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The role of wind energy production in addressing the European Renewable Energy targets: The ~~Spanish~~ case of Spain

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Abstract

Directive 2009/28/EC of the European Union (EU) defines a target of produc-tion from renewable energy (RE) for all the EU-28 countries to be achieved by the end of 2020. Spain accepted a target of at least 20% of gross final con-sumption of energy (GFCoE) from renewable energy sources (RES), which is not expected to be reached. This is because, on the one hand no new RE plants have been commissioned in Spain ~~from~~ since 2012 and, on the other ~~hand~~, the RE auctions launched by the government in the last two years are not ~~enough~~ sufficient to cover the lack of installed capacity to reach this goal. The aim of this paper is to ~~analyze~~ analyse the role of wind energy (WE) in the production of RE ~~achieving~~ to meet the 2020 target in Spain. This research presents a model to assess the combi-nation of the repowering of current wind farms (WFs) with the commissioning of new ones, and with the use of other RES like hydro, solar and solid biofuels, proposing ~~the~~ optimal ways to develop WE in Spain until 2020. Results show the most suitable combinations of repowered and new WFs according to the different scenarios expected. The findings of this study reveal that, in the most conservative forecast, a minimum repowering level of 46% in combination with new WE installed capacity would be required to reach the target. Finally, a sensitivity analysis provides an assessment of the scenarios that also include the evolution of other RES, giving the resultant energy mix in accordance with the repowering level.

Keywords: 2020 Renewable energy targets, National Renewable Energy Action Plans, Wind energy, Repowering, Wind energy sources combination, Energy mix

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1. Introduction

~~The c~~Concerns about climate change ~~is~~ are shared by ~~the~~ most countries around the world. The United Nations Framework Convention on Climate Change (U.N., 1994) is the main international agreement in this area. It was adopted at the Rio Earth Summit in 1992 and ratified by 195 countries. It started as a way for countries to work together to limit global temperature increase and climate change, and manage their impacts. In 1997, the UNFCC signatories agreed on the Kyoto Protocol (U.N., 1998), which introduced legally binding emission reduction targets for the developed countries, including all the member states (EU-28) of the European Union (EU).

The European Council (EC) plays a central role in the regulation of the climate and energy policy framework for the EU. A number of commitments have been made and measures ~~and commitments have been carried out~~taken to reduce climate change, such as the re~~-~~duction of emissions in the 2013-2020 period to 20% below 1990 levels, based on the Doha amendment (U.N., 2012), or the action plan to limit global warming to 'well below' 2°C (European Council, 2016).

Renewable energy sources (RES) are playing a key role in the achievement of commitments about on climate change in the EU. Directive 2009/28/EC (European Parliament, 2009) of the European Parliament and of the Council defines a target of production from RES in all EU-28 countries by 2020. Spain accepted a target of at least 20% of gross final consumption of energy (GFCoE) from RES. In addition to the 2020 national targets, the Renewable Energy

Directive proposes an indicative trajectory in order to assess intermediate goals with the RES share in 2005 as reference value. In Spain, the average value of the share from RES in the 2015-2016 period was 16.2%, which ~~was~~ coincided with the indicative trajectory proposed by the European Commission to reach the 2020 share, due mainly to the large-scale promotion and development of RES ~~until~~ up to 2012. In recent years, however, Spain has suffered a total collapse in the addition of new power from RES. This is mainly due to the suspension of governmental support to RES (feed-in tariffs) with the implementation of Royal Decree 1/2012 (Ministry of Industry, Energy and Tourism, 2012), and the lack of planning for the development of new transport electricity infrastructures to avoid the commissioning of new plants. This situation represents a risk for the commitment of the Spanish 2020 RE target that is not expected to be resolved with the RE auctions launched by the government in 2015 and 2017 (Ministry of Energy, Tourism and the Digital Agenda, 2017).

Wind energy (WE) is the source that has most contributed to the development of renewable energy (RE) in Europe. With a total installed capacity of 153.7 GW by the end of 2016, WE now overtakes coal as the second largest form of power generation capacity. In 2016, 12.5 GW of new WE capacity was installed, more than any other form of power generation in Europe, accounting for 51% of the total power capacity installations. Spain was the second country in Europe, after Germany, in WE installed capacity by the end of 2016 (WindEurope, 2017). Cumulative wind power capacity in Spain at the end of 2016 was 23.05 GW, representing around 15% of the total installed capacity in the EU-28 countries (Aee, 2017; CNMC, 2017; REE, 2017; WindEurope, 2017).

