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Policy and legal elements for a life cycle perspective to support a just transition of the energy sector to renewables

Summary Report

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Project: TS018

January 2022

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ABBREVIATIONS

CCS	Carbon Capture and Sequestration
CE	Circular economy
CIGS	Copper indium gallium selenide
CiP	Chemicals in products
CSO	Civil society organization
CSP	Concentrated solar power
EPR	Extended producer responsibility
GHG	Greenhouse gas
ICMM	International Council on Mining and Metals
IIED	International Institute for Environment and Development
JET	Just energy transition
JT	Just transition
LCA	Life cycle assessment
LCT	Life cycle thinking
LREE	Light rare earth elements
HREE	Heavy rare earth elements
RE	Renewable energy
SAICM	Strategic Approach to International Chemicals Management
PV	Photovoltaic
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
WEEE	Waste Electrical and Electronic Equipment

1 INTRODUCTION

With the need to address climate change and the goal to provide universal energy access high on political agendas, along with the recognition that actions to address these critical issues need to be economically, socially and environmentally sustainable, a Just Energy Transition (JET) is increasingly at the forefront of government policies. There is a relatively good understanding and strong focus on the socio-economic aspects of a JET. The intention of this **summary report** (and the companion in-depth research report) is to increase awareness of the potential environmental impacts of a JET - along with the actions needed to address them - so that individuals, societies and organisations can participate in influencing policy development and decision-making on all relevant aspects relating to a JET (social, economic and environmental).

This report aims to provide the holistic **life cycle perspective** needed for individuals, societies and organisations to have the capacity to influence decision makers around the important environmental issues associated with renewable technologies, especially around promoting the sound management of chemicals and waste. Furthermore, alongside the life cycle environmental impacts of renewable energy technologies, there is a need to consider **resource efficiency** and **circularity**, with the latter increasingly being recognised as conditional to sustainability[1].

1.1 The need for a transition of the energy sector

It is unequivocal that human activities have resulted in a significant increase in atmospheric greenhouse gases (GHG) (IPCC, 2021). This has led to global warming at an unprecedented rate[2], with the last four decades warmer than the previous and warmer than any decade since 1850 (IPCC, 2021). Temperatures are now approximately 1ºC above pre-industrial levels, resulting in widespread changes to the global climate, oceans and land (IPCC, 2021). Anthropogenic climate change has already influenced weather and climate extremes in every region across the globe (IPCC, 2021). Additional warming will further intensify the global water cycle including its variability (within seasons and from year to year), global monsoon precipitation and the severity of wet and dry events (IPCC, 2021).

If global warming should rise to 2ºC, anthropogenic climate impacts will become even more prevalent and changes in ocean, ice sheets and global sea level caused by past and future GHG emissions will be irreversible for hundreds to thousands of years (IPCC, 2021). Consequently, **it is becoming increasingly urgent to reduce emissions and stabilise the level of GHG emissions in the atmosphere**, to limit warming to 1.5ºC. To achieve this goal, global anthropogenic CO_2 emissions need to be reduced by 45% from 2010 levels by 2030 and reach net zero CO_2 emissions around 2050 (IPCC, 2018). Furthermore, it is critical to ensure lower GHG emissions by 2030 (25 – 30 $GtCO_2eq$ per year) as this leads to a higher chance of keeping below 1.5ºC warming (Rogelj *et al.*, 2018). Existing government energy plans, targets and Nationally Determined Contributions (NDCs) under the Paris Agreement are not nearly ambitious enough to meet this target, as shown in Figure 1 (IRENA, 2021). Without urgent and immediate action, the rapid decline in emissions required will be too steep to manage (Hallowes and Victor, 2019).

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[1] See for example, https://www.unep.org/news-and-stories/story/european-commission-and-unep-will-foster-circular-economyglobally

[2] There is a near-linear relationship between cumulative anthropogenic CO_2 emissions and the global warming they cause

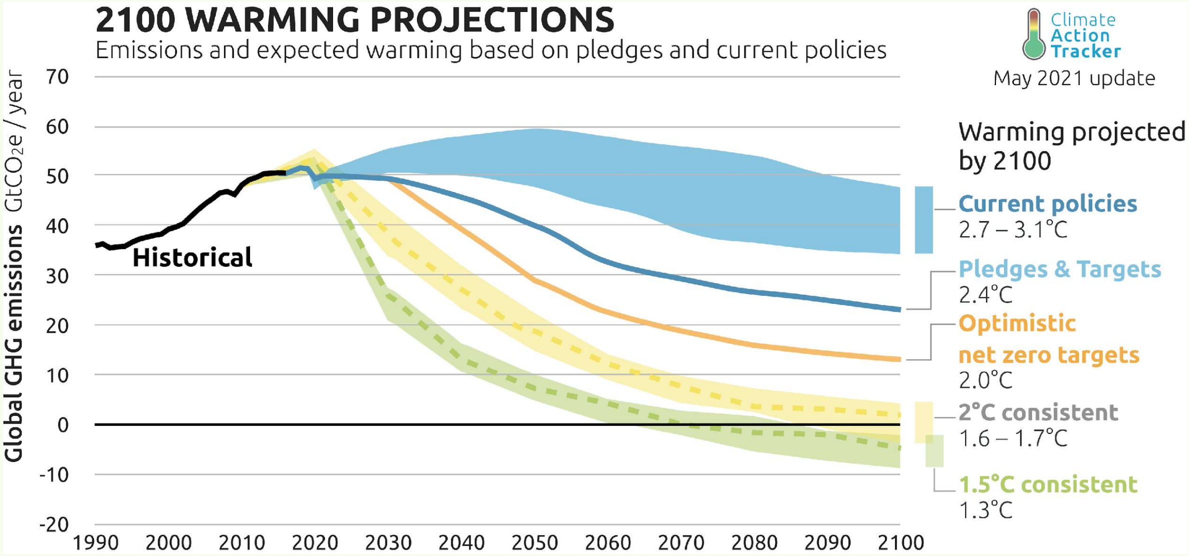

Figure 1: Emissions and warming projects based on pledges and current policies

Source: (Climate Action Tracker, 2021)

Renewable energy technologies will play central role in the energy transition. Electricity is estimated to account for over 50% of total final energy consumption by 2050 (21% in 2018) and renewable energy could potentially account for a quarter of GHG emissions abatement in that year (Figure 2) (IRENA, 2021). Whilst the transition of the energy sector is largely being driven by the climate crisis, **pollution and the inequalities that are associated with the current structure of the fossil-fuel industry are also important drivers for the shift from fossil fuels to renewables**[3].

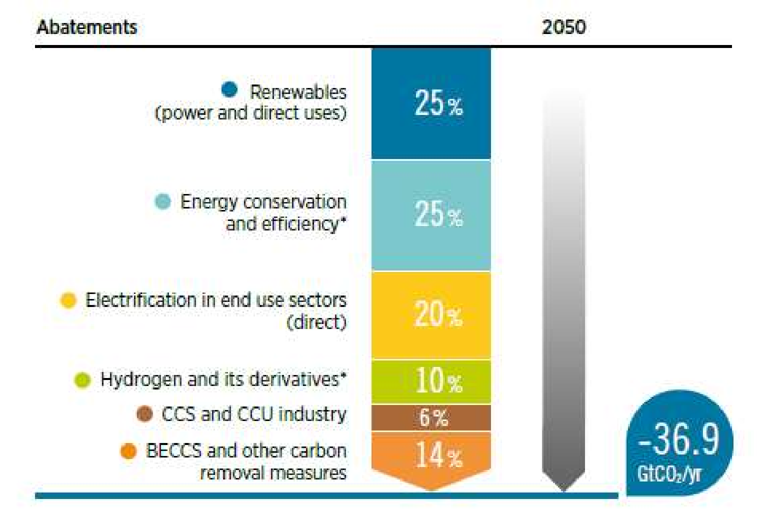

Figure 2: GHG emissions abatement under the 1.5ºC scenario (%)

Source: (IRENA, 2021)

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[3] See for example, https://unece.org/air-pollution-and-health; GroundWork (2018) Coal Kills. https://lifeaftercoal.org.za/virtual-library/resources/coal-kills-research-and-dialogue-for-a-just-transition

1.2 What is meant by a Just Transition of the energy sector?

The transition to renewable energy is already in progress. A number of countries, predominantly in the Global North, have already shifted away from coal for varying reasons[4]. These shifts are often linked to the implementation of climate change policies. Over the last decade renewable technologies have become the cheapest sources of electricity and currently dominate the global market for new electricity generation capacity, particularly solar photovoltaics (PV) and wind (Rabaia *et al.*, 2021). Accompanying this transition of the energy sector (and changes in the wider economy) are increasing calls that **the transition needs to be environmental and socially sustainable and equitable.** That is, recognising that the shift must be to systems that are better for people and the planet. This is broadly what is meant by a Just Transition (JT). Although there is no one definition, the concept is broadly understood as **needing to secure people's livelihoods when economies are shifting to sustainable production, including decarbonisation and rapidly moving to zero emissions; regeneration, rehabilitation and restoration of ecosystems and protecting biodiversity; and zero waste. In addition, the term necessitates inclusiveness in decision-making, democratic processes and the recognition of people's sovereignty of commons**.

Increasingly there is also the recognition that the JT should **harness the opportunities to create environmentally and socially sustainable societies**. The JT can be framed as a continuum (illustrated in Figure 3), moving from "business as usual" (low ambition) through to a transformative JT (high ambition) (Halsey *et al.*, 2019; Montmasson-Clair, 2021).

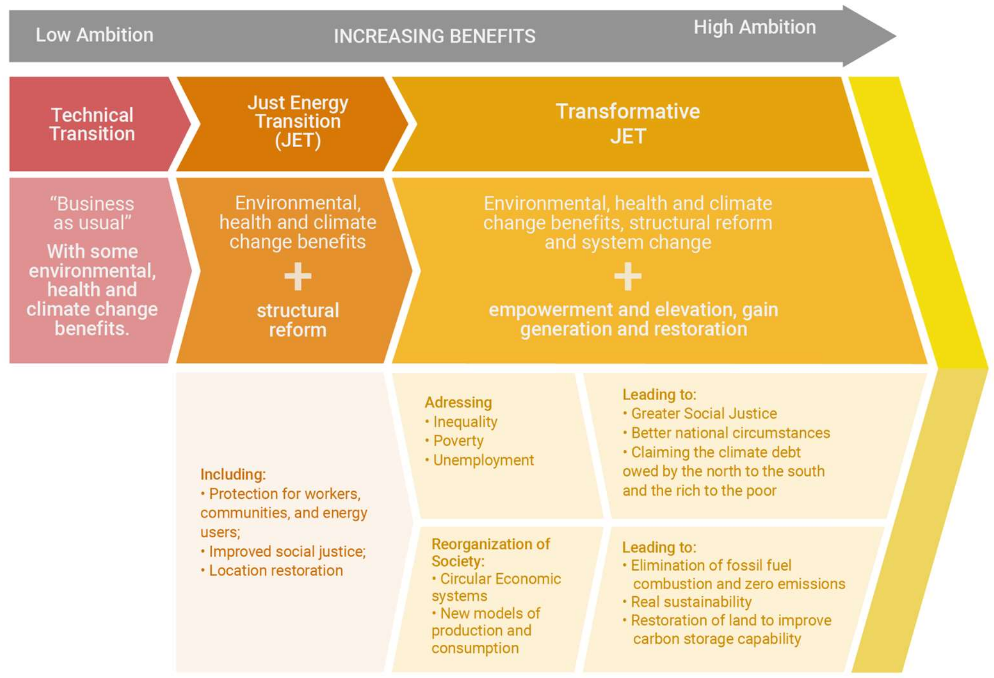

Figure 3: Just Transition seen as a continuum

Adapted from: (Halsey *et al.*, 2019; Montmasson-Clair, 2021)

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[4] Such as reduced profitability of coal mines, inability to comply with air pollution legislation and meet energy efficiency and/or decarbonization targets, and carbon tax/pricing, amongst others (Halsey *et al.*, 2019)

The ambition for a transformative JET is **an energy system powered by renewable sources that caters for the well-being of all people, whilst being within the limits of ecosystems**. Under this broader transformation agenda, the following essential building blocks and accompanying actions for a JET in South Africa are identified (based on Halsey et al. (2019)):

- **Accessible and affordable electricity:** Draft and implement a National Low-Income Household Energy Strategy; prioritise energy access for those without reliable access to electricity using renewable energy solutions; increase electricity subsidies for low-income households.
- **Corporate and business reform:** Businesses should strictly comply with all environmental regulations, and workplace and employment standards; government should monitor and enforce these obligations; the private sector must have their own transition plans that include protecting workers.
- **Shift in ownership of energy**: Support communities in setting up energy projects; support the shift from private energy monopolies to acknowledge people's sovereignty of commons and production; include more women and youth in the energy sector.
- **Empowerment of workers and communities**: Set up programmes for worker placement and re-train workers in coal and other impacted sectors; provide training and education for other workers in need of jobs; invest in infrastructure in areas in need; promote economic diversification and the creation of alternative industries.
- **Environmental restoration and protection**: Apply the Polluter Pays principle, ensuring polluters pay for restoration of degraded ecosystems; hold government and companies accountable including for legacy sites, through long term planning and creation of mine closure and legacy funds; create space for small scale agriculture that can restore and protect the environment whilst feeding people, restoration of land at the regional, catchment and local scale; long-term regeneration of soil using succession and rotation planning; restoration of land to improve carbon storage capacity.

