Final report of IEA Task 42 Life extension

1. Project details

Project title	IEAWIND Task 42 Lifetime Extension Assessment
File no.	64019-0561
Name of the funding scheme	EUDP
Project managing company / institution	DTU Wind and Energy Systems, Technical University of Denmark (DTU)
CVR number (central business register)	30 06 09 46
Project partners	Department of the Built Environment, Aalborg University (Aau) EMD A/S (EMD)
Submission date	24 August 2023

2. Summary

English version

The objectives of the IEA Wind TCP Task 42 Wind Turbine Lifetime Extension is to investigate method for supporting the decision of life time extension of operating wind turbines, when they become older than the design life time. The focus has been on inspection of the load carrying components of operating wind turbines as well as data driven support for estimating already used life time, whereby the remaining useful life time can be estimated in the context of the design life time of 20 years and 25 years respectively for on- and off-shore wind turbines as specified in the IEC 61400-1 and -3 design standards. Finally recommendation to the standard for life extension has been provided to relevant working committees.

The work has resulted in a series of deliverables published in the IEA wind TCP Task 42 website with the outline of the task in the first deliverable D1 “Lifetime Extension Assessment” (2020), where the definitions of life time assessments were formulated. Procedures for inspection and risk assessment was reported in the second deliverable (D2) “Procedures for determining risk of failure and preventive maintenance” (2021). After a reconstruction of the task due to Covid-19 and also replacement of operating agent then the two major technical deliverables “Deliverable Report 5+6: Data driven life prediction & comparison” (2022) and “Deliverable Report 3+7: Recommendations on standards and regulatory frame” (2022) were completed. The D5+6

report is showing how the lifetime of the an onshore V52 turbine was estimated to be 49 years compared 20 years design life time and that the life estimation of the Alpha Ventus offshore wind farm can be improved by adding simple binning of strain-gauge measurements. Finally the reliability index of 3.3 used for design of wind turbines has been reviewed for the life extension case and it is recommended to lower this, because of lower economical risk beyond the design life time. More work is needed to agree on the new level.

Danish version

Formålet med IEA Wind TCP Task 42 Wind Turbine Lifetime Extension er, at undersøge metoder til at understøtte beslutningen om levetidsforlængelse af vindmøller i drift, når de bliver ældre end designlevetiden. Fokus har været på inspektion af de lastbærende komponenter i vindmøller i drift samt datadrevet støtte til estimering af allerede brugt levetid, hvorved den resterende brugbare levetid kan estimeres i forbindelse med designlevetiden på henholdsvis 20 år og 25 år for on- og off-shore vindmøller som specificeret i IEC 61400-1 og -3 designstandarderne. Endelig er der givet anbefalinger til standarden for levetidsforlængelse til relevante arbejdsudvalg.

Arbejdet har resulteret i en række leverancer, der er offentliggjort på IEA wind TCP Task 42's hjemmeside med en oversigt over opgaven i den første leverance D1 "Lifetime Extension Assessment" (2020), hvor definitionerne af levetidsvurderinger blev formuleret. Procedurer for inspektion og risikovurdering blev rapporteret i den anden leverance (D2) "Procedures for determining risk of failure and preventive maintenance" (2021). Efter en rekonstruktion af opgaven på grund af Covid-19 og også udskiftning af Operating Agent blev de to store tekniske leverancer "Deliverable Report 5+6: Data driven life prediction & comparison" (2022) og "Deliverable Report 3+7: Recommendations on standards and regulatory frame" (2022) afsluttet. D5+6-rapporten viser, hvordan levetiden for en V52-mølle på land blev estimeret til 49 år sammenlignet med 20 års designlevetid, og at levetidsestimeringen for Alpha Ventus-havmølleparken kan forbedres ved at tilføje simpel binning af strain-gauge-målinger. Endelig er pålidelighedsindekset på 3.3, der bruges til design af vindmøller, blevet gennemgået i forbindelse med levetidsforlængelsen, og det anbefales at sænke det på grund af den lavere økonomiske risiko ud over designlevetiden. Der er behov for mere arbejde for at nå til enighed om et nyt niveau for pålidelighed indekset ved levetidsforlængelse.

