European Environment Agency

Emerging waste streams: Opportunities and challenges of the clean-energy transition from a circular economy perspective

Emerging waste streams: Opportunities and challenges of the clean-energy transition from a circular economy perspective

Renewable energy technologies, such as wind turbines, solar photovoltaic panels and batteries, are essential for Europe's transition to climate neutrality. Deployment, maintenance and replacement of this infrastructure requires significant resources, including many substances included in the EU list of critical raw materials. Waste arising from end-of-life clean energy infrastructure is projected to grow up to 30-fold over the next 10 years, presenting significant opportunities to reduce consumption of scarce raw materials by recycling metals and other valuable resources back into production systems. Circular economy approaches such as repair and upgrading of equipment and recycling of end-of-life infrastructure can underpin the sustainability credentials of Europe's renewable energy transition.

Key messages

- Waste arising from the development and use of renewable energy infrastructure is resource-rich and includes rare earth elements as well as other valuable materials such as steel, copper and glass.
- The fast pace of technological development means that equipment can be subject to relatively rapid obsolescence and can generate complex waste streams, thus presenting technical and logistical challenges for managing this infrastructure at the end-of-life stage.
- Recovering materials and reintroducing them into the production cycle faces challenges: complex logistics (high volumes and material often needing to be recovered from remote locations); design that does not consider end of life or recyclability; and the presence of hazardous substances.
- Policy makers and industry can address the waste and resource challenges associated with the shift to renewable energy technologies through circular economy approaches such as eco-design, material-specific recycling targets and extended producer responsibility schemes.

The resource use and waste dimensions of the clean energy transition

Climate change and environmental degradation have become an existential threat to Europe and the world. To overcome these challenges, Europe has a new growth strategy, the European Green Deal, that transforms our economy into a modern, resource-efficient, circular and climate neutral competitive economy.

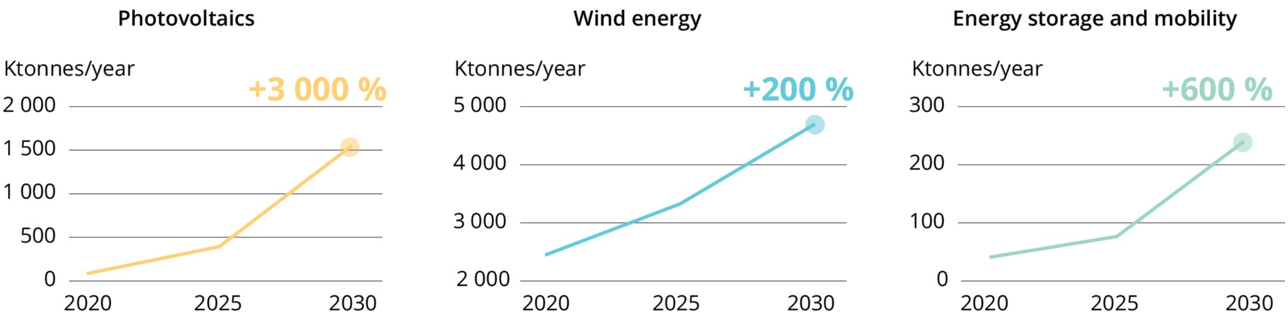
If the EU is to become climate neutral by 2050, it will have to transition to a sustainable, low-carbon energy model. Guided by EU and national targets and policy frameworks, a systemic shift is under way: from the current fossil fuel-based energy infrastructure towards renewable energy sources and greater improvements in energy efficiency.

However, the speed at which these changes need to occur to allow a net 55 % reduction in greenhouse gas emissions by 2050 is a challenge. Within the EU power sector, renewable electricity needs to become the main energy carrier within only one decade. This will require the sector to be almost completely redesigned to accommodate the fastest emerging technologies (e.g. solar photovoltaic (PV) and wind power); supported by widespread deployment of energy storage technologies. The new infrastructure will also need to be maintained during its service-life and replaced as technology improves.

