Journal of Cleaner Production 39 (2013) 191–199

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Preparing for end of service life of wind turbines

Katherine Ortegon [a,b,*], Loring F. Nies [b], John W. Sutherland [c]

[a] Ecological Sciences & Engineering Interdisciplinary Graduate Program (ESE IGP), Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907, United States
[b] School of Civil Engineering, Environmental and Ecological Engineering, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907, United States
[c] Environmental and Ecological Engineering, Purdue University, 500 Central Drive, West Lafayette, IN 47907, United States

ARTICLE INFO

Article history:
Received 7 June 2011
Received in revised form
20 August 2012
Accepted 21 August 2012
Available online 27 August 2012

Keywords:
Wind turbines
End-of-life strategies
Recycling
Remanufacturing
Reverse supply chain

ABSTRACT

The wind power industry is growing rapidly. Wind turbines (WTs) are perceived as a low environmental impact energy generation technology. While the service life of a WT is relatively long (20–40 years), at some point a significant number of WTs will reach the end of their service lives. To recover maximum value from these WTs, planning for the end-of-service life of wind turbines (EOSLWTs) is paramount. Historically, environmental life cycle assessments of WTs have often only considered the materials extraction and processing, manufacturing, and use phases, leaving the management of EOSLWTs outside the scope of their attention. Four key EOSLWTs issues that are essential for the continuing development of wind energy technologies are presented: i) The challenges of managing of EOSLWTs given the fast growth rate of the industry and the large number of existing installed WTs; ii) The EOSLWT alternatives such as remanufacturing and recycling to recover functional and material value respectively; iii) The critical activities in the WT reverse supply chain such as recovery methods, logistics of transportation, quality of returns, and quality of reprocessed WTs; and iv) The economic and business issues associated with EOSLWTs. It is expected that the discussion provided will stimulate a dialog among decision makers and raise awareness of economic opportunities and unanticipated challenges in the wind power industry.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Wind turbines (WTs) are an emerging renewable energy technology that has the potential to provide low carbon intensity power in the future. Of the total primary energy that the U.S. consumes, renewable sources provide 8%, and of this percentage, the wind power share is 9% (0.72% of total) (DOE/EIA, 2010a). Ninety percent of the U.S. electricity generation capacity added since 2005 is either natural gas or wind power (AWEA, 2010b). The total wind power capacity in the U.S. is over 47,000 MW, with an average annual growth rate of 33% over the last five years. The wind power sector has generated 75,000 jobs in the U.S. and currently, the WT manufacturing industry is led by companies such as General Electric, Siemens, Vestas, Mitsubishi, and Suzlon (AWEA, 2009).

The wind energy carbon footprint expressed by the CO_2 intensity[1] (20–38 gCO_2/kWh and 9–13 gCO_2/kWh for on-shore and off-shore applications respectively) is smaller than established energy systems such as coal (786–990 gCO_2/kWh), natural gas (488 gCO_2/kWh), nuclear power (26 gCO_2/kWh) and even some renewable systems like geothermal power (15–53 gCO_2/kWh), and solar (88 gCO_2/kWh) (POST, 2011). However, addressing the WT end-of-service life (EOSL) phase in life cycle assessment (LCA) studies has not received much attention (Hassing and Varming, 2001; Ardente et al., 2008; Weinzettel et al., 2009).

The end-of-service life of wind turbines (EOSLWTs) has not been a priority in the past; as a result, little research has been done to address the technological, environmental, and economic issues associated with this phase. A study examining 72 Life Cycle Assessments showed that only 11 of those studies included the decommissioning phase of WTs (Lenzen and Munksgaard, 2002). In the literature, the EOSL of WTs has been addressed either by making assumptions about what could occur (Rankine et al., 2006; Ardente et al., 2008; Martinez et al., 2009; Weinzettel et al., 2009;

Abbreviations: AWEA, American wind energy association; AEP, annual energy production; COE, cost of electricity; DfE, design for environment; EOSL, end of service life; EOSLWTs, end of service life of wind turbines; EU, European Union; OEMs, original equipment manufacturers; USGS, United States geological survey; REEs, rare earth elements; RL, reverse logistics; WTs, wind turbines.

* Corresponding author. Ecological Sciences & Engineering Interdisciplinary Graduate Program (ESE IGP), Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907, United States. Tel.: +1 765 714 3703; fax: +1 765 494 0395.
E-mail address: kortegon@purdue.edu (K. Ortegon).

[1] CO_2 intensity: ratio of carbon dioxide emitted during life cycle per unit of output of electrical energy over the lifetime of the device.

0959-6526/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2012.08.022

Martínez et al., 2010) or excluding the end-of-use stage (Allen et al., 2008). This is mainly due to a lack of historical data on the end-of-use of WTs and the lack of successful strategies for their management. The EOSL is assumed to occur when a WT has reached its designed life expectancy (20–30 years), cannot perform its function because of failure or fatigue, or no longer satisfies the needs or expectations of a user.

Two scenarios occur for a wind farm with WTs at EOSL: repowering or decommissioning. During the repowering process, a wind farm continues its operation while selected WTs are entirely removed and replaced by new and improved units often with higher power capacity. On the other hand, the decommissioning process is carried out when the wind farm is to be terminated. This decommissioning includes the removal of the WTs, the removal of aboveground and sub-grade structures, re-vegetation, seeding, topsoil replacement, and a two-year period of monitoring and remediation in order to return the area to its original condition (MDEP, 2010b). Either EOSLWT scenario, repowering or decommissioning, involves the dismantling, separation, recovery, and management of used WTs.

