Circular Economy Business Opportunities in Offshore Wind

Workshop proceedings

UNIVERSITY OF LEEDS

PROUD TO SUPPORT GREAT BRITAIN & NORTHERN IRELAND for a SUSTAINABLE future

CATAPULT Offshore Renewable Energy

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1. Introduction

1.1 The Sustainable Circular Economy for Offshore Wind project

This workshop was organised as part of the EPSRC knowledge transfer project of the University of Leeds, the Offshore Renewable Energy Catapult and the Department for International Trade. The project aims to start to integrate circular economy into offshore wind infrastructure design, operation and end-of-use management. A series of outputs is being delivered such as industry and government events, policy and practice briefings, and a framework for circular economy in offshore wind and baseline of current "circular" practices. It is also supporting knowledge exchange across low-carbon energy, oil & gas and offshore wind sectors, as well as preparing the ground for a 5-year joint industry partnership on circular economy for the wind sector.

1.2 Workshop objectives

On 12 January 2021 the "Circular Economy Business Opportunities in Offshore Wind" workshop was held online with the objectives to:

1. Gain insight into drivers, barriers, actors and actions for a more circular economy in offshore wind
2. Take a baseline of current business practices, identify new opportunities and the required skills and roles
3. Introduce the Circular Economy for the Wind Sector Joint Industry Partnership
4. Identify partners for a feasibility study on blade recycling solutions

1.3 Workshop programme

13:00	**Welcome and workshop introduction**
13:10	**A framework for circular economy for offshore wind** with interactive word-cloud and poll questions *Anne Velenturf, University of Leeds*
13:45	**Introducing offshore wind farms, turbine components and materials** *Tony Fong, Offshore Renewable Energy Catapult*
14:00	**Break-out groups: Existing business practices and new opportunities in circular economy for offshore wind** *Everyone*
15:00	**Circular Economy for the Wind Sector Joint Industry Partnership** *Sean Haughey, Offshore Renewable Energy Catapult*
15:15	Break
15:30	**Blade recycling hour with:** 1. State of the art in blade recycling solutions. *Lorna Bennet, Offshore Renewable Energy Catapult* 2. Introducing the Composites Leadership Forum. *Faye Smith, Composites Leadership Forum* 3. Challenges in decommissioning and blade recycling. *Bjoern Wittek, Rhenus Logistics* 4. Interactive survey for expressions of interest in focus groups for recycling solutions
16:25	**Workshop close and next steps**

1.4 Participants

More than a hundred industry, government and research, development and innovation stakeholders from various sectors participated, including for example the wind, removal services, and resources and waste sectors (Figure 1).

Organisations capable of covering the full breadth of circular economy strategies (introduced in Chapter 2) were present, with a particularly strong representation for a) Repair, maintenance, component reuse, repurposing, refurbishing and remanufacturing; b) Material recycling; and c) Design for circularity (Figure 2).

Privacy regulations prevent the disclosure of the names of the participants, but a list of organisations has been included in the Appendix.

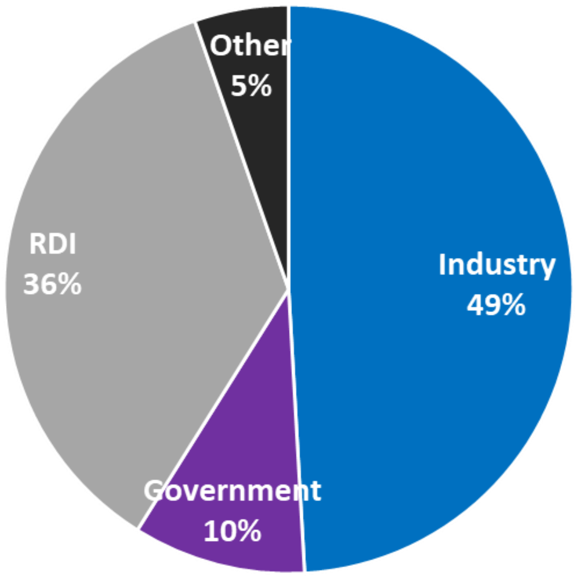

Figure 1: Participants from diverse backgrounds took part in the workshop (n=112).

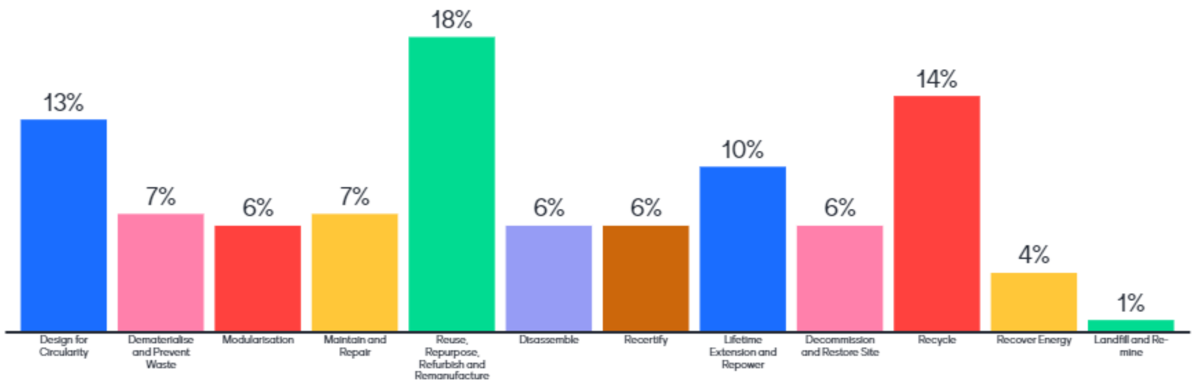

Figure 2: Alignment of participating organisations’ capabilities to circular economy strategies (n=43).

2. Circular economy in offshore wind

2.1 Circular economy related sustainability challenges and opportunities

Circular economy is important for offshore wind because the sector is running into a number of sustainability challenges. The offshore wind sector is highly dynamic with a lot of opportunities and high growth ambitions. The growing scale raises new challenges in addition to opportunities such as[1]:

- Reduce per capita energy use, as demand reduction is crucial for sustainability.
- Reduce fossil fuel reliance, but at the same time continue relying of fossil fuels for the material processing and manufacturing of components.
- Growing resource exploitation, with associated social and environmental impacts.
- Growing resource competition risking limited ability to access materials to sustain growth ambitions.
- Material innovation to find alternatives for critical materials, increase durability and reduce reliance on fossil-based materials.
- Durability and lifetime extension with opportunity to significantly reduce costs while increasing environmental performance.
- End of use management and sustainable decommissioning challenges.

2.2 What a circular economy is

A circular economy can be understood as the opposite of a linear economy, in which we take materials from the natural environment, turn them into materials, components and products that we use for a relatively short amount of time, before disposing of them often in unsustainable ways (Figure 4, left). A circular economy has been defined in hundreds of different ways and the only commonality is the striving to make better use of materials, components and products.

