Systematic assessment of end-of-life pathways for decommissioned wind turbine blades based on technical, environmental, and financial criteria

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Introduction

Wind energy is crucial to reduce fossil fuel dependence. The Biden administration has heavily invested in wind energy due to its low levelized cost of energy (LCOE)[1,2]. A challenge that the wind industry faces is the end-of-life treatment of decommissioned wind turbine blades (WTBs). Since these structures are made from composite materials that are hardly homogeneous, they are difficult to recycle at cost parity[3,4]. End-of-life (EOL) pathways such as repurposing, recycling, and cement co-processing all offer alternatives to landfilling. Each EOL strategy offers different benefits and drawbacks, but there is currently no systematic overview to help identify what these are for a given project[5,6].

Problem Statement

This project aims to develop a systematic approach for designing the fate of decommissioned blades based on:

Criteria for evaluating EOL strategies

- Decommissioning technique
- Mechanical integrity of blades
- Cost of EOL strategy
- Environmental impacts

Cost and environmental factors are available from literature and conversations with industry experts, but mechanical integrity of blades will be tested through characterization of decommissioned blade material. These criteria can then be put together to aid in the decision-making process.

Materials & Methods

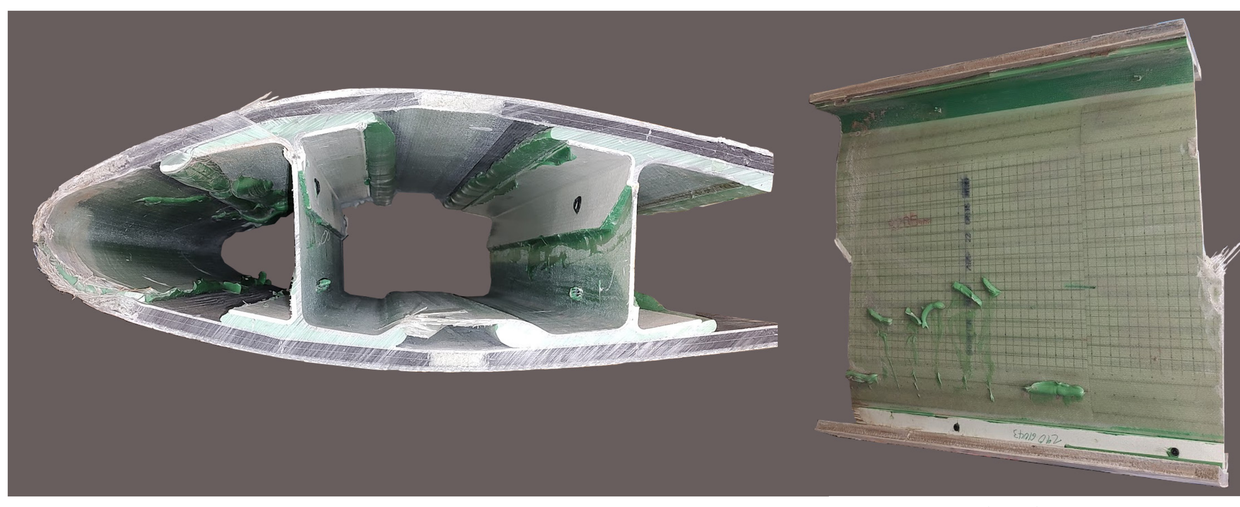


Figure 1 Sections from a Vestas V-120 blade at the erosion region (left) and crack region (right)

