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SWEDISH SOCIETY FOR NATURE CONSERVATION

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

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Project: TS018

January 2022

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ABBREVIATIONS

CE	Circular economy
CIGS	Copper indium gallium selenide
CiP	Chemicals in products
CSO	Civil society organization
CSP	Concentrated solar power
EPR	Extended producer responsibility
GACERE	Global Alliance on Circular Economy and Resource Efficiency
GHG	Greenhouse gas
ICMM	International Council on Mining and Metals
IIED	International Institute for Environment and Development
ILO	International Labour Organisation
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
SCIP	Substances of Concern In articles as such or in complex objects (Products)
SVHC	Substances of Very High Concern
OECD	Organization for Economic Cooperation and Development
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 already a relatively good understanding and strong focus on the socio-economic aspects of a JET. The objective of this report is to provide an understanding of the **potential environmental impacts** of a JET, along with the actions needed to address them.

The urgent need to shift away from polluting fossil fuels to cleaner renewable energy sources is well-argued in the literature. **The focus of this report is thus not on the need for a transition away from fossil fuels, but rather on the actions needed to ensure the roll-out of renewable energy technologies is aligned with a JET**. Although renewable energy technologies are undeniably superior to burning fossil fuels when it comes to combatting climate change and addressing the many other health and ecosystem impacts associated with extracting and burning coal, oil and gas, they are not without environmental consequences. Technologies like wind and solar have low environmental impacts during their use/generating phase but have impacts associated with their manufacture (especially the mining of metals and rare minerals for storage devices), and high potential impacts associated with their end-of-life (including potential exposure to hazardous chemicals).

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**. 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. **Circular Economy is increasingly being recognised as conditional to sustainability**[1]**.** This report therefore also aims to provide the circular economy perspective needed for individuals, societies and organisations to have capacity to promote renewable energy technologies compatible with a circular economy.

1.1 The need for a transition of the energy sector

It is unequivocal that human activities have resulted in a significant increase in the concentration of greenhouse gases (GHG) in the atmosphere (IPCC, 2021). This has led to global warming at an unprecedented rate[2], with the last four decades each being warmer than the previous one, and all being 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, intensifying very wet and very dry weather (e.g. flooding and drought), climate events (e.g. heatwaves and tropical cycles) and seasons (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

[1] See for example, https://www.unep.org/news-and-stories/story/european-commission-and-unep-will-foster-circular-economy-globally
[2] There is a near-linear relationship between cumulative anthropogenic CO_2 emissions and the global warming they cause

(IPCC, 2021). Human activities are also a driver of change in the global retreat of glaciers, warming of the upper ocean and rising sea levels and changes in land biosphere.

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). Without urgent and immediate action, reaching this climate target becomes increasingly difficult. For example, if business-as-usual is restored following the global Covid19 pandemic and the economy and emissions 'recover' to 2018 levels, emissions from 2026 would need to fall by 84% in three years to achieve the 1.5°C target (Hausfather, 2021). This rapid decline will be too steep to manage (Hallowes and Victor, 2019).

Implementing an array of mitigation actions is urgently needed to combat and limit the impact of anthropogenic climate change. Mitigation actions can be applied across all sectors of the global economy including the energy sector (e.g., renewable energy), manufacturing sector (e.g., energy efficiency and fuel switch), agricultural sector (e.g., conservation agriculture) and transport sector (e.g., electric vehicles and biofuels). Despite the urgency of the climate crisis, 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). It is clear that mitigation action is needed without further delay and at scale.

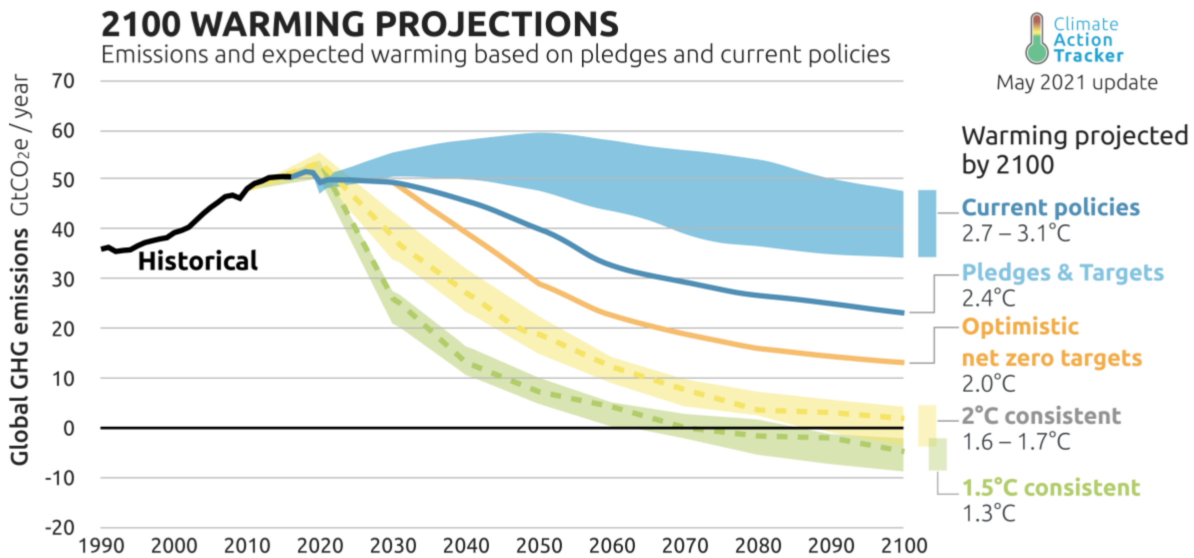


Figure 1: Emissions and warming projections based on pledges and current policies

Source: (Climate Action Tracker, 2021)

Renewable energy technologies are recognised to play central role in the energy transition and are critical to limiting global warming to 1.5ºC by 2050. It is projected that electricity will account for over 50% of total final energy consumption by 2050 (21% in 2018) and renewable energy could potentially contribute a quarter of CO_2 emissions abatement in that year (Figure 2) (IRENA, 2021). Whilst the transition in 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]. Air pollution is argued to be the greatest external threat to human health on the planet[4], with coal-burning identified as the main culprit. A transition away from fossil fuels to renewable energy technologies is essential for both people and the planet.

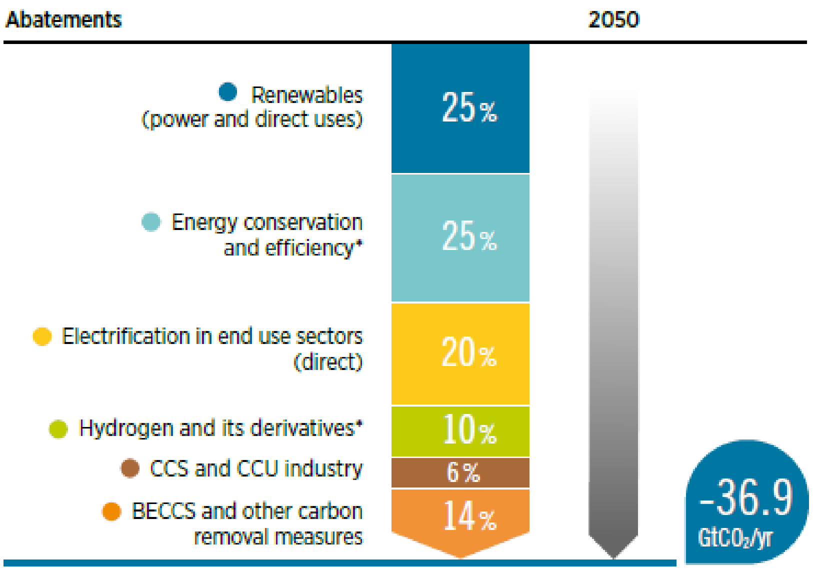


Figure 2: GHG emissions abatement under the 1.5°C scenario (%)

Source: (IRENA, 2021)

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[5]. 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 environmentally 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. 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**. The Paris Climate Agreement also contains reference to a Just Transition, albeit in a more limited sense, where governments commit to ensuring that

[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
[4] As quantified through the Air Quality Life Index. https://aqli.epic.uchicago.edu/
[5] 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)

workers are included and not left behind in the transformation through the creation of decent work opportunities (UNFCCC, 2015).

The Just Transition is thus a complex topic, the scope of which is still contested and subject to debate. The guidelines put forward by The International Labour Organisation (ILO) are recognised as providing a good framework for the guiding principles, key policy areas and institutional arrangements necessary to achieve a Just Transition (ILO, 2015). From a review of the ILO Guidelines, together with other recent literature on the topic, Halsey et al. (2019) distil eleven fundamental principles for a Just Transition[6]. These are illustrated in Figure 3, noting that they may not all be relevant in all contexts. For example, location specific solutions may be preferred in some situations, while in others harmonisation may be beneficial.

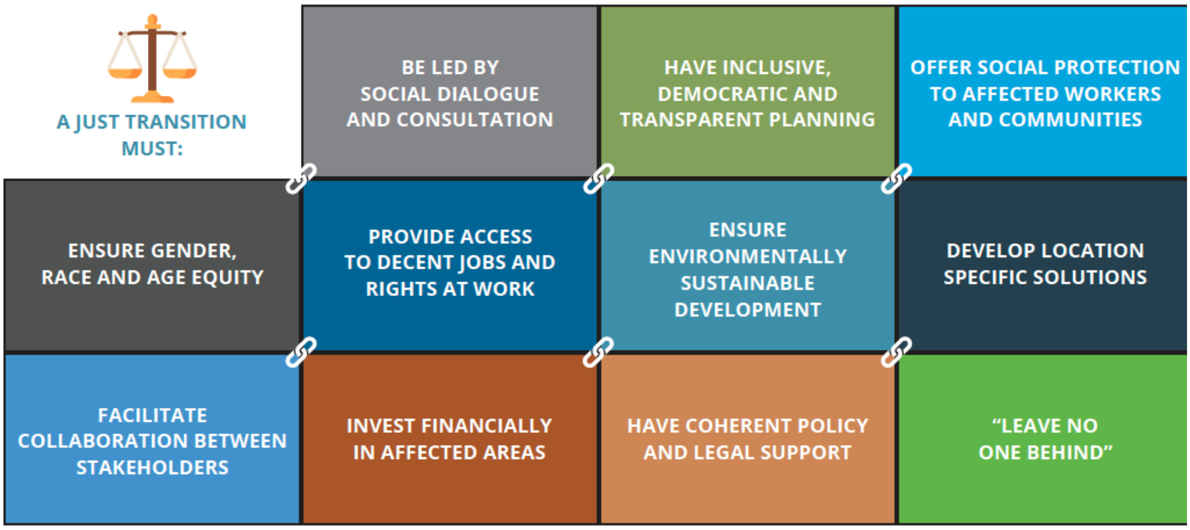


Figure 3: Fundamental principles for Just Transition

Source: Halsey et al. (2019)

Increasingly there is the recognition that the Just Transition should go beyond merely securing livelihoods and mitigating climate change (i.e., dealing with the negative consequences) but instead **harness the opportunities to create environmentally and socially sustainable societies**. Many authors therefore have framed the Just Transition as a continuum, moving from "business as usual" (low ambition) through to a transformative Just Transition (high ambition) (Halsey *et al.*, 2019; Montmasson-Clair, 2021). This continuum is illustrated in Figure 4.

[6] It is noted that location specific solutions are not always appropriate for the energy sector as it can lead to the heterogeneity of the energy system and give rise to other complications.

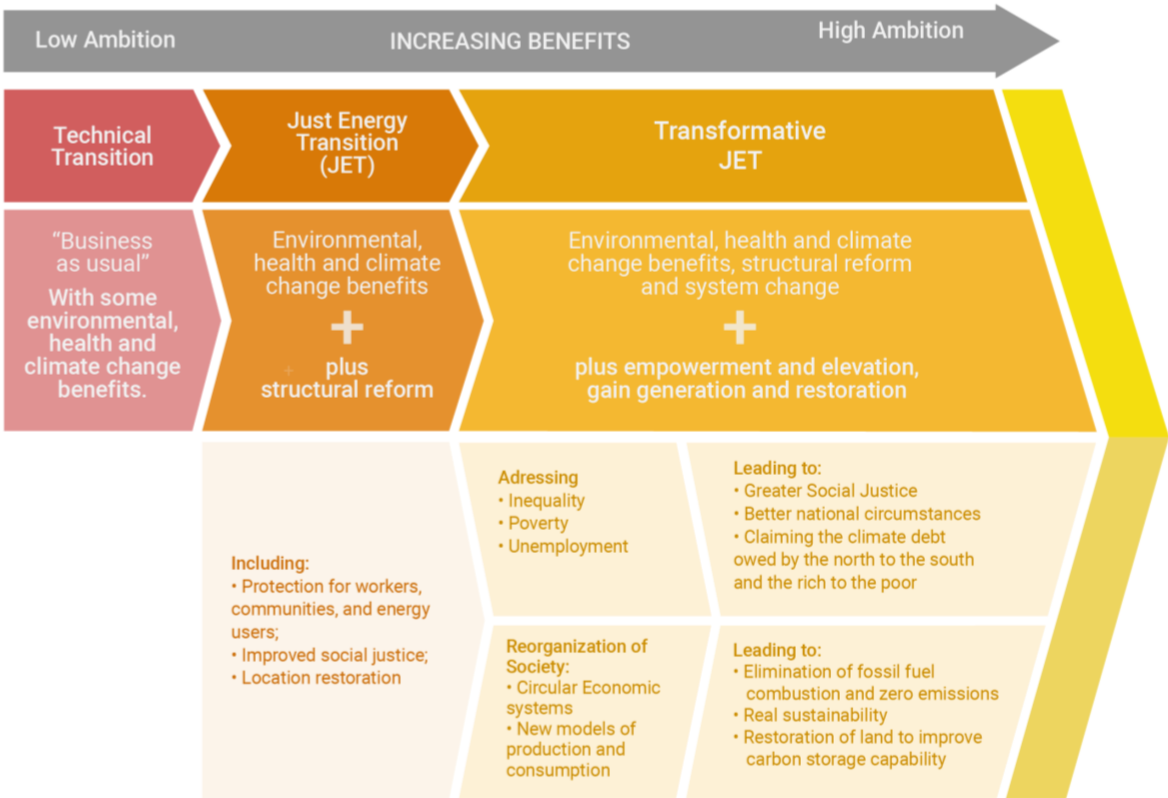


Figure 4: Just Transition seen as a continuum

Adapted from: Halsey et al. (2019) and Montmasson-Clair (2021)

The focus of this report is on the energy sector, that is, on a Just Energy Transition (JET) (although it is recognised that a Just Transition can apply to greening a country's economy more broadly, and that an energy transition has effects beyond the energy sector). The ambition for a transformative JET is an energy system powered by renewable sources that caters for the well-being of all people, whilst remaining within the limits of ecosystems. To ensure the JET is governed by public interest requires moving away from a system of private/corporate energy monopolies to one where decisions are democratic, transparent and inclusive of all local and impacted communities and the resulting energy system is owned and controlled by the people. It should not just safeguard the conditions for economic growth and provide a good standard of living but improve the protection of human health and the environment.

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:

- 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
- Understanding related issues such as land and water.

