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A techno-economic analysis of a real wind farm repowering experience: The Malpica case

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ABSTRACT

The wind industry is currently facing a major challenge due to the ageing of the wind turbines that were first commissioned. Recent wind turbine designs present higher power performance and lower maintenance requirements than older wind turbines. Furthermore, most of the old wind turbines are installed in the best sites for wind resource exploitation. Under this framework, the repowering of wind farms with the replacement of the old machines by new designs is recognised as a focus area for the wind industry. This paper performs a techno-economic analysis of a real wind farm repowering experience at the Malpica wind farm, located in the Northwest of Spain. Results show the annual energy production of the repowered wind farm increases up to twofold that of the old wind farm with the same rated power. Moreover, the economic analysis reveals the project yields satisfactory profitability, even without reliance on public subsidies as currently happens in Spain. In addition, a sensitivity analysis allows us to understand the effects of the uncertainties over the lifetime of the wind farm, and how they affect the projects performance and profitability.

1. Introduction

The integration of renewable energy sources (RES) into power systems has increased rapidly over recent years. Of the different technologies, wind energy (WE) is one of the fastest-growing sources of electricity [1]. In 2017, wind power covered an average of 11.6% of the EU's electricity consumption, with a total of 336 TW h generated [2]. It also contributed more new power generation than any other RES in the last year, with a global installed capacity of nearly 540 GW by the end of 2017. Asia leads the market with a total installed capacity of 228 GW, while Europe is second with 178 GW. Spain is recognised as an international benchmark, being second in Europe and fifth in the world with 23 GW installed [3].

The world's first wind farms (WFs) are reaching the end of their expected lifetimes (20 years according to IEC 61400-1 [4]). The first WTs installed, which have been in operation for many years, present a reduced power performance and require more maintenance operations in comparison to recent WTs [5]. Commonly, WF operators confronted with the problem of an ageing WT fleet have three options [6]: dismantling the WTs, embarking on a WT lifetime extension project or a repowering project. Repowering a WF consists of replacing older WTs with newer ones of greater power and size, increasing its Annual Energy Production (AEP) [7]. Because of the better use of wind resources, the WF's global efficiency will be improved; i.e., for the same wind speed value, the new WTs will increase power generation [8]. However, extending the lifetime of a WF involves the substitution of different WT components in order to improve its availability [9]. Nonetheless, extending the lifetime is not recommended when the machines are very old and spare parts are no longer available [7].

The repowering of WFs is particularly important in Spain. Currently, there are more than 20,000 WTs installed in Spain and the first WFs were commissioned around 20 years ago. About 51% of the total Spanish WTs have a rated power in the range of 600 kW and 850 kW, which have been in operation for close to 17 years, with most of them located at suitable sites for wind resource exploitation. However, due to the low performance of the older WT designs, the capacity factor of the oldest WTs in Spain has a low mean value [5]. Furthermore, Fig. 1 shows the installed Spanish wind capacity in operation for more than 15, 20 and 25 years. It can be seen that by 2020 almost 10 GW of the Spanish capacity will have been in operation more than 15 years [10].

Under this framework and considering the forecast given by *WindEurope* (formerly known as *European Wind Energy Association*, EWEA), where by 2030 the EU will reach a total installed wind power capacity equal to 323 GW with half of the existing capacity reaching the

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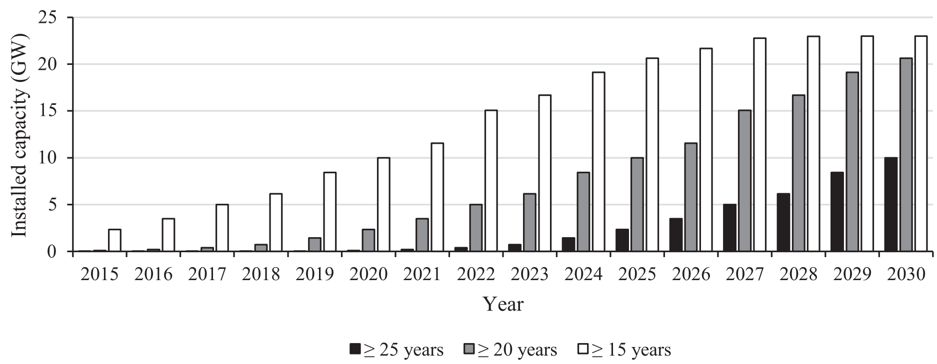

Fig. 1. Installed Spanish wind capacity (in GW) older than 15, 20 and 25 years.

end of its lifetime before that year [11], a detailed techno-economic analysis of a real repowering experience is required. Aiming to fill this gap, this paper details the repowering of the Malpica WF, located in the north-west of Spain. In addition to the real case conducted at this WF, a sensitivity analysis of the main parameters involved has been performed in order to determine how the uncertainties that might appear during the operation of the repowered WF impact on the profitability of the project. In consequence, the main contribution of the present work consists of the development of an in-deep techno-economic study of a WF repowering project, which started operation in February 2018, based on real data.