This briefing is underpinned by a report commissioned by the EEA to inform action on waste and resource issues arising from this major transformation, through an analysis of emerging waste streams related to the energy transition: Emerging waste streams – Challenges and opportunities. The study identified the key drivers and framework conditions necessary to realise opportunities and solutions for improving the circularity of renewable energy.

This transition will require significant material resources and will generate substantial amounts of new types of waste — as shown in Figure 1. This creates a unique opportunity for the EU to anticipate the change and prepare a policy framework to apply circular economy principles to this new model from an early stage.

Figure 1: Expected growth of waste materials generated by the clean-energy infrastructure.



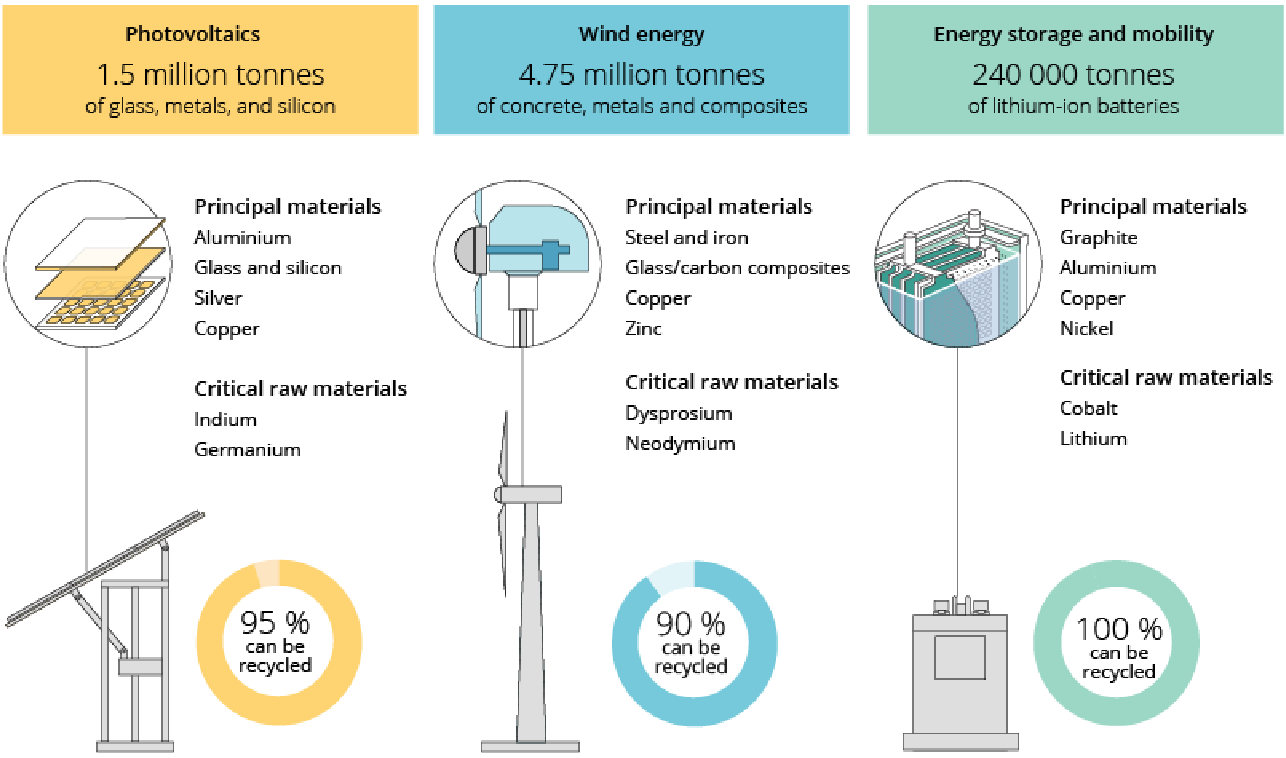
Source: Photovoltaics – Carrara et al. (2020); IRENA (2020), Wind energy – Carrara et al. (2020); IRENA (2020), Energy Storage & Mobility – Stahl et al. (2021), adapted from Emerging waste streams – Challenges and opportunities.
More info

This briefing focuses on the waste aspect of three main renewable energy infrastructure types:

- solar PV cells for electricity production,
- wind turbines
- batteries for energy storage.

