An update for wind turbine blade waste inventory

Author: Pu Liu, Claire Barlow
University of Cambridge

Introduction

The first generation of wind turbine (WT) blades are now reaching their end of life, signalling the beginning of a large problem for the future. The cumulative installed wind capacity dramatically increased from 6,100 MW to 364,270 MW from 1998 to 2014 (GWEC 2014; EWEA 2013). Since their design lifetime is about 20 years, the amount of end-of-life WT blades will reflect this increase over the next two decades. Albers noted that every kW of wind power requires 10kg WT blade materials, so predicted there will be nearly 50,000 tonnes of blade waste in 2020 rising to 200,000 tonnes in 2034 (Albers 2009). Currently most waste is sent to landfill, which is not an environmentally desirable solution: many EU countries have prohibited landfilling of composite waste (Pickering 2006). Awareness of this issue is rising. There are some limited studies of the feasibility of a range of recycling and re-use processes for end-of-life blades (e.g. Larsen 2009; Falavarjani 2012), but this is an area ripe for research.

The present study aims to assess the lifetime environmental impact of WT blades. The first step is to calculate annual amount of WT blade waste for the next 20 years. This waste inventory will be used to estimate the life cycle environmental impact of WT blades.

Approach

The three major WT blade waste sources are end-of-life waste (decommissioned blades), manufacturing waste (in-process waste, plus defective blades and blades used for testing) and service waste (from repairs and blade upgrading). This study starts by estimating the amount of blade material required per unit wind power, using data from wind energy associations and blade manufacturers. Then the total amount of WT blade materials is calculated from the wind power annual installed capacity, the average rated power of wind turbine and the material requirement per unit wind power. This is used to estimate the annual WT blade waste for the next 20 years.

Main body

Part 1: Blade material inventory

Contributing factor 1: Blade material per unit power

The WT blade mass is related to the wind turbine rotor size, which is is related to rated power. In general, the bigger the turbine, the more blade material is needed per unit rated power, as shown in. Fig. 1.

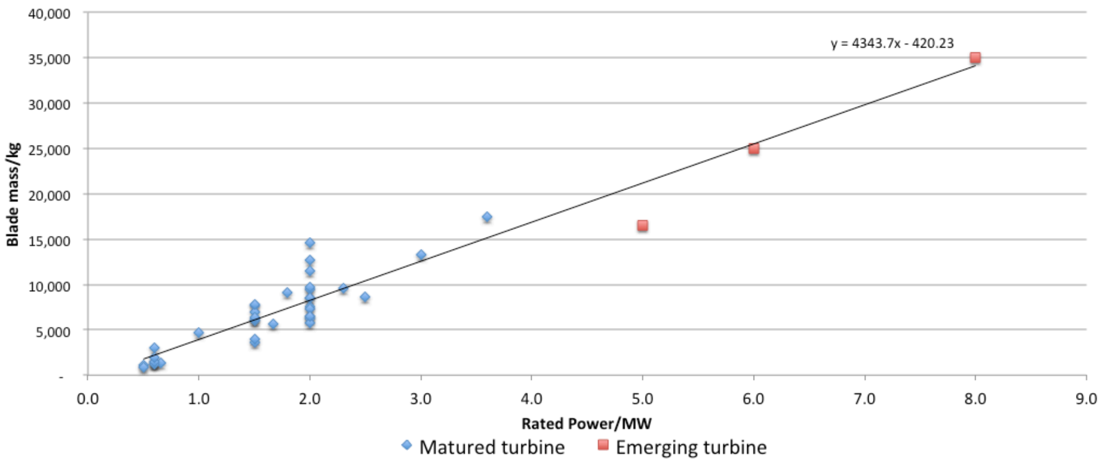

Figure 1: Relation between WT blade mass and rated power for 39 blades. Source:(Bauer 2014; Visits to LZFRP, Sinomatech Wind Power Blades, GDUPC).

Wind turbines with rated power less than 1 MW need on average 8.8 kg blade materials per kW power. This figure rises to 12.1 kg/kW for 1 MW to 1.5 MW wind turbines, and to 12.8 kg for larger turbines.

