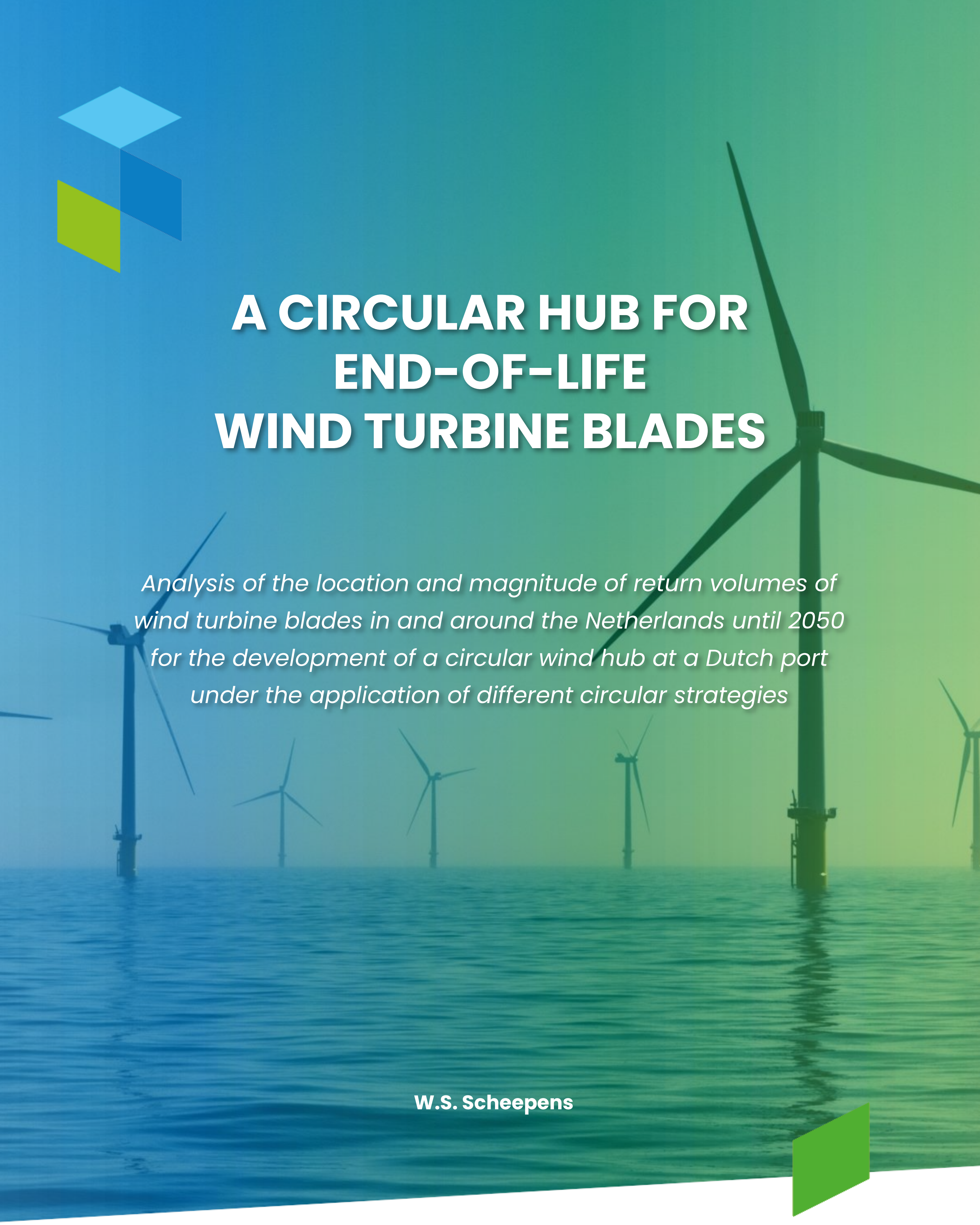


A CIRCULAR HUB FOR END-OF-LIFE WIND TURBINE BLADES

Analysis of the location and magnitude of return volumes of wind turbine blades in and around the Netherlands until 2050 for the development of a circular wind hub at a Dutch port under the application of different circular strategies

W.S. Scheepens

TU Delft

Universiteit Leiden

ECHT

Background

The implementation of a circular economy is a key component of achieving sustainability goals. A circular economy (CE) is based on the long-lasting use of products and the minimisation of waste and pollution. Hence, there are a number of strategies that may applied to a product when it reaches the end of its operational lifetime ("end-of-life", i.e. EoL) to close the material cycles. These strategies are divided in a hierarchical manner from most to least preferred, as seen on the right:

Furthermore, the CE is built on the use of renewable sources for our electricity generation. Wind energy is a crucial element of this. For instance, for the Netherlands, wind should become the main electricity producer by 2050. Yet while the focus is mainly on building and expanding such a renewable energy system, little thought is given to the EoL phase of its components.

