Circular Economy Value Chains for Decommissioned Wind Turbine Blades

Wind turbine blades are large, complex products made from a mix of materials but consist mainly of glass fiber composite materials that are difficult to reuse or recycle. Because of these material-related challenges, wind turbine blades reaching their end of life have historically been landfilled, which is unsustainable and causes a loss of resources. In addition, studies show that waste volumes from wind turbine blades in Europe will annually reach 325,000 metric tons by 2050, which emphasizes that this is a major challenge that must be solved. Thus, new systems and value chains need to be designed and implemented for end-of-life wind turbine blades to ensure that materials are reused and recycled in accordance with circular economy principles and to avoid landfilling in the future. However, the operationalization of circular economy is sparingly described in the current academic literature.

This dissertation applies a mixed-methods approach to answer the following research question: How can value chains for end-of-life wind turbine blades be designed, operated, and industrialized in accordance with the circular economy?

The dissertation combines and builds on the results of seven individual research papers. The results include the identification and mapping of five circular value chain routes for wind turbine blades reaching their end of life. The routes are: structural repurposing, cement co-processing, pyrolysis (thermal recycling), mechanical recycling, and solvolysis (chemical recycling), as well as all present viable solutions for wind turbine blades. However, it is also found that the technological development and level of circularity differ between the routes, making an environmental and economical assessment and comparison between them complex.

Four empirical case studies of end-of-life wind turbine blades have been conducted in collaboration with wind turbine owners and waste management organizations to map all the processes included in the value chains for blade recycling. Consolidated in a cohesive model for circular value chains for end-of-life wind turbine blades, the results demonstrate how multiple processes across the different assessed technologies are almost identical. Thus, a large potential for standardization and optimization of value chains processes are presented.

The findings from this dissertation lead to the conclusion that circular value chains for end-of-life wind turbine blades can be successfully designed, operated, and industrialized by 1) applying a value chain approach to system development; 2) applying the model of circular value chains for end-of-life wind turbine blades to design and implement industrial facilities; 3) assessing value chain routes using life-cycle assessment and multi-criteria decision-making methods based on specific case variables; 4) working on standardization, optimization, and automatization of common value chain processes between end-of-life routes to reduce complexity and cost; 5) investing in research and development to improve technological readiness levels of pyrolysis and solvolysis; and 6) ensuring collaboration between value chain actors, including sharing of knowledge and material data.

The implications of this dissertation apply both to wind turbine owners, stakeholders of future end-of-life value chain solutions, researchers working on recycling of large complex products and materials, policymakers, and the general public, by providing empirical evidence and roadmaps for circular material management of composite-based products.