Contributing factor 2: Installed capacity by region

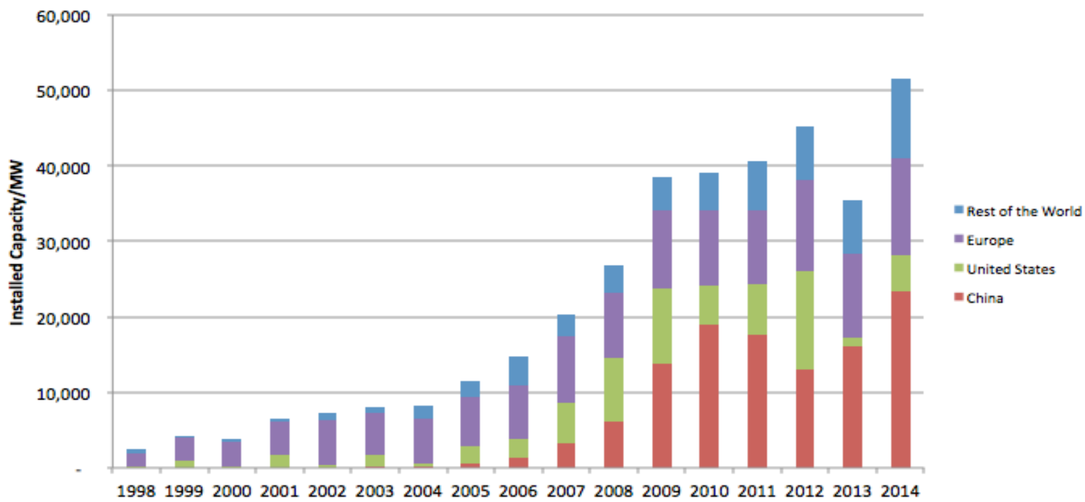

Figure 2: Annual installed wind power capacity by region from 1998 to 2014. Source: (GWEC 2015).

The world has been divided into four major regions for analysis. China, Europe and United States are the top three regions with the largest wind power installed capacity. For the rest of the world, the installed capacity for each individual country or region is much lower than the top three regions.

The blade waste can be estimated from predictions of installed capacity growth rate from 2015 to 2034. This is available for Europe (European wind energy association, EWEA) and Global (Global wind energy council, GWEC). This Global prediction has been used for the other three regions.

Contributing factor 3: Average wind turbine rated power

The new installed wind turbine average rated power has varied regionally. For example, in the United States it was less than 1 MW before 2002 and larger than 1.5 MW after 2006 (Wiser & Bolinger 2013), whilst in China, the wind turbine average rated power was less than 1 MW before 2007 and larger than 1.5 MW after 2010 (China NERI 2010).

These figures have been extrapolated to provide estimates for all four regions; those for Europe and World have been made using US and China data respectively.

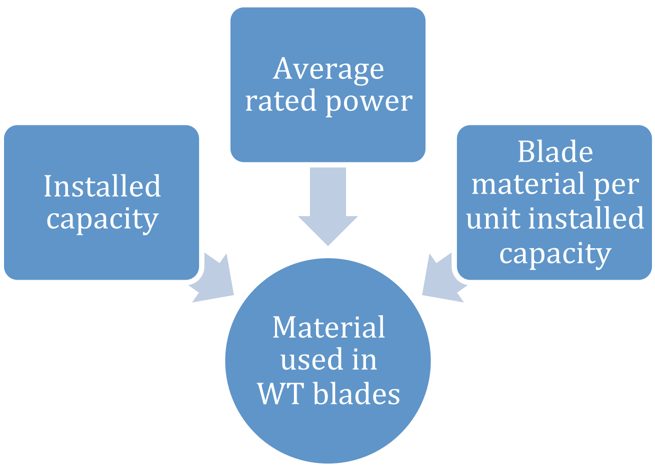

Figure 3: Logic flow of WT blade material inventory estimation.

The annual blade material usage can now be estimated, as shown in Fig. 3.

Part 2: Waste sources (see table 1)

Manufacturing waste

Bills of materials from three WT blade manufacturers were analysed. In-process waste weight varies from 20-35% of the weight of WT blades.

Manufacturing defects are another waste source. Some local blade defects can be remedied; the rate of defects requiring discard of the whole blade is very low, around 0.1% (Liu 2014).