Less recognised in the literature is the need to ensure that the energy systems that replace the existing energy systems do not create new problems in the future. That is, whilst recognising that renewable energy technologies mitigate the climate and pollution issues associated with burning fossil-fuels and provide better options for energy access (lower costs and better potential for decentralised generation when suitable), it is important to consider their potential environmental impacts and any unintended consequences. This is the focus of this report. **Especially important with renewable energy technologies is to take a life cycle perspective**, since their environmental impacts occur less at the generation stage (especially when compared to burning fossil-fuels) but rather in their supply chains, most notably in the mining of materials, manufacturing and material handing at end-of-life. Being aware of these potential impacts is imperative as renewable technologies are set to grow substantially around the world. In this way policy and legislative systems can be put in place to prevent problems before they arise and ensure the transition to renewables is indeed a just one for people and the planet.

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

This report argues for the need to have a life cycle, resource efficiency and circularity perspective for achieving a Just Energy Transition (JET). An overview of these inter-linking concepts is provided in this section.

Whilst the emissions from most renewable energy technologies are low at the energy generation stage (especially when compared to burning fossil-fuels), renewable energy technologies depend on extractive industries to provide the metals, minerals and chemicals needed in the manufacture (and installation) of turbines, solar panels, mounts, casings, batteries etc. Hazardous materials are generated during mining, manufacturing and at end-of-life, with risk of exposure to chemicals and toxic metals during mining and minerals processing and when components are manufactured, assembled, disassembled at end-of-life and/or disposed of. Thus, it is necessary to consider all stages of the value chain (or life cycle) when it comes to understanding – and mitigating - the resource use and potential environmental impacts of renewable energy technologies. The life cycle impacts of renewable energy technologies are explored in detail in Section 2.2.

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[7]. A typical product life cycle begins with the extraction of raw materials from natural resources in the ground and/or from growing them (in the case of biotic materials). These materials are then part of production and energy generating processes, and are made into products that require further materials in their packaging, distribution, use, maintenance, and eventual recycling, reuse, recovery and final disposal. The goal of LCT is to reduce a product's resource use and emissions to the environment, with the potential to reduce resource consumption and improve the environmental and socio-economic performance of products arising at each stage of their life cycle. **Life Cycle Assessment** (LCA) is a quantitative tool for applying LCT and provides a structured framework within which to model the potential environmental impacts associated with a product or service. An LCA identifies the impacts and significance of each life cycle stage of the product analysed and makes possible 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. Land provides space for humans (and other species) to live, whilst also producing biomass (in conjunction with soil). Sub-soil resources include metal ores, non-metallic minerals, and fossil fuels. Along with this definition of resources, the International Resource Panel go on to define resource efficiency as encompassing a number of ideas. At its most basic, resource efficiency is the technical efficiency of resource use (i.e., the useful energy or material output per unit input of energy or material resource). Resource productivity is similar but measures the economic value added by a given quantity of resources (i.e., the value added per unit of resource input). A broader interpretation is one that recognises that resource extraction and use has negative environmental impacts, and thus that increasing resource efficiency reduces the environmental impacts caused by the resource. Regardless of the exact definition, an important underlying concept of resource efficiency has been to identify that 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 5). 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. By extending the lifespan of products and materials, CE aims at reducing the consumption of primary

[7] 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/)

resources. Requiring fewer primary resources per economic output also reduces the extraction, production and/or refining of those resources into the materials used for manufacturing new products, along with all the energy and environmental impacts associated with these extraction (mining), production (agriculture) and refining processes. CE thus not only helps us manage limited resources better but minimises the environmental impacts associated with producing materials and products, as well as avoids environmental impacts associated with disposing of them after use.

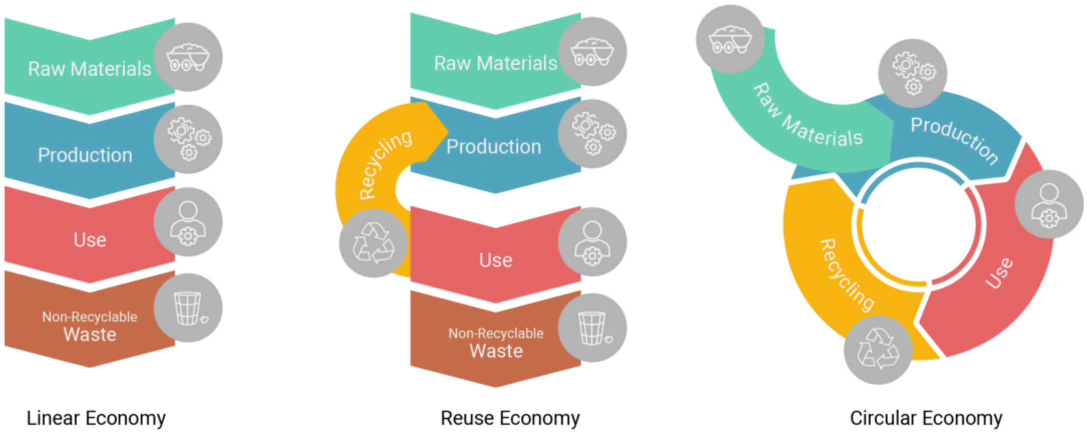


Figure 5: Linear, reuse and circular economies

The UNEP Circularity platform illustrates the many routes through which materials and products can be retained in the economy (see Figure 6). Ordered from the highest potential to reduce environmental impacts to the least impactful, UNEP group the processes contributing to circularity into four categories (UNEP, no date):

1. Reduce by design: reducing the amount of material used, particularly raw material, should be applied as an overall guiding principle from the earliest stages of design of products and services
2. From a user-to-user perspective: Refuse, Reduce and Re-use
3. From a user-to-business intermediary perspective: Repair, Refurbish and Remanufacture
4. From business-to-business: Repurpose and Recycle.

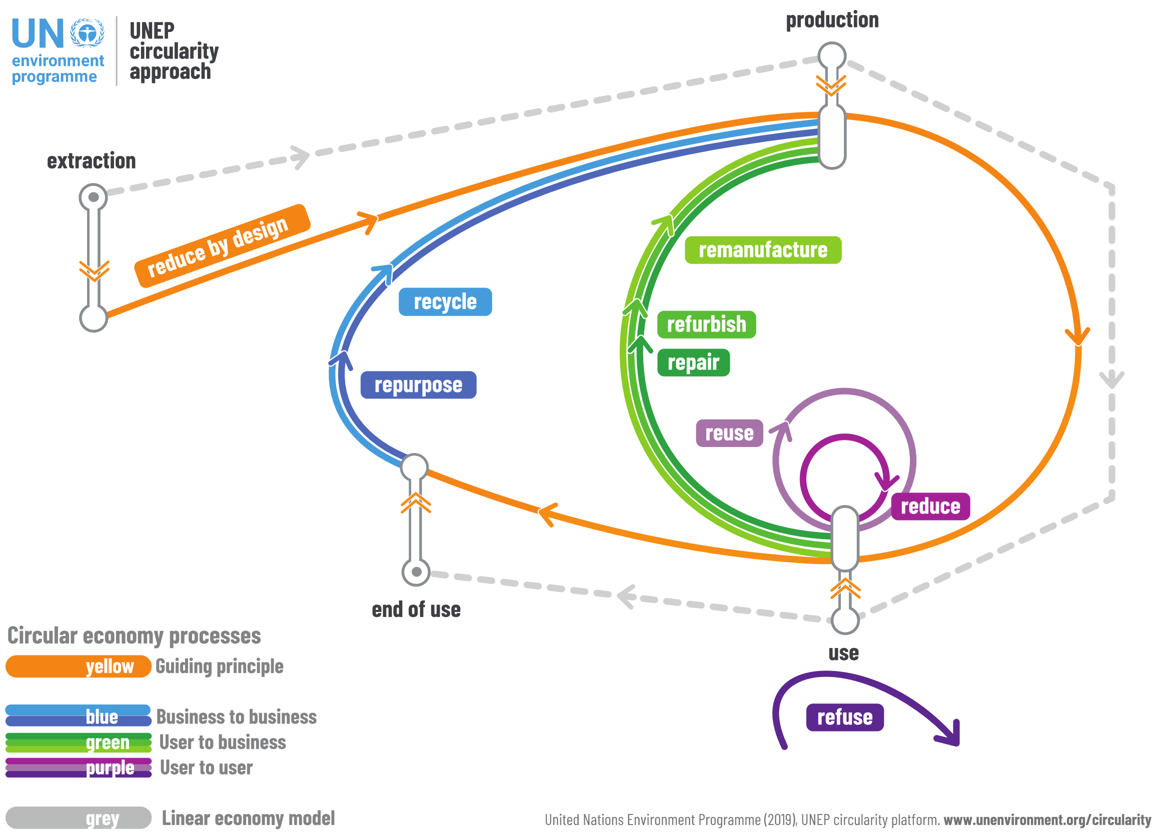


Figure 6: Value retention loops of a Circular Economy

Source: UNEP circularity platform (https://buildingcircularity.org/)

Many definitions of CE go beyond the concept of value retention loops to also include some aspect of the economy needing to be regenerative and restorative. For example, the World Economic Forum's definition is as follows:

> "A circular economy is an industrial system that is **restorative or regenerative by intention and design**. It replaces the end-of-life concept with restoration, **shifts towards the use of renewable energy**, **eliminates the use of toxic chemicals**, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems, and business models."

The definition of the Ellen MacArthur Foundation also brings in the aspect that the economy needs to address the needs of people (Ellen Macarthur Foundation, no date):

> "Looking beyond the current take-make-dispose extractive industrial model, a circular economy aims to redefine growth, **focusing on positive society-wide benefits**. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. **Underpinned by a transition to renewable energy sources**, the circular model **builds economic, natural, and social capital**. It is based on three principles: design out waste and pollution; keep products and materials in use; regenerate natural systems."

Along with the need to extend the life of materials and reduce waste, most definitions bring in the need to move to renewable energy sources and consider the whole life cycle:

> "emphasizes product, component and material re-use, re-manufacturing, refurbishment, repair, cascading[8] and upgrading as well as solar, wind biomass and waste-derived energy utilization throughout the product value chain and cradle-to-cradle life cycle" (Korhonen, Honkasalo and Seppälä, 2018).

CE thus provides a guiding principle to support a move away from a linear economy where products are produced, used and disposed of, towards a model based on designing out waste and pollution, keeping products and materials in use, and regenerating natural systems.

Circularity is increasingly being recognised as a criterion for sustainability. For example, it is included amongst the six objectives of the EU Taxonomy Regulation that an economic activity has to meet in order to qualify as environmentally sustainable (European Commission, no date a):

1. Climate change mitigation
2. Climate change adaptation
3. The sustainable use and protection of water and marine resources
4. The transition to a circular economy
5. Pollution prevention and control
6. The protection and restoration of biodiversity and ecosystems

The concepts of life cycle thinking, resource efficiency and circular economy are inter-linking and complementary. Life cycle thinking enables the identification of strategic intervention points and engages all stakeholders in changing the system, whilst resource efficiency reminds us that disconnecting natural resource use and environmental impact from economic activity and human well-being as far as possible is essential. Whilst circularity indicators are easy to communicate and provide an opportunity to make society's consumption and production more resource efficient and sustainable, they provide only a partial view of the environmental performance of a system. Furthermore, there is as yet no harmonised method to assess whether a specific CE strategy contributes towards sustainable consumption and production. Life cycle assessment is thus complementary here, as with its standardised approach it may be applied to identify the most promising circular economy strategies and options for improving the environmental performance of society's consumption and production (Rigamonti, Grosso and Sunseri, 2009; Peña *et al.*, 2021).

[8] Cascading refers to the recycling of a product, where the recycled product has a lower quality and functionality than the original product

2 RENEWABLE ENERGY TECHNOLOGIES AND THEIR IMPACTS

2.1 Renewable energy technologies meeting the needs for a Just Transition

IRENA's Transforming Energy Scenario gives an indication of the renewable energy technologies that will need to be in place in 2050 in order to meet global climate goals (IRENA, 2020b). This section provides a brief overview of these technologies, with a focus on solar and wind, which are anticipated to fulfil the bulk of the world's energy needs by 2050 under a "transforming energy scenario" (see Figure 7), but also covers hydro, bioenergy and geothermal. The section also covers energy storage, which will be required to complement renewable energy generation.

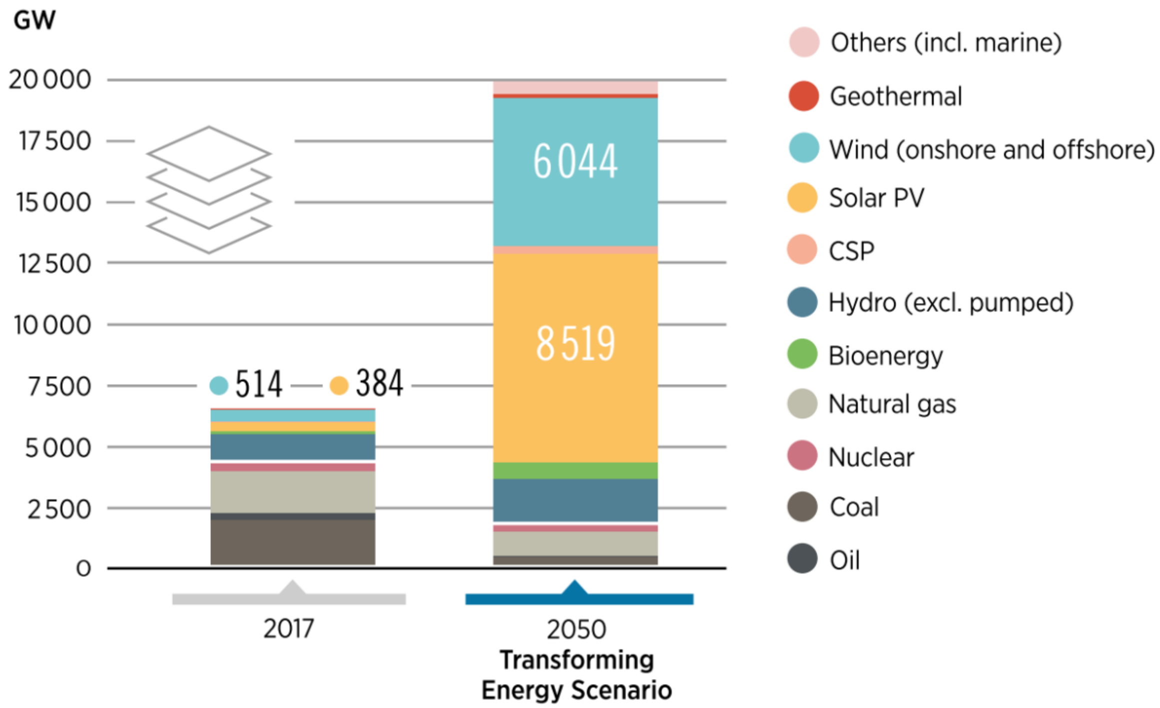


Figure 7: Breakdown of total installed capacity of solar, wind and other renewable energy technologies in 2050

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 for personal use. 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.