Overarching actions identified as essential to a JET in South Africa include the need for:

- Conducting regular public participation and stakeholder consultations that include youth and vulnerable groups;
- Drafting a joint vision of JET and undertaking transparent planning processes;
- Setting measurable goals and ensure clear accountability;
- Implementing measures to improve and ensure gender equality;
- Educating and raising awareness on energy issues; and
- Looking at related issues such as land and water.

1.3 What is meant by life cycle thinking, resource efficiency and circularity?

Given the most significant environmental impacts of renewable energy technologies are upstream and downstream in their value chains, **a life cycle perspective is crucial in understanding and managing the environmental impacts of renewable energy technologies**.

Life cycle thinking (LCT) is about going beyond the traditional focus on production sites and manufacturing processes to include the environmental, social and economic impacts of a product over its entire life cycle[5]. A typical product life cycle begins with the extraction of raw materials from natural resources. These materials are then part of production and energy generating processes, and are made into products that require further materials and energy in their packaging, distribution, use,

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[5] A wealth of resources on life cycle thinking can be found on the website of UNEP's Life Cycle Initiative (https://www.lifecycleinitiative.org/starting-life-cycle-thinking/what-is-life-cycle-thinking/)

maintenance, and eventual recycling, reuse, recovery and final disposal. The goal of LCT is to identify ways to reduce a product's resource use and emissions to the environment. **Life Cycle Assessment** (LCA) is a quantitative tool for applying LCT. An LCA identifies the impacts and significance of each life cycle stage and allows comparisons with different products or systems and between different materials. An especially valuable aspect of conducting an LCA is the ability to highlight hotspots along the value chain (i.e., show the areas of highest potential impact), and also to highlight trade-offs between different impacts (since it is seldom that one system or product performs better than another in all aspects of environmental impact).

Resource efficiency broadly encompasses using the Earth's limited resources in a sustainable manner while minimising impacts on the environment. The International Resource Panel defines resources as the elements of the physical world that have the capacity to provide goods and services for humans (UNEP, 2017). Resources therefore include air, water (marine and fresh) and land as well as renewable and non-renewable materials. Resource efficiency is, simply put, the technical efficiency of resource use (i.e., the useful energy or material output per unit input of energy or material resource), noting that increasing resource efficiency reduces the associated environmental impacts. Importantly, resource efficiency and, more specifically, resource decoupling (decreasing the absolute quantity of resources used) is a pre-requisite for humanity to continue to rely on the services derived from resources.

Circularity or Circular Economy (CE) is receiving increasing attention globally for its potential role in driving coordinated action on sustainability. **The core concept of CE is a departure from the "take, make, dispose" linear economic model to an economic model in which materials are retained at their highest value possible, for as long as possible** (as illustrated in Figure 4). As such, CE promotes extension of the life span of products through maintenance/repair, and when the products are no longer functional, repurposing, reuse or recycling of their materials. More broadly, CE provides a guiding principle to support a move towards a model based on designing out waste and pollution, keeping products and materials in use, and regenerating natural systems.

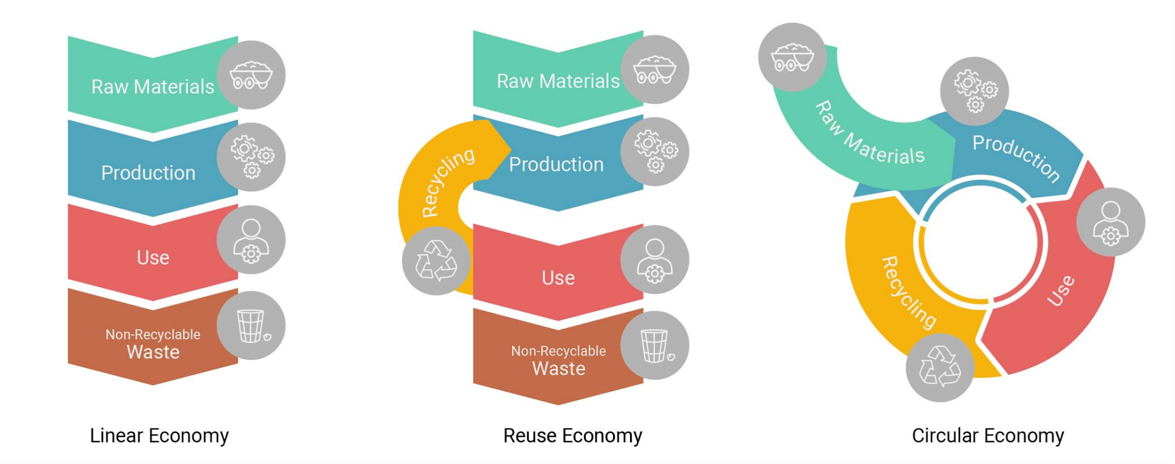

Figure 4: Linear, reuse and circular economies

2 RENEWABLE ENERGY TECHNOLOGIES AND THEIR IMPACTS

2.1 Renewable energy technologies meeting the needs for a JET

IRENA's Transforming Energy Scenario gives an indication of the renewable energy technologies that will need to be in place in 2050 to meet global climate goals (IRENA, 2020b). Solar PV and wind are anticipated to fulfil the bulk of the world's energy needs by 2050 under a "transforming energy scenario" (see Figure 5). Due to their intermittent nature, these technologies will be complemented by energy storage. These are the **RE technologies most suited to a JET** and are the focus here[6].

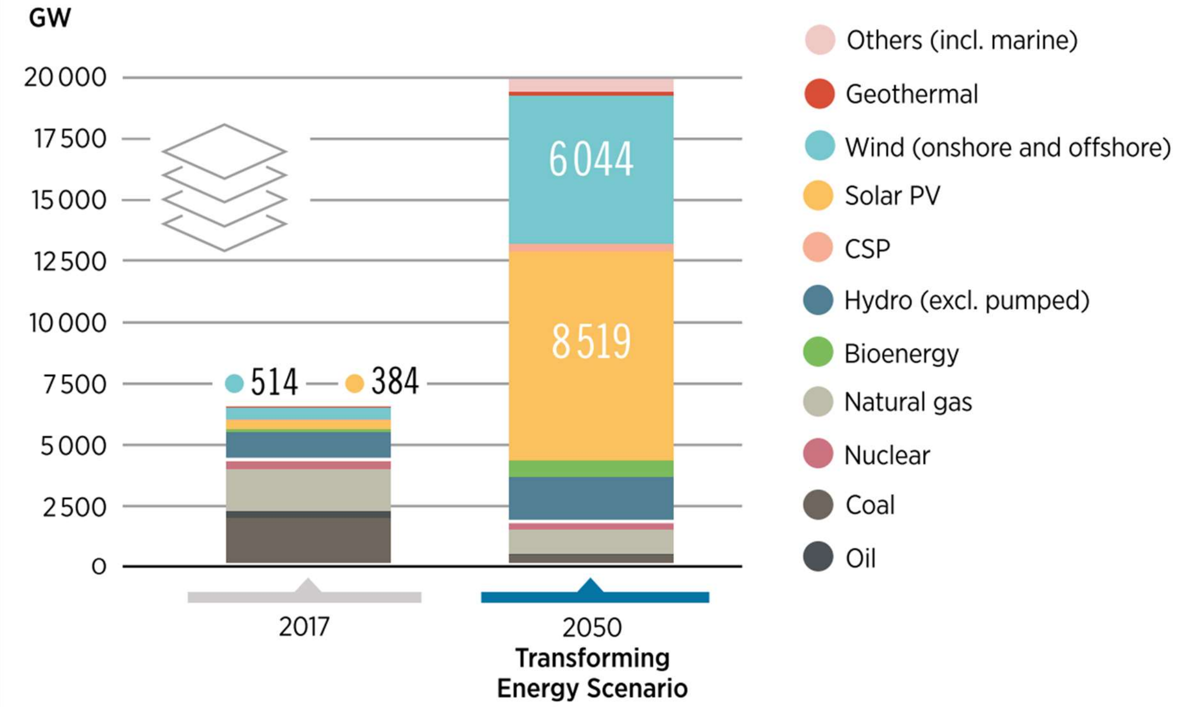

Figure 5: Breakdown of total installed capacity of solar, wind and other renewable energy technologies in 2050

Source: (IRENA, 2020b)

2.1.1 Solar energy

Solar energy (energy harnessed directly from the sun) is used globally to generate electricity and heating. The earth's surface (at sea level on a clear day) receives approximately 1,000W/m^2 of solar radiation, making the sun a massive, reliable energy source with significant environment benefits over conventional energy sources (Rabaia *et al.*, 2021).

Solar PV technologies convert sunlight directly into electricity. Solar PV represents an intermittent power source, with power output fluctuating depending on the seasons and weather conditions. It is one of the fastest growing renewable energy technologies, with approximately 60% of renewables' overall capacity growth in 2019 (Rabaia *et al.*, 2021). Solar PV can provide electricity on a utility scale, commercial scale, community scale, as well as household scale. Due to rapid cost reductions, distributed solar PV is expected to grow exponentially in the coming decade, dominated by commercial and industrial applications. Nonetheless, solar PV systems in the residential sector are expected to account for 25% of distributed solar PV by the mid-2020s (IEA, 2019b). Solar PV is well-suited to transformative JET, with its lower costs and distributed generation, and it is already showing its strong potential to address the energy inequalities of the past and improve energy access.

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[6] A more complete review of all RE technologies is provided in the full report

First generation PV technologies (Mono-Si and P-Si) are reaching market maturity, with "passivated emitter and rear contact" technology[7] (PERC) and CdTe (cadmium telluride) and CIGS (copper indium gallium selenide) thin-film technology currently at market penetration stage (Rabaia *et al.*, 2021).

2.1.2 Wind

Wind power is one of the fastest growing renewable energy technologies, increasing from 19.9 GW of installed capacity in 2000 to 621.6 GW in 2019 (IRENA, 2020a). Kinetic energy created by the air in motion is transformed into electricity energy using wind turbines or wind conversion systems. The amount of power generated is dependent on several factors including the size of the turbine, the length of the blades, and wind currents and speeds. Similar to solar PV, wind power is an intermittent power source. However, if dispersed across large geographic areas, it can act as baseload.

Wind generation capacity can be installed both onshore and offshore, with offshore wind power offering great potential. Onshore wind energy is a proven and mature technology, accounting for 95% of installed capacity in 2019 (IRENA, 2020a). Offshore wind contributed 0.3% to global electricity supply in 2018 and this is expected to grow rapidly due to steep cost reductions and performance and technology improvements (IEA, 2019a). Offshore wind capacity is likely to be concentrated mainly in Europe and China and to a lesser extent the USA, Korea, India and Japan (IEA, 2019a).

Small-scale wind turbines are primarily used for distributed generation and range in size from less than 1 kW to 100 kW. They are suitable for households, mini-grids, to charge batteries or on/off-grid applications in rural areas. Community-owned wind projects are a growing market in the wind power industry (EESI, 2012). They can range in size from small-scale wind turbines to utility-scale wind farms and demonstrate the compatibility of on-shore wind to a transformative JET.