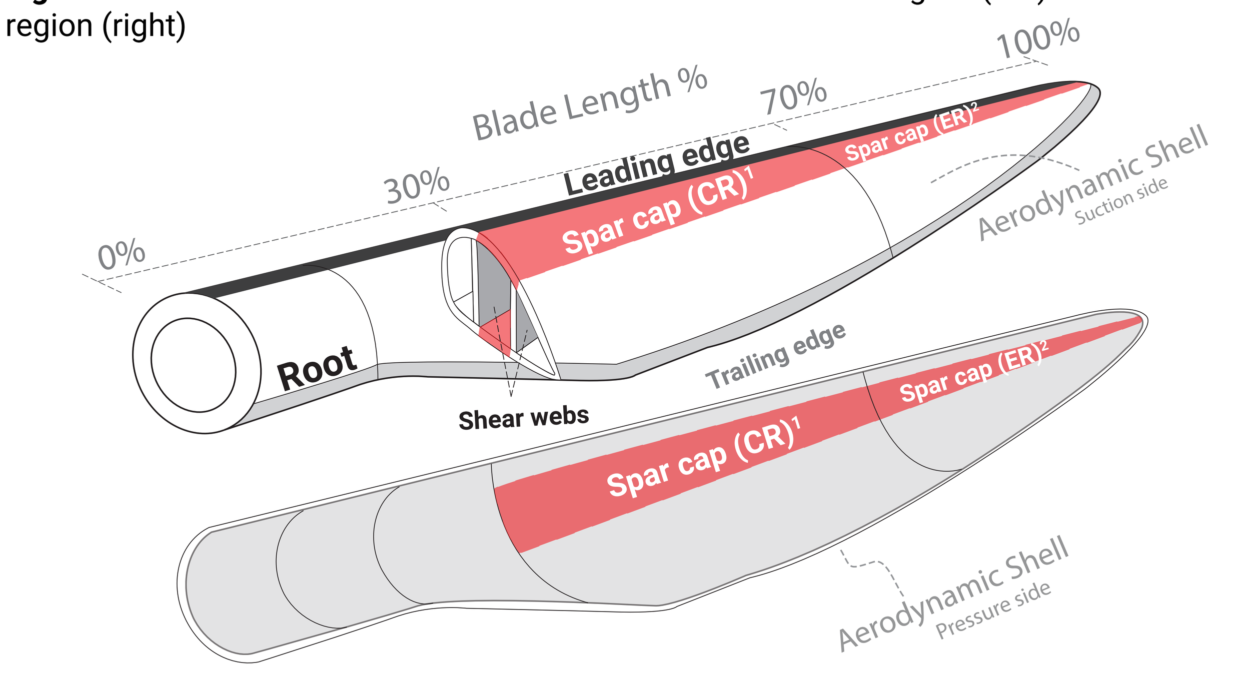


Figure 2 Map of the different sections in a blade according to failure modes

Materials

Vestas V-120 decommissioned blade 1m² sections

Crack region panels
- Shear webs
- Spar Caps
- Shell

Erosion region panels
- Shear webs
- Spar Caps
- Shell

Methods

Technical
- Mechanical testing - DSC, TGA, optical microscopy, and tensile analyses.

