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Reducing material criticality through circular business models: challenges in renewable energy

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Global decarbonisation relies on technologies such as solar and wind energy that require 'critical' materials. In this issue of One Earth, Babbitt et al propose circular economy interventions that preserve critical materials. Here we discuss how the lack of research, industry and policy readiness is challenging the adoption of such practices.

The deployment of renewable energy technologies is essential for meeting UN Sustainable Development Goals (SDGs) such as SDG7 on affordable and clean energy and SDG13 on climate action[1]. Producing renewables infrastructure, however, requires increasing amounts of materials such as indium, gallium, and rare-earth metals. This risks displacing environmental impacts, rather than reducing them, with unsustainable exploitation of fossil fuels being replaced by unsustainable exploitation of materials critical for renewable energy[2]. For example, metal ore extraction and processing for low-carbon technologies has profound and widespread environmental impacts (e.g. water, human and eco-toxicity)[3]. This risks the creation of trade-offs with SDG6 on clean water, SDG10 on reducing inequalities, and SDG14 and SDG15 on nature conservation in marine and terrestrial environments[1]. Circular economy strategies that make better use of materials and products can offer solutions, in line with SDG12 on sustainable consumption and production[1,4].

A sustainable circular economy aims to maintain or enhance social well-being, environmental quality and economic prosperity[4]. It is a whole system approach to optimise social, environmental, technical and economic values of products and materials throughout their consecutive lifecycles. This can be achieved with strategies such as dematerialisation, repair, reuse, remanufacturing and recycling (Figure 1). Circular economy has gained momentum through its potential to decouple environmental impacts from economic growth, but sufficient decoupling is unlikely to be achieved through generic resource efficiency measures such as recycling[6]. A greater focus on reduced average energy and material resource use per person is necessary. Such changes cannot be achieved by technological innovation alone, and whole-system transformations including changes in social, political and economic systems and practices – including business models, consumer behaviour, and regulation – are essential to achieve a sustainable and "circular" future[4].

Babbitt et al.[5] show that material criticality is now a universal concern for resource availability and sustainable development of renewable energy. For example, materials such as indium and gallium required for solar PV, and neodymium and dysprosium required for many wind turbines, are deemed critical in the EU and US. Circular economy strategies could offer sustainable solutions but uptake in the renewables sector is low[7]. Despite the importance of the challenge, the subject appears under-investigated. Scopus lists only 141 articles on circular economy and "solar" energy, 82 on wind and 79 on electric vehicles (as of 17 February 2021). The lack of evidence offers little platform for industry and government on which to base actions. Renewable energy infrastructure has been deployed at exponential speed driven by the urgency of climate agendas. Sustainability issues emanating from mining and processing of increasingly critical materials, and the end of life management of renewables infrastructure (both to recover materials and dispose of problematic composites) have avoided the spotlight.

Babbitt et al.[5] outline circular economy strategies, including ex-ante evaluations of material requirements of technological innovations at the R&D stage, sustainable material selection, design of resilient supply chains, design for disassembly, dematerialisation, durability and recycling, circular business models, material tracking technology and circularity passports. For offshore wind, drivers for adopting such strategies include reduced resource use and cost savings, business diversification, reduced decommissioning risks, potential job creation, social acceptance and potential carbon savings[8].

Circular economy adoption is, however, seen to be challenging. For instance, the offshore wind industry is under pressure to reduce costs, competing against artificially low fossil fuel prices. The offshore wind industry is moving from industrial exploration into exploitation, accompanied by a notable consolidation of market actors, increasing performance expectations and efficiency improvements to minimise costs in the short-term. However, cost reductions squeeze funds for innovation capacity, limiting the uptake of circular economy solutions. The industry functions under political-economic systems that measure costs and benefits primarily in monetary terms, with social and environmental performance being a secondary consideration. Short-termism and continued pressure on companies to reduce costs make it difficult to articulate circular economy business cases that focus on long-term benefits.

Offshore wind companies are largely functioning in silos along wind farm lifecycles, posing challenges to collaborative learning and innovation across supply chains[7-9]. For example, design pays insufficient attention to disassembly and recycling at end-of-use, timely communication between decommissioning and recycling is missing, and recyclers and miners are not collaborating to ensure reliable supplies of materials to manufacturers[9]. Developing circular economy supply chains will require more engagement between supply chain actors[7,9] and the sharing of data and information[7-9]. Tracking volumes and qualities of materials and components is essential for the shaping of business cases, technological innovation, guaranteeing material and component specifications, and developing policies[4,5,7]. This is currently constrained by complex ownership structures and a lack of clarity regarding responsibilities of actors at the various wind farm lifecycle stages[8]. Due to a rapid increase in the physical size of components, driven by the quest for cost-reduction, demand for reused smaller parts is limited[8]. Moreover, manufacturers do not retain ownership of components and do not expect to deal with them at end-of-use. As such, designing components for longevity and reuse is not their priority.