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

Concentrated solar power (CSP) differs from solar PV in that it uses mirrors to concentrate the solar rays. The rays are used to heat fluid which in turn generates steam to drive a turbine and generate electricity. A key advantage of CSP over solar PV is that a CSP plant can be equipped with molten salts which can store heat allowing electricity to be generated after sunset. The cost of CSP has decreased significantly over the last few years and, coupled with its ability to provide dispatchable generation, the technology penetration is expected to grow (IRENA, 2017). It is particularly attractive for industrial applications and off-grid applications in rural areas. However, it is less suited to a community ownership model with its high costs and technical requirements, and is thus currently less applicable in a transformative JET (although future developments might render it more so).

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 by 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, where the wind blows at different times, 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 globally 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 (e.g., communication towers or rural communities). Community wind projects, projects that are partially or wholly owned and developed by a local community, 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. Projects have been implemented by municipal districts, cooperatives and rural communities, demonstrating the compatibility of on-shore wind with 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. Pumped hydro storage accounted for over 96% of installed storage capacity in 2017, followed by thermal storage, electrochemical and electromechanical (Figure 8) (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 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). Finally, 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.

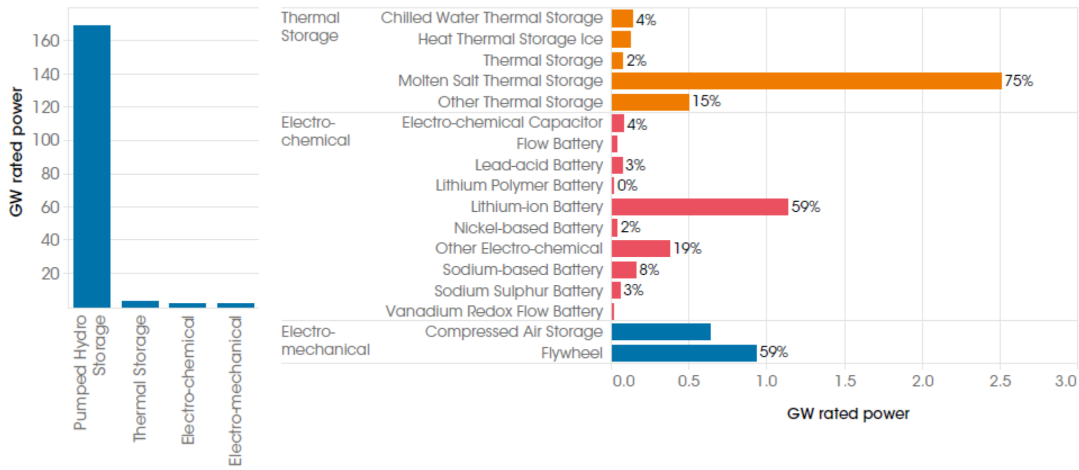


Figure 8: Global operational electricity storage power capacity by technology, mid-2017

Source: (IRENA, 2017)

Lithium-ion batteries accounted 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, shown in Table 1, and these characteristics are the reason lithium-ion batteries are the dominant technology for portable electronics and electro-mobility. As the cost of lithium-ion batteries continue to decrease they will become an economical option for stationary applications.

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 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 (Table 1) 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 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 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 using 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. VRFB are suitable for utility-scale power systems and applications include load shifting and voltage support, amongst others (US TDA, 2017).

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).

Table 1: Advantages and disadvantages of different storage options

Battery	Advantages	Disadvantages
Lithium-ion battery	High specific energy High energy and power density High rate and power discharge capability Excellent round-trip efficiency[9] Long life time Low self-discharge rate[10]	Lithium resource is finite which could result in a cap on production
Lead-acid batteries	Good cost-performance ratio High recyclability	Low energy density Heavy Poor response to deep charging Environmental concerns (toxicity)
Sodium sulphur batteries	High energy density Very low self-discharge rates Non-toxic materials High recyclability Low maintenance	Safety concerns due to high temperatures and explosivity (in event of accident)
Electrochemical capacitors	Reversible Efficient Fast storage High round trip efficiency Long cycle lifetimes	High cost Low energy density High self-discharge Short discharge time
Flow batteries	Operate at ambient temperature	Low efficiency

[9] The round-trip efficiency refers to the percentage of electricity that is put into storage that is later retrievable
[10] The discharge rate of a battery refers to the extent to which internal chemical reactions reduce the stored charge of the battery when not in use. This affects the shelf-life of batteries.

Battery	Advantages	Disadvantages
	Long cycle lifetimes Inexpensive raw materials Good safety characteristics Very deep discharge rates	High repair and maintenance costs
Hydrogen and other chemicals	Efficient energy storage for long periods of time Applicable at various scales Potential for transport over long distances	High pressure and temperature required for hydrogen storage Other chemicals not as well suited for short turnaround times

Sources: (IRENA, 2017; US TDA, 2017)

2.1.4 Hydroelectric power

In hydroelectric power generation, a dam or diversion structure is used to alter the natural flow of a water body and turbines and generators are used to convert the energy in the flowing water into electricity. In 2019 hydroelectric power accounted for 60% of renewable energy electricity generation, with China being the largest generator (30% of total generation) (IRENA, 2020a).

Hydroelectric power is flexible and can be used to support intermittent sources of renewable energy such as wind and solar. However, hydroelectric power plants are expensive and disruptive to build, and construction materials give rise to GHG emissions. Already climate change is beginning to impact the efficiency of hydroelectric systems and as well as needing to contend with the impact of droughts, they are also needing to be overengineered to handle increased flood events (Leslie, 2021). Although they are associated with no GHG emissions or air pollution during electricity generation, hydroelectric power plants have substantial environmental (e.g. habitat damage) and social (e.g. destruction of homes) impacts. Furthermore, globally there are limited locations in which to construct utility-scale hydroelectric power plants. Methane may also be produced through the decomposition of organic matter at the bottom of dams, particularly in the first 10 years after commissioning (Leslie, 2021).

Small-scale hydro can range in size from less than 20 kW (pico-hydro) to 10 MW (small hydro), with efficiencies between 60 and 80%. It is suitable to provide electricity to mainly rural areas, communities and farming enterprises, particularly where the costs of providing transmission and distribution infrastructure and services are high.

2.1.5 Bioenergy

Bioenergy encompasses the combustion of traditional forms of biomass such as wood, charcoal and animal waste as well as more advanced technologies such as liquid biofuels, biogas and wood pellet heating systems. In developing countries, the combustion of biomass remains a key source of energy for cooking and heating. Unlike wind and solar PV, bioenergy can provide a dispatchable and continuous source of electricity, which can be used as baseload. Key concerns surrounding the production and use of bioenergy include land use change, impacts on food production, water and air quality impacts, impacts on biodiversity and air pollution (IRENA, 2021).

Biogas is a methane rich gas produced through the anaerobic decomposition or gasification of organic matter. Biogas is typically collected from landfills or produced from sewage, industrial wastewater and animal wastes. The production of biogas (and bioenergy in general) requires specific conditions and is often limited by feedstock availability.

Liquid biofuels and biogas can replace petrol and diesel in conventional internal combustion engines used in passenger and freight vehicles, aeroplanes, trains and ships. Advanced biofuels can reduce emissions by up to 80%

compared to diesel engines (IRENA, no date). This means biofuels could potentially have a significant impact on global GHG emissions, especially since the transportation sector accounts for 23% of global carbon emissions (Ikram *et al.*, 2019). The main barriers to the uptake of biofuels are feedstock availability, technology commercialisation and lack of investment.

In IRENA's transforming energy scenario, bioenergy could contribute just over 10% of emission reductions in 2050 relative to a planned energy scenario. The projected split between biomass for electricity generation, liquid and solid biofuels and biogas is shown in Figure 9.

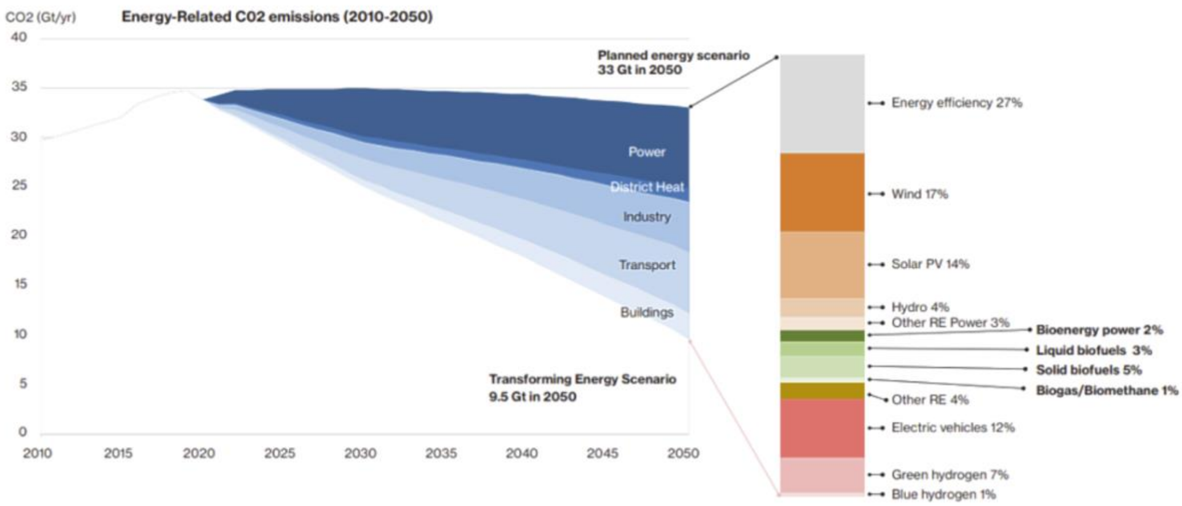


Figure 9: Annual energy-related CO_2 emissions in IRENA's Planned Energy Scenario and in the Transforming Energy Scenario and the mitigation contributions by technology in the scenarios (2010-2050), highlighting the role of bioenergy

Source: (IRENA, 2020b; Kang and Asmelash, 2021)

It is recognised that not all forms of bioenergy are compatible with a JET. If biomass is simply seen as a replacement for fossil fuels a number of negative side effects potentially occur, including deforestation, biodiversity loss and soil depletion, as well as the human health impacts of poor air quality and particulates, which are linked to combustion by-products (ETC, 2021). The Energy Transitions Commission lays out clearly the requirements for sustainable biomass production in that it must not compete with land use for food production; lead to the release of carbon stocks due to land use change; or adversely impact biodiversity and ecosystems. Thus, for a JET, biomass sources for energy should be constrained to wastes and residues as well as dedicated energy crop production on degraded or marginal lands. Furthermore, bioenergy applications should only be pursued in applications where there is no alternative (ETC, 2021). Aviation fuel is identified as a key sector for biofuels and bioenergy. Carbon capture and sequestration (BECCS) or biomass carbon removal and storage (BiCRS) are possible future applications (ETC, 2021).

2.1.6 Geothermal

Geothermal energy is heat derived from the below the earth's surface that is carried to the surface by water and/or steam and is used for heating, cooling or to generate electricity. Advantages of geothermal power are that it is not dependent on weather conditions, it has very high capacity factors and can be used for supplying baseload electricity. However, many regions do not have large scale high temperature geothermal resources. In countries with geothermal resources, geothermal energy accounts for a significant share of electricity generation: Iceland (30.9%) (90% of heating demand), New Zealand (22%), Kenya (57.7%) and the Philippines (49.9%) (IRENA, 2020a).

Geothermal technologies are at varying levels of maturity. Technologies used for district heating, and geothermal heat pumps and greenhouses are mature and widely used. Electricity generation technology from high temperature fields is also mature; however medium temperature fields use binary cycle technology, which has been developed more recently. Enhanced Geothermal Systems (EGS) are still in the demonstration stage.

2.2 Life cycle impacts 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, 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 much lower greenhouse gas emissions (See Figure 10 – note the logarithmic scale). 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. On-shore wind and solar PV have the lowest GHG emissions (of the option set considered in UNEP (2016)), with a notable variation between solar PV technologies (UNEP, 2016). It should be noted that the results presented here do not account for the GHG emissions associated with energy storage and or grid extension that may be required to support renewables roll out at scale.

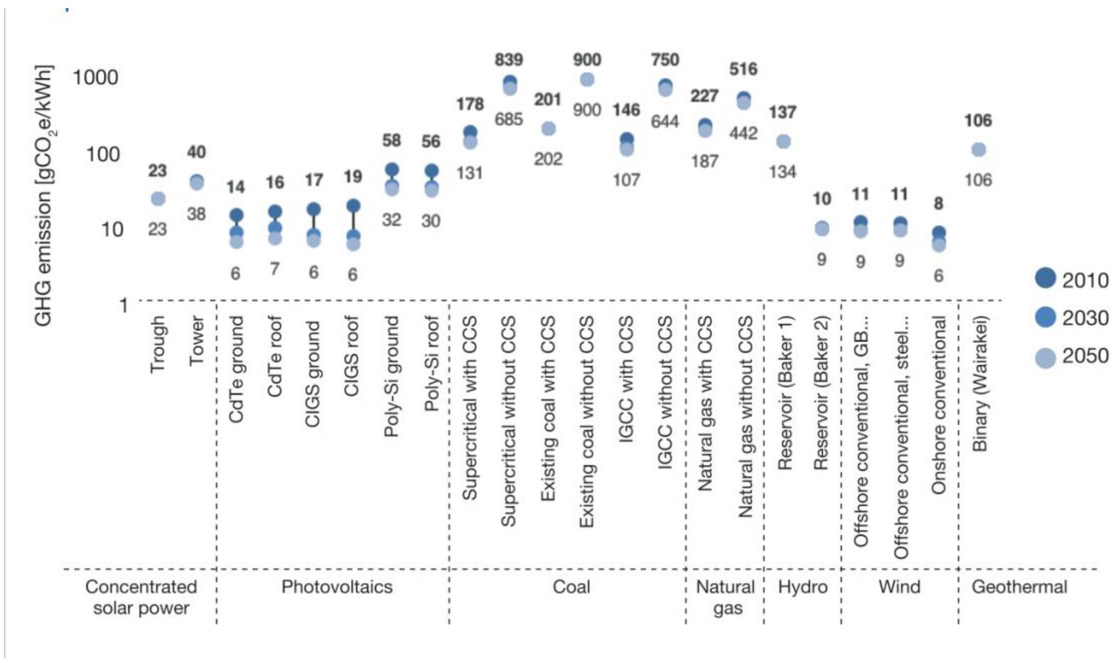


Figure 10: Comparison of the GHG emissions in gCO_2e per kWh of electricity production from different technology sources in Europe (note the logarithmic scale)

Source: (UNEP, 2016)

2.2.2 *Resource depletion*

The transition globally to a low carbon energy sector will drastically change the demand for mineral resources and metals. Many renewable energy technologies rely on rare or precious metals and niche minerals for specific components. For example, the rare earth metals neodymium and dysprosium are used in magnets in some direct drive wind turbines, whilst cadmium, tellurium, selenium, and gallium are used for certain solar PV technologies (Hund *et al.*, 2020). Batteries may require lithium, cobalt, vanadium and other metals with finite supplies, while hydrogen fuel cells require platinum and ruthenium. Renewable energy technologies 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 listed in Table 2.