What is "better" is arguable but certainly must include the reduced extraction of resources from the natural environment, the prevention of waste, and the optimisation of materials, products and components throughout their consecutive lifecycles (Figure 4, right). Circular economy is a whole lifecycle and whole systems approach, requiring proactive consideration of the selection of materials and the design, use and end-of-use management of components and products.

[1] Purnell, P, Velenturf, A.P.M., Jensen P.D., Cliffe, N., Jopson, S.J. (2018) Developing Technology, Approaches and Business Models for Decommissioning of Low-Carbon Infrastructure. Resource Recovery from Waste. https://www.researchgate.net/publication/323559685_Developing_Technology_Approaches_and_Business_Models_for_Decommissioning_of_Low-Carbon_Infrastructure; Offshore Wind Innovation Hub (2019) Technology Innovation Roadmap https://offshorewindinnovationhub.com/about-roadmaps/; Velenturf, A.P.M. (2020) Challenges and opportunities for sustainable offshore wind development: Preliminary findings from a literature review and expert survey. Geoscience and The Energy Transition Sustainable Offshore Wind Development, University of Leeds. https://sri-working-papers.leeds.ac.uk/wp-content/uploads/sites/67/2020/11/SRIPs-122.pdf

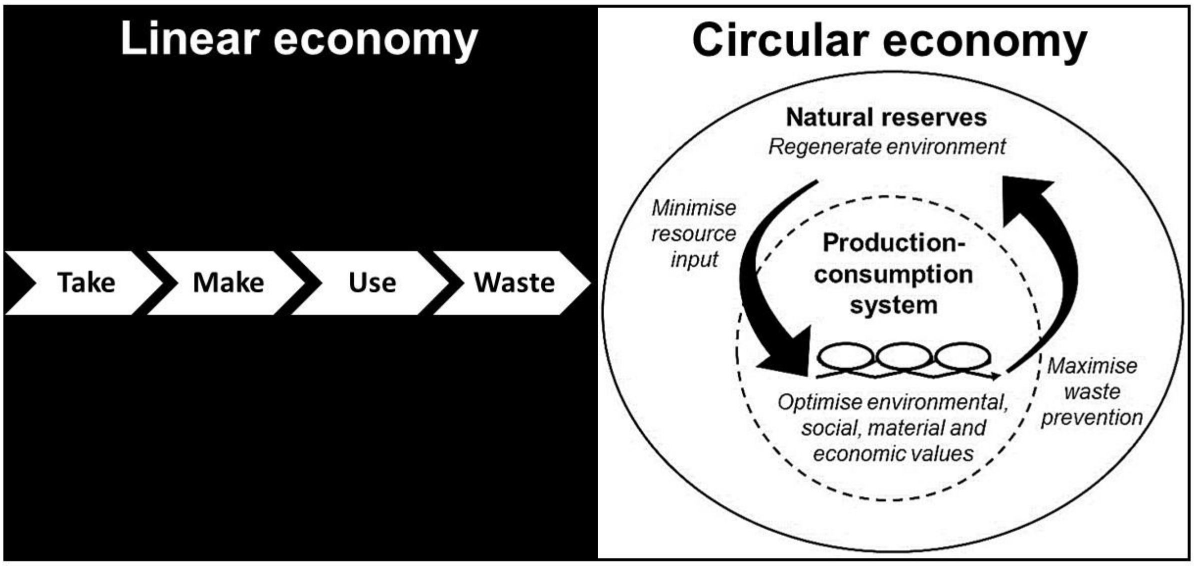

Figure 3: The difference between a linear and circular economy.

Workshop participants understood circular economy as an approach for sustainability and associated it primarily with waste reduction, recycling and resource efficiency. It was perceived positively with stronger business models, cost reductions, economic viability, social responsibility, environmental management and decarbonisation (Figure 4).

Figure 4: Circular economy perspectives from workshop participants (n=48).

2.3 Circular economy values and benefits

Circular economy has a great potential to contribute to sustainable development[2]. A sustainable circular economy aims to:

- Enhance environmental quality. For example, circular economy approaches can reduce global greenhouse gas emissions by 63% by 2050.
- Maintain or enhance social well-being. In the EU, for example, circular economy can create ca. 8 million jobs by 2030.
- Support economic prosperity. Globally, circular economy has the potential to create more than $25 trillion in new business opportunities by 2050.

Workshop participants agreed that sustainability is of key importance, with circular economy considered important with regard to waste reduction, environment and climate change, resilience and resource efficiency, and also holistic approaches, economic performance, material innovation, reduced material use, recycling, end of use, and fairness and just transitions (Figure 5).

Figure 5: Circular economy values expressed by participants (n=55).

[2] Velenturf and Purnell (2021) Principles for a Sustainable Circular Economy. Sustainable Production and Consumption. In press. https://www.sciencedirect.com/science/article/pii/S2352550921000567

2.4 Circular economy strategies

Circular economy can be implemented in offshore wind via a number of strategies[3]:

1. Design for circularity: proactive design to maximise the sustainability potential of a circular economy with a balanced mix of all the strategies listed:
2. Dematerialise: reduced resource use through, for example, shape optimisation and using alternative materials.
3. Prevent waste: eliminating waste from production through design or by putting "wastes" and by-products to use through industrial symbiosis.
4. Modularise: design to avoid irreversible joints and promote using common and easily reusable/ repairable modules[4].
5. Repair and maintain: preventative, planned or ad hoc inspection/ servicing tasks, which may involve repairs to restore a component to a good working condition[5].
6. Component reuse and repurposing: components are used again for the same (reuse) or different (repurpose) function[6] .
7. Refurbish and remanufacture components: components are sorted, selected, disassembled, cleaned, inspected and repaired/ replaced before being re-assembled and tested to function as good as new or better[7].
8. Disassemble: a key step to take components apart to enable repair, reuse, upgrading, remanufacturing and recycling, to be considered at the design stage[8].
9. Extend lifetime: wind farms kept in use beyond the designed service life of 20-25 years[9].
10. Repower: extend wind farms' service life by replacing some or all wind turbine components[10].
11. Recertify: quality assurances about the processes followed and the quality of reused, repurposed, refurbished and/or remanufactured components and recovered materials.
12. Decommission: de-energising, dismantling and removal of some or all parts of a wind farm, followed by site restoration and monitoring[11].