2.1.3 Energy storage

There are several types of electricity storage currently available: pumped hydro storage, thermal storage, electrochemical storage, electromechanical storage and chemical storage (Table 1). Pumped hydro storage accounted for over 96% installed storage capacity in 2017, followed by thermal storage, electrochemical and electromechanical (IRENA, 2017). Thermal storage is dominated by CSP plants, with molten salt technologies accounting for 75% of commercial use (IRENA, 2017). Electromechanical storage consists of flywheels and compressed air storage. **Despite only accounting for 1.1% of storage capacity, electrochemical storage (batteries) is one of the fastest growing market segments due to rapidly decreasing costs and improving performance.** There are a number of types of batteries at various stages of development on the market; typically divided into two distinct groups: solid state batteries and flow batteries. Solid state batteries include lithium-ion batteries, lead-acid batteries, nickel-cadmium batteries, sodium-sulphur batteries and electrochemical capacitors (also known as supercapacitors). Chemical storage, the production of chemicals including hydrogen, methane, methanol, ammonia and urea using renewable energy, and later converting it back to energy using fuel cells when it is needed, is showing great promise in a number of applications globally.

Table 1: Energy Storage types

Energy storage type	Description
Lithium-ion batteries	**Lithium-ion batteries** account for 59% of the electrochemical storage power capacity in 2017 and represent a commercially mature battery technology (IRENA, 2017). Lithium-ion batteries can be used for both utility-scale storage systems and small-scale residential systems, and are typically used for uninterruptable power supply (UPS) applications and load shifting (IRENA, 2017; US TDA, 2017). They have several advantages, which make them the dominant technology for portable electronics and

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[7] PERC solar cells are similar to first generation solar cells, but with an extra layer within the back side of the cell that reflects some of the sun's rays back into the cell to increase the amount of electricity generated.

	electro-mobility. As the cost of lithium-ion batteries continues to decrease they will become an economical option for stationary applications.
Lead-acid batteries	**Lead-acid batteries** are the most widely deployed rechargeable battery due to a good cost-performance ratio in a range of applications (IRENA, 2017). Although lead-acid batteries have many advantages, their relatively low energy density, weight, poor response to deep charging and environmental concerns related to their toxicity mean that they face competition from lithium-ion batteries. Typically, lead-acid batteries are used in petrol and diesel vehicles (starter batteries), forklifts and golf carts (traction battery), off-grid applications (e.g. solar home systems and communication systems in rural areas) and uninterruptible power supply (IRENA, 2017).
Sodium sulphur batteries	**Sodium sulphur batteries** are typically used for transmission and distribution grid support and load shifting and have been the dominant storage technology for utility-scale storage over the last decade. Sodium sulphur batteries have a relatively high energy density, comparable to the low end of the Li-ion energy density range. Coupled with very low self-discharge rates, high recyclability rate and other advantages they can be utilised for both stationary and mobile applications. However due to safety concerns in the event of an accident, they have only been commercialised for stationary applications.
Electrochemical capacitors	**Electrochemical capacitors** are reversible, efficient and fast storage devices, with a high round trip efficiency and long cycle life (US TDA, 2017). The main disadvantages of electrochemical capacitors are their high cost, low energy density, high self-discharge and short discharge time (US TDA, 2017). They can be used for load shifting and uninterrupted power supply.
Flow batteries	**Flow batteries** include vanadium redox flow batteries (VRFB), zinc chlorine, zinc air, zinc bromine and polysulfide bromine flow batteries. Flow batteries can operate at ambient temperature and have long cycle lifetimes. In addition, they are manufactured use relatively inexpensive raw materials, have good safety characteristics and can achieve very deep discharge rates (IRENA, 2017). The key disadvantages of flow batteries are their low efficiency and high repair and maintenance costs. VFRB are suitable for utility-scale power systems and applications include load shifting and voltage support, amongst others (US TDA, 2017).
Chemical storage	**Hydrogen, methane, methanol and ammonia** are emerging as promising large-scale energy storage options (so-called Power to Fuel options). Hydrogen, whilst efficient to produce and use at various scales of application, presents some challenges including the need for high pressure storage vessels for gaseous hydrogen and very low temperature storage for liquid hydrogen, as well as its low energy density (Moradi and Groth, 2019). Hydrogen-rich methane, methanol, ammonia and urea have the advantages of being liquid at higher temperatures and so are easier to store and distribute (Bargiacchi, Antonelli and Desideri, 2019).

2.2 Life cycle impacts and hotspots of renewable energy technologies

While renewable energy technologies are necessary to reduce our reliance on fossil fuels, for a JET it is important to understand and mitigate the other environmental impacts associated with these technologies across their life cycles. This section attempts to unpack these environmental impacts and identify hotspots for specific RE technologies, which often occur upstream or downstream of the renewable energy generation itself.

2.2.1 Greenhouse gas emissions

Compared to fossil fuel energy technologies, renewable energy technologies are associated with greenhouse gas emissions that are up to 100 times lower (UNEP, 2016). Unlike fossil fuel technologies, the GHG emissions do not arise during the operational phase, but are instead associated with upstream resource extraction, component and technology manufacturing, assembly, transport and construction as well as downstream recycling of components at end-of-life. Even if carbon capture and sequestration (CCS) can be implemented on fossil fuel energy technologies, the greenhouse gas emissions are still significantly larger (Figure 6). On-shore wind and solar PV have the lowest GHG emissions, with a notable variation between solar PV technologies, with thin film technologies lower than conventional Poly-Si installations (UNEP, 2016). The GHG emission hotspots for RE technologies are summarised in Figure 7.

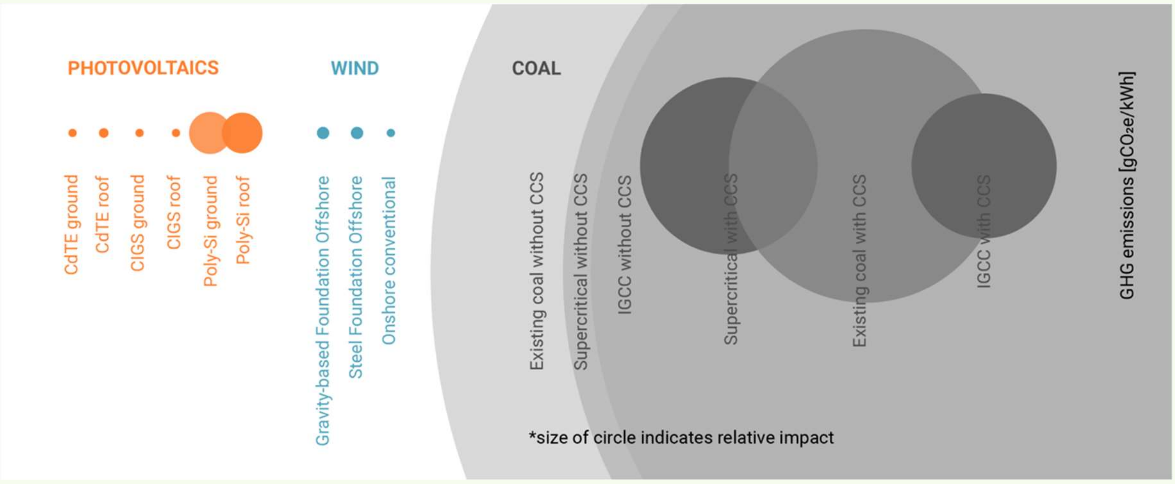

Figure 6: Relative comparison of the cumulative life cycle GHG emissions in gCO_2e per kWh of electricity production from different technologies

Adapted from: (UNEP, 2016)

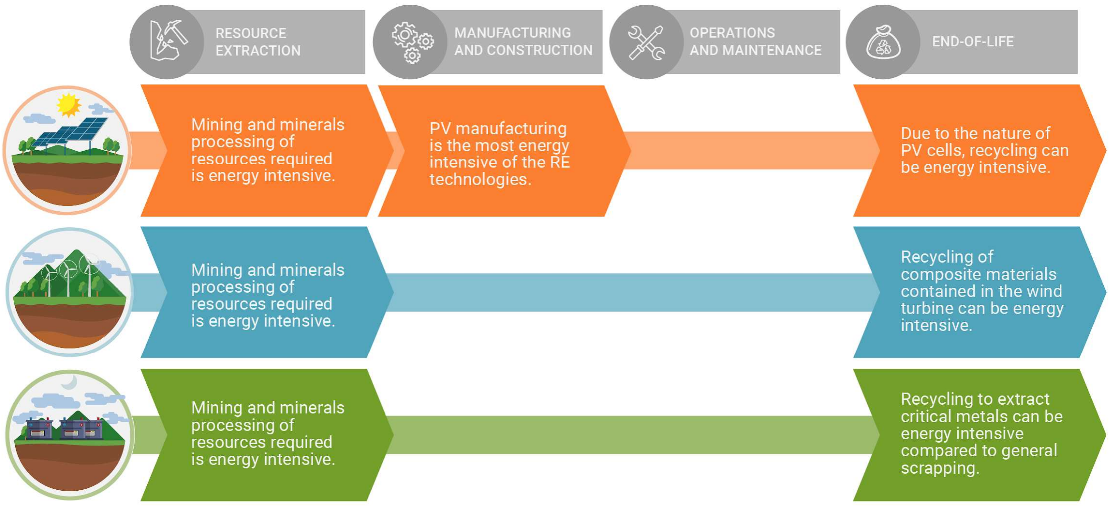

Figure 7: Greenhouse gas emission hotspots for RE technologies across their value chains

2.2.2 Resource depletion

The global transition to a low carbon energy sector will drastically change the demand for mineral resources and metals. On a life cycle basis, the metal depletion impact for PV and wind are 10 times that of fossil-fuel technologies (Figure 8) (UNEP, 2016). Renewable energy technologies rely on rare or precious metals and niche minerals for specific components and also rely on industrial metals and mineral resources such as iron and steel, aluminium, cement and concrete for their structural components. The main minerals and metals required for renewable energy technologies are shown in Figure 9.

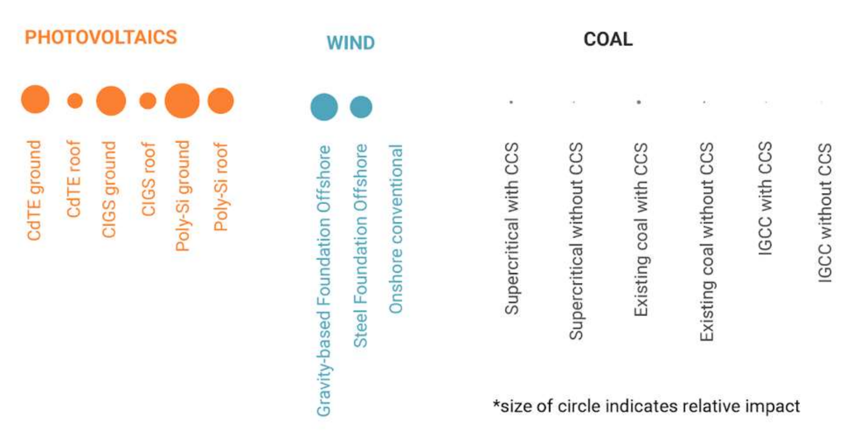

Figure 8: Relative comparison of the cumulative impact of metal depletion expressed in g Fe eq per kWh of electricity production from different technologies

Adapted from: (UNEP, 2016)

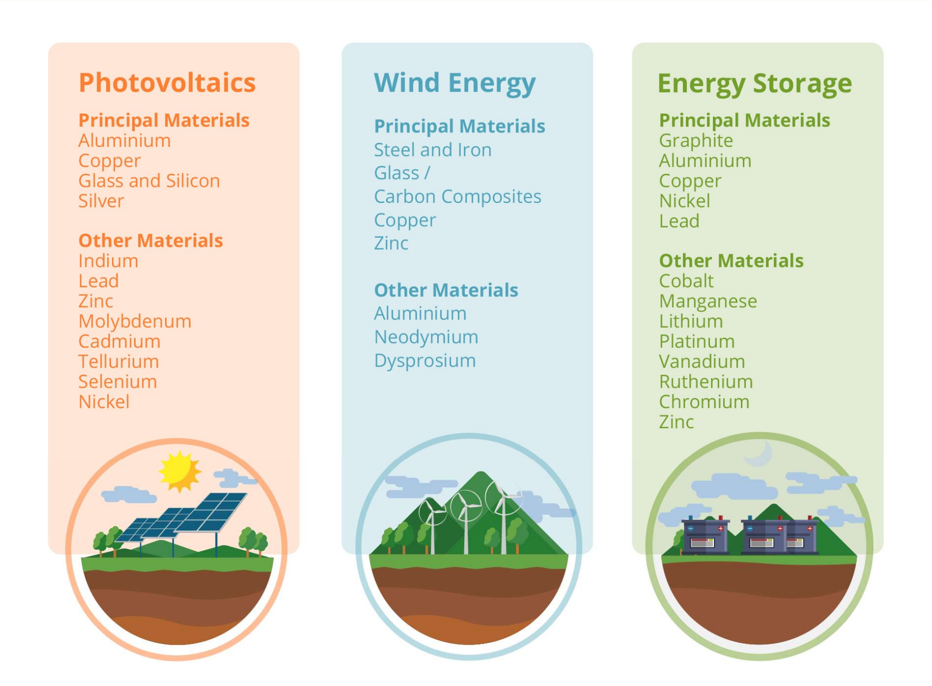

Figure 9: Mineral and metal demand mapped to renewable energy technologies

Adapted from: (Dominish, Teske and Florin, 2019; Hund *et al.*, 2020; EEA, 2021)

Many of these resources will be required in significantly larger quantities than today. Figure 10 shows the projected increase in annual demand in 2050 relative to 2018 production levels. Although this increase in demand is substantial, for the most part there is considered to be sufficient available resources to meet these demands (KPMG, 2021) Exceptions include iron, cobalt and indium.