Despite the greater opportunities for reducing environmental impacts offered by component durability and reuse, recycling remains the main end-of-use strategy for business and governments. Yet even recycling and reintegration of critical materials into renewable technology supply chains is not taking place on any notable commercial scale[5,7]. This is due to a lack of development, perceived quality concerns over recycled critical materials and high performance requirements of offshore wind components[10], with manufacturers finding it more convenient to use new raw materials[9]. This could be addressed by improved sorting and identification of specific material grades, better dismantling techniques than shredding, and more suitable pre-treatments of materials[10]. But, without the demand for recyclates, investment into advanced recycling technologies appears unattractive[9].

The lack of secondary use of critical materials in offshore wind is downplayed as an issue, with arguments that only low volumes are required and a belief that innovations will emerge when criticality becomes pressing[7-9]. This demonstrates a lack of cross-sectoral thinking, since multiple modern technologies rely on the same limited resources such as lithium, cobalt, and rare earth metals[7,11] . It also shows a limited insight into solutions using completely different technologies. For instance, using electromagnetic instead of permanent magnet technologies for wind power or electric vehicles can eliminate their shared reliance on rare earth metals with manageable loss of technical efficiency[11]. The huge global drive for electric vehicles and battery storage means demand for lithium and cobalt will soon outstrip supply, yet alternative solutions for subsurface energy storage (e.g. compressed air energy storage in disused mines, gas fields or natural caverns) go unnoticed. The benefits for cross-sectoral collaboration and learning are well-recognised but successful implementation remains challenging[8].

With low demand for recycled critical materials in offshore wind, insight into such demand from other sectors is necessary in the articulation of business cases for investment into recycling facilities[8,9]. Depending on already established infrastructure, it is likely that investment in new end-of-use logistical, disassembly and recycling infrastructure is required[8,9]. For a viable business case, recyclers must match the availability of items to recycle with demand for secondary resources by manufacturers[8,9]. To incorporate secondary resources into production processes, manufacturers must be confident in a steady supply of materials. Volatile market prices for secondary resources raise further challenges[9].

The disconnect between the impacts and implications of current and future material demands does not create the business case impetus to promote the urgent adoption of circular economy strategies[7]. This creates an important role for policy and regulation to nurture the conditions that drive a circular economy in offshore wind and related technologies[7-9]. Environmental regulation must be properly implemented to avoid loss of materials to rogue operators and illegal exports, and adapted to support high-value specialist recycling instead of low-value bulk recycling and correct application of the waste hierarchy[7-9]. The waste hierarchy prioritises waste prevention and preparation of components for reuse. The current industry preoccupation with recycling could be seen as dismissing legal obligations[7]. Where solutions for end-of-use management are not available when renewables infrastructures are built, precautionary principles should be respected via a gap analysis of missing solutions and preparation of plans to cover such gaps within decommissioning plans written as part of the permitting process at the start of the wind farm lifecycle[7]. Extended producer responsibility is currently too weak for manufacturers to transparently consider design for sustainable end-of-use management. This shortcoming is exacerbated by short-sighted decarbonisation policy that neglects potential burdens on the environment and society. Legislation must set minimum sustainability standards for the here and now, combined with a strategy for future ambitions that set the direction of travel and support investor confidence. For example, design for durability and component reuse as well as material recycling should be enforced thoughtfully, bearing in mind the technological progress and age of renewables[7]. Such governance measures should apply to renewables and other sectors, creating a level playing field where sustainable practices are rewarded so that renewables can sustainably outcompete unsustainable energy options[4].

Development and implementation of governance systems and industry practices that contribute to a sustainable circular economy also require novel data systems on the volumes and qualities of materials and components used across sectors[4,7]. This would, for example, enable ex-ante evaluations of the material requirements of technological innovations and support reuse markets and product passports[5]. Such data systems rely on the development of more advanced methods for durability testing and residual life monitoring[7].

Better data systems is one of the many inter-disciplinary research challenges for the uptake of circular economy strategies in the design, operation and end-of-use management of low-carbon infrastructure, with a view to reduce the risks that material criticality poses for ongoing renewable energy growth[5] and maximise sustainable development opportunities[1]. Other key challenges include the investigation of ownership structures to clarify who should be responsible for – and who carries the burden and/or receives the benefits of – particular circular economy solutions; development of circular business models; and creating an understanding of how learning and innovation within renewables and across sectors can be supported[8]. The criticality of materials and deployment of renewable energy technologies are interlinked. An integrated approach incorporating material demands and ambitions across renewable technologies – within the broader context of sustainable development – must be taken[7,12].