About 0.1% of blades (Liu 2014) are made for mechanical testing purposes (stiffness, strength, fatigue testing) (MTS Systems Corporation 2014) and must be discarded afterwards. They are also assumed to be processed in the same year the blades are made.

Service waste

The main routine maintenance work of wind turbine blades involves re-painting (due to sand and small stone hits on the leading edge) and re-strengthening for repairing flaws and cracks (information from LZFRP and Sinoma Blade).

Another cause of service waste is blade upgrading. Replacing blades with a new set with improved aerodynamics allows 1-4% increase in annual energy production (AEP) using the same wind turbine (Siemens AG 2014; Smith 2014).

End of life waste

Most WT blades are designed for 20 years lifetime. Decommissioning is then assumed.

Waste source	Manufacturing	Defective Blades	Test Blades	In-service	Upgrading	End of Life
Years since blade manufactured	Same year	Same year	Same year	5 years later	5 years later	20 years later
Low scenario	20%	0.05%	0.05%	0.5%	5%	See table 2
Central scenario	25%	0.1%	0.1%	1%	10%	
High scenario	35%	0.2%	0.2%	2%	20%	

Table 1: Blade waste contributing factors.

	Low scenario	Central scenario	High scenario
GWEC 2014-2015	11%	14%	15%
GWEC 2016-2020	6%	10%	13%
GWEC 2021-2025	4%	8%	9%
GWEC 2026-2020	3%	6%	7%
GWEC 2031-2035	3%	4%	5%
EWEA 2015-2030	5%	7.3%	9.18%

Table 2: Global and Europe annual installed capacity growth rate. Source:(GWEC 2014; EWEA 2014).