This is especially a challenge for wind turbine blades (WTB). The blades are composed of complex composite material structures: these are a combination of glass fibres, sometimes reinforced with carbon fibres, and a resin, oftentimes a thermoset. Thermosets undergo an irreversible reaction of hardening upon heating. While this provides the required stiffness for a WTB, it also makes the blades very difficult to treat once they reach the EoL stage. As such, they are oftentimes landfilled or incinerated. Following the CE principles, those are the least desired strategies.

With a strong growth in wind capacity the coming decades, the number of EoL WTB will also significantly increase. In an attempt to better manage this issue, the creation of a central circular hub as treatment facility for these EoL blades has been suggested. This has lead to the main research question of this thesis:

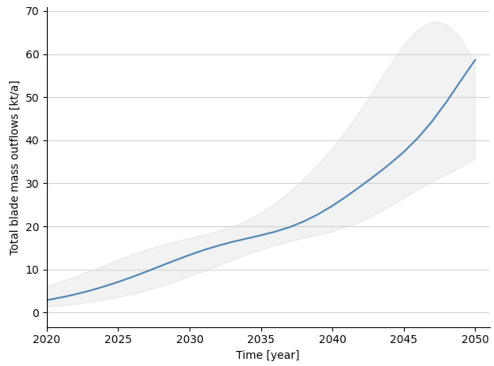
How do Dutch ports compare in terms of suitability for the development of a circular wind hub, and what return volumes of end-of-life wind turbine blades in and around the Netherlands may be treated there until 2050 under the application of different circular strategies?

Results

The first component of this research is focused on the comparison of Dutch ports for the development of a circular wind hub. For the potential development of a circular wind hub to centrally treat the EoL WTB, six relevant categories have been distinguished through interviews and literature consultation. These are: (1) port willingness; (2) available space for storage and the development of new treatment facilities; (3) current companies, infrastructure and activities that are already (indirectly) involved in the wind industry or reverse supply chain; (4) accessibility of the port; (5) the main circular strategies they presently focus on or aim to focus on; and (6) the centrality of the port with respect to the expected return volumes of WTB.

Subsequently, five ports in the Netherlands have been compared for the establishment of a circular wind hub. These are the North Sea Port (NSP), Port of Rotterdam (PoR), Port of Amsterdam (PoA), Port of Den Helder (PoDH), and Groningen Seaports (GSP). The PoDH and PoA come forward as most suitable locations, with a strong willingness and being most centrally located. However, it is also highlighted that the hub need not be limited to one single location - in fact, it could be valuable to collaborate and create synergies across ports, to make use of each port's strengths and existing facilities. In this way, the hub could even become an entity throughout the whole of the Netherlands.

Additionally, interregional collaboration with neighbouring countries of the Netherlands – Germany, Denmark, the United Kingdom, France, and Belgium – will help to improve the economic viability of such a hub. The second component of this research has therefore focused on performing a geographical explicit quantification of the availability of EoL WTB in this region between 2020-2050. This is done through the use of a dynamic Material Flow Analysis (dMFA).



The results indicate a clear increase in the outflow of EoL WTB in the defined region until 2050, reaching a cumulative amount of 690 kilotonnes of blade mass by 2050. The annual outflows grow steadily over time to around 60 kt per year in 2050, as illustrated on the right.

The minimum required throughput capacity for a mechanical recycling plant is estimated to be 4 kt/a. With the estimated annual return volumes from the dMFA, this threshold is already passed in 2022. This supports the urgency to develop a circular wind hub, and indicates that through interregional collaboration, the viability of the hub is enhanced.

However, it is not self-evident that all the wind farms within the research scope would be treated at the hub. Therefore, an indication has been made for which wind farms it is economically viable to transport the blades to each port under the application of the different circular strategies, and what this means in terms of economic potential and environmental impact. This is done based on weighing the economic value of the secondary material under each circular strategy against the transport costs. The circular strategies considered are reusing, repurposing and recycling the blades, and the transport costs are approached under a low, mid and high cost scenario.

The application of the circular strategies strongly influences the amount of material for which it is economically viable to be treated in the hub. In all cases, this is significantly lower than the total amount of material in the region. This is especially the case for circular strategies based on repurposing and recycling the WTB, where the cumulative viable volume stays below 40% of the total volume in all scenarios, and even below 10% in the mid and high transport cost scenarios. The only exception where a substantial volume is reached is for circular strategies based on reusing the blades in the low transport cost scenario, with viable volumes ranging between 75-85%.

This reduced amount of to-be treated blade material is also reflected in the time when the minimum threshold of 4 kt/a for a recycling plant is reached. In the low transport cost scenario, this is only around 2040; in the mid and high transport cost scenarios, the threshold is not reached at all.

