



# Life cycle assessment of a wind farm repowering process

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## ABSTRACT

More and more wind farms are reaching the end of their useful lifetimes, so it is necessary to consider the need and/or suitability of dismantling or repowering them. This paper presents an analysis from the point of view of the potential environmental impact and benefit of a wind farm repowering process.

The study has been performed by developing a life cycle assessment model of the repowering process of an old wind farm with low-power wind turbines. The results show the advantages of repowering wind farms of this type, especially in terms of increased capacity for electrical power generation from renewable sources and extending the useful lifetimes of wind farms.

The main impact of the repowering process comes from the wind turbines, which show values of  $2.43\text{E} + 07 \text{ kg CO}_2 \text{ eq.}$  in the Global Warming category, followed by the substation and electrical line ( $5.14\text{E} + 05 \text{ kg CO}_2 \text{ eq.}$ ). These impacts are clearly offset by the benefits of increasing electrical power generation from renewable sources, which show values of  $-9.03\text{E} + 08 \text{ kg CO}_2 \text{ eq.}$

Therefore, from the point of view of the decision-making process, the repowering of old wind farms with low-power wind turbines provides environmental benefits that must be taken into account when evaluating the future of wind farms approaching the end of their useful lifetimes.

## 1. Introduction

### 1.1. Repowering and life cycle assessment

Wind energy has proven to be a major issue worldwide [1] in the last 30 years, and one that has evolved very quickly, growing in a few years from small wind turbines outputting a few tens of kW of rated power to today's large-scale multi-megawatt wind turbines [2]. A wind turbine has a useful lifetime of 20 years, which may be extended to 25 by applying different lifetime extension retrofits offered by manufacturers. This rapid evolution of wind power technology and a useful lifetime of 20–25 years can mean that an operational wind farm becomes technologically outdated in less than half its useful lifetime.

Furthermore, the oldest wind farms are usually located in the places with the most favorable wind conditions. This means that certain locations rich in wind power resources are not exploited to the maximum, since the wind turbines installed there are relatively old and their power generating capacity is relatively low.

As these wind farms approach the end of their useful lifetimes, the option of repowering them arises [3]. Repowering involves making use

of the same place and replacing the old wind turbines by new ones, thereby increasing the power output capacity of the wind farm.

Fig. 1 shows the amount of wind power installed in Spain approaching the end of its useful lifetime in the next few years. If a useful lifetime of 20 years is considered, the turbines coming to the end of their useful lifetimes amount to 5 GW in the next five years and 15 GW in the next 10 years. This is a substantial number of wind farms, and a decision about their future is needed. It is often possible to consider extending the useful life of a wind farm by using life extension kits from the manufacturers, but many wind farms will have to be repowered. There are also many wind farms in the rest of Europe that will have to be repowered in the next few years (see Fig. 2).

When a wind farm reaches the end of its useful lifetime, the options [4] available to its operators are:

- To decommission the wind farm completely, in line with the various environmental codes and standards in force in each country.
- To purchase one of the various useful lifetime extension systems offered by wind turbine manufacturers.
- To overhaul the wind farm by dismantling and/or replacing all the

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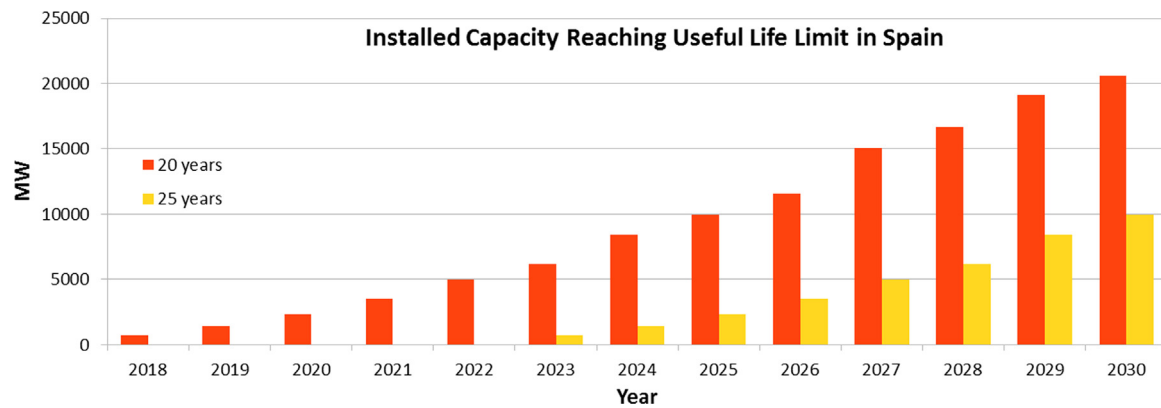


Fig. 1. Installed wind power in Spain reaching the end of its useful lifetime.