Table 2: Mineral and metal demand mapped to renewable energy technologies

	Wind	Solar PV	CSP	Hydro	Geothermal	Energy Storage
Aluminium	■	■				■
Cadmium		■				
Chromium	■			■	■	■
Cobalt						■
Copper	■	■	■	■	■	■
Dysprosium	■					
Gallium		■				
Graphite						■
Indium		■				
Iron	■					■
Lead	■	■		■		■
Lithium						■
Manganese	■			■	■	■
Molybdenum	■	■		■	■	
Neodymium	■					
Nickel	■	■		■	■	■
Selenium		■				
Silver		■	■			
Tellurium		■				
Titanium				■	■	
Vanadium						■
Zinc	■	■		■		■

Sources: (Dominish, Teske and Florin, 2019; Hund *et al.*, 2020)

There is also a time dimension to consider in this increased global demand for minerals and metals. The analysis of Boubault and Maïzi (2019) show how the demand for mineral and metal resources, including construction materials, evolve over time and are dependent on the technologies that emerge. Their analysis under a 2ºC scenario highlights increased requirements for borates, cadmium and indium in the decade beginning in 2030 as a result of thin film solar PV technologies from CdTe and CIGS. From 2040, materials related to batteries, solar and wind dominate, including graphite, sand (used in glass and glass fibre), silver, rare earth elements and gold. Many of these resources will be required in significantly larger quantities than today. Figure 11 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, as shown in Figure 12. Exceptions include iron, cobalt and indium.

Although there are sufficient resources to theoretically meet the requirements of a transition to renewable energy, the supply of required metals and minerals cannot necessarily be guaranteed. Some of these mineral 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 13). This inequal distribution of mineral resources (often 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 global 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 the material supply bottlenecks for renewable energy technologies illustrated in Figure 14. 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).

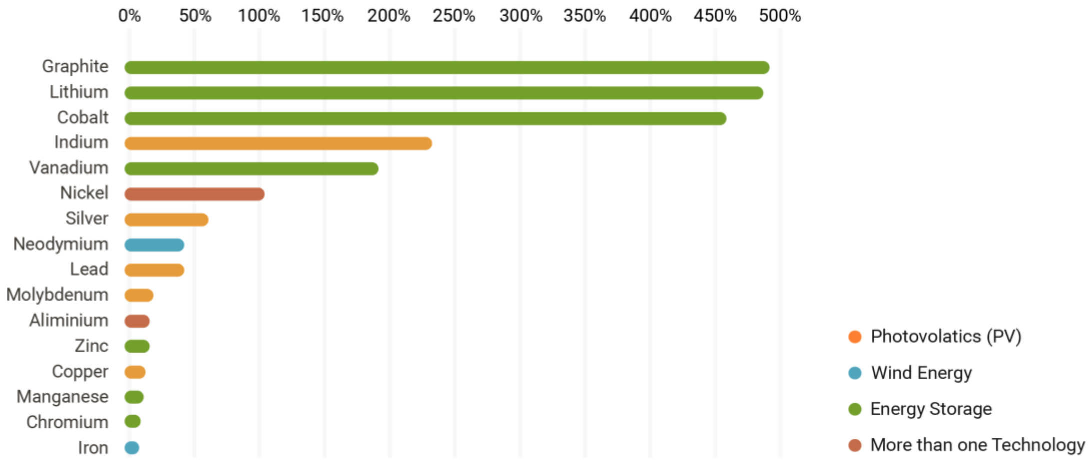


Figure 11: Projected 2050 annual demand for metals from energy technologies as a percentage of 2018 demand under a below 2ºC scenario

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

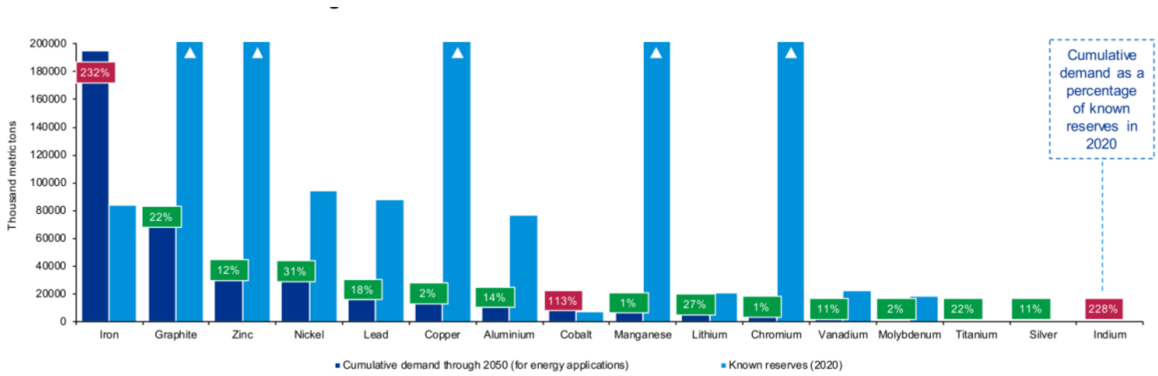


Figure 12: Estimated cumulative demand for metals to 2050 and known reserves

Source: (KPMG, 2021)

Figure 13: Countries accounting for the largest share of global production of the critical raw materials required for wind, solar PV and energy storage

Source: Based on data from the US Geological Survey (2021)

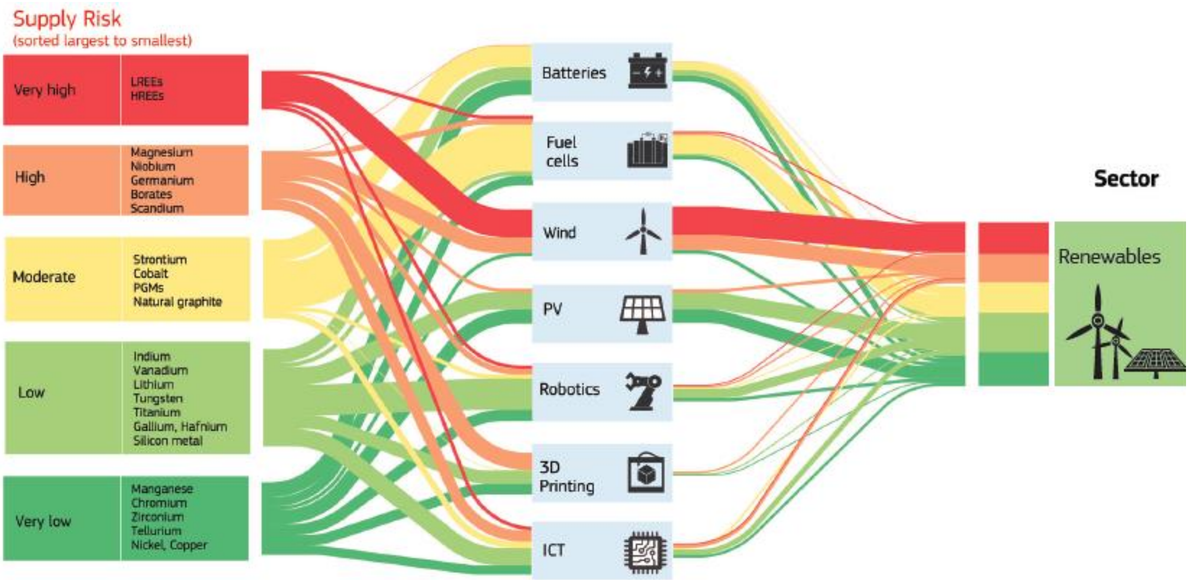


Figure 14: Raw materials relevant to the renewable energy sector and supply bottlenecks, from a European perspective.

Source: (European Commission, 2020b)

Comparing renewable energy technologies and fossil fuel technologies in terms of their metal depletion shows the much higher metals requirement for renewable energy technologies than for fossil fuel technologies (see Figure 15), with solar technologies showing the highest metal depletion per kWh of electricity produced. This analysis excludes the demand for metals associated with energy storage and grid expansion.

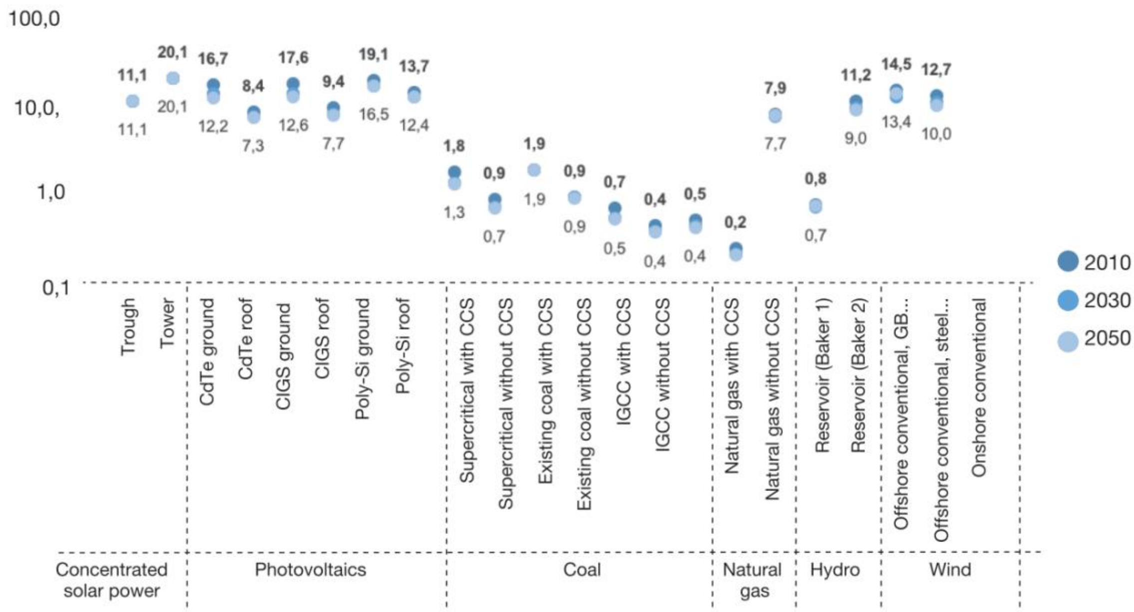


Figure 15: Comparison of the impact of metal depletion in g Fe eq per kWh of electricity production from different technology sources in Europe

Source: (UNEP, 2016)

2.2.3 *Ecosystem and human health impacts*

Notwithstanding potentially high 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 16 and Figure 17). The impacts shown in these figures are cumulative impacts over the life cycle of the technology expressed per TWh or MWh of electricity production. The lower relative impact of renewable technologies is owing to the high ecosystem and human health impacts associated with the combustion emissions of fossil fuel plants. This could partially also be owing to a lack of data on chemicals in products, and especially on potential for environmental contamination and human health impacts when such products are disposed of at end-of-life (with the lack of data on chemicals in products translating to chemical effects being missed by life cycle models). 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 their human health impacts, second generation solar PV (CdTe and CIGS) and wind technologies are fairly 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).

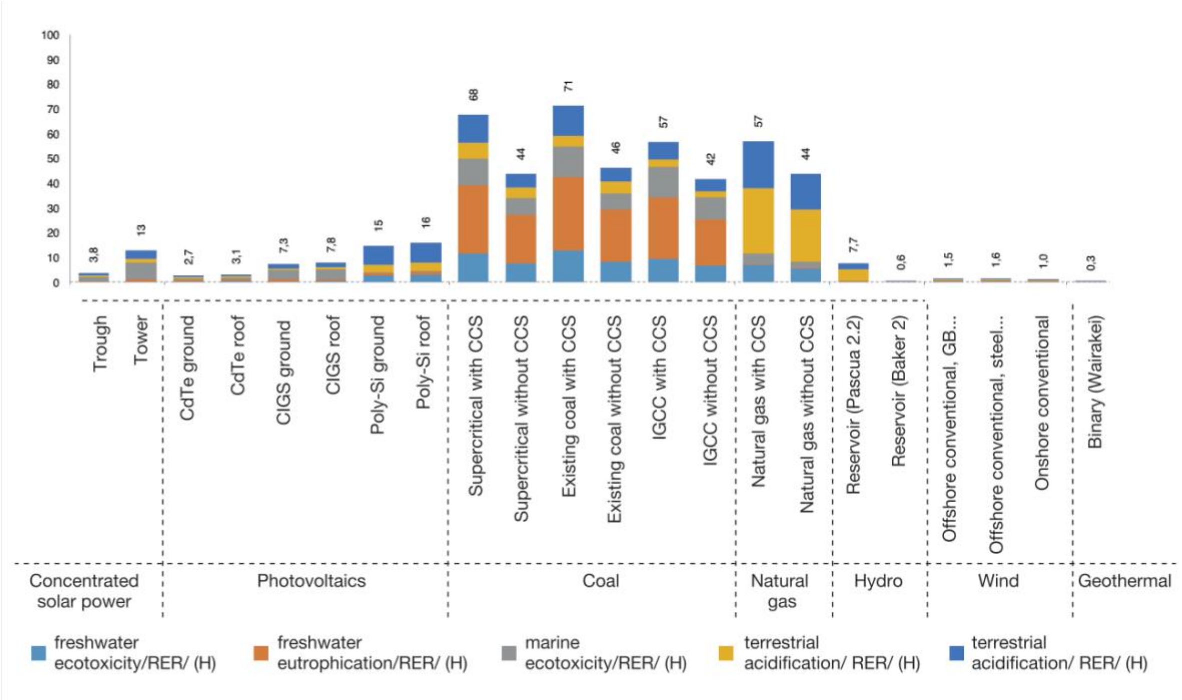


Figure 16: Comparison of the cumulative life cycle impact on ecosystem diversity in species-year per TWh of electricity production from different technology sources in Europe

Source: (UNEP, 2016)

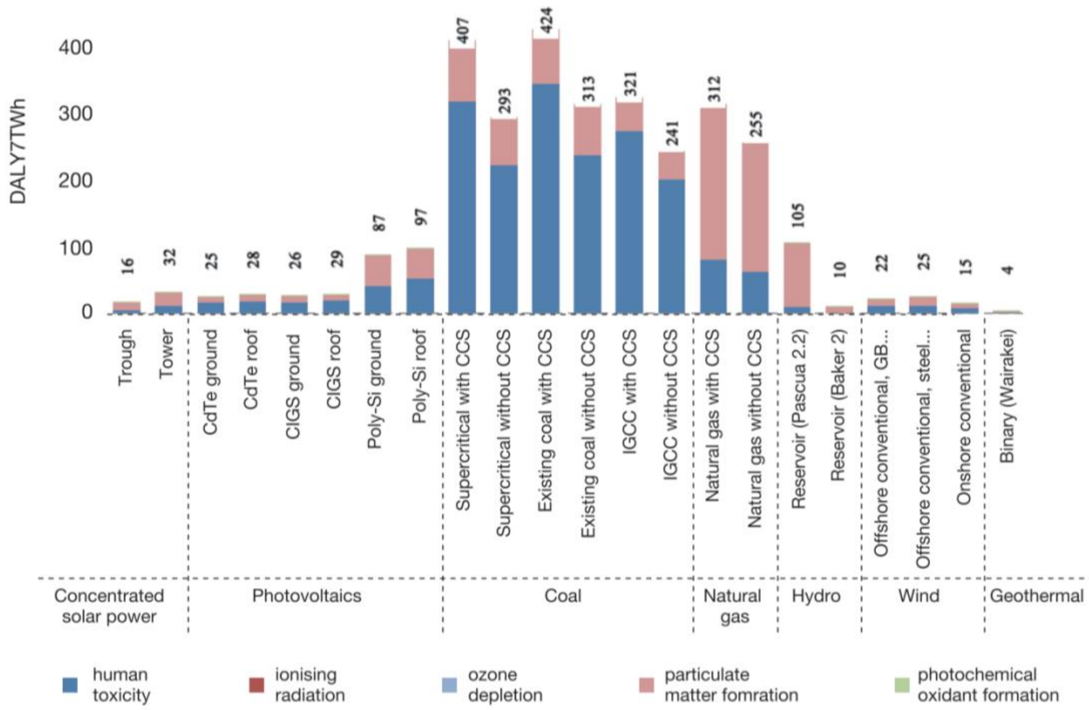


Figure 17: Comparison of the cumulative life cycle human health impact in disability adjusted life years (DALY) per TWh of electricity production from different technology sources in Europe

Source: (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.

