DG AW

RESSOURCEN NEU DENKEN.

Deutsche Gesellschaft für Abfall- und Kreislaufwirtschaft e.V.

15. DGAW-WISSENSCHAFTSKONGRESS

Kreislauf- und Ressourcenwirtschaft

am 24. und 25. Februar 2026
an der Hochschule Pforzheim

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Tagungsband

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In Zusammenarbeit mit

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End-of-life Wind turbine blade waste quantification for Europe 2025–2040

***Abstract**: Wind energy is central in achieving the European Union's climate neutrality in 2050. With the continued expansion of wind power capacity, the amount of wind turbines reaching their end of life will increase substantially in the coming decades. In particular, wind turbine blades made from glass and carbon fiber reinforced plastics (GFRP and CFRP) pose a significant recycling challenge, as sustainable and industrially established recycling solutions are still lacking. The objective of this study is to develop a robust forecast of wind turbine blade waste generation in Europe up to 2040. As part of the European research project REWIND, a dynamic lifetime approach is applied that accounts for increasing service lives of modern wind turbines, in contrast to previous studies assuming fixed operational lifetimes. The model is based on comprehensive turbine data from the German "Marktstammdatenregister" and the database "The Wind Power", complemented by literature data and expert input from industry. Key parameters include commissioning year, installed capacity, and the distinction between onshore and offshore turbines. The results show a temporal shift of waste generation towards later years, particularly after 2030. Glass fibers dominate the overall material flow, while the share of carbon fibers will increase significantly due to the growing deployment of larger turbine types. The findings underline the urgent need to advance recycling and recovery technologies for GFRP and CFRP materials in order to manage future waste streams effectively and support the transition towards a circular wind energy sector in Europe.*

1 Introduction

Wind energy is a key instrument for reducing greenhouse gas emissions from electricity generation and for achieving the European Union's target of climate neutrality by 2050 (European Commission, 2023). Supported by policy initiatives such as the European Green Deal and REPowerEU, wind power capacity in Europe has expanded rapidly in recent years (European Commission, 2023). By 2024, total installed wind capacity reached approximately 285 GW, accounting for around 19.5 % of electricity consumption in the EU-27 and the United Kingdom (Constanzo & Brindley, 2024).

Further capacity growth is expected until 2030; however, a substantial share of the existing wind energy plant fleet will reach the end of its service life during this period. Between 2025 and 2030, approximately 227 GW of wind capacity are projected to be decommissioned, of which about 101 GW will be permanently retired and 126 GW repowered (Costanzo, Brindley, & Tardieu, 2025). While most wind turbine components can be recycled, wind turbine blades (WTB) remain a challenge due to their fiber-reinforced polymer composition (GFRP and CFRP), for which environmentally sustainable recycling solutions are still under development (Beauson, Laurent, Rudolph, & Pagh Jensen, 2022).

The relevance of this challenge is expected to increase further, as the European composite market continues to grow (grandviewresearch, 2023). Reliable forecasts of future WTB waste streams therefore require robust assumptions regarding turbine lifetimes and material composition. Most existing studies assume fixed operational lifetimes of approximately 20 years, following IEC 61400-1, which may lead to an overestimation of near-term blade waste volumes (DIN EN IEC 61400-1, 2019; Hassing & Søren, 2001;

Liu & Barlow, 2017; Volk, Stallkamp, Herbst, & Schultmann, 2021). More recent studies indicate increasing turbine lifetimes, with empirical and stochastic approaches suggesting average service lives of 25 to nearly 30 years or more (Bech Abrahamsen et al., 2024; Delaney et al., 2023; Lefeuvre, Garnier, Jacquemin, Pillain, & Sonnemann, 2019; Wiser & Bolinger, 2019).

Wind turbine blades are complex composite structures designed to combine low weight with high mechanical strength. Glass fibers dominate blade production, while carbon fibers are increasingly used in larger turbines above 2 MW to reduce weight and increase stiffness (Hau, 2016; Kühne et al., 2022; Lefeuvre et al., 2019).

2 Methodology

2.1 Databases and data processing

The estimation of wind turbine blade material flows is based on turbine capacity, commissioning year, operational status, and onshore or offshore location. Two main data sources were used: the German Marktstammdatenregister (MaStR) and the European database “The Wind Power” (accessed January 2025). The MaStR provides mandatory, operator-reported data at the single-turbine level and is considered very reliable (Bundesnetzagentur, 2024). The Wind Power database aggregates data from multiple sources and is primarily structured at the wind farm level, requiring additional data processing (The WindPower, 2025).

To improve data completeness, wind farm datasets were disaggregated into individual turbine data where necessary, and missing information was supplemented through targeted desk research using publicly available reports and press releases. After data enhancement, more than 98 % of European wind turbines could be identified with sufficient data for further analysis.

2.2 Assumptions on turbine service life

For onshore wind turbines, service life assumptions were derived from decommissioned turbines recorded in the MaStR. The data indicate an increasing operational lifetime, exceeding the commonly assumed fixed lifetime of 20 years. To ensure a conservative projection, lifetime trends reported by Wiser and Bolinger (2019) were adopted for future forecasts.