[3] Velenturf (Under review) A framework for the integration of a sustainable circular economy into energy infrastructure: a case study on offshore wind.
[4] Mignacca, B., Locatelli, G., Velenturf, A. (2020) Modularisation as enabler of circular economy in energy infrastructure. Energy Policy, 139.
[5] Reike, D., Vermeulen, W.J.V., Witjes, S., 2018. The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. Resources, Conservation and Recycling 135, 246-264; den Hollander, M.C., Bakker, C.A., Hultink, E.J., 2017. Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. Journal of Industrial Ecology 21, 517-525; Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B., 2016. Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering 33, 308-320.
[6] DEFRA. 2011. Guidance on applying the Waste Hierarchy; den Hollander, M.C., Bakker, C.A., Hultink, E.J., 2017. Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. Journal of Industrial Ecology 21, 517-525; EU, E.U., 2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance).
[7] Lieder, M., Rashid, A., 2016. Towards circular economy implementation: A comprehensive review in context of manufacturing industry. Journal of Cleaner Production 115, 36-51; Priyono, A., Ijomah, W., Bititci, U.S., 2016. Disassembly for remanufacturing: A systematic literature review, new model development and future research needs. Journal of Industrial Engineering and Management 9, 899-932.
[8] Kerin, M., Pham, D.T., 2019. A review of emerging industry 4.0 technologies in remanufacturing. Journal of Cleaner Production 237; Priyono, A., Ijomah, W.L., Bititci, U.S., 2015. Strategic operations framework for disassembly in remanufacturing. Journal of Remanufacturing 5.
[9] Topham, E., Gonzalez, E., McMillan, D., João, E., 2019. Challenges of decommissioning offshore wind farms: Overview of the European experience, Journal of Physics: Conference Series, 1 ed.
[10] Bezbradica, M., Kerkvliet, H., Borbolla, I.M., Lehtimaki, P., 2016. Introducing multi-criteria decision analysis for wind farm repowering: A case study on Gotland, 1st International Conference on Multidisciplinary Engineering Design Optimization, MEDO 2016; Hou, P., Enevoldsen, P., Hu, W., Chen, C., Chen, Z., 2017. Offshore wind farm repowering optimization. Applied Energy 208, 834-844; Luengo, M.M., Kolios, A., 2015. Failure mode identification and end of life scenarios of offshore wind turbines: A review. Energies 8, 8339-8354.
[11] Welstead, J., Hirst, R., Keogh, D., G., R., Bainsfair, R., 2013. Research and guidance on restoration and decommissioning of onshore wind farms. Scottish Natural Heritage Commissioned Report No. 591; Smith, G., Lamont, G., 2017. Decommissioning

13. Restore site: returning a site to a similar state as before the wind farm development.
14. Recycle materials: the collection and preparation of wastes into materials that can re-enter production, and the reprocessing of recyclates into new components.
15. Landfill and controlled storage: storage and compaction of components and materials into defined cells that prevent pollutants from entering the surrounding environment, often combined with resource and energy recovery[12].
16. Re-mine: recover materials from "Anthropogenic Ores" such as industrial, municipal, metallurgical, and mining wastes that have been entrusted into geological storage[13].
17. Recover energy: recovery of the energetic input invested into the preparation of materials and components.

Of the participants, 52% (n=23) were missing circular economy strategies in the diagram, including:

- Co-processing (covered under recycling/ energy recovery)
- Lifetime extension through derating (specification under lifetime extension)
- Degrowth (economic model rather than a circular economy strategy)
- Information strategies (can be added to the strategies as key enabler)

Currently, most circular economy strategies remain under-investigated (Figure 6). A major exception is repair and maintenance, where research activity is very high. Offshore wind decommissioning is a growing research area. There are limited research efforts on recycling, reuse and repurpose, refurbish and remanufacture, lifetime extension, repowering and modularisation. All the other strategies – circular design, dematerialisation, waste prevention, disassembly, recertification, energy recovery, landfill and re-mining, site restoration – are virtually non-investigated yet.

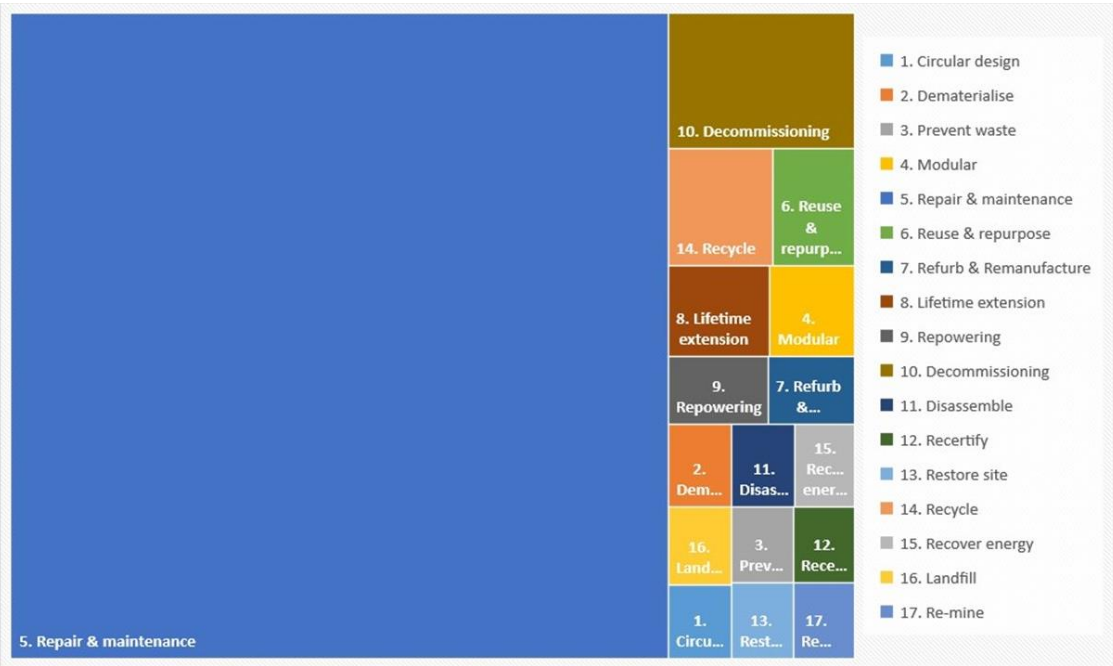

Figure 6: Peer-reviewed academic publications on the various circular economy strategies.

of Offshore Wind Installations - What we can learn, Offshore Wind Energy 2017, London, UK; Hou, P., Enevoldsen, P., Hu, W., Chen, C., Chen, Z., 2017. Offshore wind farm repowering optimization. Applied Energy 208, 834-844.

[12] Townsend, T.G., Powell, J., Jain, P., Xu, Q., Tolaymat, T., Reinhart, D., 2015. Sustainable practices for landfill design and operation. Springer, New York, USA.

[13] Sapsford, D., Cleall, P., Harbottle, M., 2017. In Situ Resource Recovery from Waste Repositories: Exploring the Potential for Mobilization and Capture of Metals from Anthropogenic Ores. Journal of Sustainable Metallurgy 3, 375-392.

2.5 Opportunities and challenges

All circular economy strategies were briefly defined and initial ideas were raised for new business opportunities, ahead of the break-out group discussions where emerging opportunities were discussed further (Chapter 3).

Initial circular economy opportunities identified by workshop participants included the potential for jobs creation, cost savings and the repurposing of components (Figure 7). Other common themes in Figure 7 are opportunities related to:

- Business: increase business and profits; expand the industry into other sectors with new supply chains and markets; lower decommissioning risk; keep the sector healthy.
- Resource management: save resources with greater resource efficiency while gaining access to cheaper materials; new materials; reduce resource use; reduce obsolescence.
- Innovation: bring innovative technologies to market; knowledge exchange; new design approach; design for decommissioning.
- Environment: save carbon; raise environmental standards.
- Social: increase community acceptance.