The first wind farms (WFs) in Spain were commissioned around 20 years ago. There are more than 20,000 installed wind turbines (WTs) in Spain. Of these, 51.4% are WTs with ~~a range of~~ capacit~~y~~ies from 600 to 850 kW, which have been in operation for close to 20 years. Moreover, 33% of the total WE installed capacity in Spain corresponds to these WFs, most of them being located in optimal sites in terms of wind conditions.

Repowering is a proven solution to enhance the use of the wind resources in existing WFs. There are different levels in the repowering of WTs, from ~~the substitution of~~substituting ~~the~~ blades, increasing hub height and ~~the use of~~using more ef~~-~~ficient generators, to ~~the complete~~completely replac~~ement of~~ing ~~the~~ old WTs for new, more technologically advanced models, permitting ~~to increase~~ the annual electricity production (AEP) to increase while~~, at the same time,~~ maintaining the initial approved installed power and the transport infrastructure to the electrical substation.

In the recent literature, several authors have focused on the analysis and assessment of WF repowering, considering legal, technical and economic per~~-~~spectives in order to ~~analyze and~~ explore it as a profitable alternative instead of the construction of new WFs. From a qualitative approach, it is worth noting the work by Del Río et al. (2011)~~,~~ providing an analysis of the instruments and design options to support repowering of on-shore WFs; the work by Rodriguez et al. (2013)~~,~~ anal~~yz~~ysing the policies related to the repowering sector and the stimuli demanded by the market; or the research by Santos-Alamillos et al. (2017) exploring alternative repowering actions in Spain. The general economic aspects of the repowering process are addressed by Castro-Santos et al. (2012) and Calvo et al. (2013). More specific studies considering the repowering of WFs in specific locations are presented by Colmenar-Santos et al. (2015) concerning a WF in Lugo (Spain); Filgueira et al. (2009), about two WFs in Bustelo and San Xoan (Spain); and other two locations in India in the studies by Nivedh et al. (2013) and Prabu and Kottayil (2015). All these studies make significant contributions to the literature on repowering of WFs but none of them anal~~yz~~yses in-depth the repowering potential at country level nor assesses the different ways to deploy WE alternatives according to the repowering level or its impact on the energy mix.

In order to cover this gap in the literature and contribute to ~~the~~ research on the deployment of RE at country level, this work proposes a novel model to assess the production of WE, combining repowered WFs with the installation of new ones, and defining suitable alternatives to reach the 2020 national targets in Spain. Furthermore, the model considers the use of other RES such as hydro, solar and solid biofuels, taking into account their evolution in the energy mix.

Results show not only the most effective and suitable alternatives combining repowered and new WFs, and with other RES, but also a sensitivity analysis of the main variables in order to forecast the possible uncertainties that arise ~~until~~ before 2020. The paper makes three main contributions to the literature. First~~ly~~, it provides an ~~extent~~ extensive analysis of the potential repowering market in Spain and proposes a reference scenario using the SHARES tool (Eurostat, 2017b) with the information provided by the Renewable Energy National Plans and the Spanish Energetic Planning 2015-2020. Second~~ly~~, based on the most ~~expected~~ likely scenarios, the model defines and assesses which combinations of repowered WFs with the commissioning of new ones are suitable to address the 2020 goals as a function of the Gross Final Consumption of Energy (GFCoE). Third~~ly~~, the work provides a sensitivity analysis to explain how WE should be combined with other RES in the generation of clean energy up to 2020.

