tonne of zinc (GreenSpec, 2024).

Geographic sources (based on 2023 mine production)

China (4,000 metric tonnes = 33% of global production); Peru (1,400 metric tonnes = 12% of global production); Australia (1,100 metric tonnes = 9% of global production) (USGS, 2024).

Alternatives

Aluminium and plastics can replace galvanized sheet in automobiles, and aluminium alloys, cadmium, paint and plastic coatings replace zinc coatings. Also, aluminium- and magnesium-base alloys are substitutes for zinc-base diecasting alloys (USGS, 2024).

Distribution of impacts across production process steps

According to an LCA, ecosystem damage (species.yr/kg) is higher in the purification/refining stage (i.e. smelting) (75%) than in the mining stage (25%). The purification/refining stage also has higher global warming potential and energy demand (Nuss & Eckelman, 2014).

Major producing companies (based on Q1–Q3 production)

Glencore (700,000 metric tonnes); Hindustan (618,000 metric tonnes); Teck Resources (507,000 metric tonnes (Statista, 2024a).

Metal to rock ratio

71 tonnes of rock needed to produce 1 tonne of zinc (Nassar et al., 2022).

Annex II-C Copper

Biodiversity impacts

- Copper is mined through open pit and underground methods. Both methods can pose risks to biodiversity through habitat degradation and fragmentation.
- The extraction of copper ore is energy intensive and can result in the release of toxic materials which can cause land, air and water pollution (Konanç et al., 2024).
- A key risk is from sulphuric acid, used to leach copper oxide minerals, which has impacts on ecosystem health via ecotoxicity and acidification (DCCEEW, 2022).
- Copper processing is also responsible for ~50% of anthropogenic arsenic emissions (Serbula et al., 2017).
- Water is required to separate the ore from unwanted material which can result in water pollution which can have significant impacts on biodiversity (Rzymski et al., 2017).
- In an LCA, out of 63 metals assessed, copper production was ranked highest for impacts on human health and ecosystem damage, and 4th highest for global warming potential (Nuss & Eckelman 2014).

Geographic sources (based on 2022 mine production)
Chile (5,200 metric tonnes = 24% of global production); Democratic Republic of Congo (2,200 metric tonnes = 10% of global production); Peru (2,200 metric tonnes = 10% of global production) (USGS, 2024)

Alternatives
Aluminium can be used as a substitute for copper in automobile radiators, electrical equipment and power cables. Titanium and steel can be used instead of copper in heat exchangers (USGS, 2024).

Distribution of impacts across production process steps
According to an LCA, ecosystem damage (species.yr/kg) is higher in the mining stage (57%) than in the purification/refining stage (47%). Both stages have similar global warming potential and energy demand (Nuss & Eckelman, 2014).

Major producing companies (based on Q1 2023 copper output)
Codelco (352,000 tonnes); Freeport-McMoRan (297,000 tonnes); BHP (279,000 tonnes) (Statista, 2024b)

Metal to rock ratio
513 tonnes of rock needed to produce 1 tonne of copper (Nassar et al., 2022).

Annex II-D Aluminium

The ore of aluminium is bauxite. The biodiversity impacts noted here relate to bauxite mining. The remaining information relates to aluminium production.

Biodiversity impacts

- Bauxite is generally mined through open pit methods which require significant removal of vegetation and thus a severe loss of biodiversity.
- The development of mine infrastructure will also result in habitat fragmentation which reduces biodiversity resilience. Studies in India, Guinea and Australia found that bauxite mining has resulted in vegetation loss, habitat fragmentation and the pollution of freshwater sources (Lad & Samant, 2012; Boldy et al., 2023; Dibattista et al., 2023).
- Dust pollution was found to be a key result of bauxite mining which causes air pollution and affects vegetation productivity (Lad & Samant, 2012).
- Freshwater pollution was also found to result from high levels of soil erosion and the buildup of sediments containing heavy metals which result in ecotoxicity and can affect all aspects of an ecosystem (Pradhan et al., 2023).