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 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 mining in the DRC. 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. 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 (often 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 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 considered 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 are also associated with human health effects, particularly NiCd batteries.

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 array of 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.

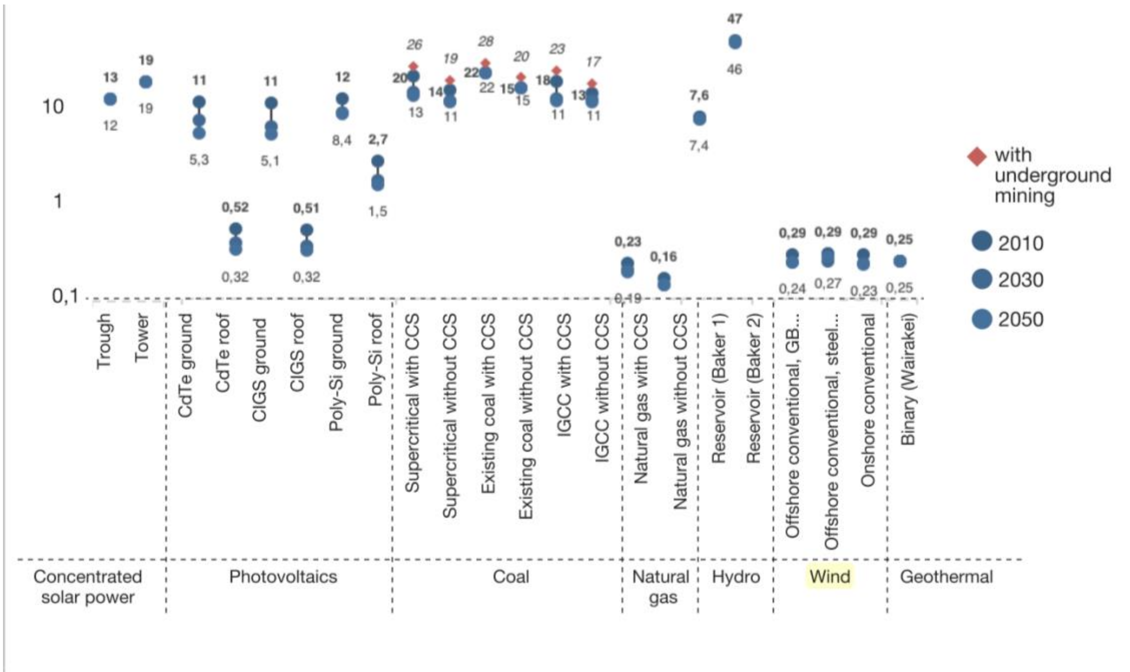
As with other technologies, the end-of-life of fuel cells needs to be properly managed to avoid negative ecosystem and human health impacts. Hazardous components include (depending on the technology) electrolytes, anodes and cathodes (Férriz *et al.*, 2019). Although technologies are available for recycling 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 JET.

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).

2.2.4 Land use

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 18).



Land occupation is measured in square meter-annum (m^2a) per MWh electricity produced, i.e. one square meter occupied over a year per MWh or one square meter for producing one MWh per year. For coal power, the light green bars represent the difference between the land occupation associated with power plants utilizing with underground mining (high) and with surface mining (low).

Figure 18: Comparison of the cumulative life cycle impact on land occupation in m^2 per MWh/a of electricity production from different technology sources in Europe

Source: (UNEP, 2016)

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 is a clear responsibility of the mining company. However, although recognised by governments as important, these activities are often not enforced due to a lack of effective policy and regulation, resulting in permanent land use change (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).

2.3 Summary of life cycle hotspots of renewable energy technologies

This section summarises the life cycle impacts of renewable energy technologies as discussed above.

Solar PV

Impacts	Resource extraction	Manufacturing and construction	Operation and maintenance	End-of-life
	Hotspots			
Resource use: minerals and metals	Requires **significant amounts of aluminium and copper as well as silver, lead, zinc, molybdenum, indium and nickel.** Silicon is also required.			
Climate Change	Mining and minerals processing of resources required is energy intensive.	**PV manufacturing is the most energy intensive of the RE technologies.**		Due to the nature of PV cells, recycling can be energy intensive.
Ecosystem health	Mining and minerals processing can negatively impact the ecosystems where they occur.	The use of chemicals (acids and solvents) in PV manufacturing can lead to emissions to the environment. Of concern is **emissions of chlorine to water**		Due to the toxic chemicals contained in PV systems, **incorrect handling at end-of-life can mean these chemicals enter the environment.** The impact of **nanomaterials** which may increasingly be used in PV panels on ecosystems is still relatively poorly understood.
Human health	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. The impact of **nanomaterials** which may increasingly be used in PV panels on human health is still relatively poorly understood.
Land use	Land disruption associated with mining.	High land-use for ground-based utility-scale systems.		Land use for end-of-life dumping/disposal of panels.
Water use	Mining may impact on water resources.			
Circularity potential	Even with recycling rates of 100% in 2050, due to the lifespan of products, primary resource extraction will still be required as secondary resources will not be available in sufficient quantities to meet 100% of demand. The distributed nature of solar PV technologies can make recovery challenging. The **composite nature of PV cells and films hampers recycling**.			

Solar CSP

	Resource extraction	Manufacturing and construction	Operation and maintenance	End-of-life
Impacts	**Hotspots**			
Resource use: minerals and metals	**Steel, aluminium, concrete, glass, silver and nitrate salts** are required. Upstream mining and quarrying of iron ore, sand, lime required.			
Climate Change	Mining and minerals processing of resources required is energy intensive.		Some systems (parabolic trough) are **backed up by a fossil fuel system.**	
Ecosystem health	Mining and minerals processing can negatively impact the ecosystems where they occur.	Land clearing and vegetation removal during construction can disrupt ecosystems, increase erosion, which in turn may impact local water bodies.		The impact of **nanomaterials** which may increasingly be used in for example mirror coatings on ecosystems is still relatively poorly understood.
Human health	Mining and minerals processing may have negative impacts on human health due to releases to air, water and soil.		Fire hazard if synthetic oil is used as a heat transfer fluid in utility systems.	The impact of **nanomaterials** which may increasingly be used in for example mirror coatings on human health is still relatively poorly understood.
Land use	Land disruption associated with mining.	**High land occupation** associated with the solar field.		Land use for end-of-life dumping/disposal of CSP infrastructure.
Water use	Mining may impact on water resources.		**High water use for cleaning and dust suppression** as dust on mirrors or panels can decrease efficiency during operation. Water use depends on site-specific conditions.	
Circularity potential	The low turnover of solar CSP plants has implications for establishing recycling value chains.			

Wind

	Resource extraction	Manufacturing and construction	Operation and maintenance	End-of-life
Impacts	**Hotspots**			
Resource use: minerals and metals	**Steel, aluminium, copper concrete, glass and carbon fibre** all require primary resource extraction. **Rare earth metals, neodymium and dysprosium** are used in magnets in some direct drive turbines.			
Climate Change	Mining and minerals processing of resources required is energy intensive.			Recycling of composite materials contained in the wind turbine can be energy intensive.
Ecosystem health	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 **nano-materials** on ecosystems is largely unknown.
Human health	**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 The impact of **nanomaterials** in wind turbines on human health is largely unknown.
Land use	Land disruption associated with mining.			Land use for end-of-life dumping/disposal of towers and materials that are not recycled.
Water scarcity	**Mining impact on water resources.**			
Circularity potential	**The composite nature of wind turbines presents challenges for recycling**. In addition, the relatively low volumes of end-of-life equipment present a challenge.			

Energy storage

Impacts	Resource extraction	Manufacturing and construction	Operation and maintenance	End-of-life
	Hotspots			
Resource use: minerals and metals	Significant quantities of **graphite, nickel, cobalt, lead, manganese, lithium** depending on which battery technology emerges. Also, represent demand for **vanadium, aluminium, chromium, copper, iron and zinc**.			
Climate Change	Mining and minerals processing of resources required is energy intensive.			
Ecosystem health	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 potentially nanomaterials can cause contamination of water and soil** and enter the food chain.
Human health	Mining and minerals processing may have negative impacts on human health due to releases to air, water and soil.			**Recycling in the informal sector can result in lead poisoning and even fatalities.** **Hazardous materials that leach from batteries** that are not properly managed at end-of-life can impact human health by **contaminating water and soil and accumulating in food chains.** The impact of **nanomaterials** from energy storage technologies is still relatively poorly understood.
Land use	Land disruption associated with mining.			Land use for end-of-life dumping/disposal of batteries and other equipment linked to storage.
Water use	Mining may impact on water resources.			
Circularity potential	Even with recycling rates of 100% in 2050, due to the lifespan of products, primary resource extraction will still be required as secondary resources will not be available in sufficient quantities to meet 100% of demand. The **distributed nature of energy storage can make collection and recycling problematic**.			

Hydro

	Resource extraction	Manufacturing and construction	Operation and maintenance	End-of-life
Impacts	**Hotspots**			
Resource use: minerals and metals	Metals are required for hydro plants including aluminium, copper and titanium, and limestone and other inputs are required for cement production.	Non-metallic mineral resources, during construction involving massive earthworks and large quantities of concrete.		
Climate Change	Mining and minerals processing of resources required is energy intensive.		High biogenic methane emissions from some dams.	
Ecosystem health	Mining and minerals processing can negatively impact the ecosystems where they occur.			
Human health	Mining and minerals processing may have negative impacts on human health due to releases to air, water and soil.			
Land use	Land disruption associated with mining.		Hydropower reservoirs occupy significant land areas causing massive disruption to ecosystems and often cultural losses due to displaced communities.	
Water scarcity	Mining may impact on water resources.			
Circularity potential	The long lifespan and nature of hydro plants does not lend itself to circularity as it is usually conceived (changes are permanent).			

Geothermal

Impacts	Resource extraction	Manufacturing and construction	Operation and maintenance	End-of-life
	Hotspots			
Resource use: minerals and metals	Geothermal plants use significantly more steel than wind. In addition, corrosion-resistant alloys are required, which translates to a demand for titanium and molybdenum. Nickel, chromium, copper and manganese are also required.			
Climate Change	Mining and minerals processing of resources required is energy intensive.		Some geogenic greenhouse gases may be released during operation.	
Ecosystem health	Mining and minerals processing can negatively impact the ecosystems where they occur.		Air, water and soil pollution from geofluid flow in some sites.	
Human health	Mining and minerals processing may have negative impacts on human health due to releases to air, water and soil.		Air, water and soil pollution from geofluid flow in some sites.	
Land use	Land disruption associated with mining.			
Water scarcity	Mining may impact on water resources.			
Circularity potential				

Biomass/bioenergy

	Resource extraction	Manufacturing and construction	Operation and maintenance	End-of-life
Impacts	**Hotspots**			
Resource use: minerals and metals	Fertilisers used in growing biomass*, Petroleum, gas or coal for the hydrocarbon stock used for production of pesticides.	Biomass power plants will use significant quantities of non-metallic minerals in their construction.		
Climate Change	Agricultural processes are energy intensive*	Processing of biomass to biofuels can be energy intensive.	Combustion of biomass and biofuels does give rise to short cycle **greenhouse gas emissions.**	
Ecosystem health	Chemicals used in agriculture.*		Unsustainable use of biomass can lead to deforestation, biodiversity loss and soil depletion.	
Human health	Chemicals used in agriculture.*		Combustion of biomass and biofuels can still lead to **air pollution and human health impacts from particulates.**	
Land use	Biomass fuels require significant land area.*		Biomass fuels require significant land area.	
Water scarcity	Significant water used in growing biomass.*			
Circularity potential	Bioenergy can contribute to a circular economy through the utilisation of biomass wastes and residues.			

*These impacts can be avoided if biomass is sourced from residues (second generation biomass) and/or minimised if grown from crops that do not require fertiliser and chemical inputs.

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

The Sustainable Development Goals (SDGs) adopted by the international community in 2015 envisions "the future we want". The 17 goals and accompanying targets set out a sustainable development agenda, Agenda 2030, providing the actions required to end poverty, protect the planet, and ensure prosperity for all. The SDGs therefore provide an appropriate lens with which to look at the actions required for a JET. A group of seven environmental civil society organizations[11] (CSOs) from around the world did just that and developed a mapping of the most important SDGs and targets to achieve a JET, as well as suggesting strategies to address the targets (from an energy production and supply perspective). The SDGs and targets identified as relevant to a JET are listed in Table 3, with a summarized version of the suggested strategic actions and the energy supply issues and SDGs addressed by the proposed actions included in Appendix A. The mapping highlights that many of the strategic actions required for a JET are cross-cutting, and address more than one issue and associated SDG/target. The strategic actions relevant to the specific topic of this report - that of addressing the circularity and sustainability of RE technologies - are integrated into the sub-sections that follow.

The actions suggested in this section **focus on wind, solar PV and storage as the RE technologies most suited to a JET**. This follows from the review of RE technologies in Section 2.1 and the suggested strategic actions for a JET to address the SDGs (Appendix A). That is, 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 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.

Thus, whilst use of biomass for energy recovery has a potential role in a JET in some circumstances (and specifically excluding purpose-grown biomass crops), as does small-scale hydro, these technologies are less compatible with the SDGs and furthermore apply in geographically-limited circumstances.

Section 2 highlights the environmental impacts of renewable technologies along their value chains. The **use of critical raw materials is identified as a particular hotspot for wind, solar PV and energy storage technologies**. 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. The fact that these technologies – and their accompanying use of resources – are set to grow exponentially in the coming decades makes this a particularly important issue. Furthermore, **many of the materials used are hazardous** which results in **end-of-life** being a further hotspot, when products are dismantled and/or disposed. Batteries are especially notable here. The **manufacturing stage of solar PV** is also identified as a hotspot with respect to its use of hazardous chemicals and high energy use.

[11] 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).

The remainder of this section considers the actions required to address the hotspots in renewable technologies' life cycles, focusing on products, chemicals and waste, whilst recognising that many of the actions are cross-cutting.