For offshore wind turbines, empirical end-of-life data are scarce. Therefore, service life assumptions are based on available decommissioning records and literature values, indicating average lifetimes of around 25 years. A similar lifetime development trend as for onshore turbines was assumed (Fig. 1).

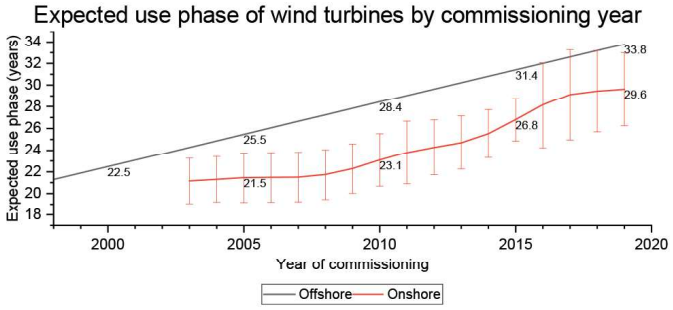

Figure 1: Expected service life of onshore and offshore wind turbines by commissioning year.

2.3 WTB waste forecasting approach

Annual WTB waste generation until 2040 is calculated by combining turbine commissioning dates with projected service lifetimes. Blade mass is derived from turbine capacity, and material composition is assigned based on turbine size, distinguishing between turbines below and above 2 MW, with carbon fiber usage assumed for larger turbines commissioned after 2010 (Lefeuvre et al., 2019). To avoid discontinuities in the time series, decommissioning is distributed evenly within each year.

Table 1: Turbine blade mass across rated capacity classes.

Turbine rated capacity (MW)	Total specific blade mass (kg/kW)
≤1	8.43
1-1.5	12.37
1.5-2	13.34
2-5	12.75
≥5	13

3 Results

3.1 Age structure of the European wind turbine fleet

As of January 2025, approximately 113,000 wind turbines are in operation in Europe, comprising 106,877 onshore and 6,461 offshore units. Germany accounts for 29,766 onshore and 1,637 offshore turbines, while the remaining European countries include 77,111 onshore and 4,824 offshore turbines with available turbine count data.

The onshore fleet is dominated by turbines commissioned between 2000 and 2017, with a peak around 2009, indicating an advanced average age. Offshore installations are younger, with most turbines commissioned after 2009 and a peak around 2015, and are primarily located in the United Kingdom, followed by Germany and Denmark. These distributions indicate increasing decommissioning and repowering relevance for onshore turbines, while offshore capacity continues to expand.

3.2 Wind turbine blade inventory in operational use

The total mass of wind turbine blades in operation in Europe is approximately 3.18 million tons, of which 2.74 million tons originate from onshore turbines and 0.44 million tons from offshore turbines. Onshore blade mass is concentrated in turbines with rated capacities between 1.5 and 5 MW, while offshore blade mass is dominated by turbines of 5 MW and above.

Blade mass is unevenly distributed across Europe. The highest onshore inventories are found in Germany, followed by Spain, France, and Sweden. Offshore blade mass is concentrated in a small number of countries, with the United Kingdom holding the largest share, followed by Germany and the Netherlands.

3.3 End-of-life wind turbine blade waste forecast until 2040

Annual end-of-life wind turbine blade waste remains largely stable until 2040. An elevated value in 2025 results from the allocation of accumulated blade masses from turbines exceeding their assumed service life by the end of 2024. Excluding this effect, onshore blade waste ranges between 50,000 and 110,000 tons

per year, with maximum in 2028, 2032, and 2037. Offshore waste volumes are substantially lower and show intermittent peaks linked to clustered wind farm decommissioning (Figure 2).

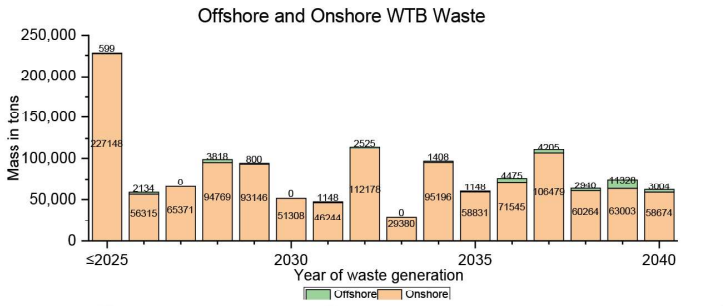

Figure 2: The distribution of offshore and onshore wind turbine blade waste by mass over time.

From 2038 onwards, both onshore and offshore waste volumes decrease, with onshore waste converging toward approximately 60,000 tons per year and offshore waste falling below 3,000 tons per year.
Material-specific projections show that glass fiber and resin dominate throughout the period, while carbon fiber waste increases from 2033 onward, exceeding 5,000 tons per year from 2036 and remaining above this level in subsequent years.

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