Report 2023
Task 42

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Wind Turbine Lifetime Extension

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The objective of Task 42 is to provide information about methods for estimating the consumed life of wind turbines, which can be used for decisions of lifetime extension.

The main activity of 2023 has been on the initiation of the second phase of the Task (2023-2026) and the work is centred around three Work Packages (WPs) addressing the following topics:

- WP1: Integrating economical reliability and risk
- WP2: Data drive life estimation.
- WP3: Preparing for a sustainable future (2050)

A result of 2023 is a study of the historic evolution of the Danish wind turbine fleet and a model description of the fleet decommissioning

[1]. It was found that the age of the Danish turbines, when half of the capacity of an installation year is decommissioned, is 29 years. Secondly, the speed by which the decommissioning changes from 10% to 90% of the installed capacity is about 9 years. This shows that the turbines of Denmark are entering a life extension mode characterised as "continued operation" above the design lifetime of 20 and 25 year for on- and offshore wind turbines.
A follow-up study showed a different German decommissioning market with an age of 25 years when half of an installation year is decommissioned since a lifetime-extension review is requested as the design lifetime is reached [2]. Finally, it was estimated that the fraction of the Danish and German decommissioned turbines that were resold for a second lifecycle are 59% and 48%, which will result in a large reduction of materials for recycling.

Introduction

The age of the wind turbines installed globally are in several regions reaching their design lifetime as specified in the IEC 61400-1 and -3 standards. This requires decisions to be made whether the turbines should be decommissioned or enter a period of life extension operation. This is considered through a technical review of the wind turbine to ensure that it will be safe to operate the turbine for additional years, and the life extension review will address the consumed lifetime of the structural components such as tower, main bearing and blades for onshore turbine as well as substructures such as monopiles and transition pieced for offshore turbines.

The wear components of the turbines, such as gearboxes and other drive train components, are not critical for safety but can have large consequences for the business case of a lifetime extension investment. Thus, the second phase of Task 42 will, in Work Package 1, investigate how to evaluate if the business case of lifetime extensions can be quantified by balancing the economical reliability against the risk of major failures of the turbines. In essence, the turbines will keep running if the income from selling the electricity is higher than the cost of repairing the turbines. WP2 focuses on the technical evaluation of the consumed life of the turbines, whereas WP3 focuses on the consequences of different lifetimes when the green transition has been implemented in 2050.

The list of participants has been expanded to 14, representing seven countries and involving five companies in 2023.

Table 1. Countries Participating in Task 42.

COUNTRY/SPONSOR	INSTITUTION(S)
Korea	Changwon National University (CWNU); Royal Institute of Technology (KTH)
Sweden	Chalmers University of Technology (Chalmers)
Denmark	EDepartment of the Built Environment, Aalborg University (AAU); Department of Wind and Energy Systems, Technical University of Denmark (DTU); EMD International
Belgium	Vrije Universiteit Brussel (VUB)
Germany	Institute for Steel Construction, Leibniz University Hannover (LUH); Technical University of Munich (TUM); Rambøll; EnBW
Ireland	University College Dublin (UCD)
China	Xinjiang Goldwind Science & Technology Co