3. Project objectives

The objective of the project was to investigate methods to support the decision of life extension of on- and offshore wind turbines, where they become older than the design life time of 20 and 25 years respectively.

The technology in focus was computer based methods to predict the consumed life time of the wind turbines by either using information about the wind condition that the wind turbine has been exposed to as well as measurements of the strain response of the major components of the wind turbine, such as the tower or blades.

4. Project implementation

The project was started in 2019 with Anand Natarajan as the Operating Agent of IEA Wind TCP task 42 and the EUDP task 42 project was created to provide Danish contributions to the collaboration. The task started out with two deliverable reports in 2020 and 2021, but did gradually face challenges due to the Covid-19 situation on arranging physical meetings and to obtain sufficient work input from the IEA task 42 partners. This resulted in several initial partners to withdraw during 2021. A second challenge was that Anand Natarajan left

DTU and Asger B. Abrahamsen was assigned as temporary Operation Agent. A restructuring of the IEA task 42 was initiated by Asger B. Abrahamsen and Professor Athanasios Kolios was later proposed as Operating Agent for the task. The restructuring was approved in 2022 and an extension of the Task 42 has been submitted to IEA wind TCP for another 3 years.

5. Project results

The main results of the EUDP IEA task 42 project are listed below

1) A collaboration between DTU Wind and Energy systems and EMD A/S on the exchange of the high quality SCADA data from the DTU V52 research wind turbine at the DTU Risø campus and the training of a surrogate model of EMD A/S for life time estimation of wind turbines. It was found that the fatigue life time of the DTU Risø V52 turbine is expected to about twice as high as the design life time of 20 years (see Figure 1).

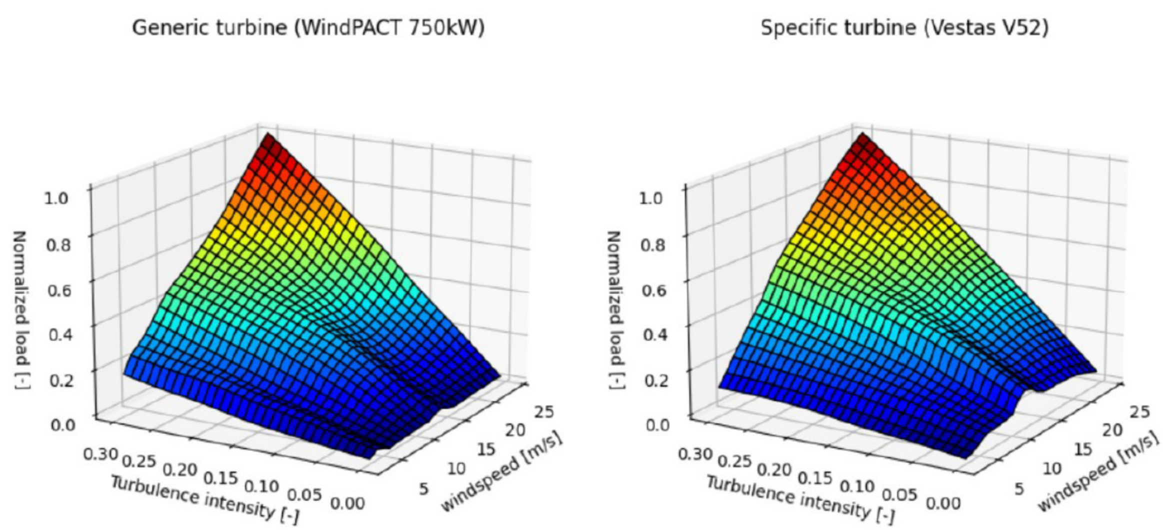

Figure 1. Illustration of the V52 wind turbine loads as predicted by the surrogate model (left) compared to specific V52 loads calculated using state of the art aeroelastic models. The resulting life time of the V52 turbine at the Risø campus was found to be 45-49 years (see [6] in Appendix 8).