Table 3: Sustainable development goals and targets important to a JET

	Sustainable Development Goal	Target
3 GOOD HEALTH AND WELL-BEING	Ensure healthy lives and promote well-being for all at all ages	Target 3.9: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination
6 CLEAN WATER AND SANITATION	Ensure availability and sustainable management of water and sanitation for all	Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
7 AFFORDABLE AND CLEAN ENERGY	Ensure access to affordable, reliable, sustainable and modern energy for all	Target 7.1: By 2030, ensure universal access to affordable, reliable and modern energy services Target 7.2: By 2030, increase substantially the share of renewable energy in the global energy mix
8 DECENT WORK AND ECONOMIC GROWTH	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Target 8.4: Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead
11 SUSTAINABLE CITIES AND COMMUNITIES	Make cities and human settlements inclusive, safe, resilient and sustainable	Target 11:6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Ensure sustainable consumption and production patterns	Target 12.2 By 2030, achieve the sustainable management and efficient use of natural resources Target 12.4: By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment Target 12.5: By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse
14 LIFE BELOW WATER	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Target 14.1: By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution Target 14.3: Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels
15 LIFE ON LAND	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Target 15.5: Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species

3.1 Actions for products

The **high use of resources – many of them hazardous, scarce and/or with high extractive impacts - is a hotspot of wind, solar PV and energy storage**. Wind is especially notable with respect to its use of materials with high mining impacts, with mining of rare earth elements having particularly high current and potentially future impacts. Solar PV and batteries are especially notable with respect to the use of hazardous chemicals, leading to potentially high human health impacts and environmental impacts during manufacturing and when these products ultimately reach end-of-life. These aspects are broadly addressed under "Actions for products", recognising that it is in the design of products where the greatest leverage in changing their impacts lies.

The following high-level actions 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, 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.

The high use of raw materials in wind, solar and storage products translates to circularity of these products being imperative to manage limited resource stocks and minimise mining impacts. Circular Economy actions and especially the potential of Extended Producer Responsibility (EPR) to drive circularity are discussed in Sections 3.1.1 and 3.1.2 below.

The mining of resources is a hotspot with respect to the life cycle impacts of wind and solar PV technologies and associated energy storage (batteries) linked to the land and water pollution associated with mining and quarrying operations and during manufacturing. Whilst CE approaches (including EPR) seek to maximise recovery of end-of-life materials, the rapid growth of wind, solar and storage required to achieve global energy access and clean energy transitions, coupled with their long service lives in the economy, mean that there will be ongoing demand for the primary minerals used in these technologies for the foreseeable future (Dominish, Teske and Florin, 2019). Actions around mining are therefore essential and are also covered here (Section 3.1.3).

3.1.1 Circular Economy as a framework for renewables policy

Circular Economy can support the design of renewable energy 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.

The following actions 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, reproduced in Figure 19):

- Materials: 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[12] in new energy-generating products, or by the supply of waste materials for use in other manufacturing sectors.

- 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.

Leasing models for minerals and metals are a possible way to address the negative impacts on countries heavily dependent on mining (Schroder, 2020). In such models, metals are leased, rather than sold, to companies by producer countries, with the country of origin retaining ownership, with the idea that the resource is leased for a certain period of time and then "returned". The country receives revenue from leasing the materials, with the purchaser paying a premium if they fail to return the resource. Leasing is an established practice for traders and refining companies in the precious metals sectors. Leasing mechanisms would help ensure that producer countries retain long-term ownership of their natural resources (to the intended benefit of their economies). It would also provide incentives for recycling and improved design of equipment to ensure recovery of metals. Transparent governance measures at both international and country level would be critical to ensuring the success of such leasing schemes. As such, multilateral organisations, such as the World Trade Organization (WTO), would need to play a facilitating and supervisory role. A multilateral mechanism could also enable technology transfer to producer countries in the developing world, ensuring that the minerals needed for high-tech products are made available, while a lease is transferred to the developing world using new technologies (such as blockchain) to ensure the needed high degree of transparency. 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. These digital product passports would further need to be underpinned by global harmonization and global standards on disclosure of metals as well as other substances including hazardous chemicals, as discussed in Section 3.2.

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[12] 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.

For proposed interventions at all stages, **LCAs and related assessments are required to ensure product designs and processes are those least harmful to human health and the environment**. To that end, guidelines/product category rules need to be developed for renewable energy technologies and data/methods provided so that LCAs are consistent, comparable and reproducible (somewhat along the lines of the EU's Product Environmental Footprint initiative (European Commission, no date b)). This recognising that LCAs have limitations in their assessment of chemicals in products, with better methods and data being required to ensure LCAs cover all relevant impacts.

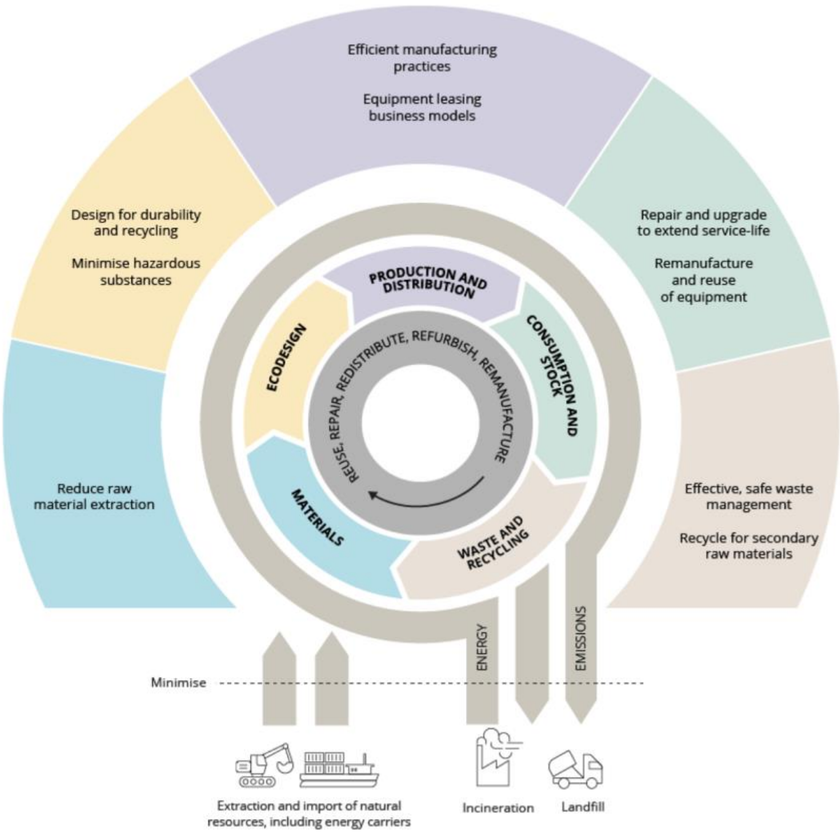

Figure 19: Actions required in a circular renewable energy system

Source: (EEA, 2021)

While the concept is not new, adoption of CE principles to guide policy and industry interventions has been slow[13] and thus far only evident with batteries in the context of energy transitions. The European Union has been at the forefront of development of CE, for example with the publication of the Circular Economy Action Plan in 2015 and 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

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

3. Policies for improving secondary materials markets.

Policy recommendations across the life cycle are illustrated in Figure 20, with possible policy instruments to support the recommendations (from a European perspective) given in Table 4. These policy recommendations should 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. Further policy instruments will also be required at the international level to account for products and wastes that flow into and out of a country or region's economy. These relate specifically to transparency on product composition and harmonization around chemicals or materials of concern (see Section 3.2 for further details).

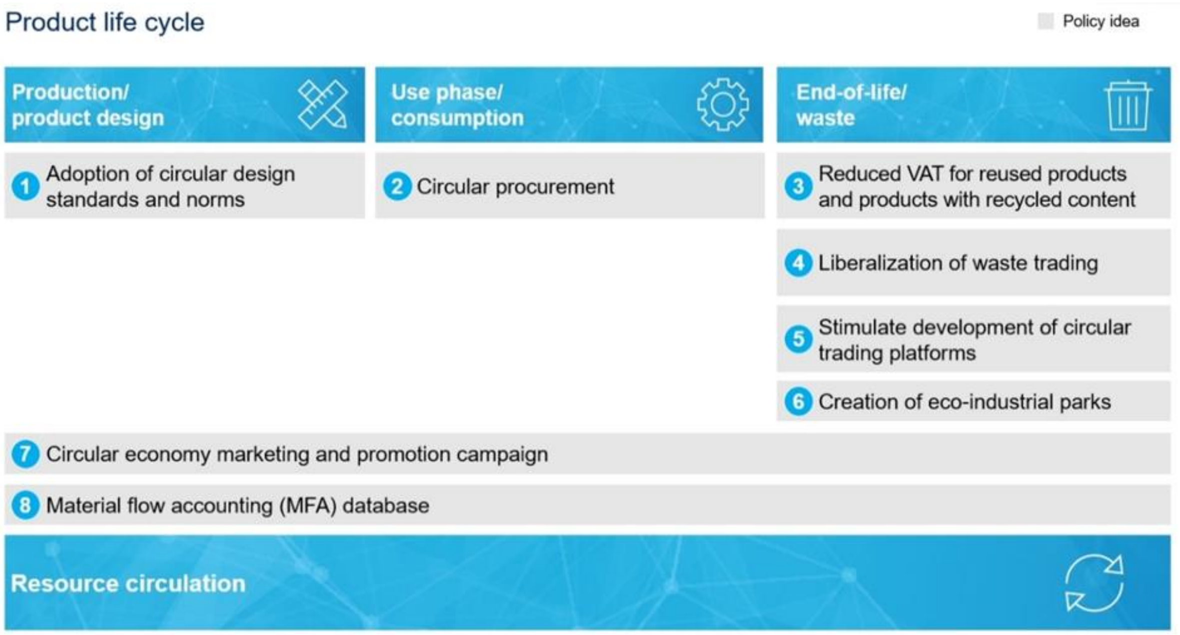

Figure 20: Policy required across the product life cycle to accelerate the transition towards a circular economy

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

Table 4: Policy recommendations and accompanying actions to accelerate the transition to a CE (Hartley, van Santen and Kirchherr, 2020)

Policy Recommendation	Proposed actions
Adoption of circular design standards and norms	• Stakeholder engagement • Subsequent top-down establishment and dissemination of standards • Mandatory period (e.g., two years) for achieving compliance targets • Development and dissemination of guidance about how to incorporate standards Example: EN45558 and EN 45559 standards on durability, reparability, and recyclability of products
Expand circular procurement	• Reorientation of procurement rules towards circular procurement (with circular products favoured over linear alternatives) • Procurement standards through thresholds for percent of recycled content, reusability, and eco-efficiency (based on a holistic view of CE) • Continuous expansion of circular procurement to create markets for circular product producers Example: Circular Procurement Green Deal initiated by the Dutch government and representing more than 100 circular procurement pilot projects

Policy Recommendation	Proposed actions
Alterations to taxes on CE-based products	• Tax relief for reused products and those having a certain percentage of recycled content • Increased taxes for linear-based products • Reduction of corporate taxes for firms engaging in CE-related behaviours (e.g., recycling, sorting, and treating) Example: Swedish VAT rates were reduced by 50% (from 25% to 12%) on repair jobs for a variety of goods including bicycles and clothing.
Liberalization of waste trading	• Reduced regulations on trading and using waste where doing so does not compromise other policy goals such as protecting health and safety • Analysis of and reform to current related waste legislation Example: "Green listed wastes" have exemptions within the European Waste Shipment Regulation
Facilitate development of circular trading platforms	• Fund-matching schemes and tax breaks for new and existing platforms • VAT exemption for products and resources sold through such platforms • Reduced regulations on trading and using waste where doing so does not compromise other policy goals such as protecting health and safety Example: The Netherlands' Circle Market, a virtual platform for connecting post-production, pre-consumer, and post-consumer excess materials to reuse and recycling markets
Creation of eco-industrial parks	• Review and institutionalisation of eco-industrial parks success factors • Eco-industrial park pilots and test-beds for experimentation • Replication and up-scaling of successful eco-industrial parks pilots Example: Sino-Singapore Tianjin Eco-city, a collaboration between the governments of China and Singapore, that includes consideration of social, environmental, and economic dimensions
Circular economy marketing and promotion campaign	• Campaigns focusing on the importance of CE, through traditional channels (e.g., TV, radio, and magazines) and other channels (e.g., social media such as Snapchat, Instagram, and Facebook) • Crowd sourcing competitions to generate ideas and ownership • Financial "top-ups" for CE awareness campaigns in operation Example: British mass media campaign against smoking, in which higher expenditures were shown to raise awareness and therefore higher rates of smoking cessation
Global material flow accounting (MFA) database	• Funding for the development and operation of an MFA database, making access transparent, user-friendly, and available at minimal or no cost • Requirements for producers to collect information about the type, volume, and condition of their own waste outputs for feed-in to the database Example: UN Environment International Resource Panel Global Material Flows Database, which covers most countries and enables visualization and analysis for policymaking and research

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 is thus about extending producers' responsibility to the post-consumer stage of a product life cycle, through requiring manufacturers of goods to take financial and/or physical responsibility for their products at the end of their useful lives. 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, including the collection and recycling of materials, there has been an expansion of focus to including business model innovation, such as "products-as-service", whereby rather than purchasing products the services they provide are procured. EPR is thus an important policy tool to drive the Circular Economy.

EPR policy interventions have been introduced in a number of countries and sectors across the world, with several European countries, including Sweden, Germany and France, having launched the first EPR schemes back in the 1990s. Europe continues to be at the forefront, with its Circular Economy Action Plan (European Commission, 2020a).

EPR legislation has been applied to renewable technologies to varying degrees. In Europe, the Waste Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU entered into force on 14 February 2014, superseding the original WEEE Directive 2002/96/EC, which entered into force in 2005. This Directive 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, 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[14] 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 around wind turbine end-of-life. These recommendations can be categorised into i) recommendations for composite recycling technologies to process existing turbine blades, and ii) recommendations for the development of new blades (ETIPWind Executive Committee, 2020).

Recycling or recovery processes for wind turbines include mechanical grinding, thermal processes (pyrolysis), thermo-chemical treatment (solvolysis) and electro-mechanical technologies (high voltage pulse fragmentation). However, the main technology currently used for end-of-life management of composites is through using them as an energy source in cement production processes, with combustion requiring careful controls to avoid releases of hazardous emissions. (cefic, EuCIA and Wind Europe, 2020). The recommendations for increased uptake of composite recycling technologies to process existing turbine blades, which would be preferred to combustion, include the establishment of a cross-sectoral platform to share best practices in the recycling of composites and can extend to the development of large-scale demonstration facilities. There are also recommendations to direct funding towards research that determines the feasibility of various emerging recycling technologies. Funding should be made available to provide support to manufacturing processes that use materials from recycled blades in the production of other products. Policies promoting the proliferation of existing treatment and recycling routes are also recommended, and reinforcement of the value chain for recycling of composite waste should be promoted through policy. Policy interventions are needed to create a larger market for the recycling of composites to ensure that these are able to be recycled at end-of-life (see Section 3.3 for a consideration of policy and legislative actions that can be taken to support secondary materials).

Policy recommendations around the development of new blades focus on the design approach and particularly on the development of new materials for the manufacture of wind turbine blades. The first major recommendation is to allocate funding to the research and development of high-performance materials such as aramid and basalt fibres that have increased recyclability. The next major policy recommendation is to require the incorporation of sensor technology in turbine blades in order to collect data on turbine health and monitor performance. This will assist in scheduling turbine maintenance which increases the life span of the turbine and leads to a lower turbine turnover

[14] https://pvcycle.org/

rate. The final major policy recommendation is to encourage turbine blade designers to consider reuse options and recycling technologies in the design process and in the selection of materials.