Geographic sources (based on 2022 smelter production)
China (40,000 metric tonnes = 58% of global production); India (4,000 metric tonnes = 6% of global production); Russian Federation (3,700 metric tonnes = 5% of global production) (USGS, 2024).

Alternatives
Composites, magnesium, steel and titanium can substitute for aluminium in ground transportation uses. Additionally, copper can replace aluminium in electrical and heat exchange applications (USGS, 2024).

Distribution of impacts across production process steps
According to an LCA, ecosystem damage (species.yr/kg) is much higher in the refining stage (80%) than in the mining (16%) and purification (4%) stages. The refining stage also has higher global warming potential and energy demand (Nuss & Eckelman, 2014).

Major producing companies
Reliance Steel & Aluminium; Norsk Hydro; Aluminium Corporation of China; Chinalco, Hongqiao, Rusal, Xinfa (Statista, 2024c)

Metal to rock ratio
7 tonnes of rock needed to produce 1 tonne of aluminium (Nassar et al., 2022)

Annex II-E Lead

Biodiversity impacts

- Lead is mined through open pit and underground methods. Both methods can pose risks to biodiversity through habitat degradation and fragmentation.
- Lead is commonly found in hard rock sulfide deposits, usually in association with zinc and silver. The sulfide minerals in the mine wastes can undergo chemical reactions to become sulfuric acid, leaching high concentrations of salts and heavy metals into the environment. The lead itself can also be leached into the environment; at many historic and current lead mine and smelter sites in Australia there are ongoing issues of soil, water and air contamination (Mudd, 2010).
- Lead in the environment can be transmitted and biomagnified through food chains and can have a destructive impact on terrestrial, freshwater and marine species, including birds (Raj & Das 2023).
- Energy and water requirements increase as ore grades decline, and out of 63 metals assessed in an LCA, lead production was ranked 10th highest for global warming potential (Nuss & Eckelman, 2014).

Geographic sources (based on 2023 mine production)
China (1,900 metric tonnes = 42% of global production), Australia (440,000 metric tonnes = 10% of global production), US (270,000 metric tonnes = 6% of global production) (USGS, 2024).

Alternatives
Antimony tin oxide coatings have been used as an alternative to indium, tin, and oxide (ITO) coatings. Carbon nanotube coatings have been developed as an alternative to ITO coatings in flexible displays. Copper or solver nanowires have been explored as a substitute for ITO in touch screens, graphene has been explored as a replacement for ITO in flexible touch screens (USGS, 2024).

Distribution of impacts across production process steps
According to an LCA, ecosystem damage (species.yr/kg) is higher in the purification stage (65%) than in the mining (22%) and refining (13%) stages. The purification stage also has higher global warming potential and energy demand than the mining and refining stages (Nuss & Eckelman, 2014).

Major producing companies
Glencore, Hindustan Zinc, Teck, BHP (Statista, 2024d)

Metal to rock ratio
50 tonnes of rock needed to produce 1 tonne of lead (Wang et al., 2024).

Annex II-F Indium

Biodiversity impacts

- Most indium is obtained as by-product of zinc processing. Some indium is mined but in small quantities in China and Republic of Korea. Zinc mining has been recorded to result in the release of zinc and lead from tailings deposits into the surrounding environment causing freshwater ecotoxicity and resulting wider biodiversity impacts (Gutiérrez et al., 2016).

Geographic sources (based on 2022 refinery production)
China (530 metric tonnes = 59% of global production); Republic of Korea (200 metric tonnes = 22% of global production); Japan (66 metric tonnes = 7% of global production) (USGS, 2024).

Alternatives
Antimony tin oxide coatings have been used as an alternative to indium, tin, and oxide (ITO) coatings. Carbon nanotube coatings have been developed as an alternative to ITO coatings in flexible displays. Copper or solver nanowires have been explored as a substitute for ITO in touch screens, graphene has been explored as a replacement for ITO in flexible touch screens (USGS, 2024).

Distribution of impacts across production process steps
According to an LCA, ecosystem damage (species.yr/kg) is higher in the purification stage (65%) than in the mining (22%) and refining (13%) stages. The purification stage also has higher global warming potential and energy demand than the mining and refining stages (Nuss & Eckelman, 2014).