2) An investigation of the reliability index of 3.3 of the current design standard for wind turbines in connection with life extension beyond the design life time (see Figure 2). It was shown that the reliability can be reduced, but further work is needed to settle on a new lower limit.

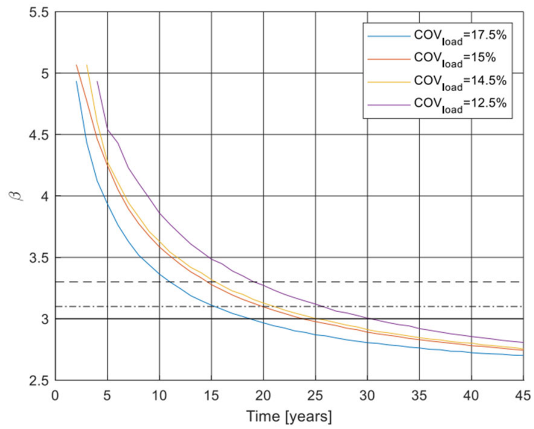

Figure 2. Annual reliability $\boldsymbol{\beta}$ for different values of $\boldsymbol{COVload}$ as function of time (with deterministic design for 25 years). Reproduced from [5] in appendix 8.

3) A study of the decommissioning of Danish wind turbine fleet in term of the installed blade mass has indicated that the age of the Danish turbines are about 24 years, 29 years and 33 years when 10 % , 50 % and 90 % of an installation year has been decommissioned (see Figure 3). This is providing information about the time spread that is associated with the removal of many turbine installed in the same year. A consequence of this spread is that the many companies that might be expecting a large amount of blades to recycle might have to wait for 9 years more than expected if the design life time has been used to estimate when the blade masses needing waste handling. A prediction of the de-commissioned mass of blades of Denmark has been provided and can guide industrial partner of the recycling industry.

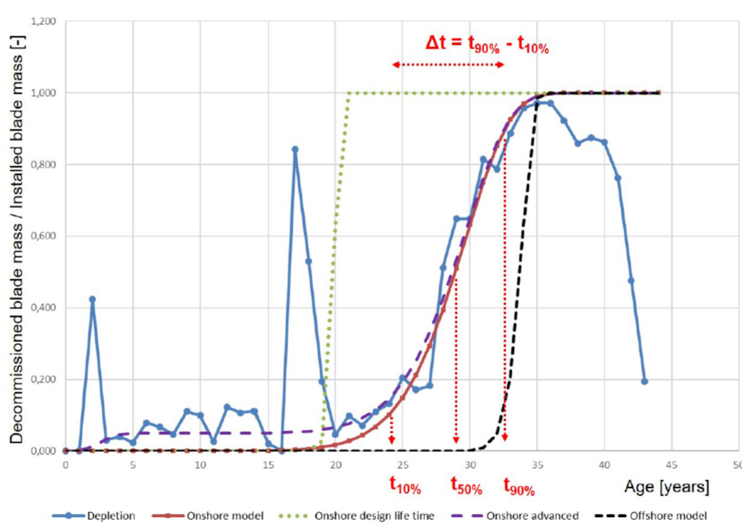

Figure 3. Time evolution of the ratio between decommissioned blade mass and installed blade of the Danish wind turbine fleet by the year 2022. It can be seen that 10 %, 50 % and 90 % of the installed blade mass of an installation year is removed at 24, 29 and 33 years respectively. This is much longer than the design life time of 20 years and will cause a delay in blade mass for the recycling sector. Secondly the

analysis shows that a large fraction of the Danish turbines are performing the life extension version of “continued operation” for more than 10 year. Reproduced from [9] in appendix 8.

6. Utilisation of project results

Members of the task force are deeply engaged in related developments and have forged relationships with pivotal industry partners. Their academic publications, some of which have already been accepted, combined with forthcoming presentations at relevant forums like WindEurope, offer stakeholders insights into the challenges of lifetime extension. These insights explain how the task force's outcomes can be of assistance. Both asset owners and operators are keen to understand how to maximize the value from their active and future assets. Simultaneously, policymakers need clarity on the potential of existing installations and current technologies in achieving future targets. Recognizing the goals set for 2040-2050, it's essential to adopt a disruptive mindset and re-evaluate conventional design assumptions, such as the standard 20-25 year design life. In line with this, during the period of this task, we have explored several pivotal topics.