The EU's Directive 2006/66/EC on batteries and accumulators, otherwise known as the Batteries Directive, was amended in 2018. The Directive 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 through financing of 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).

Looking ahead, emerging economies which do not have such legislative frameworks in place could explore adopting elements of the EPR frameworks used in Europe towards supporting just transitions in the renewables sector in their own countries, recognising that not all approaches are universally applicable, and learning from the challenges in implementing EPR in Europe, particularly with regards to transparency. These challenges relate specifically to difficulties in getting information about the chemical composition of complete products that are imported, or the chemical composition of product components from international supply chains that fall outside the jurisdiction of EU legislation. In addition, there are challenges in terms of accountability once products leave the EU jurisdiction, for example as e-waste for recycling, which may end up in the informal sector. In both cases, multilateral collaboration and global harmonization and global standards for disclosure/transparency for hazardous chemicals (through product passports as an example) are imperative to address these issues. Such harmonized standards can also help companies identify priority chemicals for substitutions.

There is also some developing country experience emerging on EPR as well that can be drawn upon. South Africa has recently introduced EPR legislation (Government of South Africa, 2020, 2021), and although this does not cover renewable energy technologies it could be adapted to doing so. Kenya is introducing EPR on packaging at the time of writing this document. India applied EPR to lead-acid batteries in 2001 and to e-waste in 2011, as did China in 2009 and Vietnam in 2013. Nevertheless, without global agreements and standards in place, low to middle-income countries will face the same challenges as the EU and will have less resources and prospects to solve these issues without multilateral collaboration and global harmonization and standards.

3.1.3 Addressing the impacts of primary resource mining

Section 2.2.2 details the large array of metals to be mined as inputs for the production of wind, solar PV and energy storage technologies. In many cases, impacts occur in countries or locations other than where the renewables technologies are installed.

The need for measures for managing the impacts of mining operations are not unique to the renewables sector, and society has long grappled with the best policy and legislative interventions in this regard. The International Council for Mining and Minerals (ICMM), an organisation with membership of 28 of the world's largest mining and metals company members and over 35 national, regional and commodities association members, has defined a set of principles to guide sustainable mining, to which members must subscribe (ICMM, 2022). The principles map onto the challenges of a JET and the SDGs. Principle six relates specifically to environmental performance and covers five 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

If adequately addressed, the five performance expectations would go some way to addressing the land and water impacts associated with mining and quarrying. It is recognised, however, that holding companies voluntarily accountable to their commitments to the principles of an international association is not sufficient to minimise environmental harm. As such**, appropriate policy, legislation and regulation is required where minerals for renewables infrastructure (and other purposes) are extracted and processed**. Each jurisdiction has different measures in place, with an extensive review of mining legislation from around the world being available in Global Legal Group (2020). Areas typically covered by environmental legislation include (GLG, 2020):

- Water access, management and water resource protection;
- Tailings and hazardous and non-hazardous waste management;
- Air pollution;
- Soil/land contamination; and
- Mine closure.

Despite legal instruments covering these topics being in place in most parts of the world where there is primary resource extraction, the level of enforcement is not always consistent, giving rise to environmental risks. This has been reflected in both catastrophic once-off events and long-term negative impacts on communities and the environment in parts of the world. **Ongoing enforcement of policy legislation and associated regulation is thus 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**. At a global level, the **Convention on Biological Diversity seeks to protect life on land and in water.** As one of the Convention's cross-cutting issues the incorporation of biodiversity considerations in impact assessment, including for mining and minerals processing, is considered, The United Nations Convention on the Law of the Sea, provides the legal framework for the conservation and sustainable use of oceans and their resources. The SDGs, which are recognised to be voluntary, also address these issues. Actions under the SDG14, Life below Water, are notable in the protection of marine biodiversity and the prevention of seabed mining, particularly Target 14C: Implement and Enforce International Sea Law. Target 14C calls to enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in the Convention of the Law of the Sea. Actions under SDG15 Life on Land (particularly 15.1 Conserve and Restore Terrestrial and Freshwater Ecosystems and 15.5 Protect Biodiversity and Natural Habitats) are notable in the fight towards preventing mining in sensitive areas and the substantial ecosystem damages that result, particularly on water resources.

3.2 Actions for chemicals

The presence of hazardous chemicals in RE technology products are identified as a hotspot, particularly in solar PV cells and storage batteries. These hazardous chemicals give rise to impacts at end-of-life, where they pose a health risk to recyclers and to the environment if incorrectly handled and disposed of. Chemicals used during the manufacture of PV panels is also identified as a hotspot.

The following high-level considerations are proposed to shape chemical legislation around renewable energy technologies:

- 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, as 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 the following 11 basic elements to be critical at the national and regional levels to attaining sound management of chemicals and waste (SAICM, 2015):

1. Legal frameworks that address the life cycle of chemicals and waste;
2. Relevant enforcement and compliance mechanisms;
3. Implementation of chemicals and waste-related multilateral environmental agreements, as well as health, labour and other relevant conventions and voluntary mechanisms;
4. Strong institutional frameworks and coordination mechanisms among relevant stakeholders;
5. Collection and systems for the transparent sharing of relevant data and information among all relevant stakeholders using a life cycle approach, such as the implementation of the Globally Harmonized System of Classification and Labelling of Chemicals, the establishment of globally harmonized transparency standards, product passports and similar;
6. Industry participation and defined responsibility across the life cycle, including cost recovery policies and systems as well as the incorporation of sound chemicals management into corporate policies and practices;
7. Inclusion of the sound management of chemicals and waste in national health, labour, social, environment and economic budgeting processes and development plans;
8. Chemicals risk assessment and risk reduction through the use of best practices;

9. Strengthened capacity to deal with chemicals accidents, including institutional-strengthening for poison centres;
10. Monitoring and assessing the impacts of chemicals on health and the environment;
11. Development and promotion of environmentally sound and safer alternatives.

Many countries have incorporated (or are incorporating) the SAICM elements into their national legislation, with examples of national legislation on the management of chemicals provided in Table 5. 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 able to 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 OECD Global Portal to Information on Chemical Substances (eChemPortal)[15] 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

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

is especially critical for safe 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[16], 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[17], 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.

Table 5: Examples of national legislation on the management of chemicals

Country	Elements of national legislation on the management of chemicals	Sources
India	The Indian Draft Chemicals (Management and Safety) Rules, which have long been under development, provides for the notification, registration and restriction/prohibitions of certain substances The Rules will introduce a REACH-like system of registration and requirements for certain priority substances All importers or manufacturers will need to notify the National Chemicals Authority of all existing substances that they have placed in Indian territory if those substances are in excess of 1 tonne per year. New chemical substances must also be notified before they are manufactured in India or imported into the country Importers who are planning to bring priority substances into the country in quantities of greater than 1 tonne must follow stringent reporting measures and liaise with the concerned authority to ensure proper documentation and record keeping The Priority Substance Unit of the National Chemical Authority will assess if a registered substance poses an unacceptable risk to human safety or the environment and will propose to restrict or prohibit the use of such substance Manufacturers, distributors and importers of priority substances and hazardous chemicals and mixtures must comply with labelling and packaging requirements related to the use of substances, substances in mixtures, substances in articles and intermediates placed or intended to be placed in Indian Territory	(Indian Chemical Regulation Helpdesk, no date; SGS, 2020)
China	Decree 591 on the Regulations of Safe Management of Hazardous Chemicals is the major decree governing chemical control in China and was implemented in 2011. The decree is supported by several regulations and guidance documents Decree 591 regulates the entire supply chain of hazardous chemicals which includes manufacture, importation, distribution, storage, transportation and use The Ministry of Environmental Protection (MEP), the State Administration of Work Safety (SAWS) and the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) are the three main ministries involved in the enforcement of the decree The decree introduced mandatory Globally Harmonized System (GHS) of the Classification and Labelling of Chemicals Article 15 of the decree requires chemical manufacturers to provide safety data sheets and labels in accordance with relevant national standards. Article 37 of the decree prohibits distributors from selling hazardous chemicals without labels or safety data sheets	(The National Law Review, 2020b, 2020a)

[16] See the relevant legislation here: https://echa.europa.eu/legislation
[17] The database can be accessed through this link: https://echa.europa.eu/scip-database

Country	Elements of national legislation on the management of chemicals	Sources
	Over 2800 chemicals are listed in China's catalogue of hazardous chemicals which was published in 2015. Any organisation handling these chemicals are subject to license requirements and stringent handling measures Any organization involved in the producing, importing, distributing or utilization of hazardous chemicals as listed in the Catalogue of Hazardous Chemicals must obtain a license from the State Administration of Work Safety. A production license, operation license or safe use license must be procured depending on the nature of the organization's operations	
Brazil	The Preliminary Bill for the Inventory, Evaluation, and Control of Chemical Substances is a draft law that sets provisions on the creation of a national existing chemical substance inventory, and on the evaluation and control of chemical substances The bill also makes mandatory the Globally Harmonized System (GHS) of the Classification and Labelling of Chemicals for industrial chemicals in any workspace The draft law applies to industrial chemical substances in quantities of greater than 1 tonne per year Article 6 and 7 of the draft bill requires importers or producers of industrial chemical substances to adhere to stringent documentation requirements that will be submitted to the country's National Chemical Safety Commission (CONASQ). This information will be used to build a National Inventory of Chemical Substances Once the National Inventory of Chemical Substances has been finalised, any new industrial chemical substances being imported or produced in the country will need to be registered as a new substance	(ChemSafetyPRO, 2018a, 2018b)
South Africa	The Hazardous Substances Act of 1973 (authorised by the Department of Health) is the major chemical legislation that sets requirements on the prohibition and control on the manufacture, importation, sale, use, modification and disposal of hazardous substances Hazardous substances covered by the Act are listed classified into four groups: Group I: industrial chemicals (IA) and pesticides (IB); Group II: 9 classes of wastes excluding Class 1: explosives and class 7: radioactive substances; Group III: electronic products and group; Group IV: radioactive substances Anyone who intends to sell or distribute any hazardous substance must obtain a license from the Department of Health before doing so. Mixtures containing any of the listed hazardous substances are also considered as hazardous substances and therefore also require a license before sale or distribution Another piece of legislation which has relevance to chemicals is the National Environmental Management Act of 1998 which prohibits the manufacturing, use, import or export of asbestos and introduces regulations directing the phasing out Polychlorinated Biphenyls (PCBs)	(Government of South Africa, 1973, 1998)

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.

As discussed in Section 3.1.1, 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. Most national legislation around waste includes some provision around encouraging recycling (see Table 6). Nonetheless 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.
- 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 can inadvertently 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. Reprocessing tailings might become increasingly feasible as prices for metals rise and processing technologies advance. Again, this should only be contemplated if it can be done without undue risks to human health, safety and the environment.

Table 6: Examples of national legislation on the management of waste

Country	Elements of national legislation on the management of waste	Sources
China	The major law regulating waste management is the Solid Waste Environmental Pollution Prevention and Control Law (commonly abbreviated to the Solid Waste Law) of 1995 The Solid Waste Law regulates the pollution from industrial waste, household waste, construction waste, agricultural waste, and hazardous waste. The latest amendment was made in April 2020 The newest iteration of the law emphasises the need for reduction of solid waste, the need to increase recycling and to decrease streams of waste that are considered harmful or hazardous The amended Solid Waste Law requires solid waste generators to record the types, quantities, flow, storage, utilization, disposal and other information about their industrial solid waste. This facilitates traceability of waste streams Waste generators must use the services of registered waste vendors to transport and dispose of their waste. Waste generators will also be held liable for any damages or breach of regulation caused by the waste vendors in the waste management process The amended Solid Waste Law requires solid waste generators to perform a production auditing process. The purpose of the audit is to identify reasons for heavy pollution and propose solutions for reducing and recycling wastes. Other audit outcomes include the selection and implementation of a technically, economically, and environmentally feasible clean production scheme The amendment requires actions that move towards “zero” imports of solid wastes and prohibits the use of imported solid waste as raw materials	(The National Law Review, 2020c; Wang, 2020)

Country	Elements of national legislation on the management of waste	Sources
India	There are several laws and acts that govern waste management in India. The Environmental Protection Act of 1986 enabled the Central Indian Government to develop and implement the Environmental Protection Rules which are a series of legislation guiding waste management in India The Bio-medical Waste Rules of 1998, the Batteries Rules of 2001, the Hazardous Waste Rules of 2008, the Plastic Waste Rules of 2011 and the e-Waste Rules of 2011 are all a result of the Environmental Protection Act (which was revised in 2016) The Environmental Protection Act confers the power to regulate all forms of waste to the Central Government of India. A key provision of the act is the prohibition on any activity emitting or discharging environmental pollutants in excess of the prescribed standards. The Act also includes a polluter pays principle whereby any act of environmental degradation results in a fine which is to be paid by the perpetrating party The Batteries Rules were put in place in order to deal with the waste generated from the disposal of lead acid batteries. These Rules apply to any organisation or individual handling and utilising lead acid batteries (manufacturer, distributer, importers, recyclers and bulk consumers). Consumers are required to return spent batteries to registered collection centres who must then send the collected used batteries to recyclers The Hazardous Waste Rules provide guidelines on the management, handling and transboundary movement of hazardous waste. Producers of hazardous waste are required by the Rules to call upon the services of specialised hazardous waste management companies to dispose of their hazardous waste. The import of hazardous waste to India for the purpose of recycling and resource recovery is permitted with the relevant permissions The E-waste Management Rules aim to regulate the disposal and recycling of E-waste by providing firm handling, management and disposal guidelines	(Bhattacharya, 2016; Sambyal, 2016; Central Pollution Control Board, 2021)
South Africa	The National Environmental Management: Waste Act of 2008 is the major legislation concerning waste management in South Africa. The National Waste Management Strategy of 2020 is a legislative requirement of the Act and was put in place to achieve the objectives of the Waste Act The purpose of the Act is to provide requirements and timeframes for the management of certain wastes; provide guidelines on how to classify types of waste; prescribe requirements for disposal to landfill; prescribe duties of waste generators, transporters and managers The implementation plan for the National Waste Management Strategy is designed to increase awareness and compliance around waste and facilitate creation of jobs in the waste sector The strategy is focused on preventing waste and diverting waste from landfill by leveraging the concept of the circular economy The National Waste Management Strategy is structured around a framework of eight goals: – Ensure that people are aware of the impact of waste on the environment as well as on their health and well-being – Promote waste minimisation, re-use, recycling and recovery of waste – Increase the contribution of the waste sector to the green economy – Achieve integrated waste management planning – Ensure sound budgeting and financial management for waste services – Provide measures to remediate contaminated land – Establish effective compliance with and enforcement of the Waste Act – Ensure the effective and efficient delivery of waste services. EPR regulations came into effect in May 2021, covering the electrical and electronic equipment sector, the lighting sector, and paper, packaging and some single use products	(Government of South Africa, 2008, 2011, 2013, 2020, 2021)

Guiding and supporting national legislation are global agreements that aim to limit the impacts of hazardous wates. The Basel Convention (1992) was designed to reduce movement of hazardous waste between nations, and specifically to prevent transfer of hazardous waste from developed to developing nations. The Basel Convention considers toxic, poisonous, explosive, corrosive, flammable, ecotoxic and infectious wastes, with categories relevant to renewables including those linked to solvents and metal content of wastes. In 2019, the Basel convention was also amended to include plastic wastes, given the scale of their ongoing transboundary movement and persistence in the environment, including in the marine environment. Other relevant conventions include the Bamako Convention of 1998 which focuses on imports into and control of transboundary movement and management of hazardous wastes within Africa (UNEP, 1998), and the Waigani Convention which serves a similar function in the Pacific region (SPREP, 2001).