This briefing describes the nature and scale of the circular economy aspects, the opportunities and challenges that the deployment of these three technologies brings and how policy can help drive the changes to achieve the best environmental outcome. A more detailed report on this topic is also available. Some of the key circular economy opportunities for clean energy infrastructure are shown in Figure 2.

Figure 2: Material recovery opportunities arising annually from the clean-energy sector by 2030



Source: EEA

Circular economy opportunities and challenges

Europe has a significant infrastructure for wind and solar energy production and for energy storage and the use of portable batteries. As this infrastructure is replaced by more modern facilities, and as the maintenance cycle prompts replacement of parts, applying circular economy principles is key to untapping the resource potential of the waste generated and minimising the challenges of managing it.

Waste generation, related to emerging streams from the three energy infrastructure types that were studied, is currently rather low, since the installations are relatively new and, generally, have not yet exhausted their useful life span. However, as Figure 1 indicates, waste generation in this sector will undergo a dramatic increase in future and requires immediate attention from policymakers. This increase will be challenging to manage, though there are strong potential benefits because much of the wastes arising either belong to established recycling systems (e.g. steel, glass, aluminum); or are high-value critical raw materials.

Recovering these materials and reintroducing them into production cycles presents challenges such as:

- processing difficulties due to: (1) use of composite materials, (2) presence of hazardous substances, and/or (3) low concentrations of more-valuable elements;
- equipment not designed to facilitate end-of-life/recyclability aspects;
- underdeveloped recycling capacity and technologies;
- market conditions that do not properly price the externalities of using virgin materials versus recycled ones;
- logistical issues due to the remote locations, size, and safety requirements associated with energy infrastructure.

Implementing innovative circular business models is also impeded because the ecological and climate benefits of using recycled materials are not yet fully accounted for in the costs of the materials. Therefore, suitable secondary materials regularly have to compete on price with primary materials that are often cheaper.

Timeframes are also important in developing policies and protocols for dealing with the future wastes generated by this sector. Much of the infrastructure being installed will have a relatively long service life, and as such provisions are required to plan now for the environmental and financial impacts of dealing with these wastes as they arise in future.

Applying circular economy principles will mitigate the impacts; for this sector, they include (Table 1):

1. applying circular business models to maintain producer responsibility.
2. designing infrastructure in a circular manner to facilitate reuse of components.
3. supporting the development of recycling to maximise recovery of materials.