We've delved into formulating methods to ensure the safety of wind turbine primary structures and components while setting the desired reliability levels. We've also addressed the need for bridging the gaps between data-based reliability and traditional structural reliability methods when assessing various limit states. Investigating the suitability and completeness of pertinent standards for lifetime extension, to be made accessible for national bodies instituting regulations, has been a focus. We've given thought to studying methods to pinpoint damage and classify damages using established methodologies, like Failure Modes and Effects Analysis (FMEA). The importance of handling data effectively, recognizing its significance for life extension, has been highlighted. Furthermore, the task emphasized the necessity of predictive maintenance techniques, especially for turbine blades.

7. Project conclusion and perspective

Deliverable Report 1 primarily addresses the complexities surrounding life extension for wind turbines. The report emphasizes the importance of making informed decisions regarding failure probabilities for turbines after their original lifespan. The propagation of uncertainties from wind assessments to turbine loads and the quantification of these uncertainties, especially in the context of available wind data, are crucial. Tools such as uncertainty models for fatigue load effects, fatigue strength, and strategies for estimating failure probabilities are integral. Equally important is the advancement in inspection techniques – the push for improved drone inspections, non-destructive testing (NDT) methods, and the digitalization of inspection records. The potential of machine and deep learning in identifying damages also deserves more attention.

Deliverable Report 2 delves into risk assessments and maintenance. An overarching theme is the importance of routine comprehensive risk evaluations to streamline maintenance costs and optimize power output. The Risk Priority Number (RPN) emerges as a crucial tool for this, encompassing factors like severity, occurrence, and detectability of failures. Ensuring the RPN's accuracy demands analyses of potential failure modes, monitoring systems, and historical data reviews. Predictive maintenance, leveraging prognostics-based methods, becomes a focal point. The digitalization of inspection and maintenance records, extrapolative fatigue damage techniques, and factoring in various environmental and logistical considerations in maintenance planning are essential for effective risk-based decisions.

Deliverable Report 3+7 concerns standards and regulatory frameworks. A salient point here is the consideration of the fatigue life of turbine components, especially structural elements like the tower. The report brings out the nuances in the IEC 61400-1 ed. 4 standards regarding design and fatigue life assessments. Interestingly, the document discusses the trade-offs between design conservatism and accuracy, and how these might shift when considering life extension as opposed to initial design. Notably, the report suggests that economics may motivate accepting lower reliability levels for life extension. The distinction between turbines designed using different turbulence intensity considerations in standards becomes significant when considering life extensions.

Lastly, Deliverable Report 5+6 underscores the role of data in predicting turbine lifespan. Highlighting the scarcity of open-access, high-quality data, the report divides relevant data into three categories: SCADA/meteorological data, strain/acceleration data, and turbine design data. Each data type's availability determines the precision of fatigue life predictions. For instance, while SCADA data alone may give general predictions, combining it with strain data offers detailed insights for specific components. The report concludes that while more data invariably leads to enhanced remaining lifespan assessments, the cost-efficiency of collecting this data remains a point of deliberation.

Cumulative Conclusion:

Ensuring the successful and economically viable extension of wind turbine lifetimes necessitates a multi-faceted approach. Decisions must be grounded in comprehensive risk assessments, predictive maintenance techniques, and current standards and regulations. The potential of technology, especially in data collection and analysis, can significantly impact the precision of lifespan predictions. As the wind energy sector evolves, it is clear that a balance between accurate data, advanced predictive models, and economic considerations will be central to achieving optimal turbine lifetime extensions.