Major producing companies
3M, American Elements, Densitron Technologies (IMARC Group, 2024)

Metal to rock ratio
Indium is a critically endangered element. Supply is dependent upon the zinc mining industry of which indium is a small byproduct. Recovery of indium from post-consumer scarp is cost prohibitive (ACS, n.d.)

Annex II-G Molybdenum

Biodiversity impacts

- Molybdenum is mined through open pit and underground methods. Both methods can pose risks to biodiversity through habitat degradation and fragmentation.
- The mining of molybdenum can cause its release into the environment ,which can lead to freshwater and marine eutrophication as well as freshwater, marine, and terrestrial ecotoxicity (Deng et al., 2017).
- Molybdenum can be toxic in high doses, and animals and plants can suffer from exposure to, and uptake of, these higher amounts. High levels of molybdenum in the diet of livestock has been found to cause chronic molybdenum poisoning (heart disease) (Frascoli & Hudson-Edwards, 2018; Tallkvist & Oskarsson, 2015).
- Out of 63 metals assessed in an LCA, molybdenum was ranked 6th highest for human health and ecosystem damage, and 20th for global warming potential (Nuss & Eckelman, 2014).

Geographic sources (based on 2023 mine production)

China (110,000 metric tonnes = 42% of global production); Chile (46,000 metric tonnes = 18% of global production); United States (34,000 metric tonnes = 13% of global production) (USGS, 2024)

Alternatives

There is little substitution for molybdenum in its major application in steels and cast irons. Potential substitutes include boron, chromium, niobium, and vanadium in alloy steels; tungsten in tool steels; and graphite, tantalum, and tungsten for refractory materials in high-temperature electric furnaces (USGS, 2024).

Distribution of impacts across production process steps

According to an LCA, ecosystem damage (species.yr/kg) is much higher in the mining stage (90%) than in the purification/refining stage (10%). The mining stage also has higher global warming potential and energy demand than the purification/refining stage (Nuss & Eckelman, 2014).

Major producing companies (based on production volume in 2013)

Freeport-McMoran (47,000 metric tonnes); Codelco (23,000 metric tonnes); Southern Copper (19,896 metric tonnes) (Statista, 2024e)

Metal to rock ratio

4,478 tonnes of rock needed to produce 1 tonne of molybdenum (Nassar et al., 2022)

Annex III Case studies

Annex III-A ICMM position on nature

The International Council on Mining and Metals (ICMM) is an industry body and global leadership organisation for sustainable development. In 2024, ICMM and its membership committed to contributing to a nature positive future, capturing this commitment in a Nature Position Statement. Recognising that responsibly produced minerals and metals play a critical role in advancing global sustainable development goals, ICMM members, representing a third of the global industry, have pledged that meeting this demand for critical materials must not be at the expense of nature. ICMM's approach is guided by the KMGBF 2030 targets (Box 1) and ICMM's existing commitments in relation to Indigenous Peoples, climate change, water and respecting human rights as per the United Nations Guiding Principles on Business and Human Rights (UNGPs).

The commitments of ICMM apply to all members, generally at the corporate level. They apply to activities across all four realms of nature (land, freshwater, oceans, and atmosphere). The design and implementation of activities to meet these commitments should avoid causing or contributing to negative human rights impacts.

ICMM members commit to contributing to a nature positive future by taking the following actions:

1. **Direct operations**: Managing land and natural resources to drive positive change for nature and those that depend on it through commitments to:
   a) Respect protected areas and ensure) that operations are compatible with their objectives;
   b) Not explore or mine in UNESCO World Heritage sites;
   c) Address impacts on biodiversity and ecosystem services by implementing mitigation hierarchy actions to achieve at least no net loss or net gain of biodiversity.

2. Value chain: Partnering with suppliers and key stakeholders to support value chain action for nature by 2030 through commitments to:
   a) Identify sourcing locations with significant nature-related risk, and opportunities for action;
   b) Based on the opportunities, support initiatives or partnerships to help halt and reverse nature loss in the value chain;
   c) Roll-out requirements for high-risk direct suppliers to disclose nature-related impact, dependency, risk and opportunity assessments for activities in priority locations.