EOSLWTs alternatives include recycling for material recovery, reconditioning to extend the service lifetime, reuse of some components, and even the remanufacturing of the entire WT system. Although these alternatives have been applied to automobiles, electronics, tires, and appliances (Sasikumar and Kannan, 2009), their application to WTs requires further analysis of several issues. The economic value of a restored, functionally performing WT is substantially greater than that of just the recovered material value. Furthermore, relative to the manufacturing of new WTs from virgin materials, the energy conserved, reduced water footprint, and reduction of CO_2 emissions associated with remanufacturing or recycling could be significant.

The successful EOSL management of WTs requires the consideration of reverse supply chain issues. Reverse logistics (RL) is the process of managing the flow of products, components, and materials from the point of use back to a point of disposition (e.g., reuse, remanufacturing, recycling, incineration, or disposal). RL seeks to recapture material and/or functional value. Hence, the structure of the recovery channel, the logistics for managing oversized and overweight components, and the variability in the quality of returned WTs are all issues that need to be addressed. In addition, it is expected that a robust EOSL strategy makes sense not only environmentally but also economically (Subramoniam et al., 2010). Therefore, the development of secondary markets for used WTs, process improvements to ensure the quality of remanufactured products, and high value derived from scrap materials are required to ensure the sustainability of WT recovery companies.

This paper aims to address these issues in detail in order to raise awareness of the economic opportunities and unanticipated challenges that are likely to arise in the wind industry. First, the challenges associated with end-of service life of WTs are analyzed. Then, remanufacturing and recycling as potential alternatives for functional and material value recovery are discussed. Next, some key reverse supply chain issues that need to be resolved to ensure successful recovery of WTs are examined. Economic opportunities associated with remanufacturing and recycling of WTs are explored. The paper concludes with a summary, key findings, and suggestions for future research work.

2. The challenge of end-of-service life of wind turbines

2.1. EU & US: different approaches, similar targets

Since 1980, the European Union (EU) has been fostering the implementation of wind energy as a renewable alternative to traditional technologies such as nuclear and coal-fired power plants. The Renewable Energy Directive published in 2009 establishes a goal of 20% renewable energy in the EU by 2020. The wind power leaders in the EU are Germany with 29,060 MW (7% of the net power consumption) and Spain with 21,674 MW of installed capacity (15% of the net power consumption).

While the U.S. approach for managing EOSL products has been market-driven, the EU approach has been driven by regulations. This regulatory framework entails three aspects: (1) the promotion of sustainable production and consumption; (2) the development of pollution prevention initiatives; and (3) waste management directives (ECE, 2010).

Because of this regulatory framework and the need to minimize landfill discharges, several studies examining EOSLWTs have been conducted in Germany (Kehrbaum, 1995, 1996; Nicolai and Watson, 1998; Albers et al., 2009), Sweden (Rydh et al., 2004), and Denmark (Andersen et al., 2007; Larsen, 2009). Despite different approaches, the U.S. and the EU share similar targets for using wind as a future source of energy. The EU is projected to increase installed wind power capacity from 74.6 GW to 400 GW by 2030, which will meet approximately 30% of electricity demand. The U.S. is projected to increase installed wind power capacity from 47 GW to 300 GW by 2030, which will meet approximately 20% of the electricity demand (Table 1). This growth in wind energy infrastructure will create life cycle challenges that include EOSLWTs.

Table 1
Current and projected wind power capacity.

	European Union	United States
Current 2009		
Total power capacity (all sources)	896 GW	1138 GW
Total installed wind power capacity	93.96 GW	47 GW
% of the total electricity generating capacity	10.5%	4.1%
Total installed power capacity in 2011	45 GW	40 GW
New installed wind power capacity in 2011	9.6 GW	6.8 GW
% New installed wind power capacity in 2011	21.4%	17%
Employment to 2011	238,154 jobs	75,000 jobs
By 2020		
Total installed wind power capacity	230 GW	150 GW
% of the electricity demand	14–17%	10% (by 2012)
% of the total electricity generating capacity	24%	12% approx.[a]
Annual avoided Mt CO_2	333 million Mt CO_2	300 million Mt CO_2
Employment	446,419 jobs	n.a.
By 2030		
Total installed wind power capacity	400 GW	300 GW
% of the electricity demand	26–34%	20%
% of the total electricity generating capacity	38%	14% approx.[a]
Annual avoided Mt CO_2[b]	600 million Mt CO_2	825 million Mt CO_2
Employment by 2030	479,224 jobs	500,000 jobs
Sources	(EWEA, 2012a,b,c)	(DOE/OSTI, 2008; DOE/EIA, 2010b; GWEC, 2011)

[a] Includes all renewable energies: hydroelectric, solar, wind, geothermal, and wood.
[b] The U.S. produces six billion Mt of CO_2 per year. By 2030 this number could reach 6.75 billion Mt. (AWEA, 2010a).

Download English Version:

https://daneshyari.com/en/article/8107768

Download Persian Version:

https://daneshyari.com/article/8107768

Daneshyari.com