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). Some EU member states have largely fulfilled the sub-targets set out in the Directive, while others have until 2030 to do so.

Solar PV, wind turbines and energy storage have substantial potential for material recovery at end-of-life (see Figure 21). Although they are currently mostly treated as general waste and landfilled, this is likely to change as the volumes requiring processing increase (allowing recycling at scale), along with increasing demand for the critical materials they contain (translating to high prices and more financially viable recycling processes). Nonetheless, governments, working with producers, should consider some sort of financial support and/or subsidies in the near-term to allow recycling processes and markets for the secondary materials they produce to become established. Table 7 summarises the key opportunities and challenges with regards the recycling of these energy technologies.

Depending on the renewable energy technology and recycling facilities in place in a particular jurisdiction, there is likely to be still the need for components of the renewables infrastructure to require final disposal measures to be put into place. 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. In order to ensure minimisation of human and environmental risks associated with the impacts of disposal of such components, 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.

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. One option identified previously is 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). Recovery of energy from waste is a highly contested option for waste management around the world, with concerns about potential for generation of toxic pollutants if infrastructure is not operated properly. As such, 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.

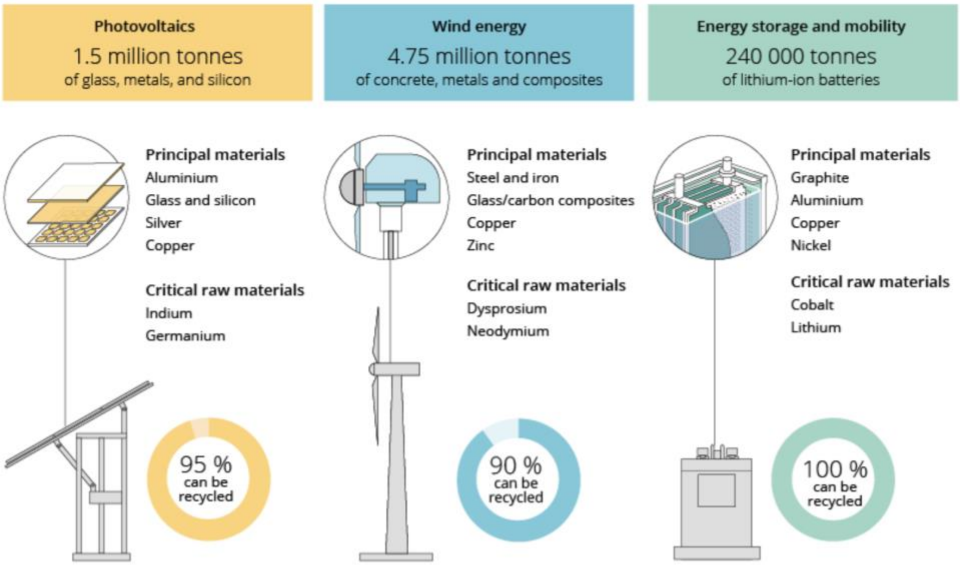

Figure 21: Material resource recovery opportunities for solar PV, wind and energy storage (Li-ion batteries)

Source: (EEA, 2021)
Note: the diagram shows technical recyclability, which does not consider feasibility in terms of energy costs and required economies of scale

Table 7: Summary of opportunities and challenges around the recycling of solar PV, wind turbines and energy storage batteries (EEA, 2021)

RE Technology	Opportunities	Challenges
Solar PV	• 95 % of the materials can be recycled (e.g., glass, copper, aluminium, etc.)	• Economic and technological challenges with delamination, separation and purification of the silicon from the glass and the semiconductor thin film • The presence of hazardous substances such as cadmium, arsenic, lead, antimony, polyvinyl fluoride and polyvinylidene fluoride • Access issues for working on panels installed at height
Wind	• 90 % of the mass of resources can be recycled (e.g., steel, aluminium, copper, cast iron and concrete) • Critical raw materials (neodymium, praseodymium, boron, dysprosium and niobium) could make recycling of permanent magnet generators of wind turbines profitable (depending on the concentration and future demand/prices)	• Recycling infrastructure is still under development for turbine blades made of lightweight materials like carbon fibre, glass fibre and composite materials, with further research and implementation needed • Downcycling of carbon fibres is applied, e.g., as plastic moulded Euro pallets, polymer concrete and other construction applications, such as noise proof barriers and thermal insulation materials • Huge size of blades can make transportation costs prohibitive for long-distance hauls to recycling facilities located far away

RE Technology	Opportunities	Challenges
Storage batteries	• All metals used in batteries can be recycled. Cobalt and nickel could be valuable enough to make recycling profitable, depending on price levels and the amounts recoverable • Increased circularity can be supported though modular/standardised design to promote remanufacturing; and enhanced information about the content of high impact materials	• There is a variety of different battery designs requiring specific and different logistics approaches. New battery technologies and chemistries are likely to emerge in the future • The infrastructure to transport and store the growing number of waste batteries is inadequate and needs to be expanded to cope with predicted future high volumes of EoL batteries • There is a lack of battery recycling technologies and large-scale recycling capacities • Economic efficiency of battery recycling can be difficult to achieve, due to fluctuating material values • Safety measures to reduce risks of a "thermal runaway" during logistics and reprocessing are expensive

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 (social, economic and environmental) relating to a Just Energy Transition (JET).

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. 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. 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 8.

Table 8: 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[18], IIED[19] 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 and agreements
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

[18] International Council on Mining & Metals (ICMM) https://www.icmm.com
[19] International Institute for Environment and Development (IIED) https://www.iied.org

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APPENDIX A

Strategic action required	Issue to be addressed for a JET	SDGs and targets addressed
Promote participatory decision making in use and management of natural resources by those affected or potentially affected by extractive activities.	• Extraction of raw materials for RE technologies contaminate air, water and soil	3, 6 (5.5, 16.7)
Use the materials least harmful to human health and environment.	• Extraction of raw materials for RE technologies contaminate air, water and soil • Unsustainable management and use of chemicals in materials and fuels in energy producing/transmitting devices and energy production	3, 6, 7, 11, 12, 14, and 15
Request LCAs on RE technologies prior to their release in the market (so that materials used are those least harmful to human health and environment). Studies should cover all relevant impacts (including chemical safety).	• Production of raw materials for RE technologies contaminate air, water and soil • Dependency on fossil fuel • Linear economy, requiring large inputs of energy, raw materials and processing chemicals. • Unsustainable management and use of chemicals in materials and fuels in energy producing/transmitting devices and energy production • Marine pollution from atmospheric fallout of pollution caused by energy production, or leakage from hazardous ashes from energy production. Acidification of aquatic ecosystems due to energy production with fossil fuels. • Degradation of terrestrial ecosystems and loss of biodiversity due to impacts from energy production throughout the life cycle of fuels and materials. Acidification due to energy production from fossil fuels.	3, 6, 7, 8, 12, 14 and 15 (12.2, 12.4 and 12.5)
Decouple economic growth from environmental degradation, i.e. create a CE using less raw materials, energy and processing chemicals	• Production of raw materials for RE technologies contaminate air, water and soil • Dependency on fossil fuel • Linear economy, requiring large inputs of energy, raw materials and processing chemicals. • Unsustainable management and use of chemicals in materials and fuels in energy producing/transmitting devices and energy production • Waste is wasted • Marine pollution from atmospheric fallout of pollution caused by energy production, or leakage from hazardous ashes from energy production. • Acidification of aquatic ecosystems due to energy production with fossil fuels. • Degradation of terrestrial ecosystems and loss of biodiversity due to impacts from energy production throughout the life cycle of fuels and materials. Acidification due to energy production from fossil fuels.	3, 6, 8, 12, 14 and 15 (3.9, 6.9, 8.4, 12.2, 12.4 and 12.5)

Strategic action required	Issue to be addressed for a JET	SDGs and targets addressed
Sound management of chemicals and waste regulated by law (i.e., fulfilling the 11 core elements in the SAICM Overall Orientation and Guidance Document for achieving the 2020 goal of sound management of chemicals)	• Extraction and production of raw materials for RE technologies contaminate air, water and soil • Unsustainable management and use of chemicals in materials and fuels in energy producing/transmitting devices and energy production • Unsound management and waste in materials and fuels in energy producing/transmitting devices and energy production. • Waste is wasted • Marine pollution from atmospheric fallout of pollution caused by energy production, or leakage from hazardous ashes from energy production	3, 6, 12 and 14 (3.9, 6.9, 8.4, 12.2, 12.4 and 12.5)
Promote ecolabelling of energy producing and transmitting devices to spur additional innovation by forerunners	• Production of raw materials for RE technologies contaminate air, water and soil • Unsustainable management and use of chemicals in materials and fuels in energy producing/transmitting devices and energy production	3, 6 and 12 (3.9, 6.9, 8.4, 12.2, 12.4 and 12.5)
Preferentially produce RE with non-combustion techniques (less air emissions and toxic ashes)	• Energy production based on combustion contaminate air, water and soil in the fuel extraction and refining processes, potentially hazardous combustion products and hazardous ashes that may cause illness and deaths. • Local communities, particularly women, are often excluded in energy decision making processes (one billion people without access to electricity and 2.7 billion dependent on traditional energy sources for cooking and heating) • Cities supplied by energy from fossil fuels and produced with combustion techniques. Energy inefficient buildings • Unsustainable management and use of chemicals in materials and fuels in energy producing/transmitting devices and energy production • Marine pollution from atmospheric fallout of pollution caused by energy production, or leakage from hazardous ashes from energy production. • Acidification of aquatic ecosystems due to energy production with fossil fuels. • Degradation of terrestrial ecosystems and loss of biodiversity due to impacts from energy production throughout the life cycle of fuels and materials. Acidification due to energy production from fossil fuels.	3, 6, 7, 11, 12, 14 and 15 (3.9, 5.5, 6.9, 7.2, 8.4, 8.6, 12.2, 12.4 and 12.5)
Promote through policy advocacy the phase out of coal mining by declaring moratorium on mine licensing	• Energy production based on combustion contaminate air, water and soil in the fuel extraction and refining processes, potentially hazardous combustion products and hazardous ashes that may cause illness and deaths. • Dependency on fossil fuel.	3, 7, 12 and 13
Transparency in the labelling and disclosure of chemical composition of materials used in the oil and gas sector	• Energy production based on combustion contaminate air, water and soil in the fuel extraction and refining processes, potentially hazardous combustion products and hazardous ashes that may cause illness and deaths.	3, 12 and 13
Promote the use of cost-effective abatement technology through advocacy and improved enforcement of regulation	• Energy production based on combustion contaminate air, water and soil in the fuel extraction and refining processes, potentially hazardous combustion products and hazardous ashes that may cause illness and deaths.	9, 12 and 13

Strategic action required	Issue to be addressed for a JET	SDGs and targets addressed
Promote local community participation, particularly of women, in decision making at all levels with respect to energy access and supply	• Local communities, particularly women, are often excluded in energy decision making processes (one billion people without access to electricity and 2.7 billion dependent on traditional energy sources for cooking and heating)	7 (5.5)
Promote supply and demand for decentralised community controlled RE solutions, preferentially non-combustion techniques, by awareness raising, lobbying, and easy access to financial services, including affordable credits.	• Local communities, particularly women, are often excluded in energy decision making processes (one billion people without access to electricity and 2.7 billion dependent on traditional energy sources for cooking and heating) • Dependency on fossil fuel • Cities supplied by energy from fossil fuels and produced with combustion techniques. Energy inefficient buildings	3, 7, 11, 14 and 15 (3.9, 5.5, 6.9, 8.4, 12.2, 12.4 and 12.5.)
Promote abolishment of subsidies for fossil fuels.	• Dependency on fossil fuel. • Cities supplied by energy from fossil fuels and produced with combustion techniques. Energy inefficient buildings • Unsustainable management and use of chemicals in materials and fuels in energy producing/transmitting devices and energy production • Marine pollution from atmospheric fallout of pollution caused by energy production, or leakage from hazardous ashes from energy production. • Acidification of aquatic ecosystems due to energy production with fossil fuels. • Degradation of terrestrial ecosystems and loss of biodiversity due to impacts from energy production throughout the life cycle of fuels and materials. Acidification due to energy production from fossil fuels.	7, 11, 12, 13, 14 and 15 (3.9, 6.9, 8.4, 12.2, 12.4 and 12.5)
Promote energy production with domestic energy sources, and local solutions creating independence from large-scale energy supply systems.	• Dependency on fossil fuel. • Degradation of terrestrial ecosystems and loss of biodiversity due to impacts from energy production throughout the life cycle of fuels and materials. Acidification due to energy production from fossil fuels.	7 and 15 (12.2)
Promote regulation promoting eco-design to spur innovation of energy producing/transmitting devices that are more easily recycled.	• Linear economy, requiring large inputs of energy, raw materials and processing chemicals • Waste is wasted	8, 12, 14 and 15 (3.9, 6.9, 8.4, 12.2, 12.4 and 12.5)
Promote legally binding rules for full information disclosure on chemical contents in all constituent components of products, and requirements for information transfer between all stakeholders in supply chains. This is a prerequisite for a safe circular economy. Spurs substitution of hazardous chemicals/materials. Use of, e.g., the SIN list, as a starting point for globally harmonized transparency rules.	• Linear economy, requiring large inputs of energy, raw materials and processing chemicals • Waste is wasted	8, 12, 14 and 15 (12.2, 12.4 and 16.10)
Promote EPR with take back schemes for companies producing energy producing/transmitting devices	• Linear economy, requiring large inputs of energy, raw materials and processing chemicals	8 (12.2, 12.4)

Strategic action required	Issue to be addressed for a JET	SDGs and targets addressed
Promote a JT through deliberate economic diversification, of regions previously depended on fossil fuel production, towards locally owned low-carbon economies	• Linear economy, requiring large inputs of energy, raw materials and processing chemicals	3, 8, 9,12, 13 and 17
Promote energy efficient building codes	• Cities supplied by energy from fossil fuels and produced with combustion techniques. Energy inefficient buildings.	11 (7:2 and 7:3)
Promote the adoption of the theory of *New Urbanism* in Regional and urban planning at the local government level	• Cities supplied by energy from fossil fuels and produced with combustion techniques. Energy inefficient buildings.	11, 12, 13 and 17
Improvement of institutional capacity for Marine spatial planning and management of Marine protected areas	• Marine pollution from atmospheric fallout of pollution caused by energy production, or leakage from hazardous ashes from energy production	7, 12 and 14
Improve institutional readiness and risk management capacity to deal with marine disasters such as chemical and oil spills	• Marine pollution from atmospheric fallout of pollution caused by energy production, or leakage from hazardous ashes from energy production	7, 12 and 14