3. **Landscapes**: Enhancing landscapes around operations through local partnerships, including with Indigenous Peoples and local communities. By 2030, members commit to working with stakeholders to identify risks and opportunities and address these through one or more of the following options in priority landscapes:
   a) Restore, Conserve and Regenerate
   b) Collaborative Landscape-Scale Action
   c) Repurpose and Regenerate (abandoned mine sites and mining waste)

4. **Systems transformation**: Enabling nature positive transformation within and beyond the industry by 2030. Members commit to implementing one or more of the following options:
   a) Collaborative Research and Development
   b) Advancing Data Sharing
   c) Sustainable Finance (partnering with investors and financial institutions to increase private sector funding for nature).

5. **Governance and transparency**: Embedding nature positive approaches through commitments to:
   a) Integrate nature considerations into business decision-making processes by 2026;
   b) Disclose material nature-related impacts, dependencies, risks and opportunities for operations in priority locations by 2026 and the most material value chain issues by 2030;
   c) Develop metrics for reporting progress towards nature positive outcomes from 2026.

Annex III-B RE-SOURCING Project

The RE-SOURCING Project is a global stakeholder platform for responsible sourcing in mineral value chains, designed to create the necessary framework conditions for responsible sourcing in the European Union (EU) and globally (Figure 13). It is coordinated by the Vienna University of Economics and Business, with funding from the European Union's Horizon 2020 research and innovation programme. The Project is focused on wind and solar PV energy and the respective supply chains because of their importance for future energy supply in Europe (mobility and electrical and electronic equipment are also focus sectors). The focus is on mining (especially copper, rare earth metals, and silicon), manufacturing of equipment (mainly turbines and solar PV panels), and their collection and treatment.

The Project led a gap analysis of existing supply chain initiatives and minerals and metals standards, finding that environmental issues were under-prioritised in comparison with social and economic issues, and that there was insufficient focus on resource efficiency. Based on this assessment, they have developed a Vision and a Roadmap for creating a sustainable wind and solar sector in Europe. This includes the following five target areas: i) circular economy and decreased resource consumption; ii) Paris agreement and environmental sustainability; iii) social sustainability and responsible production; iv) responsible procurement; and v) level playing field and international cooperation. The Project has also developed Good Practice Guidelines for the Renewable Energy Sector aimed at extractives companies, to share good practices based on principles of transferability.