Challenges that participants listed with the adopting of more circular economy approaches in offshore wind included (Figure 8):

- Collaboration: cross-sectoral collaboration and learning; establishing relationships; supply chain development and collaboration; knowledge sharing.
- Data sharing: data and information availability; OEM secrecy.
- Mental barriers: short-term thinking vs long-term horizon; vested interests; locked in investments; board member understanding; lack of interest and knowledge.
- Understanding: fuzzy concept; translation into practice; education; skills development.
- Business: new business model; business cases; market demand; competitiveness; costs; risk management; include recycling in LCOE.
- Investment: R&D costs; funding; initial cost; lack of support.
- Policy and regulation: producer responsibility; no carbon pricing; lack of regulation; price driven subsidies; political frameworks.
- Standardisation: design; certification; inflexible work practices; validation of repairs.
- Logistics: reverse logistics, technology.
- Acceptance: public perception; consumer acceptance.

Figure 7: Circular economy opportunities (n=41).

Figure 8: Circular economy challenges (n=48).

3. Break-out session results

The break-out sessions covered 20 subjects divided over different tables and participants were encouraged to freely join discussions of interest focused on the following questions:

- Which circular economy solutions are available and which are missing?
- Who (could) offer(s) circular economy solutions?
- What role could you play? Are there any quick wins? What matching expertise could you bring?
- What are the business opportunities?

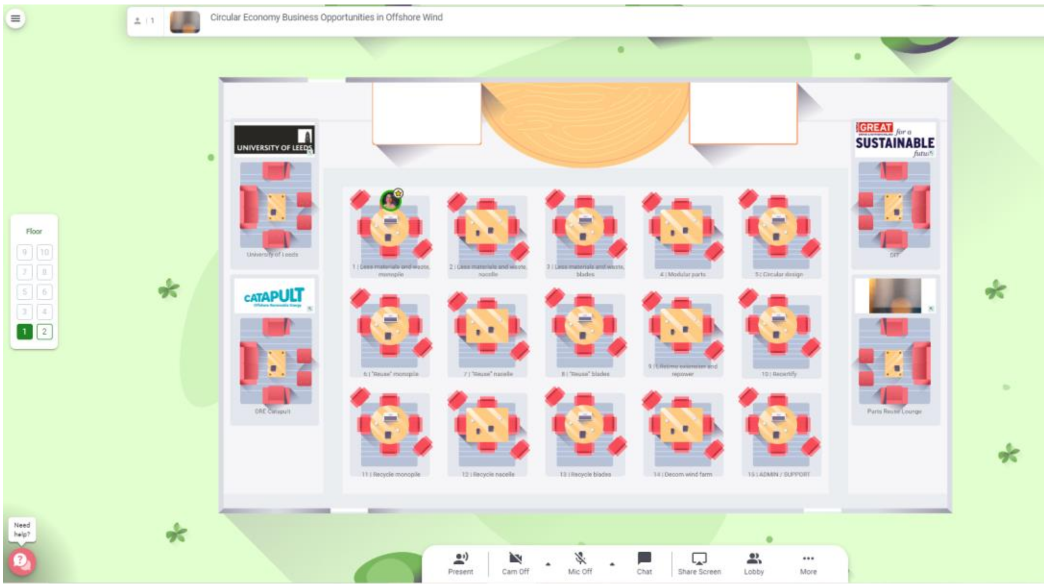

Figure 9: Online event space in which participants could freely join tables to discuss specific circular economy strategies for offshore wind.

The results shared in the next sections are the combined input from the break-out tables and the on-going discussions via the chat function during the plenary sessions.

3.1 Monopiles

Three groups of circular economy strategies were discussed for monopiles:

Less materials and waste

This table covered dematerialisation and waste prevention. It was argued that designing foundations and monopiles effectively is something that industry should already be targeting because it reduces CAPEX. There was not much clarity reported regarding missing solutions, who could offer solutions and business opportunities. More capacity building is necessary to discuss in greater detail what dematerialisation and waste prevention are, and what roles there are for business and other stakeholders to enable circular economy via these strategies.

Reuse components

This table covered repair and maintenance, reuse and repurposing, and refurbishing and remanufacturing. Reuse of monopiles is challenging because it only allows for similar sized or smaller structures, thereby going against industry trends. It was also noted that the designs of monopiles are bespoke to a location. Reuse of monopiles from offshore wind farms on land instead, for the repowering of onshore wind farms, was pulled into question because of the design differences – as on land usually concrete monopiles are used instead of the monopiles primarily made of steel for the offshore environment. Solutions would be required to take away the uncertainty over structural performance/ fatigue loads, which is a concern especially due to corrosion. Business opportunities were spotted in the form of managing material inventory data. Communication is required to explain what the various circular economy strategies constitute, alongside of developing solutions to enable component reuse.

Recycle materials

Steel components are commonly scrapped for recycling. New solutions may be required for the steel recovery due to the use of coating on steel monopiles. Concrete can be crushed for use as aggregate, but this will likely bear a cost rather than a positive value to wind farm owners. The oil & gas decommissioning industry already removes offshore assets and obtains scrap value, and scrapping steel from offshore wind was seen as a business opportunity. Depending on the scrap value, this could also reduce cost for wind farm operators depending on the cost of monopile removal. There was still uncertainty about the removal technologies available and the costs involved.

3.2 Nacelles

Less materials and waste

The switch from gearboxes to permanent magnet generators (PMG) was seen as a circular economy solution (though bring there own considerations of REEs as well). Challenges remain in terms of scaling up solutions of any kind. Dematerialisation and waste prevention can be supported by EU (and equivalent) bodies for shared policy solutions. Government, industry and trade association engagement was considered important to facilitate conversations. Business opportunities include the cost savings from scarce materials.

Reuse components

It was argued that nacelles do not contain many reusable components. Contradicting this is the ability to refurbish whole nacelles in Denmark, and suggestions to reuse nacelles in onshore applications. Repurposing of equipment such as GPS systems may also be an option. Questions were raised about the existence of a legal framework to enable the move of (equipment in the) nacelles, and logistics are a challenge. Along similar lines, there was uncertainty about the transferability of obligations and accountability, and some perceived a high risk in reusing nacelles (though unclear what risks and for who). Structural assessments can help in enabling reuse, as can insight into the value of components. Proprietary rights (patents) can limit operators in implementing solutions.

Complex ownership structures form a challenge in determining who could offer solutions, but clearly operators need to buy into allowing components to be taken away for reuse and/or to reuse components themselves. Enabling reuse, however, requires insight into the whole lifecycle data of components and this is a supply chain responsibility. Other industries could come into play to offer solutions and/or repurpose components. Government has an important role in regulating and incentivising reuse, for example setting targets for a minimum percentage of refurbished components, which can be expressed in carbon savings. New partnerships can be formed, possibly facilitated by a third party, to enable more reuse.