The core Task 42 consortium members have already delved into the conclusions and future recommendations from the course of this activity and as such have priorities a series of objectives which will be investigated in a subsequent stage of Task 42. More specifically, these objectives account for the following:

- Assessment of rules and best practice for lifetime extension relevant for different regions.
- Optimal procedures for structural reassessment through load modelling and uncertainty quantification.
- Technical and project risk identification relevant for lifetime extension.
- Process mapping and gap analysis of incoming data from operational wind farms and a plan for optimal data collection for future assets.
- Specification of monitoring systems to return maximum value to the lifetime extension decision making process.
- Recommendations around technology and assessment related aspects that can offer further opportunities in the design of assets in support to 2050 targets.

It is our clear intention and priority, to liaise further with key industry stakeholders and specifically certification authorities who can uptake results of this Task into revisions of upcoming standards as well as design assumptions for the design of future wind farms.

8. Appendices

8.1 Links to annual reports of IEA Wind TCP task 42

Here are the links to the annual reports of IEA Wind TCP

[1] Anand Natarajan, "Task 42 Report 2020" (2020) : https://iea-wind.org/wp-content/uploads/2022/03/task-42.pdf

[2] Asger Bech Abrahamsen and Athanasios Kolios, "Task 42 summary" (2021, see page): https://iea-wind.org/wp-content/uploads/2022/12/IEA_Wind_TCP_Annual_Report_2021.pdf

8.2 Links to IEA WIND TCP Task 42 Life extension deliverable reports

The link to deliverable reports are collected at the task 42 web site (https://iea-wind.org/task42/t42-publications/) and listed below. The EUDP task 42 project has been playing a leading role in most of the deliverable report produced.

[3] Anand Natarajan, Dheelibun Remigius, Jannie Nielsen, René Meklenborg, Lasse Svenningsen, Clemens Hübler, Tanja Greissmann, Aiko Leerhoff, Vasilis Pettas, Rupp Carriveau, "Deliverable Report D-1: Gap Analysis of Existing Procedures required for Life Extension*" (2020) : https://iea-wind.org/wp-content/uploads/2021/02/Task-42-report-D10.pdf*

[4] Anand Natarajan, W. Dheelibun Remigius, Jannie S. Nielsen, Clemens Hübler and Tanja Greissmann, "Deliverable Report 2: Procedures for determining risk of failure and preventive maintenance" (2021) : https://iea-wind.org/wp-content/uploads/2021/05/IEA-Wind-Task-42-Deliverable-D2-Risk-Analysis-V3.pdf

[5] Jannie S. Nielsen, John D. Sørensen, Asger Bech Abrahamsen and Athanasios Kolios, "Deliverable Report 3+7: Recommendations on standards and regulatory frame" (2022) : https://iea-wind.org/wp-content/uploads/2023/06/Task-42-report-D37_RecommendationStandardsRegulatoryFrame-v3.pdf

[6] René Meklenborg, Lasse Svenningsen, Clemens Hübler, Andreas Vad, Anik Hirenkumar Shah, Asger Bech Abrahamsen, Athanasios Kolios and Stavroula Tsiapoki, "Deliverable Report 5+6: Data driven life prediction & comparison" (2022): https://iea-wind.org/wp-content/uploads/2023/06/IEA-Task-42-Report-D56_DataDrivenLifePredictionAndComparison.pdf

8.3 Publication related to EUDP IEA Wind TCP task 42 project

The following journal papers have been produced by the partners EUDP task 42 project

[7] J. S. Nielsen, J. D. Sørensen (2021). Risk-based derivation of target reliability levels for life extension of wind turbine structural components. Wind Energy, 24(9), 939-956. doi:10.1002/we.2610

[8] J. S. Nielsen, L. Miller-Branovacki, & R. Carriveau (2021). Probabilistic and Risk-Informed Life Extension Assessment of Wind Turbine Structural Components. Energies, 14(4), 821. doi:10.3390/en14040821

[9] A. B. Abrahamsen, J. Beauson, K. Wilhelm Lund, E. Skov Madsen, D. P. Rudolph, J. Pagh Jensen, " Method for estimating the future annual mass of decommissioned wind turbine blade material in Denmark", Accepted August 2023 for Wind Energy with minor changes,

Pre-print : https://www.authorea.com/doi/full/10.22541/au.168105743.37926484/v1