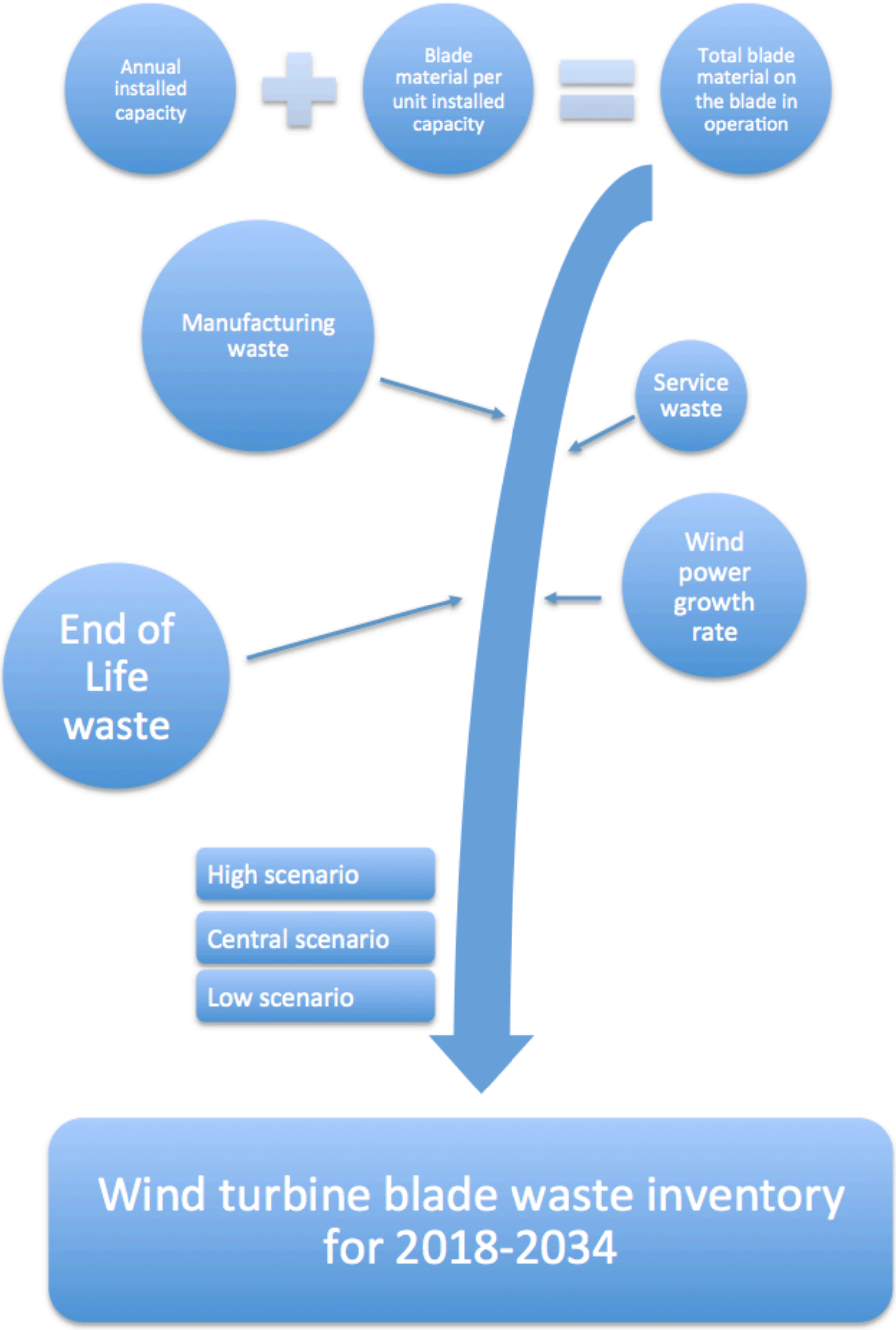

Figure 4: Logic flow of WT blade waste inventory estimation.

Situation setting

Five situations are used and are presented in fig. 5. The first and fifth situations represent minimum and maximum boundary conditions, with all contributing factors set to minimum or maximum values respectively. In the second, third and fourth situations, the waste contributing factors were set to central values, but the wind power growth rates were set to low, central and high respectively. These three situations represent the most likely situations of blade waste inventory with different wind power growth rates.

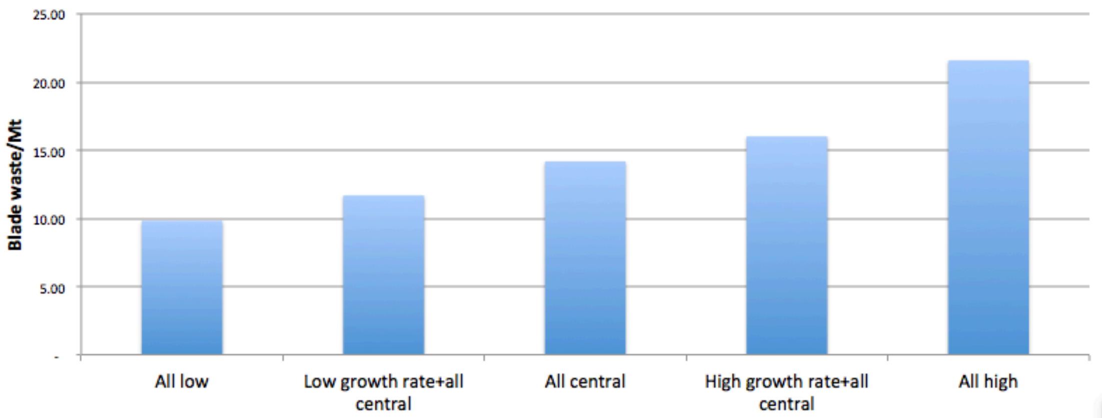

Figure 5: Five situations of WT blade cumulative waste inventory in 2034.