Examples can be drawn from other sectors. Aerospace in particular was mentioned. The wind energy sector could learn a lot from the airline sector, and how the decommissioning of aircrafts (at end of life) leads to effective component reuse in the servicing of aircrafts still in use, such as tyres, engines etc. All are certified fit for reuse. Similarly, the automotive industry, and especially heavy good vehicles, has much experience in remanufacturing of engines. Conferences or other knowledge exchange activities would be valuable for the wind sector.

Business opportunities include: Decommissioning for component reuse; Second life use of generators; PMG repurposing/ possibly upgrading PMGs without complete remanufacture; Repurposing the nacelle casing e.g. for homes; Development of a parts market; Electrical components reuse; and Cost savings as refurbished parts are ca. 60% of “new” price.

Recycle materials

Different parts wear at different rates and this complicates end of use management. It was suggested that offshore wind nacelles would fall under the Waste Electronic and Electrical Equipment but this, as far as we know, is not the case. Lubrication oil and hydraulic fluids can be recycled. While the ageing and reliability of components is not an issue for recycling, recycling solutions that are not energy intensive are still missing. Offshore wind could learn from other sectors, and trade bodies could play an important role in informing others about where information can be found. No business opportunities were identified, which is surprising given the high value of materials used in nacelles.

3.3 Blades

Less materials and waste

Solutions to use less or alternative materials include the preparation of new recyclable matrix materials that may become available. Material use could be reduced with automated and smart solutions but these technologies are not considered to be mature yet. In the UK the lack of end-user field available for on-site demonstration projects or pilots for new technologies and systems is a constraint. Bringing solutions to market requires European/ international collaboration. Innovation and professional organisations can support the development and embedding of new solutions. Business opportunities include the use of bio-based and nano materials. There are also advantages from supporting cross-sector collaboration, such as transferring expertise from automotive and oil and gas to the wind sector.

Reuse components

Existing circular economy solutions include composites repair, inspection and monitoring and repurposing of parts for insulation. Missing are generally cost effective solutions and processes to turn turbine blades into construction materials such as planks. There was no clarity on the role of industry in the reuse, repurposing, refurbishing and remanufacturing of turbine blades, aside from the role of researchers in assisting industry with research and innovation. Business opportunities may include the repurposing of turbine blades into affordable building solutions.

Recycle materials

Widely quoted as recycling was the use of blade materials in concrete, by co-firing cement kilns (i.e. energy recovery/ disposal) with shredded glass fibre reinforced composite blade material, and integrating the remaining fibres into concrete. It should be noted, however, that this solution may not be considered "recycling" in every national regulatory context. Moreover, using recovered fibres in novel cements was identified as a missing solution.

Cement manufacturers can offer a solution in the short-term, but it was recommended to look for solutions beyond the cement sector. Other solutions combining energy and resource recovery were suggested as well. For example, turning the blades into heat or fuel, and using the remaining material if possible.

It was proposed that composite materials should be recycled down a hierarchy of applications of ever-reducing demands for quality. However, more capacity building is necessary to identify which actors could play a part in developing and implementing blade recycling solutions because, beyond research and innovation bodies and the cement sector, no actors were identified to support this part of the supply chain. This is also important to enable the identification of business opportunities. While composites wastes are a big problem for the offshore wind sector, the volume of materials is relatively modest compared to the total scale of the composites market. There is opportunity in joining up with other sectors such as ship building to reach economies of scale for recycling solutions.

The development of blade recycling solutions can be supported by regulation. For example, a landfill ban for turbine blades, provided there are potential solutions in the pipeline, would catalyse innovation and upscaling of solutions because they must. It was raised that industry and government should use a part of the profits from offshore wind to support responsible innovation. There was a general consensus that blade landfilling should not be allowed.

Legislation is also important in prompting a market for recovered glass fibres. Support is needed to match the supply of recovered fibres – in terms of quantities and qualities – with the demand for fibres across sectors. This requires better information on composites materials flows. Given the low value of primary glass fibres, and the relatively high cost of recyclate, there has not been a market pull to implement glass fibre recycling solutions. Conversely, carbon fibre has a higher value and this has driven more technological innovation.

Blade disassembly is a particular area of interest that can enable higher value recycling, rather than the hierarchy of down-cycling proposed above. Research is on-going to enable de-bonding of materials for disassembly and recycling. The business case for carbon fibre recycling is generally more positive already when compared to glass fibre, and can be strengthened further with solutions for disassembly of renewable carbon. Others suggested solutions that might exclude a role for recycling, with the development of bio-fibres and resins that would not be recycled but instead used in thermal energy recovery only at end of life.

A radical rethink is needed with feedback on design. It was argued that the very existence of the blade recycling challenge indicates that this issue has been insufficiently considered up-front and should have been highlighted by whole lifecycle analyses earlier, and feed into the business case and business models for wind farm development.

General points

Finally, a few general points were made that may apply to all components:

- More attention should go to remanufacturing, which is a key element of sustainable practice, enabling products to be returned to as good as new or better state (designs allowing for up-grade).
- Offshore wind should create a second hand equipment market as in onshore wind.
- Crucial in enabling recycling is the presence or creation of secondary materials markets.
- The oil and gas sector can support circular economy solutions in the wind sector but care must be taken, because circular economy performance in oil and gas is very low.

Cables were not discussed in particular in any of the groups, but their recovery and recycling was raised nevertheless. It was suggested that pyrolysis could perhaps be used to remove resins and recover the metals. Concrete mattresses, which are used to keep cables on/in the seabed, also need specific attention.

3.4 Circular design

It is necessary to take a holistic approach to sustainability, and lifecycle analysis could help with this. The waste hierarchy needs to be considered up front, and this ties into the importance of changing mind-sets from thinking of recycling as the end-game to preventing down-cycling of materials and take a greater focus on component reuse and remanufacturing.

Eco-design solutions are already available for electrical components. Some parts can be designed for modularity to allow for replacements of only the parts that are degraded, but there is a greater scope to embed modular design more within offshore wind. Parts can also be repurposed as rail sleepers.

Missing solutions include the absence of standards that would enable circular economy solutions in offshore wind. For example, standards to validate recovered materials would enable the use of more recyclates in new designs. There is also a limited recognition of circular economy in general and this makes it difficult to articulate business cases; and this also reveals that long-term board level support for circular economy is crucial rather than short-term project level support. Involving other sectors in the creation of more circular designs in offshore wind was seen as one of the solution directions.

There was much discussion about the design life of 25-30 years. The design life seems directed by the duration of permits/ leases for wind farms. In the UK leases have been extended to 50-60 years and this means that wind farms and components can be designed for greater durability.

3.5 Lifetime extension and repowering

Expertise in/ directly reusing oil and gas assets could be transferred to offshore wind; direct reuse of oil and gas infrastructure and wind could be supported by innovative spatial analysis tools and open new business opportunities.

The wind sector has expertise in load calculations, currently used for assessment of designs prior to construction, which can be used in the assessment of the potential for lifetime extension and repowering. Key to lifetime extension is inspection and service history monitoring, which also requires availability of the right instruments.

