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LIFE CYCLE ANALYSIS AND END-OF-LIFE STRATEGIES FOR WIND TURBINES IN ATLANTIC CANADA

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ABSTRACT

Despite the significant environment benefits of wind energy over the combustion of fossil fuels, there remain sustainability-related issues throughout the former's life cycle, particularly within the resource extraction, manufacturing, and end-of-life stages. Where installed wind capacity is constantly increasing, addressing these gaps is crucial to the sustainable adoption of wind power.

Life Cycle Assessment (LCA) is a powerful tool used to pinpoint environmental hotspots. While LCA studies of wind turbines have been completed previously, research has shown that regionality can impact the results. This work addresses a gap in the study of wind turbines located in Atlantic Canada. Working with the Wind Energy Institute of Canada (WEICan), an LCA was completed for their 2-MW wind turbines located in North Cape, Prince Edward Island. As part of this, a hotspot analysis was completed to identify the most impactful life cycle stages, impacts, processes, and flows associated with the wind turbines. Three end-of-life scenarios for the blades were also compared: municipal incineration, landfilling, and cement co-processing.

The hotspot analysis identified freshwater ecotoxicity (long-term), water availability (human health), and human toxicity cancer (short term) as the most significant environmental impact categories. Manufacturing was found to be the most impactful life cycle stage, with the production of the steel tower, the glass-fiber-reinforced plastic (GFRP) for the blades, and the motors/generators being the primary contributors. Key emissions include chromium (VI) to water (99.4% of human toxicity cancer impacts), and aluminum and aluminium (III) to water (75% to freshwater ecotoxicity impacts). These emissions can be traced to the extraction and manufacturing of steel, copper, and permanent magnets. The findings highlight that the environmental impacts of wind turbines are primarily rooted in material extraction rather than their operational phase.

Cement co-processing was found to be the most promising blade disposal option within Atlantic Canada at this time. This process valorizes the blades for use as materials and as an energy source by reducing the need for raw materials and minimizes the transportation of end-of-life material.

Finally, this study quantifies the impact of life extension and repurposing of materials in the context of Atlantic Canada and Prince Edward Island. A sensitivity analysis showed that extending the lifespan of one turbine by 2.5 years can reduce lifetime impacts per kWh by 10%. By re-using high impact components such as the tower in future projects, manufacturing impacts can also be reduced.