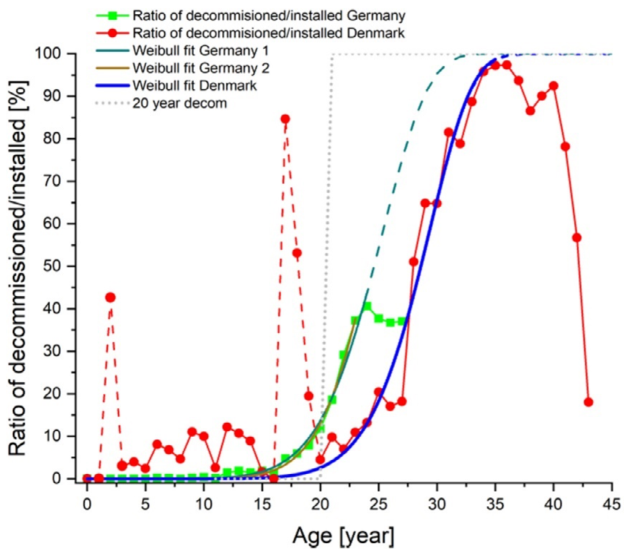
Progress and Achievements

Parts of the scientific work of Task 42 was part of the Danish project, DecomBlades, which investigated turbine blade recycling technologies. It showed that the amount of blade material available for the recycling industry in Denmark was about an order of magnitude lower than most predictions. This discrepancy was investigated by examining the Stamdatabasen of the Danish Energy Agency that holds information about all operating and decommissioned wind turbines of Denmark. The study found that the average age of the turbines decommissioned in Denmark is about 18 years, which is close to the design lifetime of 20 years of the onshore turbines. It seems tempting to conclude that all Danish wind turbines are decommissioned when they reach their design lifetime of 20 years, but this is by far not the case, since the majority of the Danish wind turbines are operating for much longer than their design lifetime.

The historic evolution of the Danish fleet was examined [1] by adding the "in operation" fleet with the "decommissioned" fleet into the "installed" fleet, whereby the ratio of decommissioned turbines with respect to the installed fleet could be obtained per installation year. A Weibull function was proposed to describe the evolution of the Danish fleet as shown in Figure 1 and a prediction of the decommissioned blade material in the future was provided [1]. An expanded study was performed in [2] to also investigate the decommissioning of the German onshore turbine fleet as shown in Figure 1. The studies show that the Danish turbines are gradually depleted, since they can enter the lifetime extension state of "continued operation" with an annual inspection, whereas the German depletion shows a plateau most likely reflecting the request of a lifetime extension review when extending the design lifetime.

A consequence of the life extension operation in Denmark and Germany is that the amount of turbine material sent to the recycling industry is delayed by about 10 years in both Denmark and Germany. Secondly, Kramer et. al. interviewed stakeholders related to the decommissioning industry in Denmark and Germany about the fraction of decommissioned turbines that were resold for a second lifecycle after the decommissioning. The estimated fractions were 59% and 48%, respectively, and this caused a further 50% reduction in the turbine material for recycling in Denmark and Germany [2]. Figure 2 shows the resulting estimated blade mass for recycling in Germany in the next decades when new installations are not included.

Thus, it is concluded that the lifetime extensions expanding far beyond the design lifetime, as well as the reselling of decommissioned turbines in Denmark and Germany are the main reasons why the material flow into the recycling industry is an order of magnitude lower than previously predicted.



Model	Weibull DNK
Lambda	29.79 ± 0.25
k	9.11 ± 0.88
R-Square	0.96

Model	Weibull GER 1
Lambda	25.83 ± 0.18
k	7.49 ± 0.34
R-Square	0.99

Model	Weibull GER 2
Lambda	25.06 ± 0.12
k	8.71 ± 0.29
R-Square	0.99

Figure 1. Illustration of the decommissioning of the Danish and German onshore wind turbine fleet as of 2022, shown as the ratio between the decommissioned and installed blade mass of the different installation years. The figure shows that the age of the turbines when 50% of an installation year is decommissioned is 29 years for Denmark, whereas the German curve shows a plateau at 40%, which is most likely related to the request for a life consumption review of German turbines in order to obtain approval for lifetime extension. The Danish turbines can enter a lifetime extension mode of "continue operation" if they pass an annual technical inspection. Reproduced from Kramer et. al. (2024) [2].