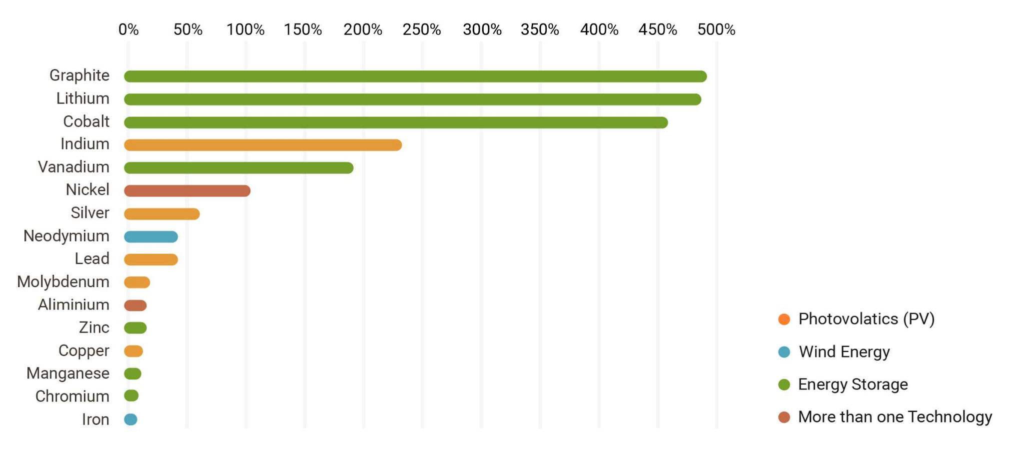

Figure 10: Projected 2050 annual demand for metals from energy technologies as a percentage of 2018 demand under a below 2ºC scenario

Source: (Hund *et al.*, 2020)

Although there are sufficient resources to theoretically meet the requirements of a transition to renewable energy, the supply of the necessary metals and minerals cannot necessarily be guaranteed. **Some of these resources are only found in a few countries and/or supply is highly concentrated** (e.g. 70% of global production of cobalt occurs in the DRC; 60% of global graphite production occurs in China) (KPMG, 2021), whilst 98% and 99% of the Europe Union's supply of Heavy Rare Earth Elements (HREEs) and Light Rare Earth Elements (LREEs) respectively are supplied by China (see Figure 11). **This inequal distribution of mineral resources (which are often found in developing countries) creates a geopolitical risk, where the dominance of one country or company in a supply chain can lead to disputes or resource nationalism** (Bloodworth, Gunn and Petavratzi, 2015). These supply risks can be exacerbated if there are other disruptions to trade as has been seen for certain supply chains during the Covid19 pandemic. The localised nature of deposits can also mean that supply can be disrupted due to conflict or natural disasters. The risks associated with the concentration of production are in many cases compounded by low substitution and low recycling rates. Together, these factors result in material supply bottlenecks for renewable energy technologies. Furthermore, supply risks are likely to shape future demand patterns. For example, understanding that natural resources are limited has led to efforts to replace cadmium, for which reserves are unlikely to meet future demand, with other alternatives – recognising that this will result in an increase in demand for other metals such as nickel and lithium (Dominish, Teske and Florin, 2019).

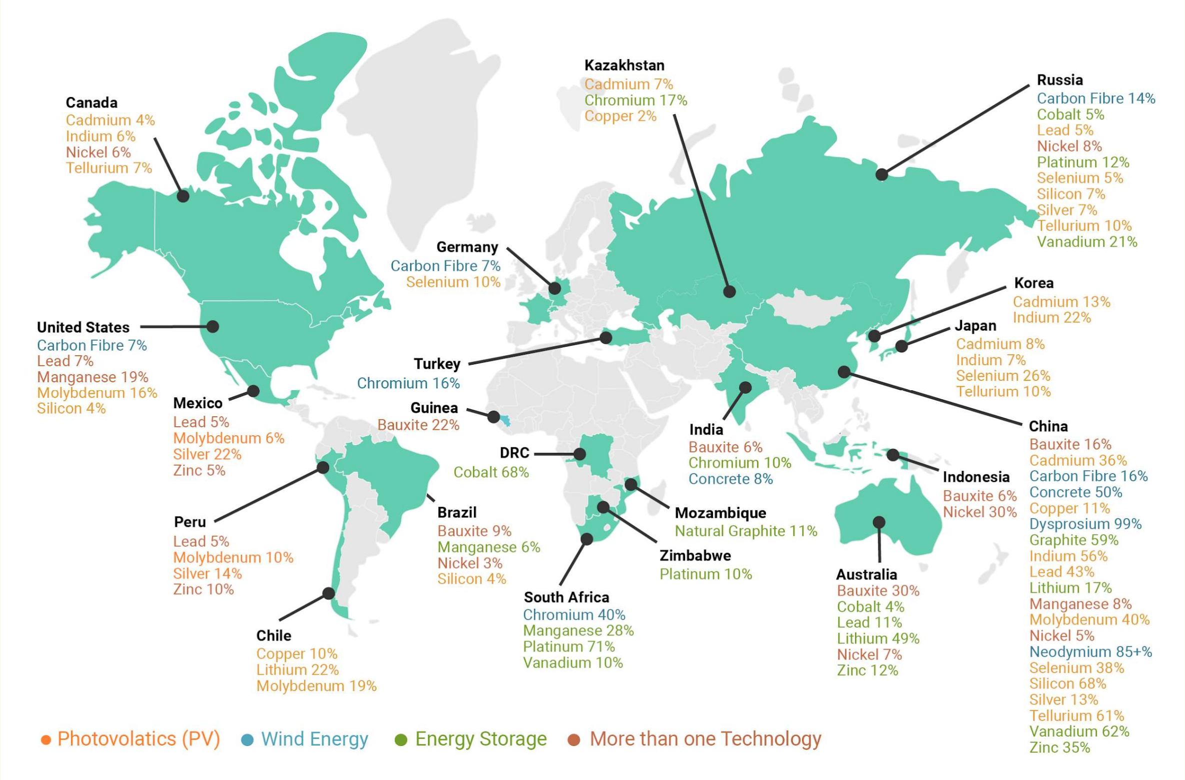

Figure 11: Countries accounting for the largest share of the EU supply of critical raw materials

Source: Based on European Commission (2020b)

2.2.3 *Ecosystem and human health impacts*

Notwithstanding potentially significant mining, manufacturing and end-of-life impacts associated with the chemicals and metals in renewable energy technologies (as discussed in the sub-sections below), LCAs show renewable energy technologies to have substantially lower ecosystem and human health impacts than fossil fuel technologies (see Figure 12 and Figure 13). This is owing to the high ecosystem and human health impacts associated with the combustion emissions of fossil fuel plants.

In terms of ecosystem impacts, solar technologies perform worse than wind, with the second-generation thin-film solar PV technologies (CdTe and CIGS) having significantly lower potential ecosystem impacts than the first-generation solar PV technologies (Poly-Si). This is because, even though the materials used in thin-film PV are considered more toxic, they are used in far smaller quantities. With respect to human health impacts, second generation solar PV (CdTe and CIGS) and wind technologies are similar in the potential human health impacts, with second-generation thin-film solar PV technologies (CdTe and CIGS) again having significantly lower potential impacts than the first-generation solar PV technologies (Poly-Si).

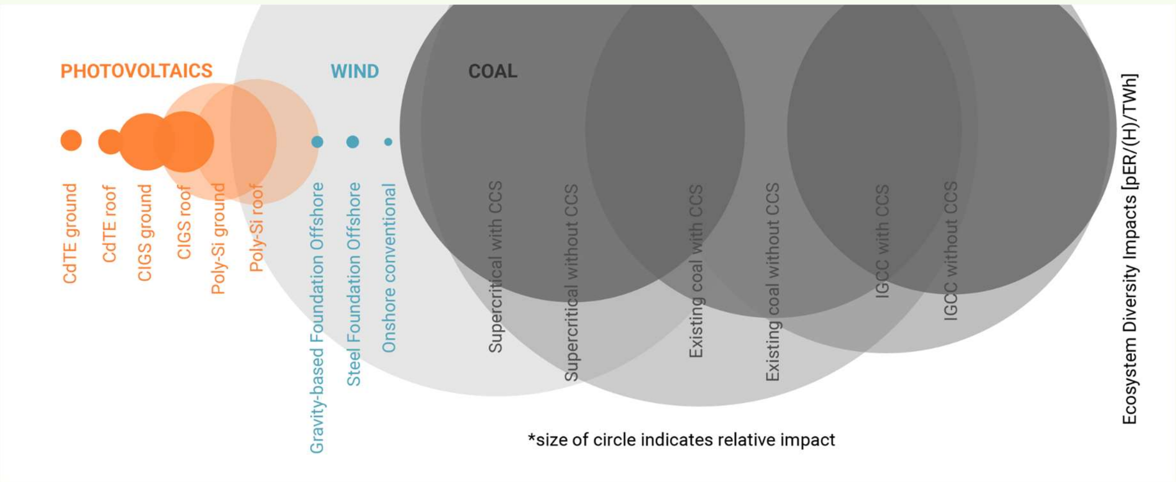

Figure 12: Relative comparison of the life cycle impact on ecosystem diversity in species-year per TWh of electricity production from different technologies

Adapted from: (UNEP, 2016)

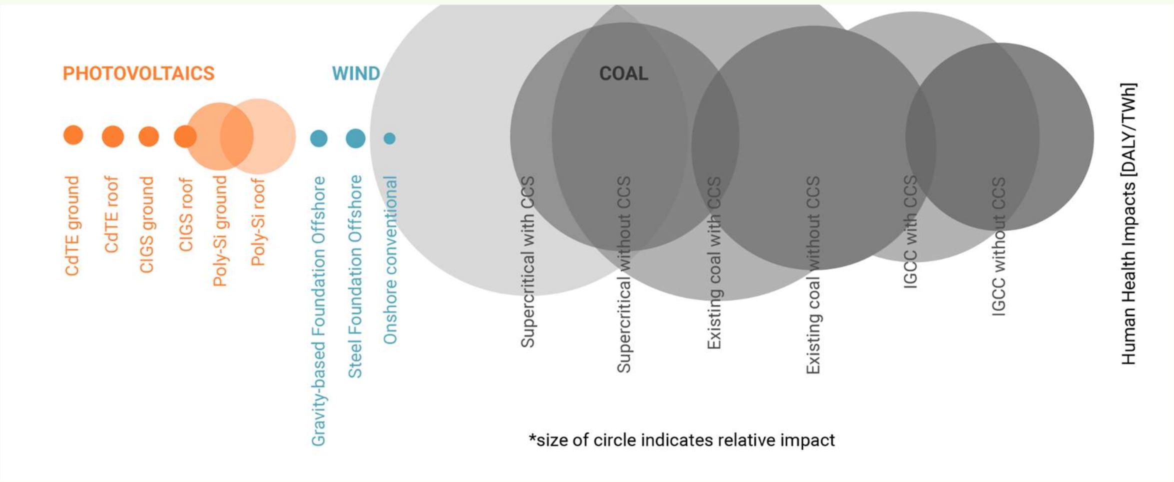

Figure 13: Relative comparison of the life cycle human health impact in disability adjusted life years (DALY) per TWh of electricity production from different technologies