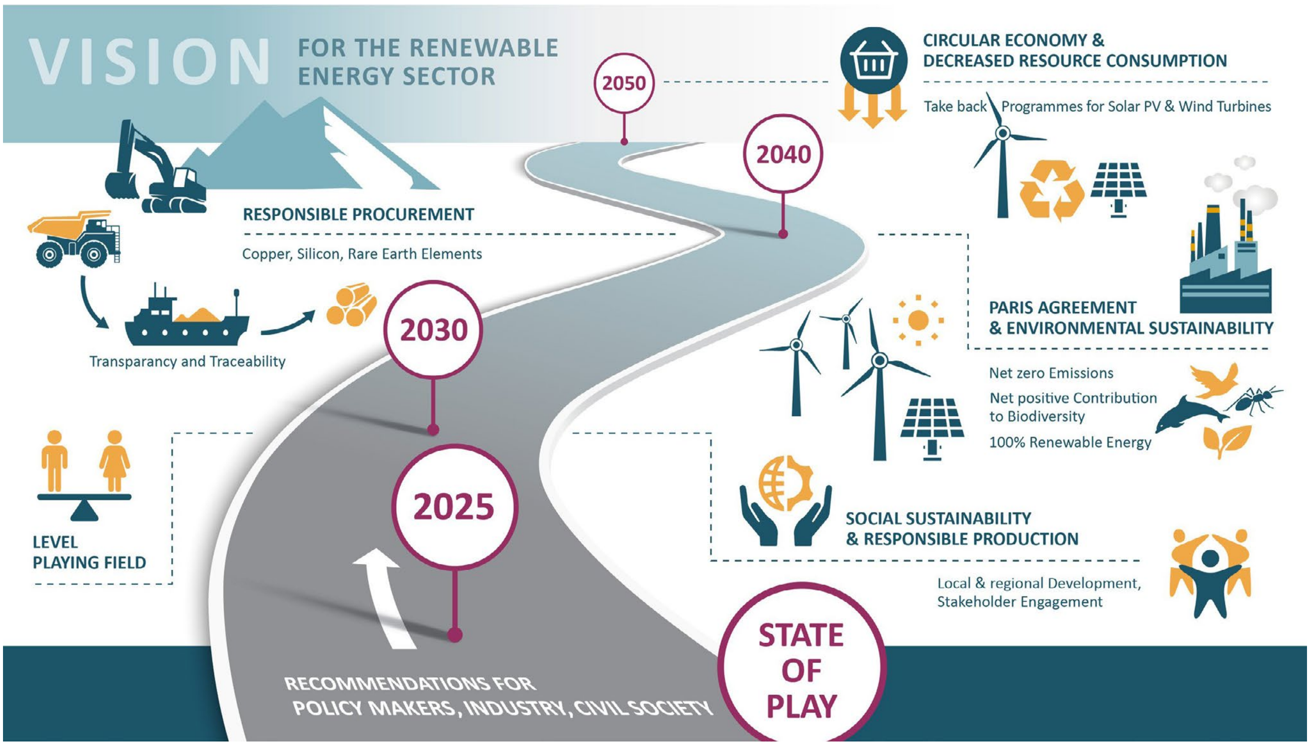

Figure 13 Vision of RE-SOURCING for the renewable energy sector
Source: Kügerl et al. (2023, p. 2).

Contributed by The Biodiversity Consultancy

Annex IV Further reading

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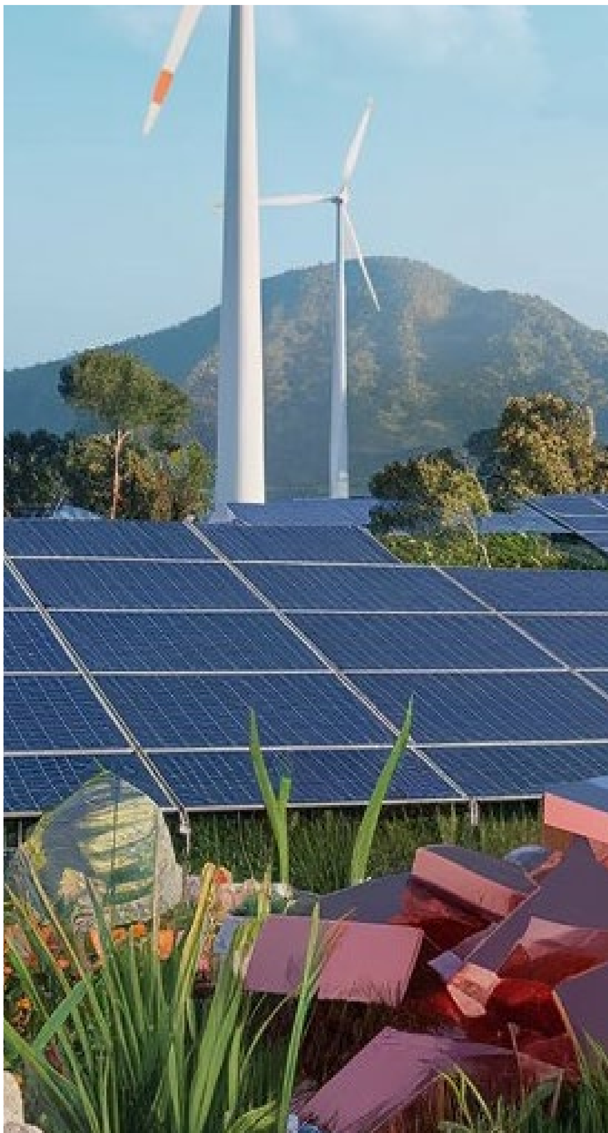

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