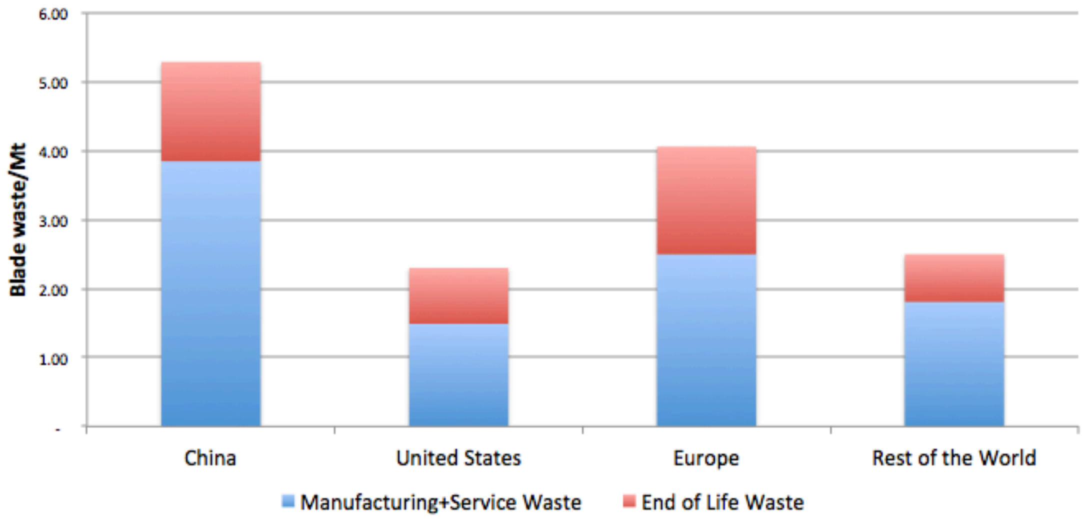

Figure 6: Waste inventory by region in 2034 under all central situation.

As shown in fig. 6, China and Europe will be the regions with the largest wind turbine blade waste in 2034 with 37% (5.29Mt) and 29% (4.06Mt) of blade waste respectively. The next stage will be quantitative assessment of the lifetime environmental impact of wind turbine blades up to 2034, including investigation into existing and potential options for recycling and re-use. There are many interconnected challenges in this area, and economics is fundamental. However, inclusion of robust data on environmental impacts may help to drive improvement.

Conclusions

Detailed analysis has been used to estimate the current and projected volume of wind turbine blade waste over the next 20 years, divided into four geographical areas. This will be used to inform the assessment of environmental impact for the next stage of the research.

Learning objectives

The wind energy business is global, but there are geographical differences in the way it is evolving which will lead to a range of environmental impacts. There is scope for transferring best practice across areas.

References:

Albers, H., 2009. Recycling of Wind Turbine Rotor Blades - Fact or Fiction ? *DEWI Magazine*, 34, pp.32–41.

Bauer, L., 2014. The portal for wind turbines and models. Available at: http://en.wind-turbine-models.com [Accessed November 1, 2014].

China NERI, 2010. *China Wind Power Development Outlook for 2030 (In Chinese)*, Beijing.

EWEA, 2013. *EWEA 2013 Annual Report*, Available at: http://books.google.com/books?hl=en&lr=&id=NkTWxqDX588C&oi=fnd&pg=PA6&dq=EWEA+2013+Annual+Report&ots=nON53dqXv9&sig=8v8mbJKvFGrAAb1arLScKo-6GDo [Accessed August 26, 2014].

EWEA, 2014. Wind energy scenarios for 2020. , (July), pp.1–8.

Falavarjani, B., 2012. Feasibility of Using Wind Turbine Blades Structure as Artificial Reef. *proceedings.ewea.org*, pp.4–8.

GWEC, 2014. *Global Wind Energy Outlook 2014*, Available at: http://www.gwec.net/wp-content/uploads/2014/04/Market-forecast-2014-2018.pdf.

GWEC, 2015. *Global Wind Report: Annual Market Update 2014*,

Larsen, K., 2009. Recycling wind. *Reinforced Plastics*, 53(1), pp.20–25. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0034361709700438 [Accessed October 2, 2014].

Liu, W., 2014. Commnication with LZFRP CTO.

MTS Systems Corporation, 2014. Wind Turbine Blade Fatigue Testing. Available at: https://www.mts.com/en/products/application/energy/wind-turbine-components/blade-fatigue-testing/index.htm [Accessed March 25, 2015].

Pickering, S.J., 2006. Recycling technologies for thermoset composite materials—current status. *Composites Part A: Applied Science and Manufacturing*, 37(8), pp.1206–1215.

Siemens AG, 2014. Power Curve Upgrade Kits for Wind Turbines.

Smith, P., 2014. Vestas to offer turbine upgrades. *Wind Power Monthly*. Available at: http://www.windpowermonthly.com/article/1292569/vestas-offer-turbine-upgrades [Accessed May 6, 2015].

Vestas, 2006. *Life cycle assessment of offshore and on shore sited wind power plants based on Vestas V90-3.0 MW turbines*,

Wiser, R. & Bolinger, M., 2013. *2012 Wind Technologies Market Report*, Available at: http://escholarship.org/uc/item/3d3661ds.pdf [Accessed November 17, 2014].