Adapted from: (UNEP, 2016)

Mining and refining

The mining, extraction and refining of critical metals is often technically difficult and poorly understood, as the tonnages currently produced are relatively small compared to industrial metals. They are often produced as by-products of other metals, and occur in low concentrations in low grade or complex ores. The extraction and processing of these metals and minerals is thus often associated with huge energy and labour demands with significant impacts on ecosystems and human health (Bloodworth, Gunn and Petavratzi, 2015). The environmental impacts of **mining can include surface disruption, soil erosion, sinkholes, contamination of surface, ground and drinking water, and loss of biodiversity and habitat loss** (KPMG, 2021). **Minerals processing can involve treatment with chemicals that generate waste streams that are hazardous and in some cases even mildly radioactive** (Bloodworth, Gunn and Petavratzi, 2015). Bottlenecks in the supply of critical raw materials may lead to further exploration, and mining of lower-grade ores, which would further increase environmental impacts associated with mining, extraction and refining (Boubault and Maïzi, 2019). A particular threat here is that of seabed mining, particularly for rare earth elements, but also for a range of other metals (including copper, lithium, manganese, molybdenum, titanium and vanadium) (Heffernen, 2019). If supply is too constrained, alternative materials (including nanomaterials) or renewable energy technologies may emerge, which would change the resource extraction landscape, potentially leading to abandoned mining sites, inadequate rehabilitation and social disruption. New materials such as nanomaterials may also lead to other environmental and health impacts as their interaction with environmental and biological systems is not yet fully understood.

The impact of increased demand for resources on communities cannot be overlooked. **Mining in developing countries has historically been associated with community displacement, human right abuses, unsafe working conditions, child labour and human health impacts due to toxic releases to the environment and contamination of water sources.** These impacts may be exacerbated by the volatile nature of the demand. Illegal mining is a substantial problem in many developing countries, particularly in sub-Saharan Africa and Latin America. Artisanal and small-scale mining contributes to armed conflict, funds criminal networks, and damages the environment. Illegal mining profoundly impacts local populations, bringing significant health risks to the miners and the wider communities (USAID, 2020). The influx of workers can lead to the displacement of local people, a rise in prostitution and crime, and the decline of culture and traditional livelihoods (Veit and Vallejos, 2020). Child labour exploitation, intimidation, money laundering, illegal drug trade and smuggling are also often linked to mining. Illegal artisanal mining is currently mainly around the mining of gold, diamonds, tin, tantalum, niobium and gemstones. Most of these are not particularly linked to renewable energy technologies, with the exception of illegal coltan[8] mining in the DRC. The global experience with these metals clearly demonstrates the humanitarian and environmental damage that results when conditions are “right” for illegal mining, i.e., high prices, a weak state and accessible ore bodies (typically small, dispersed deposits that are not viable for large-scale mining).

Manufacturing

The manufacture of **solar PV cells** requires the use of a number of hazardous chemicals, although often in small amounts. In addition to the metals and materials that make up the PV cells, other chemicals including hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride and acetone are used in the manufacturing process to clean and purify the semiconductor surface (Rabaia *et al.*, 2021). The manufacturing of PV solar panels is also energy intensive. Thin film PV technologies are associated with a higher use of toxic materials compared to conventional silicon PV, although the overall quantities of hazardous materials used are lower and the manufacturing process is simpler (Tchognia Nkuissi *et al.*, 2020). Exposure to chemicals during manufacture is due to vapour or dust release and inhalation or accidental spills. If lead-containing solders are used during assembly (in standard PV cells), these can also cause harm to workers.

The manufacturing of wind turbines from fibre-reinforced plastics using epoxy resins can expose workers to volatile emissions of styrene, leading to irritation and even carcinogenic effects (Karanikas *et al.*, 2021). Exposure to hazardous chemicals including epoxy resins, synthetic chemicals and fibreglass dust can also occur during maintenance of wind turbines, where repairs are required to the wind turbine blade. There are also occupational hazards associated with installation and maintenance of wind turbines due to the difficulties associated with working on large structures often in difficult environments (e.g. off-shore and/or in adverse weather conditions). Due to the increased use of nanomaterials and composites in wind turbines, together with the fact that work on wind turbines often takes place in confined spaces, exposure to these new materials may pose a high risk, which is yet to be fully understood (Karanikas *et al.*, 2021).

The manufacture of lead-acid batteries is extremely hazardous due to the exposure of workers and surrounding communities to lead either in the form of vapours, dust or leached from wastes. The other main component of lead acid batteries

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[8] Tantalum and niobium are produced from coltan, with niobium used in superalloys and superconducting magnets (application in wind technologies), whilst tantalum is used in high-end electronics.

is sulphuric acid. Historically, lead acid battery manufacturing has taken place in rural areas, where air pollution regulation is less strictly enforced with devastating consequences for the most vulnerable (van der Kuijp, Huang and Cherry, 2013),

Li-ion battery production is energy intensive, with heat and energy required for drying of electrodes and solvent recovery and the dry room used for cell assembly (Liu *et al.*, 2021). The production of Li-ion batteries causes sulphur dioxide emissions (an acid gas with ecosystem and human health impacts), as well as water contamination.

End-of-Life

A wide range of chemicals can be used in existing and potential future PV recycling processes, including different kinds of organic solvents, some of which can be carcinogenic (Chowdhury *et al.*, 2020). Furthermore, the **metals present in renewable energy technologies are problematic at end-of-life, and may lead to toxic releases when solar PV panels, wind turbines and batteries are disassembled, recycled or disposed**. C-Si panels, the predominant installed PV technology globally, are more than 90% glass, polymer and aluminium. There are, however, small amounts of lead and tin. Thin-film panels, which made up about 9% of global annual production in 2015, are more than 98% glass, polymer and aluminium, although there are small amounts of copper and zinc, as well as potentially hazardous semiconductor materials such as indium, gallium, selenium, cadmium tellurium and lead (IRENA, 2016). If incorrectly handled, especially by informal recyclers, exposure to these hazardous metals poses a health risk to communities.

The global battery market is seeing significant growth and changes as the demand for energy storage increases and the transport sector moves to electric vehicles. Currently, lead acid batteries still dominate, but lithium-ion battery demand is growing rapidly. If lead acid batteries are not properly managed at end-of-life, the environmental and human health impacts can be significant (Zhao *et al.*, 2021). Lead is highly toxic and has been associated with a range of adverse effects on human health. The acid contained in the batteries is also corrosive, which can accelerate the entry of lead into the environment. There is thus a strong incentive to collect and recycle these types of batteries and in many countries this has been successfully achieved (Zhao *et al.*, 2021).

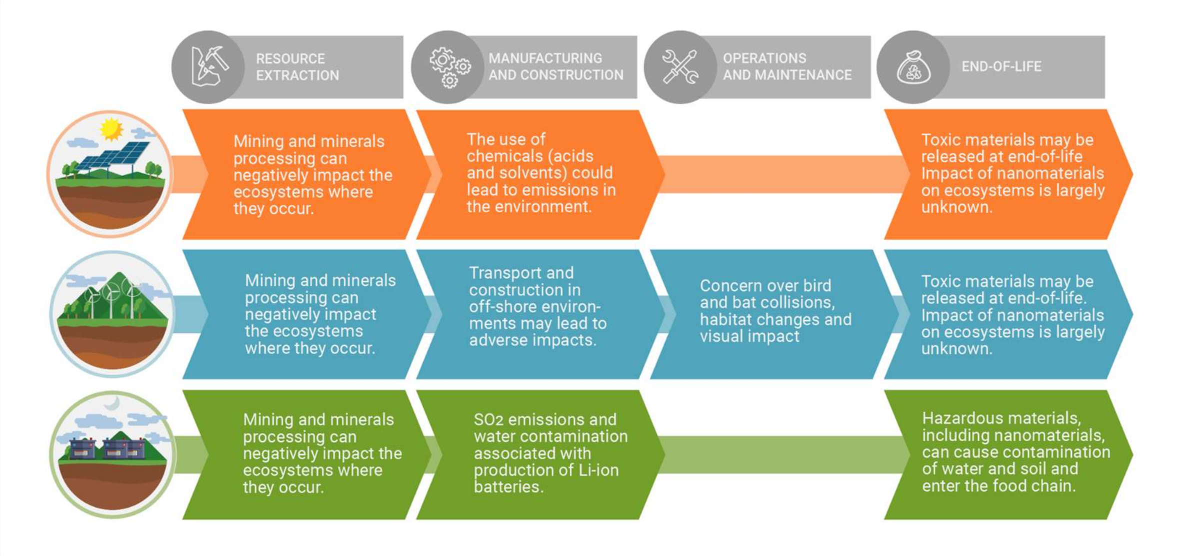
Although lithium is less toxic than lead, it is still an environmental and human health concern. Lithium hexafluorophosphate ($LiPF_6$) is a common lithium salt contained in the batteries and can lead to toxicity, respiratory failure and cardiac arrest at relatively small doses (Zhao *et al.*, 2021). The salt is reactive with water releasing hydrofluoric acid and releasing further toxic chemicals, with the organic carbonate solvent also flammable and toxic. If not handled correctly, they may explode or catch fire (Winslow, Laux and Townsend, 2018). In addition, Li-ion batteries contain a number of other metals that may pose a hazard if leached into the environment, including cobalt, nickel and manganese. Nickel-based batteries, and particularly NiCd batteries, are also associated with human health effects.

Recycling of batteries is not straightforward and the processes (including hydrometallurgical and pyrometallurgical processes) can lead to environmental releases and human exposure, particularly if undertaken in the informal sector in sub-standard facilities. Li-ion batteries present further challenges due to the different battery material chemistries and the complexity of battery structures (Zhao *et al.*, 2021). With current low stocks of Li-ion batteries reaching end-of-life and questions over the economic viability of recycling, many Li-ion batteries currently end up in landfill.

As with other technologies, the end-of-life of fuel cells needs to be properly managed to avoid negative ecosystem and human health impacts. Hazardous components include (depending on the technology) electrolytes, anodes and cathodes (Férriz *et al.*, 2019). Although technologies are available for recycling and recovery, these may potentially not be available in all jurisdictions, including developing countries. If renewable technologies are not recycled and dumped, there is the potential for hazardous components to leach out and negatively impact ecosystems and nearby communities through contaminating water bodies and soil. It is noted that for all renewable technologies, shipping of hazardous wastes from developed to developing countries which are less able to recover, treat or dispose of these safely is a particular concern when considering the JT.

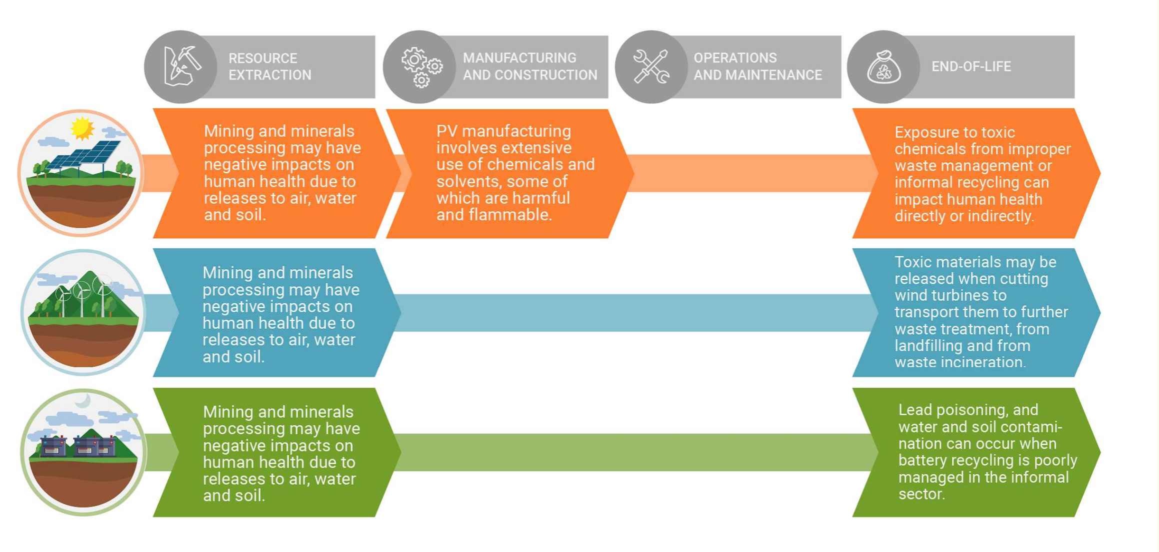
Nanomaterials are increasingly being researched for their potential application in renewable energy technologies (wind and solar PV) as well as in battery storage. The development of nanomaterials and commercialisation of products containing nanomaterials has occurred more rapidly than the development of necessary legislation and approaches to ensure that ecosystems and human health are not adversely impacted. A particular issue is that there is a distinct lack of adequate detection and characterization techniques and methods to study and fully understand the toxicological effects of nanomaterials both in operation and at end-of-life (Johnston *et al.*, 2020).