The economic benefits and energy savings that may be realised follow the same pattern as the viable volume and are therefore very limited compared to what could theoretically be achieved by treating the total volume in the region. The cumulative economic benefits generated by recycling the blades in each scenario are not sufficient to cover the total expected variable costs of a recycling plant, let alone the required fixed costs and investments. With regard to the environmental impact, reusing, repurposing and recycling all the blades in the region as opposed to landfilling them could save 41, 21, and 10 PJ of energy, respectively. The results show that in each of the scenarios, the achieved energy savings are much lower. For instance, in the mid transport cost scenario, these are only 14, 0.7 and 0.8 PJ, respectively.

All in all, among the three strategies, reusing the blades results in the highest amount of material treated, energy saved and economic benefits realised. However, there is a mismatch between expected revenues and potential market size: most economic benefits are generated by reusing the blades, whilst the market potential is largest for recycling and lowest for reusing them. This disparity calls for regulation. Furthermore, there is no one-size-fits-all, i.e. no market that can fully absorb the total expected return volume of EoL WTB, hence a combination of strategies will need to be applied.

The results show a strong response to a marginal change in the transport costs and economic value of the secondary material. This means that the definition of these parameters is of large influence on the final results, and means that policy interventions on these are advised. Despite this influence on the generated results, the overall conclusions remain the same.

For more detailed results, the reader is referred to the full thesis report.

Recommendations to industry/policy-makers

From the findings in this research, various recommendations can be made to industry players and policy-makers.

- For the development of a circular wind hub, none of the Dutch ports is deemed unsuitable. It is recommended to the ports to work together on this initiative and collaborate in the development of such a hub. With the PoA and PoDH as most centrally located ports with regard to WTB return volumes, and simultaneously as two of the ports with most clear and eager ideas about a circular wind hub, it would be advised that these parties take the lead in this. PoDH could for instance offer the space to set up treatment facilities for the various circular strategies, while PoA can offer innovation and the Amsterdam metropolitan area;
- Based on the modelled material outflows, interregional collaboration with neighbouring countries of the Netherlands is highly advised to reach high annual material throughputs in the hub;
- For the application of the different circular strategies analysed, most can be achieved by reusing the blades in terms of to-be treated volume, economic benefits and energy savings. However, the market potential is largest for recycling the blades and smallest for reusing them. This imbalance asks for regulation;
- It is imperative that the viable volumes under application of the circular strategies better approach the total volume in the region. For this, a number of hurdles will need to be addressed. For instance, the economic value of the secondary material must be increased, to create a more substantial financial margin. Furthermore, it is crucial for the application of each of the circular strategies that the documentation of WTB and transparency in the value chain be improved. This includes quality monitoring during the operational lifetime of the blade and the

availability of information with respect to blade design and material composition. Such information must be gathered, properly documented, and shared with the receiving party.

Research contribution

This research has offered a more concrete and tangible analysis of the challenge of EoL WTB in the geographical region relevant to the Netherlands until 2050. The return volumes have been determined for the specified scope, and have been enhanced through a spatio-temporal quantification. The synthesis of the three research objectives aids the establishment of optimal waste management infrastructure for EoL WTB. The research has illustrated that substantial environmental and economic benefits can theoretically be achieved, especially under implementation of higher circular strategies, provided that measures or incentives are introduced to support this. Seeing as numerous circular wind hubs will need to be developed throughout Europe, or even globally, this research offers guidance in the considerations to make. Furthermore, the results from this research shed additional light on the reverse logistics and EoL component of WTB, which is oftentimes left outside of consideration in analyses of this sector. All in all, this research expresses the urgency, feasibility and potential value of the development of a circular wind hub for end-of-life wind turbine blades in the Netherlands.

Discussion

While the research findings offer valuable insights for the development of a circular wind hub, there are a number of aspects of the research for which further research or consideration is advised. For instance:

- Sustainable development is based on three main pillars: social, economic and environmental. This research has only looked at the economic and environmental pillar. Further research could expand the economic and environmental analysis, and include the social dimension;
- It is advised to better model the transport costs and the economic value of the secondary material since the results have shown significant sensitivity to these parameters;
- Inclusion of other circular strategies to complete the circular ladder in the analysis. This could also include research into the minimum required throughput for each circular strategy, and the evaluation of the effects of redesign of the blades on the different available treatment options. Furthermore, analysis could look at possible scenarios for the application of a mix of strategies. Such analyses would aid the actual implementation and feasibility of a circular wind hub;
- Evaluation of potential policy measures to increase the viable volume are recommended: to investigate how effective these could be in increasing the viable volume and to aid the general development of a circular wind hub. For instance, assessment of what the economic value of the secondary material would need to be under each circular strategy to reach the desired increase in viable volume.