Table 1: Opportunities and challenges for the three selected energy technologies

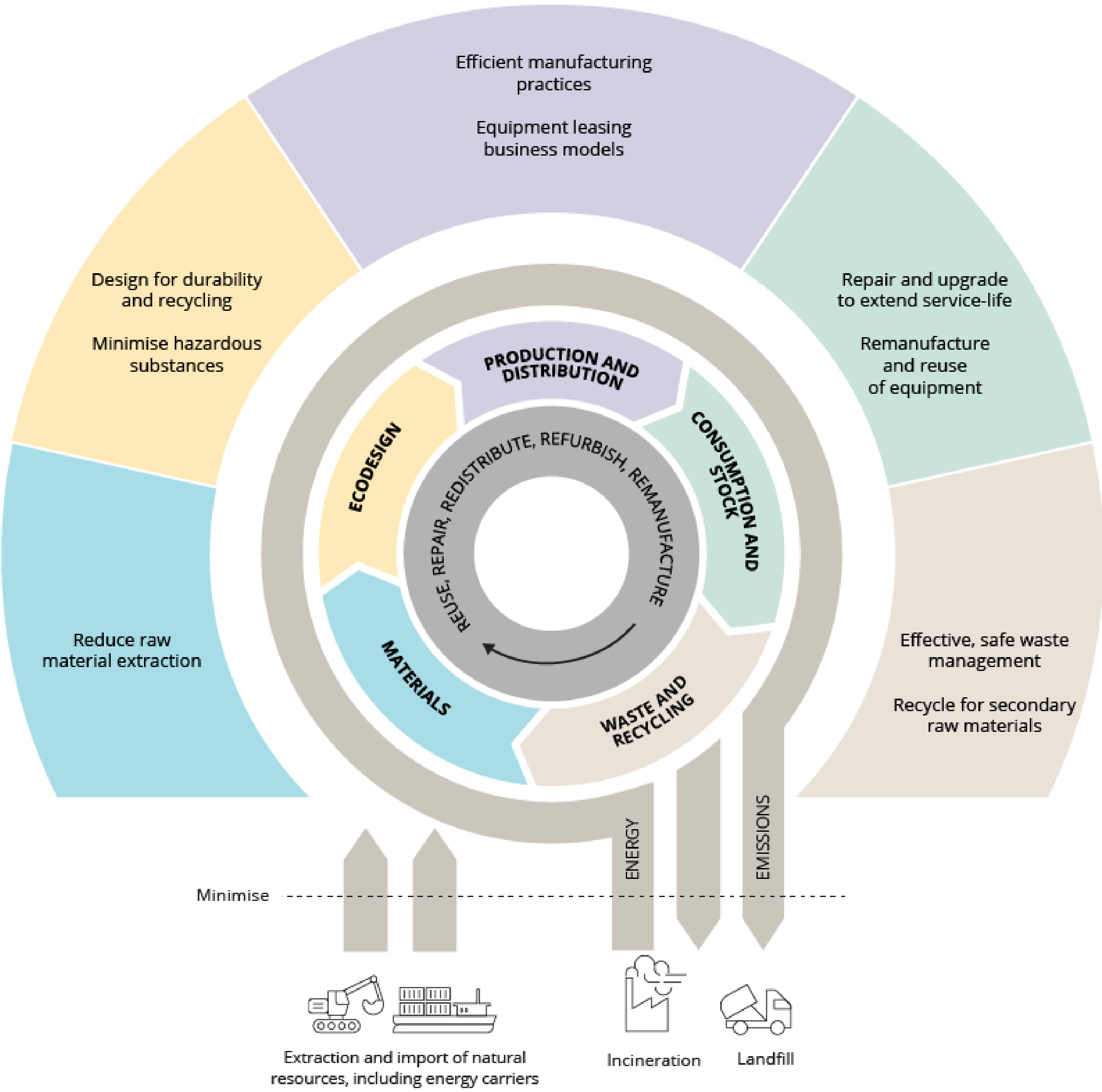
Photovoltaic (PV)	
Opportunities	■ 95 % of the materials can be recycled (e.g. glass, copper, aluminium, etc.)
Challenges	■ Key challenges in PV recycling, both in economic and technological terms, are the delamination, separation and purification of the silicon from the glass and the semiconductor thin film. ■ Other challenges for recycling of PV modules come from the presence of hazardous substances such as cadmium, arsenic, lead, antimony, polyvinyl fluoride and polyvinylidene fluoride. ■ Difficulties also arise due to access issues for working on panels installed at height, which is often not anticipated at the design stage of PV systems.
Wind	
Opportunities	■ 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 future and concentration.
Challenges	■ 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 as plastic moulded Euro pallets and polymer concrete as well as other construction applications such as noise proof barriers or thermal insulation materials is applied. ■ Huge size of blades can make transportation costs prohibitive for long-distance hauls to recycling facilities located far away.
Energy storage	
Opportunities	■ 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 within batteries. ■ Increased circularity can be supported though modular/standardised design to promote remanufacturing; and enhanced information about the content of high impact materials.