The paper is structured as follows: Section 2 describes other WF repowering experiences found in the literature, highlighting the lack of specific data related to real cases. Section 3 introduces the methods used in this paper with regard to both the energy production analysis and the economic analysis. Section 4 describes the Malpica WF, including both the old and the repowered WF, while Section 5 presents the results according to these analyses. Section 6 performs a sensitivity analysis of the main parameters involved in the repowering project. Finally, Section 7 summarises the main conclusions.

2. Literature review

The existing literature includes different studies regarding general analysis of repowering processes in WFs, where legal, economic and technical aspects are considered. Other studies related to repowering tasks on onshore WFs or exploration of different alternatives in Spanish WFs are also noteworth. In [8], a qualitative study of instruments, in which their advantages and drawbacks are analysed, and an overview of different design options to support repowering tasks of onshore WFs is carried out. In [12], the feasibility and costs of repowering WFs are determined by considering two study methods, which provide nine different alternatives. Optimal alternative repowering actions are explored through the application of the mathematical framework known as Markowitz's mean variance portfolio optimization theory in [13]. Furthermore, a report elaborated by the National Renewable Energy Laboratory (NREL) estimated the age at which it is viable for a WF to be repowered by using an original NREL tool [6]. They focused on creating proto-typical Wind Power Plants (WPPs) of four different representative features and vintages and on evaluating the repowering costs of three actual WPPs operating in the US.

Further specific studies about the repowering of WFs are also found in the scientific literature. One of the most noteworthy contributions is presented in [5], where the number of WFs installed from 1998 to 2012 is analysed in order to estimate the Spanish repowering market. As a result, it is concluded that the WFs with an operation period of more than 13 years should be taken into consideration for a repowering project. Different repowering approaches are evaluated for the Bustelo and S. Xoán WFs, located in Galicia (northwest Spain) in [14], where a sensitivity analysis is also conducted to find out the most economically viable alternative. In [15], an old WF located at Kayathar (India) is selected to design a general method for assessing the repowering potential of WFs, while [16] presents the evaluation of different economic and energy performance indicators when several repowering approaches are assessed for an old Indian WF. In [17], an analysis of different repowering alternatives of the Buenavista WF in Cádiz (Spain) is performed. In [18,19], a similar but shorter process is observed, where a general analysis of the economic viability of repowering tasks in Spain is carried out using different WT models, and also by making a sensitivity analysis of different economic parameters.

In addition to the previous studies regarding repowering of WFs, it is worth noting a number of real repowering experiences conducted in recent years in different countries. Although these experiences are more widespread in other countries, Spain has an enormous potential due to the large number of old WFs with obsolete WTs. In 2006, Los Valles WF in Lanzarote was repowered, replacing 48 old WTs with 9 Gamesa (currently known as Siemens Gamesa Renewable Energy) G52 WTs of 850 kW rated power [9], increasing the efficiency of the WF up to 75%. In Denmark, Siemens repowered the Nørrekær Enge WF in 2009 by replacing 77 old WTs by 13 WTs of 2.3 MW [20]. A repowering project was conducted in 2011 in Coimbatore (India), substituting some of the 31 WTs with a total power of 9.7 MW by 15 G58 WTs of 850 kW each [21]. Table 1 shows, in addition to those previously mentioned, other real repowering experiences. The commissioning and repowering years, as well as the location and main characteristics of these repowering experiences are shown.

As can be observed, the existing literature on the repowering of WFs follow a similar structure, based on the analysis of economic variables in hypothetical repowering tasks together with simulation works and policy analysis related to repowering activities in WFs. In addition, some works address the tasks required to achieve the renewable energy targets set by governments and organizations, also analysing the repowering potential of different countries [33,34]. Nevertheless, due to the general character of these studies, it is necessary to perform a detailed calculation of the technical and economic viability of a specific repowered WF, along with a sensitivity analysis. Thus, the Malpica WF, whose repowering process is currently being carried out (the dismantling process of the old WTs finalised in March 2017), is analysed in the present paper. Therefore, the lack of information about a real repowering implementation is mitigated by the present work, where a WF repowering is evaluated from the technical and economic point of view for the first time. To better identify the research gap and highlight the work carried out in the present study, Table 2 shows a comparative assessment with other works related to repowering of WFs. It clearly reflects the lack of techno-economic analysis regarding the repowering of WFs, i.e., the lack of studies using real data from wind farms, which justifies, once again, the need to conduct the present study.