The ecosystem and human health impact hotspots for RE technologies across their value chains are summarised in Figure 14 and Figure 15.



RESOURCE EXTRACTION	MANUFACTURING AND CONSTRUCTION	OPERATIONS AND MAINTENANCE	END-OF-LIFE
Mining and minerals processing can negatively impact the ecosystems where they occur.	The use of chemicals (acids and solvents) could lead to emissions in the environment.		Toxic materials may be released at end-of-life Impact of nanomaterials on ecosystems is largely unknown.
Mining and minerals processing can negatively impact the ecosystems where they occur.	Transport and construction in off-shore environments may lead to adverse impacts.	Concern over bird and bat collisions, habitat changes and visual impact	Toxic materials may be released at end-of-life. Impact of nanomaterials on ecosystems is largely unknown.
Mining and minerals processing can negatively impact the ecosystems where they occur.	SO_2 emissions and water contamination associated with production of Li-ion batteries.		Hazardous materials, including nanomaterials, can cause contamination of water and soil and enter the food chain.

Figure 14: Ecosystem impact hotspots for RE technologies across their value chains



RESOURCE EXTRACTION	MANUFACTURING AND CONSTRUCTION	OPERATIONS AND MAINTENANCE	END-OF-LIFE
Mining and minerals processing may have negative impacts on human health due to releases to air, water and soil.	PV manufacturing involves extensive use of chemicals and solvents, some of which are harmful and flammable.		Exposure to toxic chemicals from improper waste management or informal recycling can impact human health directly or indirectly.
Mining and minerals processing may have negative impacts on human health due to releases to air, water and soil.			Toxic materials may be released when cutting wind turbines to transport them to further waste treatment, from landfilling and from waste incineration.
Mining and minerals processing may have negative impacts on human health due to releases to air, water and soil.			Lead poisoning, and water and soil contamination can occur when battery recycling is poorly managed in the informal sector.

Figure 15: Human health impact hotspots for RE technologies across their value chains

2.2.4 Land use

The mining and quarrying of metals and other raw materials required for renewable energy technologies is associated with extensive land use disruption and change, which continues throughout the life of the mine. Land use impacts are brought about through deforestation, land clearing, erosion, contamination and alteration of soil profiles, water bodies and wetlands (Haddaway *et al.*, 2019). Land use is also impacted by the infrastructure required to support mining, including roads, railways and power lines. Often communities and indigenous people are displaced without adequate compensation. **Rehabilitation and restoration of land post mine closure, which is a clear obligation of the mining companies, is often not undertaken due to the lack of effective policy and regulation and enforcement** (ICMM, 2021).

While solar PV installations and wind farms can occupy land and also require supporting infrastructure to be constructed, the greatest disruption to land is caused by hydroelectric power. The knock-on effects of this land occupation are significant with estimates of reservoirs being responsible for the forced resettlement of 100 million people worldwide and another half a billion people downstream being impacted by the resulting ecosystem change (Leslie, 2021). In regions where RE technologies and batteries are not adequately managed at the end of their life, they may be dumped, both occupying and contaminating land. Informal recycling operations can also lead to contamination of land and water (Awasthi, Zeng and Li, 2016; Wu *et al.*, 2019).

Compared to fossil fuel energy technologies, renewable energy technologies typically occupy less land. Roof--mounted PV has substantially lower land requirements than ground-mounted PV (Figure 16). Figure 17 summarises the land use hotspots across the value chain of RE technologies.

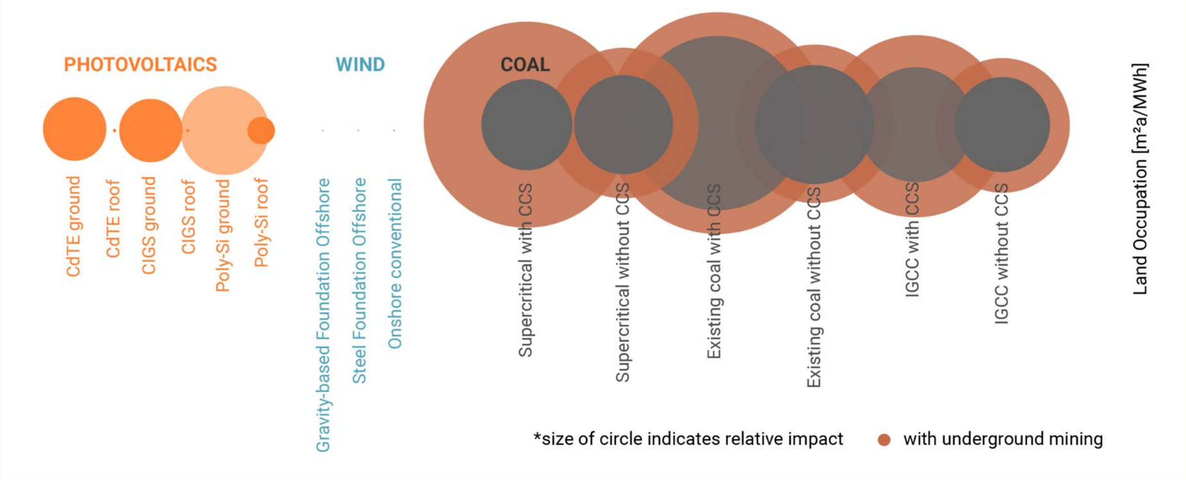


Figure 16: Comparison of the impact on land occupation in m^2 per MWh/a of electricity production from different technologies

Adapted from: (UNEP, 2016)

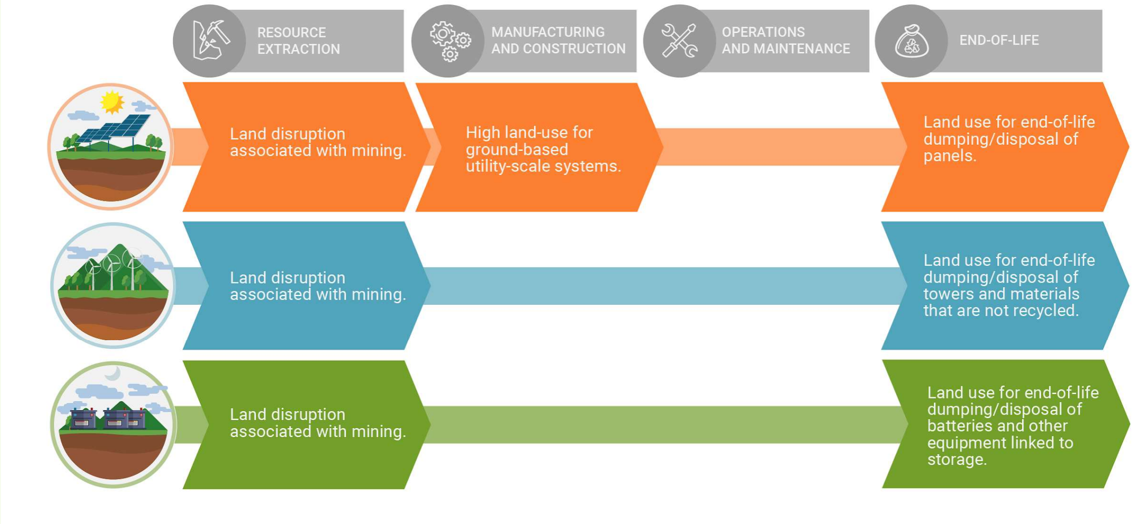


Figure 17: Land use hotspots for RE technologies across their value chains

3 ACTIONS NEEDED TO IMPROVE THE CIRCULARITY AND SUSTAINABILITY OF RENEWABLE ENERGY TECHNOLOGIES

Environmental Civil Society Organisations (CSOs)[9] have considered the RE technologies that are most compatible with the "Future we want" as expressed in the Sustainable Development Goals (SDGs). Specifically, to achieve a JET compatible with the "Future we want" we need to:

- Preferentially produce RE with non-combustion techniques;
- Promote local community participation in decision-making with respect to energy access and supply;
- Promote RE options which have the optimal outcomes for local communities, which may be centralised or decentralised depending on the local context; and
- Promote energy production with domestic energy sources, and using local solutions where relevant and available.

The actions therefore **focus on wind, solar PV and storage as the RE technologies most suited to a JET**. The actions focus on products, chemicals and waste, recognising that many of the actions are cross-cutting.

3.1 Actions for products

Product design is where the greatest leverage exists to influence overall environmental performance. The following high-level "actions for products" are proposed to shape product legislation around renewable energy technologies:

- **Require technologies to be consistent with a circular economy**. That is, products that use fewer raw materials, less energy and processing chemicals, including less hazardous chemicals, and that can be reused, repaired and/or refurbished before being recycled.
- **Require Life Cycle Assessments** (LCAs) on renewable energy technologies prior to their release on the market, so as to be sure that the materials and processes used are those least harmful to human health and the environment. Studies must cover all relevant impacts (including chemical safety), be based on up-to-date data and be peer reviewed.
- **Require participatory decision-making** in the use and management of natural resources, including all those affected or potentially affected by extractive activities.

3.1.1 Circular Economy as a framework for renewables policy

Circular Economy can support the design of RE technologies that have raw material inputs with reduced impacts; that can be reused, repaired, refurbished and/or recycled at the end of their functional lives; that are optimised for electrical efficiency; and that have been produced in processes where environmental impacts have been minimised as far as possible.

While the concept is not new, adoption of CE principles to guide policy and industry interventions has been slow[10] and thus far only evident with batteries in the context of energy transitions. The European Union has been at the forefront of development

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[9] groundWork (South Africa), Movement of People Affected by Dams (Brazil), National Ecological Center of Ukraine (Ukraine), Nature University (China), Center for Financial Accountability (India), National Association of Professional Environmentalists (NAPE) and The Swedish Society for Nature Conservation (Sweden).

[10] The global economy is only 9% circular (with Europe 12% and China 2%), and the trend is negative (https://www.circularity-gap.world/)

of CE, for example with the publication of the Circular Economy Action Plan in 2015 (with an update in 2020 (European Commission, 2020a). More recently, the Global Alliance on Circular Economy and Resource Efficiency was launched on 22 February 2021, to provide a global driver on the CE transition, amongst others (European Commission, 2021). Recognising that a life cycle approach is needed to transition to a CE from the current dominant linear economic models, **three essential policy areas** are identified by Milios (2018):

1. Policies for reuse, repair and remanufacturing;
2. Green public procurement and innovation procurement; and
3. Policies for improving secondary materials markets.

Policy recommendations across the life cycle are illustrated in Figure 18.