A key challenge for lifetime extension and repowering is uncertainty about the historical usage, loading and maintenance (though uncertainty can be reduced with appropriate documenting of regular checks and maintenance in line with industry standards). A data passport, certificate or standard for all components, offered by e.g. ISO/IEC, could enable lifetime extension and repowering by increasing the transparency with evidence of through-life management, data, loads and inspections. This would give assurances for continued operation.

Generally the cheapest solutions are preferred and this limits the potential of, for example, repowering where there are challenges with the economics. Circular options are available but perceived as expensive, not aided by the current tax system and the still increasing scale of infrastructure to achieve further efficiency gains. Repowering is considered to have a high potential but currently an underused strategy. The limited understanding regarding of roles that various actors could play in lifetime extension and repowering is also unhelpful.

3.6 Decommissioning

The need for full decommissioning was questioned, and the pros and cons of complete pile removal or cutting at seabed were discussed. For example, the wind farm area could be reused for the same or other purposes, such as using remaining parts of monopiles to support fisheries/ other industries and nature conservation. The ability and preference for complete removal of cables was questioned, as were the monopiles. The oil and gas sector has solutions to cut monopiles with explosives at the base, but there is demand for more advanced solutions to enable the economical complete removal and disassembly of monopiles. Better designs could support full removal but are currently missing. It was also felt that guidelines are missing (but note wind decommissioning guidelines available in some countries such as Germany). Sharing experiences and data can help in the development of solutions, and could build on existing platforms for oil and gas. There is also a need for more vessels to deliver decommissioning operations. Business opportunities were identified in the form of brokerage services to match downstream component reuse and material recycling with decommissioning activities.

3.7 Policy and regulation

This table pointed towards a number of ways in which policy and regulation could support circular economy practises in offshore wind:

- Include carbon in procurement, such as done by the national grid. This can also apply to other externalised costs such as social value. Counting full economic, social and environmental costs and benefits will help business cases for circular economy.
- It was argued that buying from the UK currently costs more, and that circular economy supply chains are a global opportunity. Domestic supply chains and manufacturers can be innovative if incentivised or if circular economy is mandated.
- It was argued that there is a lack of domestic reprocessing infrastructure and that action should be taken in line with the industrial strategy. The UK Government should take action to increase UK supply chain content to support new projects.
- Ensure sufficient funds for decommissioning costs are accrued during operation.
- Capacity building with training for industry, regulators and policy makers.
- Clarify the definitions of wastes and resources, which directly impact on handling, permits, transportation etc.
- Regulation to mandate data sharing on materials, for example by introducing component and material passports.

4. Workshop evaluation

A workshop evaluation was circulated to the participants and 26 (response rate 23%) completed the survey in whole or parts (Figure 10).

Respondents came from research, development and innovation organisations, government, and from the wind, resources, cement and decommissioning sectors.

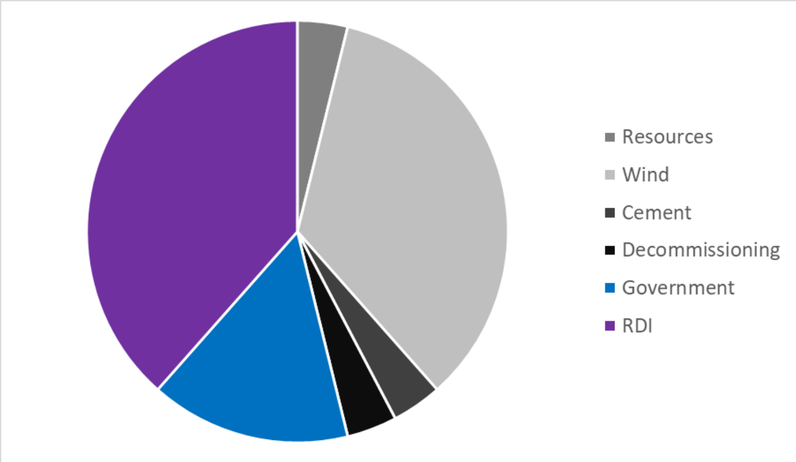

Figure 10: The evaluation survey was completed by 26 participants from research, development and innovation (RDI) organisations, government bodies, and various industries.

4.1 Workshop organisation

The event content and format were well received (Figure 11) with good averages of 4.3 and 4.2 respectively (n=26). The platform worked well but some technical issues were experienced (4.3, n=26) and more joining information up-front and support for more complex issues would be helpful. Overall the event received a good score of 4.1 (n=25) and was well-organised. Strong points were the event platform with the table format conducive to networking and making new contacts. This could have been enabled further by sharing a participant list and information beforehand. The mix of academics and practitioners was good but more visible presence of asset owners was missed. The balance between networking and high quality presentations was good with very active discussions. Questions answering times could have been longer. Good insightful baseline of understanding to be followed by more focused events.

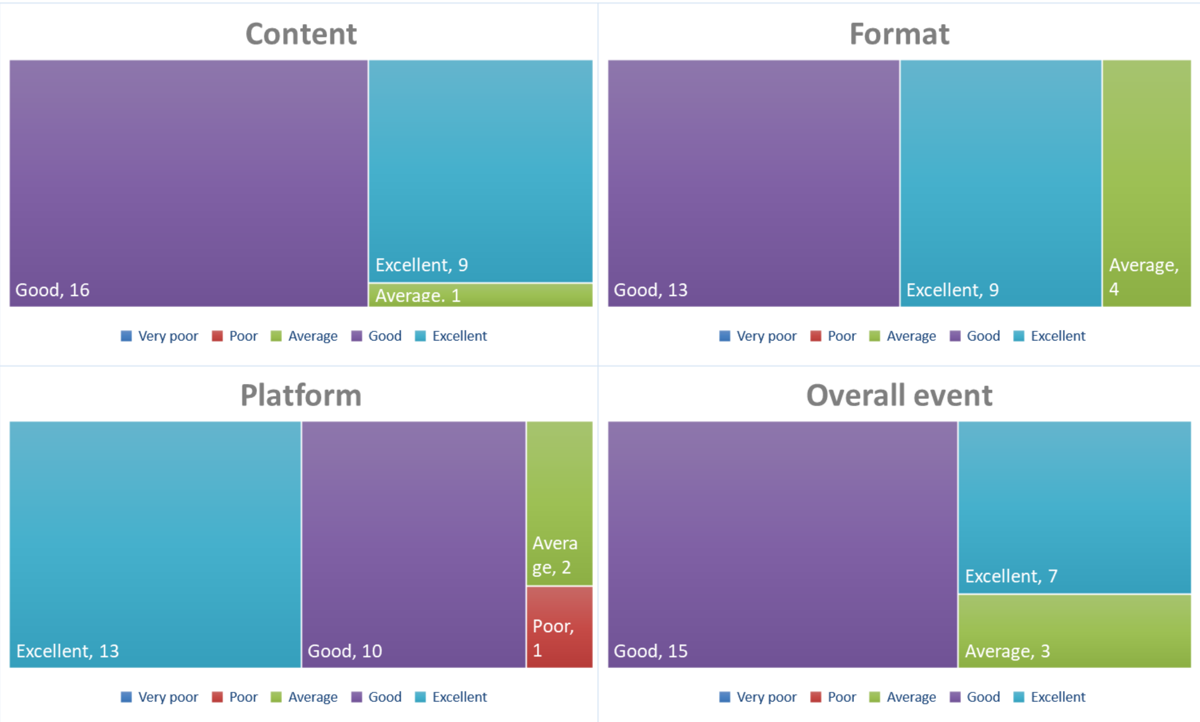

Figure 11: Survey results on event organisation.