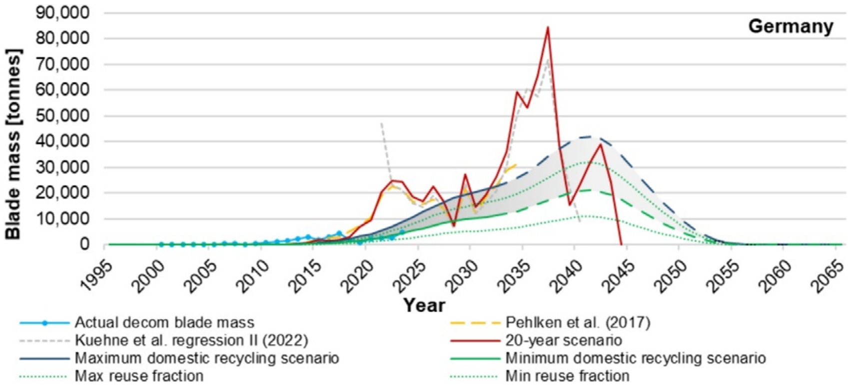


Figure 2. Illustration of the consequences of the lifetime extension activity in Germany in terms of the estimated annual amount of wind turbine blade material to be recycled in the years to come. The simple prediction that the blades are sent to recycling when reaching the design lifetime is shown by the red line and the actual observed decommissioned of turbine blades is shown by the blue line with circular marker, indicating an order of magnitude difference. When including the delay due to the lifetime extensions and that half of the turbine blades are resold, the solid green prediction is obtained. The threshold of a blade recycling facility is estimated to be about 10,000 tons per year, which will become realised around year 2030 for Germany. The Danish market will never reach this level, indicating that a cross-border collaboration will be beneficial. Reproduced from Kramer et. al. [2].

Highlight(s)

- The initialisation of the second phase of the lifetime extension Task and the expansion of the Task participants list.
- An analysis of the decommissioning of the Danish wind turbine fleet shows that most of the Danish wind turbines, with an age exceeding the design lifetime of 20 years, are entering a lifetime extension mode of "continued operation" by complying to an annual technical inspection. Thus, the age of a Danish wind turbine, when 50% of an installation year is decommissioned, is 29 years and the age when 10% and 90"% are decommissioned is 24 and 33 years respectively, resulting in a transition period of nine years. This is very different from the simple assumption that all turbines will be decommissioned when they reach their design lifetime, and predictions of the amount of turbine material for recycling is therefore delayed by about nine years.
- A comparative analysis of the decommissioning of the German and Danish onshore market reveals that the Germany is experiencing a faster decommissioning rate than Denmark. This is indicated by a plateau at 40%, likely due to the German request of a design review before granting lifetime extension operations.
- Furthermore, the proportion of decommissioned wind turbines that were resold as complete systems has been determined to be 59% in Denmark and 48% in Germany. This resale rate reduces the amount of turbine material available for the recycling industry in both countries. Combined with delays due to lifetime extension activities, this explains the significantly lower amount of turbine material being received by the recycling industry.

Outcomes and Significance

The analysis of the decommissioning at the fleet level in Denmark and Germany have provided some insight into the large-scale signatures of lifetime extension activities, whereby the consequences at the country or region level become visible. This was illustrated by the example of predicting the amount of wind turbine blade material that is expected to enter the recycling industry of Denmark and Germany over the next decades. The analysis reveals that previous predictions of blade material for recycling often assume that all turbine blades will enter the recycling route as the turbine age exceeds the design lifetime. However, this is not the case for either Denmark nor Germany, and recycling blade mass prediction seems to be an order of magnitude too high, and a delay of about 9 years is expected before the material will be recycled. Hence, investments in blade recycling facilities will be needed to handle the aging turbines, but a 9-year delay in receiving enough material volumes can be economically detrimental. A positive aspect of the lifetime extensions of the Danish and German turbines is that the material-related CO2 emission per kWh has been decreased by approximately 30%.

Next Steps

The second phase of Task 42 will focus on writing collaborative papers on the topics of Task 42's three Work Packages. This involves a formulation of an economic model for the lifetime extension scenarios of different markets, and a collaboration with Task 53 Wind Energy Economy is considered. The work in WP2 will continue comparing methods for estimation of the consumed life of wind turbines, whereas WP3 will investigate the sustainability consequences of different design lifetimes, as the wind energy capacity is saturating worldwide in 2050. Most offshore tenders today indicate operational lifetimes of more than 35 years.

References

[1] Bech Abrahamsen A, Beauson J, Wilhelm Lund K, Skov Madsen E, Philipp Rudolph D, Pagh Jensen J. Method for estimating the future annual mass of decommissioned wind turbine blade material in Denmark. Wind Energy. 2024; 27(2): 165-178. doi:10.1002/we.2882

[2] Kathrin Julia Kramer, Asger Bech Abrahamsen, Justine Beauson, Ulrich Elmer Hansen, Niels-Erik Clausen, Anne P.M. Velenturf, Matthias Schmidt, "Quantifying circular economy pathways of decommissioned onshore wind turbines: The case of Denmark and Germany", Sustainable Production and Consumption, Volume 49, 2024, Pages 179-192, ISSN 2352-5509, https://doi.org/10.1016/j.spc.2024.06.022.'

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