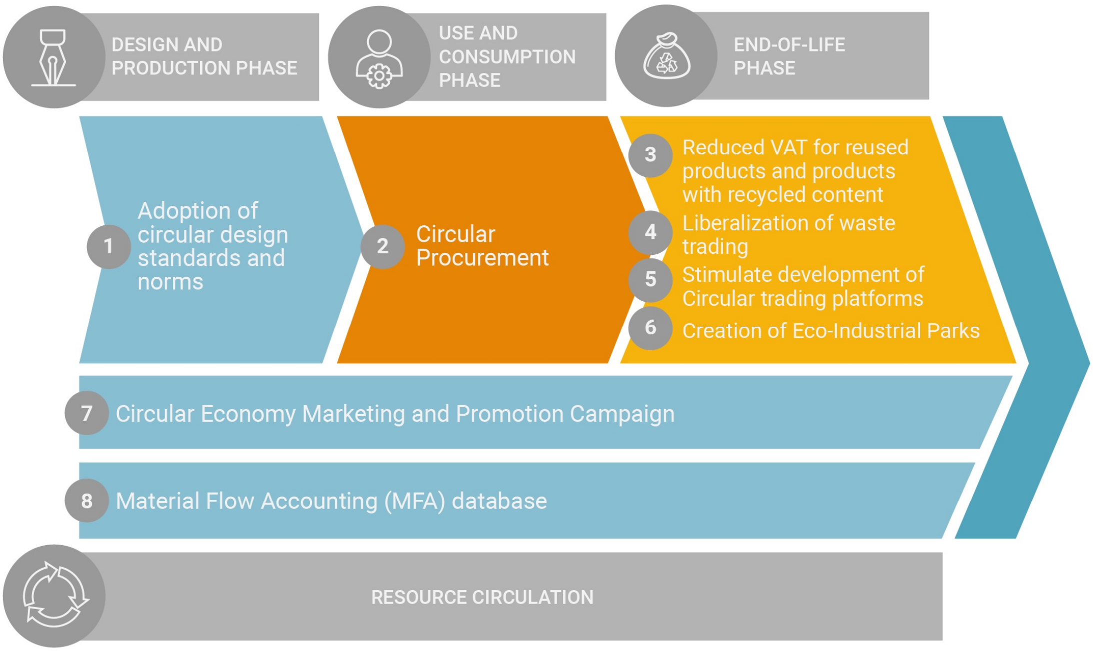

Figure 18: Policy required across the product life cycle to accelerate the transition towards a circular economy

Source: (Hartley, van Santen and Kirchherr, 2020), adapted in turn from Milios (2018)

These policy recommendations should also be complemented by chemical policy reforms which focus on phasing out of particularly hazardous chemicals and promotion of substitution with materials that can be safely reused and recycled in line with circular economy principles.

The following specific actions, which will be supported by necessary policy reforms in line with the above, are needed to drive the circularity of wind, solar PV and battery storage technologies (derived from the EEA (2021) framework for a circular clean-energy system,):

- **Reduce primary material use**: Reduce raw material extraction through increased use of secondary raw materials in manufacturing. This can be achieved through specifying criteria for minimum content of recycled material[11] in new energy-generating products, or by the supply of waste materials for use in other manufacturing sectors.
- **Responsible primary material extraction:** Leasing models for minerals and metals is a possible way to address the negative impacts on countries heavily dependent on mining (Schroder, 2020). Transparent governance measures at both international and country level would be critical to ensuring the success of such leasing schemes. The development of digital product passports, as intended by the EU in the context of its Circular Economy Action Plan, would facilitate the implementation of metal leasing models (see Section 3.2 for further discussion on product passports).
- **Design**: Apply circular design principles to facilitate recycling and re-use and significantly improve the durability, reparability and recyclability of future energy infrastructure; consider recycling potential and hazardousness of materials used, as an integral aspect of design.
- **Production and distribution**: Apply resource efficient manufacturing practices and optimised logistics approaches; implement digital product passports for equipment to provide information about constituent materials and to highlight presence of high impact materials; apply leasing models and other service-based contracts to prioritise whole-life approaches to equipment operation and maintenance.
- **Consumption and stock**: Extend the service-life for infrastructure through preventive maintenance, repair of faulty components and phased upgrading of modular components; remanufacture and reuse decommissioned equipment for either original-tier applications where possible or alternatively lower-tier applications; avoid/prohibit the dumping of technologies and the export of equipment to countries/locations where technologies are unsuitable and waste management practices are sub-optimal.
- **Waste and recycling**: Ensure effective waste management for end-of-life infrastructure through high collection rates and appropriate processing; expand capacity and develop new treatment technologies that are fit-for-purpose and applicable in local contexts; maximise recycling of components and materials to provide secondary raw materials for new energy infrastructure and for other manufacturing sectors; implement standards for the treatment of WEEE and other wastes (critical to ensuring recycled materials are of consistent and high quality); prohibit product and waste movement to countries which do not have the facilities to manage these.

3.1.2 Extended Producer Responsibility (EPR) as an instrument to drive more circular products and effective end-of-life management

EPR is a policy tool designed to hold manufacturers accountable for the end-of-life impacts of their products, as well as to encourage the concepts of eco-design, design for repurposing/recovery or design for environment in the business sector. EPR policy instruments and measures that have been applied include product take-back, deposit/refund, advanced disposal fees, product/material taxes, combined upstream tax and subsidies and minimum recycling requirements (EU-India Technical Cooperation Project, 2021). Whilst EPR schemes have tended to focus on waste management, there has been an expansion of focus to include “products-as-service” business models.

EPR legislation has been applied to renewable technologies to varying degrees. In Europe, the Waste Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU places the responsibility for disposal of WEEE, which includes **solar PV modules and inverters**, on manufacturers or distributors, requiring them to take responsibility for collecting or taking back used goods and for sorting and treating their post-consumer waste (European Parliament, 2012; EU-India Technical Cooperation Project,

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[11] Minimum content requirements require a good understanding of stocks and flows of secondary materials, with economy-wide models and reporting requirements essential in this regard (this is also an important global requirement). This is so that minimum content requirements are attainable and can be adjusted over time as more secondary materials become available.

2021). National producer compliance schemes or Producer Responsibility Organisations (PROs) have been established to help manufacturers and distributors to meet their obligations. An annual fee is paid for the collection and recycling of waste electronics from waste recycling centres. PV CYCLE[12] is a not-for-profit organisation that was established by the PV industry to help members to meet global legislative requirements including those linked to EPR legislation. The Directive also requires provision to be made in design of WEEE to facilitate reuse, dismantling and recovery thereof (European Parliament, 2012).

Wind turbines are excluded from the EU's WEEE Directive as they are classified as large-scale fixed installations making them unsuitable for being processed with municipal waste streams (cefic, EuCIA and Wind Europe, 2020). However there is a push towards increased circularity around the world, under broader legislative and policy frameworks (cefic, EuCIA and Wind Europe, 2020). The European Wind Energy Technology Platform has provided recommendations for policy makers to consider (ETIPWind Executive Committee, 2020):

- **Recommendations to increase the uptake of composite recycling technologies to process existing turbine blades**:
    - Establish a cross-sectoral platform to share best practices in the recycling of composites
    - Establish large-scale demonstration facilities
    - Direct funding towards research that determines the feasibility of various emerging recycling technologies and to support manufacturing processes that use recycled materials in new products.
    - Policy interventions to promote and reinforce a composite recycling industry and support markets for secondary materials
- **Recommendations for the development of new wind turbine blades**:
    - Allocate funding to the research and development of high-performance materials such as aramid and basalt fibres that have increased recyclability
    - Require the incorporation of sensor technology in turbine blades to collect data on turbine health and monitor performance to increase life spans
    - Encourage turbine blade designers to **consider reuse options and recycling technologies in the design process and in the selection of materials**

For batteries and accumulators, The EU's Directive 2006/66/EC seeks to minimise the negative impacts of batteries, through limiting the entry of mercury, cadmium and lead into the environment. This is achieved **through reducing the levels of these chemicals contained in the batteries, and ensuring the proper management of batteries at the end of their service lives**, through implementation of recycling schemes and, through EPR, assigning a responsibility to producers of batteries and other products that incorporate batteries to be responsible for the waste management of batteries. This includes providing finance for collection and recycling schemes. New regulation, which would replace the batteries directive, is now being proposed. This includes a host of provisions including those relating to the operations of repurposing and remanufacturing for a second life of industrial and electric vehicle batteries, increased targets for recycling and recycled content and minimum performance standards (EU Parliament, 2021).

Implementing EPR policy in both developed and developing countries has had challenges, the most prominent of which is difficulties in obtaining information about the chemical composition of imported products and components from international supply chains. This is because the EU directives, whilst mandatory, only cover the EU and not the parts of the supply chain that fall outside this jurisdiction. **This underscores the need for and importance of multi-lateral collaboration on EPR and Circular Economy and, in particular, global harmonisation and/or global standards for the disclosure of chemical composition (e.g. through product passports) and transparency regarding hazardous chemicals.** Although developing

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[12] https://pvcycle.org/

countries can learn from and adapt elements of EPR legislation in Europe and other parts of the world in developing their own EPR policy and legislation, this would need to be supported by global initiatives and harmonisation. A further benefit of such standards would mean that manufacturers could more readily identify hazardous materials/components to replace as a priority. The matter of global harmonisation is discussed further in Section 3.2 below.

3.1.3 Addressing the impacts of primary resource mining

Measures for managing the impacts of mining operations is not unique to the renewables sector, and society has long grappled with the best policy and legislative interventions to manage these. The International Council for Mining and Minerals (ICMM) has defined a set of principles to guide sustainable mining (ICMM, 2022), which includes, amongst others, the following performance expectations:

1. Planning for closure,
2. Implementing water stewardship practices,
3. Effective tailings management,
4. Preventing pollution and managing releases and waste, and
5. Improving energy efficiency and reducing greenhouse gas emissions

It is important that **appropriate policy, legislation and regulation is in place where minerals for renewables infrastructure (and other purposes) are extracted and processed**. In addition, **ongoing enforcement of policy legislation and associated regulation is as critical as the establishment of the legislation itself to ensure protection of environment and society** (Carvalho, 2017), as the growth in the renewables sector increases demand for primary resources.

Illegal mining raises an even greater set of challenges, as it is often linked to organised crime syndicates. Ensuring **strong and secure land rights**, especially of indigenous peoples (and protecting these rights) is one way governments can help fight illegal mining. If small-scale miners' rights to prospect and dig are formal and secure, they are more likely to sell through legal channels, enabling the government to track the origin of minerals and prevent them from fuelling conflict. The **OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas** (OECD, 2016) provides detailed recommendations to help companies respect human rights and avoid contributing to conflict through their mineral purchasing decisions and practices. International mechanisms certifying supply channels (that implement the OECD guidance) have proven effective, such as the Kimberley Process Certification Scheme (KPCS) for diamonds. Tantalum is covered by a similar initiative (Responsible Minerals Initiative, no date). Global cooperation and the development of a **global strategy to combat the organised crime aspects of illegal mining** is also required, such as that initiated through bodies such as the United Nations Interregional Crime and Justice Research Institute (UNICRI) and the United Nations Office on Drugs and Crime (UNODC).

Finally, **strong international collaboration is required to prevent the over-exploitation of resources and impacts of resource extraction**.

3.2 Actions for chemicals

Hazardous chemicals in RE technology products are a hotspot, particularly in solar PV cells and storage batteries. These chemicals in particular pose a health risk to recyclers and to the environment if incorrectly handled and disposed of. **Chemicals used in the manufacture of PV panels** is also identified as a hotspot. The high-level considerations proposed to shape chemical legislation around renewable energy technologies are:

- **Ensure sound management of chemicals regulated by law**, with the necessary laws fulfilling the 11 core elements in the SAICM Overall Orientation and Guidance Document for achieving the 2020 goal of sound management of chemicals, discussed here.
- **Require full disclosure of the chemical composition of materials**, including transparent product labels in the form of product passports. Full disclosure of chemical composition will take time to implement; **in the short-term hazardous chemicals should be prioritised for disclosure/transparency**.

The **Strategic Approach to International Chemicals Management** (SAICM), hosted by UNEP, is a policy framework to promote global chemical safety. The SAICM *Overall orientation and guidance for achieving the 2020 goal of sound management of chemicals* identifies 11 basic elements to be critical at the national and regional levels to attaining sound management of chemicals and waste (SAICM, 2015). Many countries have incorporated (or are incorporating) the SAICM elements into their national legislation. Thus, for solar PV panels and batteries manufactured in well-run facilities (as is necessary to achieve high-quality products), the impact of chemicals should be readily managed through national workplace health, safety and environment legislation and regulations, which are in place in many parts of the world. Similarly, chemicals used in existing and potential future recycling processes can be managed with appropriate national workplace level regulations and legislation. Nonetheless **compliance with legislation is as important as the legislation itself, with institutional capacity and enforcement a critical issue** in many developing countries. An important action point identified in the SAICM guidance for achieving the 2020 goal of sound management of chemicals is thus improving capacity of health, environment, industry, labour, and planning agencies, among others, to establish and address priorities of sound chemical management.