Participants were expecting to make new contacts and network across sectors, share experiences, broaden understanding and gain new insights into solutions and business opportunities (Figure 12). Expectations were partly met. This workshop was the start of a conversation and more input and focused discussions are required to coproduce solutions making the most of circular opportunities.

Figure 12: Workshop expectations by participants (n=37).

4.2 Objectives achieved

It was necessary to convey what a circular economy is, what it may look like in offshore wind and what materials and components are going around in offshore wind infrastructure, in order to achieve the workshop objectives regarding: [1] Gaining an insight into drivers, barriers, actors and actions for a more circular economy in offshore wind, and [2] Taking a baseline of current business practices, identifying new opportunities and the required skills and roles.

Following the introduction, most participants felt that they understood what a circular economy is, and the majority gathered what the circular economy strategies are although a relatively high number of participants responded "neutral" to this evaluation question (Figure 13), highlighting that continued communications to introduce circular economy and the various strategies is important. Participants gained a good understanding of offshore wind materials and components (Figure 14).

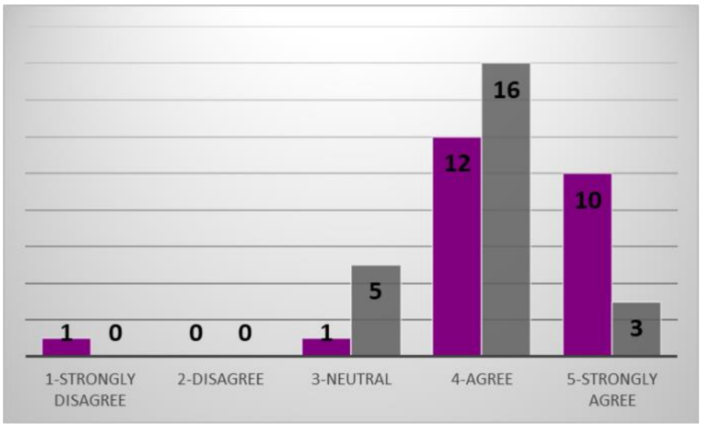

Figure 14: Participants felt that they gained an understanding of what circular economy is about (purple series, n=24) and what circular economy strategies may apply to offshore wind (grey series, n=24).

The break-out sessions highlighted that a part of the stakeholders were catching up on appreciating the whole system perspective of a circular economy on offshore wind, with others feeling the subject was too big to cover at once, emphasising the value in cross-sectoral learning across for example the resources and wind sectors in addition to joining up onshore and offshore wind as well.

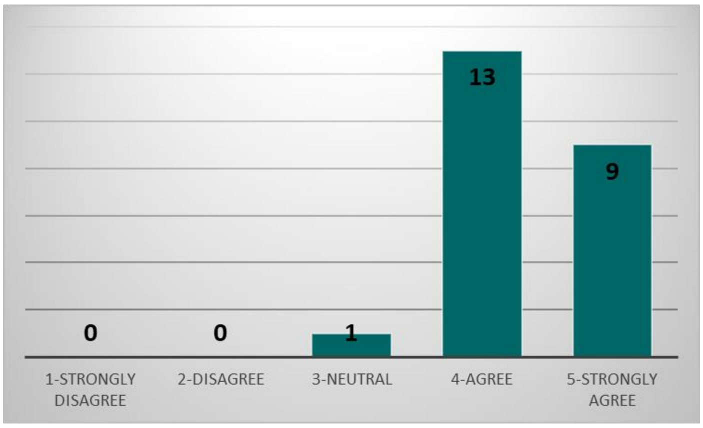

Figure 13: Participants felt that they developed a good understanding of the anatomy of offshore wind farms (n=23).

There is a need for more horizon scanning for innovative technologies. This would ideally be stratified more to gain a better insight on the level of equipment and components within the bigger turbine parts.

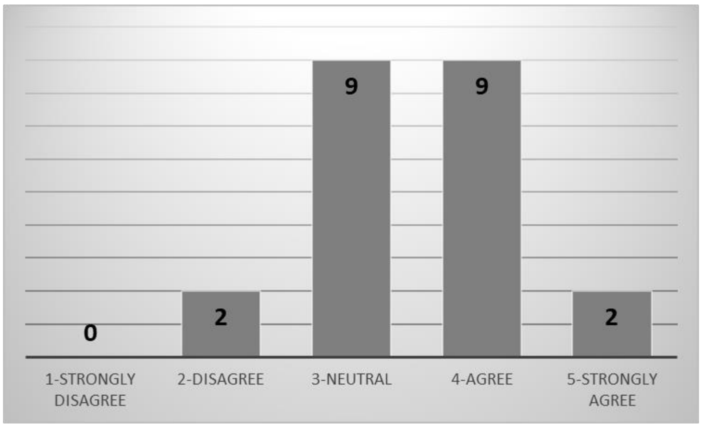

Figure 15: Participants felt that they developed some understanding of the proposed joint industry partnership.

The workshop aimed to introduce the Circular Economy for the Wind Sector Joint Industry Partnership. Half of the respondents grasped what this partnership will cover, indicating added value for further communications introducing the proposed contents (Figure 15). Interest in the partnership is large, with ten respondents expressing a wish to become involved and contacts initiated during the workshop.

The final workshop objective was to identify partners for a feasibility study on blade recycling solutions. This first required conveying information on the challenges and solutions regarding blade recycling, which most participants grasped (Figure 16). It is possible that participants left the workshop before the finish, which would explain why the Composites Leadership Forum introduction was not picked up as much. Fifteen participants expressed their interest in focus groups on blade recycling technologies (Figure 17), confirmed by five respondents to the evaluation survey, with the greatest interest in 1) Mechanical grinding and reprocessing of milled fibre, 2) Cement kiln co-processing, and 3) Reprocessing of chopped fibre (post pyrolysis/ solvolysis). Overall the interest in blade recycling was significant and will be followed up with further events and collaborations.

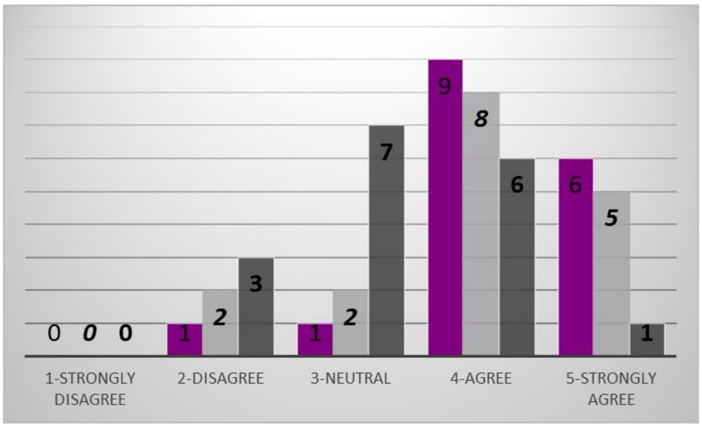

Figure 16: Extent to which participants developed ar understanding of the blade recycling challenges (purple series), potential recycling solutions (light grey series, bold italic) and the role of the Composites Leadership Forum (dark grey series, bold).