Challenges	■ There is a variety of different battery designs requiring specific and different logistics approaches. ■ The infrastructure to transport and store the growing number of waste batteries is deficient and needs to be built up to cope with predicted future high volumes of EoL batteries. ■ Currently, there is also a lack of battery recycling technologies and large-scale recycling capacities in Europe. ■ Economic efficiency of battery recycling can be difficult to achieve, due to fluctuating material values. ■ Measures to reduce safety risks of a "thermal runaway" during logistics and reprocessing are expensive.

A circular clean-energy system

Harnessing the opportunity to increase the circularity of the three infrastructure types and their emerging waste streams requires the circular economy principles to be applied throughout the life cycle of energy supply technologies. The EEA study underpinning this briefing sets out the factors that would make the renewable energy system more circular. Figure 3 highlights some key features of a circular clean energy system, which are explored further in the following text.

Figure 3: Circular clean-energy system



Source: EEA

MATERIALS

- Reduce raw material extraction through increased use of secondary raw materials in manufacturing. This can be characterised through criteria for minimum content of recycled material in new energy-generating products (closed loop); or by the supply of waste materials for use in other manufacturing sectors (open loop).

ECODESIGN

- 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 a fundamental design principle.

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 service-life for infrastructure through preventive maintenance; repair of faulty components; and phased upgrading of modular components.
- Remanufacture and reuse decommissioned equipment for lower-tier applications. Dumping of unsuitable technologies on third countries, and export of equipment to locations where waste management practices might be sub-optimal must be avoided.

WASTE (AND RECYCLING)

- Ensure effective waste management for end-of-life infrastructure through high collection rates and appropriate processing. The rapid growth of the sector indicates a pressing need for expansion of capacity and development of new treatment technologies.
- Maximise recycling of components and materials to provide secondary raw materials for new energy infrastructure and for other manufacturing sectors. Implementation of European standards for treatment of WEEE and other wastes is critical to ensuring recycled materials of consistent and high quality.

Enabling transformation to circular clean-energy systems

There are many different approaches for addressing the challenges and promoting the solutions identified in this briefing. These range from legislative measures to voluntary actions to be taken by stakeholders. Policy gaps and market barriers also need to be addressed to optimise treatment and management of these waste streams.

Implementation of actions across the three energy systems examined here will mitigate the increasing waste generation predicted in the coming years. This, in turn, will significantly improve the sustainabilty of the renewable energy sector and underpin its green credentials. The report highlights key actions to lead and support a circular transformation in this sector for industry and policy.

References

Carrara, S et al. (2020) Raw materials demand for wind and solar PV technologies in the transition towards a decarbonised energy system, JRC Technical Report No 119941, Joint Research Centre, accessed 4 August 2021.

IRENA (2020) 'Tends in Renewable Energy', International Renewable Energy Agency, accessed 4 August 2021.

Stahl, H et al. (2021) Assessment of options to improve particular aspects of the EU Regulatory Framework on Batteries, accessed 4 August 2021.

Identifiers

Briefing no. 07/2021
Title: **Emerging waste streams: Opportunities and challenges of the clean-energy transition from a circular economy perspective**
HTML - TH-AM-21-007-EN-Q - ISBN 978-92-9480-384-9 - ISSN 2467-3196 - doi: 10.2800/174813
PDF - TH-AM-21-007-EN-N - ISBN 978-92-9480-383-2 - ISSN 2467-3196 - doi: 10.2800/927429

The European Environment Agency (EEA) is an agency of the European Union. The EEA aims to support sustainable development and to help achieve significant and measurable improvement in Europe's environment, through the provision of timely, targeted, relevant and reliable information to policymaking agents and the public. For more information, visit: eea.europa.eu.

Publications

subscriptions.eu/subscribe

Published on 24 Aug 2021