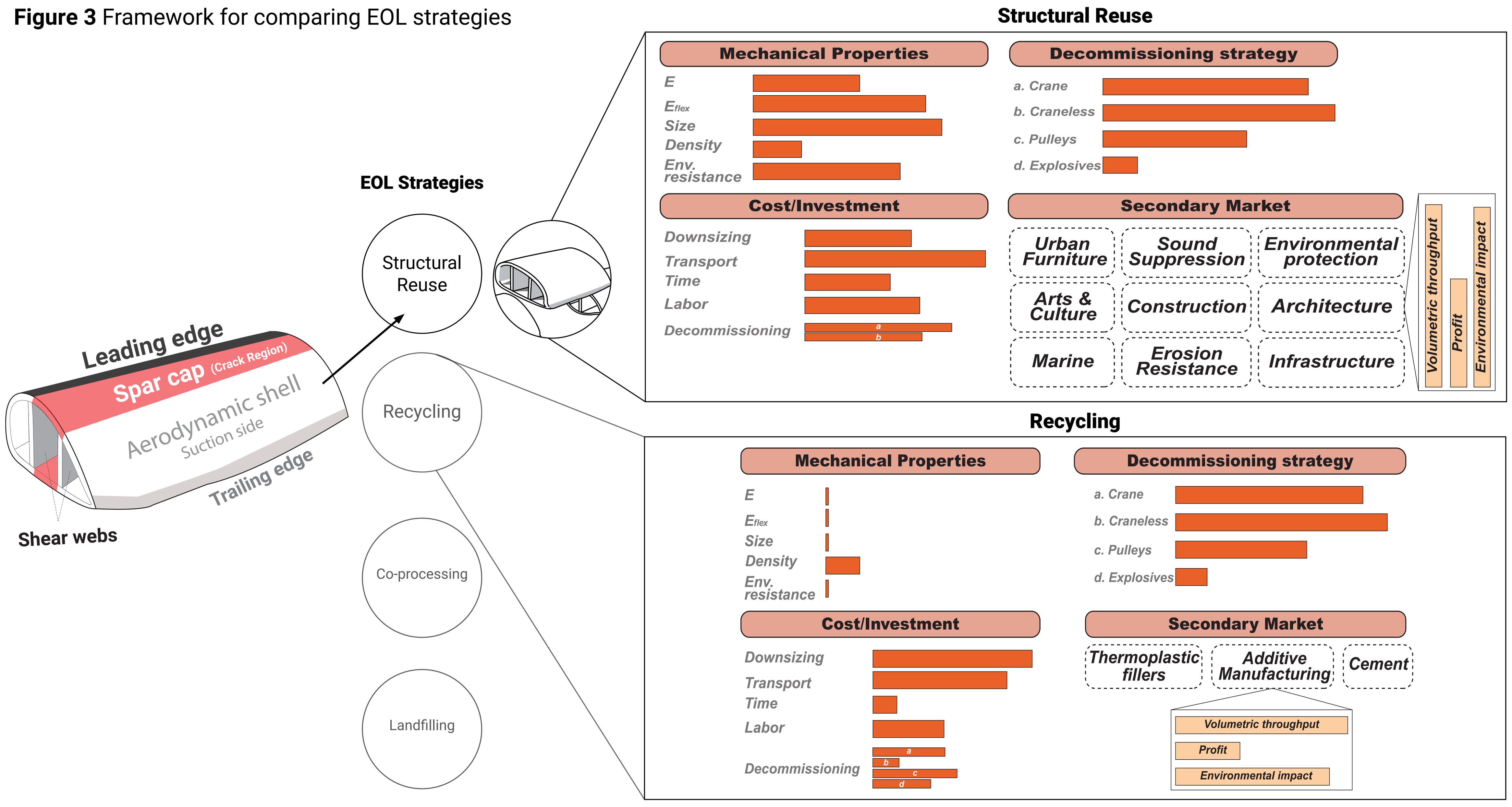
Environmental
- Life Cycle Assessment (from literature)

Financial
- Expert interviews

Results

- **Figure 2** identifies the sub-sections of a blade with unique loading conditions in the crack region (CR) and erosion regions (ER) of the blade[8].
- Material harvested from each of these sections offers different properties and potential secondary applications as illustrated by the examples that follow:
- **Figure 3** illustrates the benefits and drawback of two EOL strategies (recycling and structural reuse) for the spar cap.
- The spar cap has potential for structural applications, but it also has high recovery value from recycling.
- Shear webs (not shown) are suitable candidates for applications in bending while their recycling value is lower.

Figure 3 Framework for comparing EOL strategies



What's next?

- Flexural testing of shell regions
- Compiling mechanical analyses
- Expert interviews
- CATSS Methodology [7]
- Exploring structural reuse opportunities

Remaining Questions

- Is the does the cost-benefit of structural reuse make it a strong end-of-life strategy?
- Are the secondary markets enough to encourage original manufacturers to consider structural reuse in their original designs?
- Which factors most affect the implementation of structural reuse?

Conclusion

A holistic overview of the EOL strategies available upon decommissioning of a blade is presented here. With information on the technical, environmental, and financial effects of these, it is possible to systematically decide which strategy is best for a given project.

Key Points

- Decommissioning processes limit available EOL processes
- Recycling processes have a higher volumetric throughput and lower cost.
- Structural reuse offers a strategy that retains material integrity and opens the door to new secondary markets.
- There is enough variety in integrity and properties along the length of the blade that multiple EOL strategies should be used even with one single blade.

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