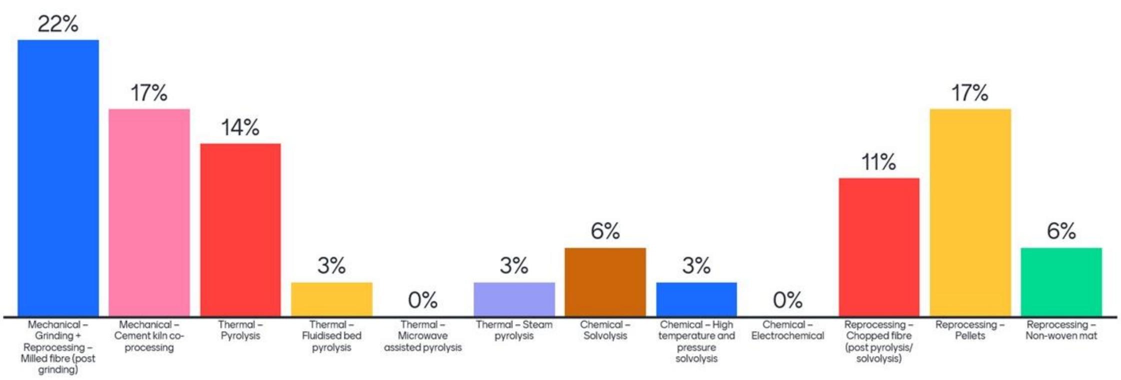

Figure 17: Expressions of interest in blade recycling solutions expressed at the workshop (n=15).

4.3 Key messages articulated by participants

Key messages that participants picked up could be grouped into:

Circular economy: Interest in circular economy in offshore wind is growing but it is not well-understood yet in the sector and perceived as difficult to put into practice. It needs structure and collaboration to pull it together, and in that regard the framework and overview are helpful. The “right solution” is still missing and more proactivity to embed circular economy now rather than an afterthought at end of use is needed. There are some good ideas but there is a long way to go to realise the potential of a circular economy in the renewables sector.

Collaboration and cross-sectoral learning: It is essential to collaborate to increase circular economy and decommissioning competences in offshore wind. Offshore wind seems behind the curve given the older age of some wind farms and the lack of circular economy solutions. The desire to collaborate is there, as is the interest from other sectors to support circular economy in offshore wind, but it does need coordination to bring the people together. Coordination is also important to bring coherence in circular economy narratives and the practices that are being embedded. The rush to get offshore wind off the ground has led to the repetition of many of the same mistakes as in oil & gas, and here too cross-sectoral learning can be valuable.

Innovation support: Better regulation needs to be coupled with more innovation support and investment in the supply chain. There are many technical challenges in a difficult environment, and more needs to be done on design and innovation. There is a drive now to deal with end of use offshore wind turbines before it becomes a major issue, and many business challenges and opportunities were identified.

Blade recycling: Blade recycling is a big unsolved problem, but interest to solve end of use management of wind turbine blades is finally growing. Several people stated that their 'go-to' disposal method is to store the blades, as they expect that a more sustainable and viable option for blade waste is likely coming soon. Technical developments and logistical solutions are beginning to accelerate with many people working on this. Wind turbine blades are being used in the cement sector as fuel and raw material replacements already and may be a potential source for UK manufacturers.

5. Concluding remarks and next steps

This workshop offered insight into the perspectives on circular economy and the aspirations from across sectors involved in the resource management, from start till end, of wind farms. Offshore wind research and practice are currently at the beginning of integrating circular economy practices into the whole lifecycle management of wind farms and turbine components and materials.

The results highlight six important next steps:

1. Communications to explain what a circular economy is and which strategies a circular economy entails in the offshore wind sector.
2. Facilitate cross-sectoral learning including the transfer of best practice and learning from past mistakes.
3. Clarification conversations with industry and government regarding the current roles and responsibilities and how they may change with the uptake of circular economy strategies.
4. Evidence on the environmental, social, technical and economic costs and benefits of circular economy strategies to actors involved throughout the lifecycle of a wind farm.
5. Coproduction of regulatory ambitions and boundaries to support the most sustainable circular economy strategies.
6. Support research and innovation to solve current issues, and to design better systems that prevent sustainability challenges arising from the installation of new wind turbines.

The results will also be shared in further publications and communications, and will feed into the preparation of a policy and practice brief in offshore wind circular economy and decommissioning.

A number of actions will be taken shortly on blade recycling, including the organisation of supply chain focus groups on technical, economic and legal feasibility of potential solutions, and further research and innovation for a report for the Department for International Trade and via the Energy Transition Alliance project and the Circular Economy for the Wind Sector Joint Industry Partnership.

Appendix: Participant list

A list of full names could not be included due the data protection regulations, unless participants explicitly gave consent, but the organisations can be listed:

ABP
Petrofac
Breedon Cement
Broadwater Mouldings Ltd
Burns & McDonnell
CEMEX
Circulonomy
CIWM
The Crown Estate
Department for International Trade
DNV GL
Dragon Decommissiong Cymru (Nils Cohrs)
DTU
ECHT (Suuz Kamper, Maarten Lobregt, Erwin Coolen, Claire den Hartog)
EDF Energy
Environment Agency (Mike Tregent)
Erhvervshus Nord (Thorbjørn Stenholm)
F&S Renewable
Fraunhofer IFAM (Katharina Haag)
GE Renewables
Georgia Tech (incl. Lawrence Bank)
Greenology
Gurit UK Ltd
Heerema Marine Contractors (Fay de Waal)
HS Bremen

Hull City Council (Paul Jensen)
HVM Catapults
Independent
Innosea
Jacobs
John Lawrie
Lloyds Register
MPI UK (Peter Barnard)
National Composites Centre
NexStep
NRC
NREL
Ofgem
OGTC
Offshore Renewable Energy Catapult (incl. Lorna Bennet, Tony Fong, Sean Haughey)
Queen's University
RDR Wind
Regnan
Remondis/ DE Rhenus
Renewable Parts
RES-Group
Royal Society of Chemistry
RWE (incl. John McKenzie)
Schneider Electric (incl. Laurent Truquet, Cyril Domenech)
Sealand Projects
Siemens Gamesa
Steelwind Norderham

Strathclyde University
STRUCTeam Ltd (incl. Gerry Northwood OBE)
Targe Environmental
The E-group
TWI
University College Cork (incl. Angela Nagle, Peter Deeney, Paul Leahy)
University of Aveiro
University of Leeds (incl. Leon Black)
University of Strathclyde
Virol
Wilton Engineering
Zatani Ltd (Nils Cohrs)
Zero Waste Scotland