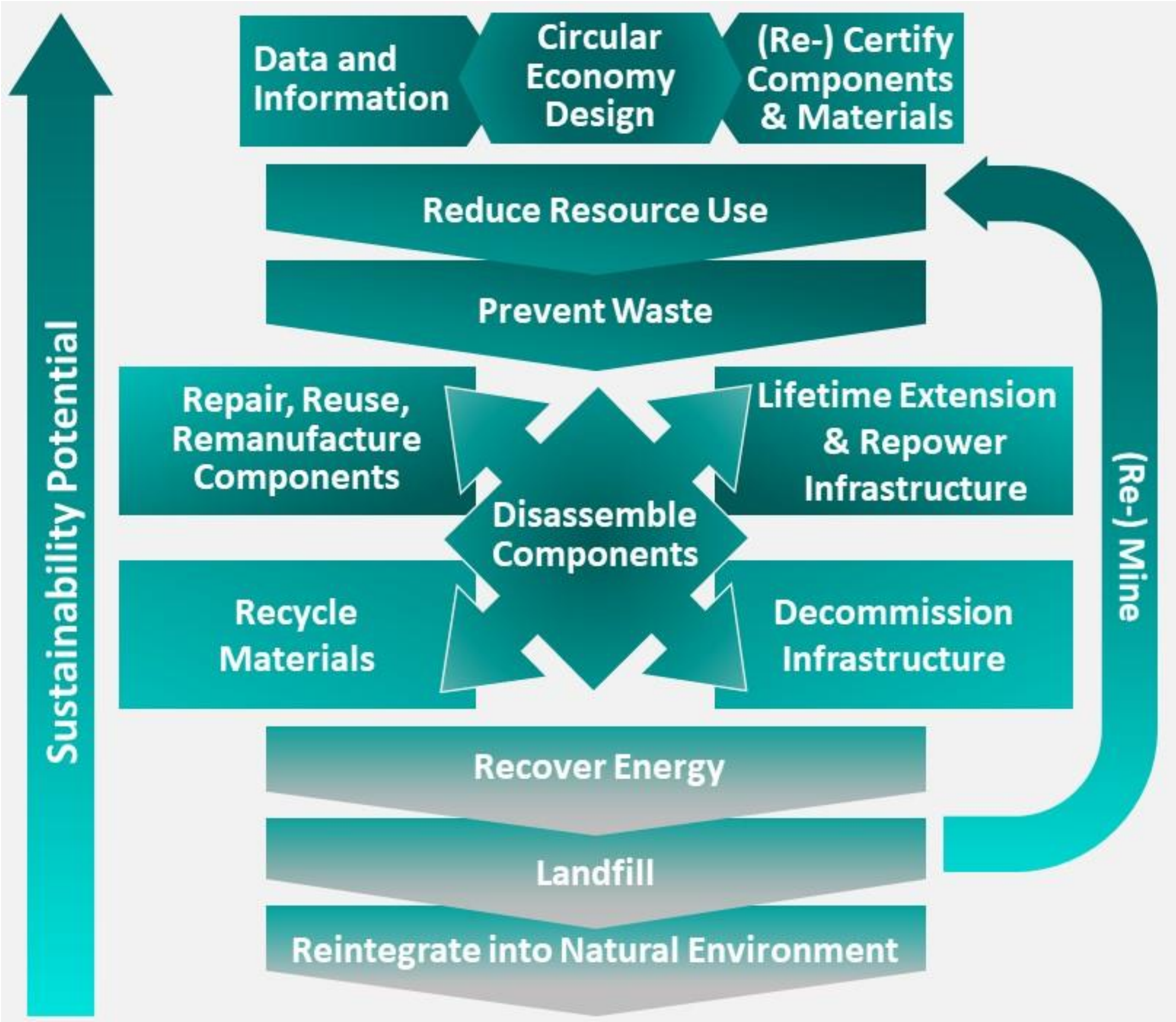

Figure 1: Circular economy strategies for renewable energy technologies.

A sustainable circular economy can be implemented in renewable energy technologies with strategies to narrow the flow of resources such as reducing resource use and preventing wastes; slow resource flows with component repair, reuse and remanufacturing and lifetime extension and repowering of infrastructure; close resource flows with recycling materials and decommissioning infrastructure; and store resources in landfills that can be re-mined for valuable resources and gradually return remaining resources that have been made safe to natural processes.

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