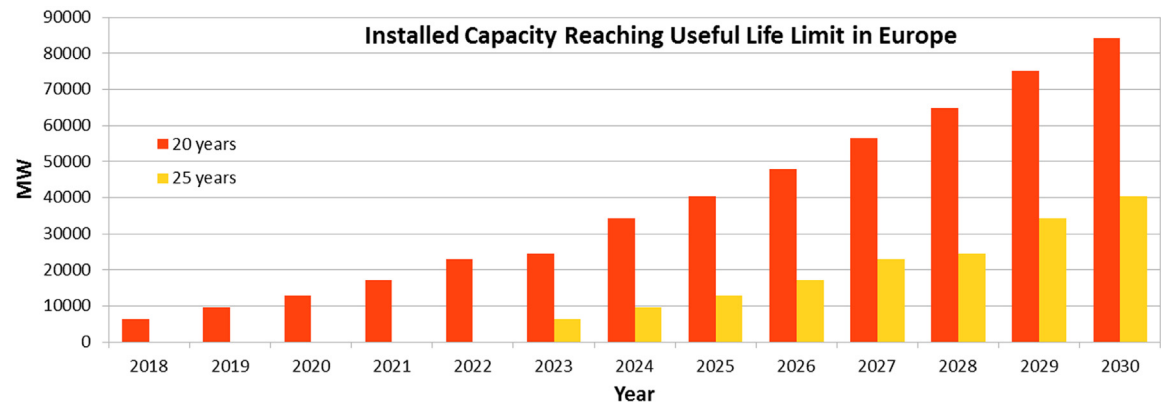


Fig. 2. Installed wind power in Europe reaching the end of its useful lifetime.

**Table 1**  
Type of dismantling.

Material	Type of dismantling
Iron	Recycling with a loss of 10%
Fiberglass	Landfill 100%
Oil	Incinerated 100%
Plastics – PVC	Landfill 100%
Other plastics	Incinerated 100%
Rubber	Incinerated 100%
Steel	Recycling with a loss of 10%
Copper	Recycling with a loss of 5%

necessary wind turbine components and the rest of the electrical equipment.

Most scientific literature focuses on either the financial aspects or the optimization of repowering processes [5,6]. There are no papers

analyzes the process from an environmental point of view. This can be done via the Life Cycle Assessment (LCA) methodology [7,8], which is useful for analyzing the environmental impact caused by any type of product or process, such as those related to energy systems [9–11], or those related to construction [12–14], biofuel [15,16], and agricultural systems [17–19], among others. The LCA methodology has also been applied successfully to studying the environmental impact of renewable energy [20–22].

## 1.2. Literature review

In the scientific literature there are several recent studies devoted to wind farm repowering. For example, Frantál [23] presents the results of a survey with local governments and inhabitants of municipalities in the Czech Republic where wind turbines have been implemented and are in operation. The findings prove that perceived positive effects predominate over negative impacts and that most local authorities and

**Table 2**  
LCA results of the 2 MW wind turbine.

Impact category	Unit	Total	Maintenance	Tower	Foundation	Rotor	Nacelle
Abiotic depletion	kg Sb eq	3.75E – 05	2.78E – 06	7.28E – 06	4.39E – 06	1.88E – 05	4.33E – 06
Global warming (GWP100)	kg CO <sub>2</sub> eq	6.58E – 03	3.51E – 04	1.35E – 03	1.56E – 03	2.61E – 03	6.96E – 04
Ozone layer depletion (ODP)	kg CFC-11 eq	5.21E – 10	4.98E – 11	1.41E – 10	8.69E – 11	1.83E – 10	6.11E – 11
Human toxicity	kg 1,4-DB eq	1.55E – 02	6.48E – 03	1.40E – 03	3.63E – 04	4.36E – 04	6.84E – 03
Fresh water aquatic ecotox.	kg 1,4-DB eq	2.81E – 03	8.19E – 05	1.65E – 03	4.00E – 04	2.43E – 04	4.43E – 04
Marine aquatic ecotoxicity	kg 1,4-DB eq	4.41E + 00	3.25E – 01	1.69E + 00	4.48E – 01	1.04E + 00	9.26E – 01
Terrestrial ecotoxicity	kg 1,4-DB eq	1.56E – 04	2.78E – 05	4.89E – 05	1.48E – 05	1.55E – 05	4.99E – 05
Photochemical oxidation	kg C <sub>2</sub> H <sub>4</sub>	2.13E – 06	5.10E – 07	1.84E – 07	1.06E – 07	6.75E – 07	6.51E – 07
Acidification	kg SO <sub>2</sub> eq	5.43E – 05	7.64E – 06	5.34E – 06	3.53E – 06	1.94E – 05	1.84E – 05
Eutrophication	kg PO <sub>4</sub> – eq	5.68E – 06	3.24E – 07	1.71E – 06	8.25E – 07	1.91E – 06	8.98E – 07

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