With many chemicals (and products containing chemicals) not consumed or disposed of in the country in which they were manufactured, **global agreements linked to chemicals management are important to limiting environmental impacts and supporting national efforts**. The SAICM guidance identifies the following multilateral agreements being relevant in this regard: the Basel Convention; the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade; the Stockholm Convention on Persistent Organic Pollutants; the Minamata Convention on Mercury; the International Health Regulations (2005); the International Labour Organization's Convention concerning Safety in the use of Chemicals at Work; and the International Code of Conduct for Pesticide Management. The Rotterdam Convention is especially relevant with its focus on shared responsibilities with respect to the importation and use of hazardous chemicals, including through supporting information exchanges between parties. However, individually these multilateral agreements are limited in scope. The broader Chemical in Products (CiP) Programme, discussed further below, potentially provides a platform for addressing hazardous chemicals and products not captured by the agreements.

Promoting **information access is a critical component of sound chemicals management**. The SAICM guidance identifies the availability of data and knowledge of the impact of substances on the environment and health as a prerequisite for well-functioning chemicals control. **Implementing the Globally Harmonized System of Classification and Labelling of Chemicals** (UNECE, 2021) is identified in the SAICM guidance as **among the most important measures a country can take**, as it provides information on the hazards along the supply chain for chemical products in a globally harmonized way. The Organization for Economic Cooperation and Development Global Portal to Information on Chemical Substances (eChemPortal)[13] is accessible globally and provides another source of chemical hazard data.

Chemical hazard and risk reduction information for manufactured products is, however, not covered by the Globally Harmonized System. The **Chemicals in Products (CiP) Programme** (SAICM, no date) is a global initiative aimed at managing chemicals in products to ultimately reduce the risk to humans and the environment, and to help ensure reuse and recycling activities are safer for human health and the environment. **Access to information on chemicals in products is a necessary condition for enabling sound management of chemicals** across the product life cycle, but is especially critical for safe

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[13] https://www.echemportal.org/echemportal/

handling of products at end-of-life. The CiP programme has so far focused only on the textiles, toys, electronics and building materials sectors, with uptake still being low (due to it being a voluntary system). Extending it to renewable energy technologies could be considered given the expected rapid expansion of these products and their inclusion of hazardous chemicals, although it is not certain that this would be the preferred platform for achieving the desired outcomes given it is voluntary.

The EU is currently the only jurisdiction to have adopted the principles of the voluntary CiP Programme into law, and is systematically implementing them. This is being achieved via the EU Chemicals and Waste legislation[14], which is based on the Substances of Very High Concern (SVHC) and public information disclosure in the "Substances of Concern In articles as such or in complex objects (Products)" (SCIP) database[15], and through the implementation of product passports which is currently under discussion. Product passports, which would include information on composition of goods on the European market, would help facilitate increased reuse and recycling and improved end of life management (Taylor, 2021).

The SVHC list, which is aligned with the CiP Programme criteria, already includes 219 substances, and continues to grow as more SVHCs have been identified. **To avoid duplication of effort, the SVHC list could be adopted in establishing a harmonized global transparency system for priority chemicals identification and management, and thereby contribute to the creation of globally standardised approaches for human health and environmental protection, and simplify trade and communication of hazards in multinational material supply chains.**

3.3 Actions for waste

Actions for waste are essential to enabling more circular products and ensuring the protection of workers handling wastes. The following high-level actions are proposed to shape waste legislation around renewable energy technologies:

- **Implement legally binding rules for full information disclosure on chemical contents** in all product components, along with requirements for information transfer between all stakeholders in supply chains.
- **Introduce regulations requiring eco-design,** incentivising products that are more easily reused, refurbished, repurposed or recycled and/or contain recycled content.
- **Implement extended producer responsibility** with take back schemes for companies producing solar PV panels, wind turbines and storage batteries.
- **Involve all stakeholders across the product value chain** (raw material production, brands, retailers, waste management, including the informal sector), government, research institutions, finance sector, civil society and consumers to take a coordinated approach to addressing waste issues.

A circular economy approach is key to avoiding/minimising waste disposal impacts through the design of longer-lived products than can be reused, repurposed and/or recycled at end-of-life. A waste legislative environment that is conducive to a circular economy is therefore crucial.

While most national legislation around waste includes some provision around encouraging recycling, the relatively low recycling rates for most materials around the world shows that much more needs to be done to create a regulatory environment that supports a CE. Components of such a regulatory environment could include:

- Regulatory and economic instruments that disincentivise disposal, such as landfill bans and waste disposal fees/taxes.
- Economic instruments that incentivise recycling and reused/recycled products, such as VAT and corporate tax exemptions.

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[14] See the relevant legislation here: https://echa.europa.eu/legislation

[15] The database can be accessed through this link: https://echa.europa.eu/scip-database

- Legislative support for secondary markets, such as minimum recycled content regulations and recycled content requirements in public procurement.

National waste legislation tends to have a high focus on safety, restricting the transport and utilisation of wastes. This inadvertently can work against the requirements for a CE, which requires access to sites for reprocessing and markets for the secondary materials produced. Thus, an important action is to revisit national (and regional and international) waste management legislation to allow the trading and utilisation of waste (where doing so does not compromise protecting human health and the environment). This could include reprocessing mining tailings, which – as an interim solution - has potential to avoid new mining for critical minerals.

Guiding and supporting national legislation are global agreements that aim to limit the impacts of hazardous wates. Notable here is the **Basel Convention** (Basel Convention, 1992) which was designed to reduce movement of hazardous waste between nations, and specifically to prevent transfer of hazardous waste from developed to developing nations. At a regional level, the **Bamako Convention** focuses on imports into and control of transboundary movement and management of hazardous wastes within Africa, with the **Waigani Convention** serving a similar function in the Pacific region.

EPR, covered in Section 3.1.2, is an **important enabling legislation for driving recycling and improved waste management**. Well-managed EPR can also help drive the design of more circular products, such as through eco-modulation of EPR fees. In line with the EU Waste Directive, landfill bans on untreated waste are mandatory for all EU member states, thus requiring separate collection of end-of-life products covered by EPR-regulations (including solar PV modules and storage batteries) (EU-India Technical Cooperation Project, 2021).

Solar PV, wind turbines and energy storage have substantial potential for material recovery at end-of-life. Even so, depending on the renewable energy technology and recycling facilities in place in a particular jurisdiction, there is likely to still be the need for certain components of the renewables infrastructure to require final disposal. In general, solar panels are considered to be general rather than hazardous wastes, even though small amounts of metals (such as lead, tin, cadmium tellurium and lead) render them potentially hazardous. To minimise human and environmental risks effective legislation for identifying, handling and disposal of materials that are classified as hazardous wastes is required to ensure that these do not end up in landfill (with potential for toxics to leak into the environment) or for recyclers to inadvertently be exposed. Mandatory requirements for ensuring transparency of the chemical composition of materials will play an important role on this regard.

Although a highly contested option with its own associated environmental impacts, for certain residual components of RE technologies which cannot be recovered for their resource value by any other means, and that have a residual energy value, there is the possibility that recovery of energy from waste could be considered. For example, the recovery of energy from composite wind turbine blades through using them as an energy source in cement production or in pyrolysis processes (cefic, EuCIA and Wind Europe, 2020). If this continues, effective legislation which is properly implemented is required where waste to energy technologies are employed, to minimise emissions and ensure only resources for which alternative recovery options are not available are used for energy recovery.

4 CONCLUSIONS

The intention of this report is to raise the potential environmental impacts of renewable energy technologies - along with the actions needed to address them - so that individuals, societies and organisations can participate in influencing policy development and decision-making on all relevant aspects relating to a Just Energy Transition (JET) (social, economic and environmental).

The urgent need to shift away from polluting fossil fuels to cleaner renewable energy sources is clear. Wind and solar are undeniably superior to burning fossil fuels when it comes to combatting climate change and the many other health and ecosystem impacts associated with extracting and burning coal, oil and gas. Renewable energy technologies are, however, not without their own environmental impacts, and policies and legislation need to be in place to manage these and support the anticipated exponential growth in renewable energy technologies as countries transition away from fossil fuels. A **life cycle perspective is crucial in understanding and managing the environmental impacts of renewable energy technologies**. This is because wind, solar and associated energy storage technologies have low impacts at the energy generation stage, with their most significant environmental impacts upstream and downstream in their value chain. Life Cycle Assessment as a methodology is constantly evolving and improving and studies undertaken should strive to use the most recent methods and include up-to-date primary data that best represents the inventories of the RE technologies under study. LCA studies should also be subject to peer review.

Following from a review of renewable energy technologies and assessment of compatibility with a transformative JET, the **actions proposed to achieve a JET focus on wind, solar photovoltaics and energy storage technologies**. Biomass has a potential role in a JET under certain circumstances, as does small-scale hydro, but these technologies are less compatible with the SDGs and furthermore apply in more geographically limited circumstances.

The **use of critical raw materials is identified as a particular hotspot of wind, solar photovoltaics and energy storage**. The high number of metals and minerals required in these technologies translates to resource depletion, and energy use and environmental impacts associated with extracting and refining the metals. Wind is especially notable here, with mining of rare earth elements associated with particularly high current and potentially future impacts. The fact that wind, solar and batteries – and their accompanying use of resources – are set to grow exponentially in the coming decades makes this an especially important hotspot. Furthermore, **many of the materials used are hazardous** which translates to **end-of-life** being a hotspot when products are dismantled and/or disposed of. Batteries are especially notable here. The **manufacturing stage of solar photovoltaics and batteries** are also identified as hotspots.

Having **sound chemical, waste and mining legislation** in place - and ensuring that legislation is enforced – is foundational to managing the potential impacts of renewable energy technologies. National legislation should follow global best practice (such as the SAICM guidance for achieving the 2020 goal of sound management of chemicals (SAICM, 2015)) and be compatible with international conventions (including the UNEA Resolution on Mineral Resource Governance (UNEA, 2021)). Further to this, a set of high-level actions are proposed to shape legislation for renewable energy technologies. These are summarised in Table 2.

Table 2: Summary of high-level actions needed to improve the sustainability of renewable energy technologies

Legislative area	Strategic action	Scale of action
Products	● **Require technologies and materials to be consistent with a circular economy. That is, products that use fewer raw materials, less energy and processing chemicals, and that can be reused and/or refurbished before being recycled. Products and materials (including composite materials) should be easily disassembled and ultimately recyclable.**	Best achieved through global and/or trading block level agreements due to the global nature of supply chains.
	● **Require life cycle assessments on renewable energy technologies prior to their release on the market,** so as to be sure that the materials and processes used are those least harmful to human health and the environment. Studies must cover all relevant impacts (including chemical safety).	National requirement as LCAs are site/location specific
	● **Require participatory decision-making** in the use and management of natural resources, including all those affected or potentially affected by extractive activities.	National level legislation required. Should draw on best

		practice and guidance from ICMM[16], IIED[17] and others
Chemicals	● Ensure **sound management of chemicals** regulated by law, with the necessary laws fulfilling the 11 core elements in the SAICM Overall Orientation and Guidance Document for achieving the 2020 goal of sound management of chemicals.	International harmonization required with alignment of national legislation
	● **Require full disclosure of the chemical composition of materials, including transparent product labels.**	International harmonization required with alignment of national legislation
	● **Implement a global standard for harmonized global transparency system for priority chemicals identification and management,** which could be based on the SVHC list developed in the EU	International harmonization required with alignment of national legislation
Waste	● **Implement legally binding rules for full information disclosure on chemical contents in all product components, along with requirements for information transfer between all stakeholders in supply chains.**	International harmonization and agreements
	● **Introduce regulations requiring eco-design**, incentivising products that are more easily reused, repurposed or recycled and/or contain recycled content.	National legislation supported by international best practice
	● Implement **extended producer responsibility** with take back schemes for companies producing solar PV panels, wind turbines and storage batteries.	National legislation supported by international best practice
	● **Involve all stakeholders** across the product value chain (raw material production, brands, retailers, waste management, including the informal sector), government, research institutions, finance sector, civil society and consumers.	Global initiatives supported by national legislation and initiatives

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[16] International Council on Mining & Metals (ICMM) https://www.icmm.com

[17] International Institute for Environment and Development (IIED) https://www.iied.org

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