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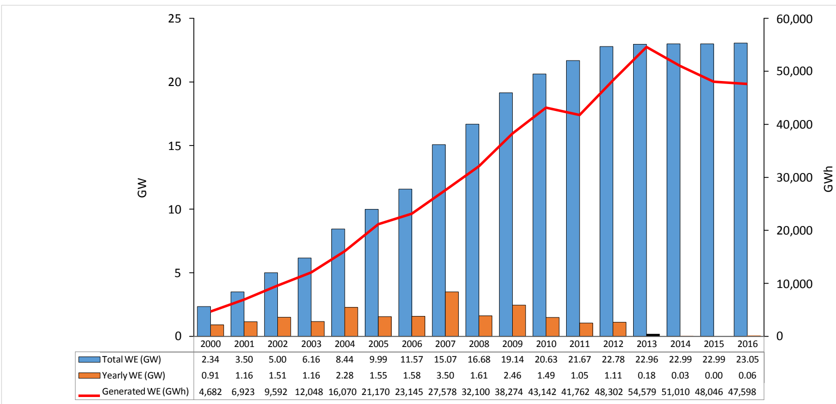
The remainder of this paper is structured as follows: Section 2 anal~~yz~~yses the evolution of WE in Spain and explains the indicative 2020 trajectory of energy share from RES using the main indicators of the Renewable Energy National Plans and the Spanish Energetic Planning 2015-2020. Section 3 is devoted to the data analysis and the methodology. Section 4 presents and discusses the results and the comparative analysis for the different scenarios considered according to the repowering level and the combination with other RES in the energy mix, and finally Section 5 ~~summarizes~~ summarises the main conclusions of the work.

2. Background

2.1. Wind energy in Spain

WE was the second technology in electricity generation from RES in the Spanish electric system by the end of 2016 (REE, 2017). The total electricity generated from WE in this year was 47,598 GWh (CNMC, 2017), 50.56% of the total power generated with RES, fulfilling 19.3% of the electricity demand. In addition, the WE sector in Spain employed 22,468 people and contributed 0.25%



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total WE (GW)	2.34	3.50	5.00	6.16	8.44	9.99	11.57	15.07	16.68	19.14	20.63	21.67	22.78	22.96	22.99	22.99	23.05
Yearly WE (GW)	0.91	1.16	1.51	1.16	2.28	1.55	1.58	3.50	1.61	2.46	1.49	1.05	1.11	0.18	0.03	0.00	0.06
Generated WE (GWh)	4,682	6,923	9,592	12,048	16,070	21,170	23,145	27,578	32,100	38,274	43,142	41,762	48,302	54,579	51,010	48,046	47,598

Figure 1: Spanish WE cumulative installed capacity (GW) and generated power (GWh) 2000-2016.

of the Spanish Gross Domestic Product (GDP) with 2,925 M€ by 2016 (Aee, 2017).

Fig. 1 shows the evolution of the cumulative installed capacity and the generated power in Spain from 2000 to 2016. The main growth and development of the WE sector in Spain started in 2000 from a cumulative installed capacity of 2,340 MW. Until 2012, Spain had the most significant WE development in Europe with a total cumulative installed capacity of 22,780 MW. 2007 was the year with the highest yearly WE installed capacity (3,500 MW) followed by 2009 (2,460 MW) and 2004 (2,280 MW). After different regulatory changes in the policy instruments that reduced the feed-in tariffs (FiT) and the incentives to RES (Ministry of Industry, Energy and Tourism, 2012) the WE sector stagnated and only 240 MW was installed from 2013 to 2016. At the end of 2016, Spain had a total installed capacity of 23,049 MW (CNMC, 2017).

Spain is divided into 17 autonomous communities. With the exception of Madrid and Extremadura, all communities have promoted and installed WFs in the recent years. Table 1 shows the total installed capacity in the Spanish

Table 1: Total wind farms, wind turbines and generated power per Region in Spain.

Autonomous Community	Total installed capacity (MW)	Wind Farms (units)	Wind Turbines (units)	Generated power in 2016 (GWh)
Andalusia	3,326	179	2,134	7,052
Aragon	1,816	94	2,081	4,254
Asturias	494	21	470	856
Balearic Islands	4	1	4	5
Canary Islands	153	52	374	392
Cantabria	35	4	40	70
Castilla-La Mancha	3,800	129	3,083	7,593
Castilla and Leon	5,679	255	4,291	11,008
Catalonia	1,284	52	810	2,709
Valencian Community	1,193	40	785	2,224
Galicia	3,344	183	4,018	7,223
La Rioja	448	17	400	934
Murcia	263	14	186	457
Navarre	1,016	69	1,198	2,401
Basque Country	194	7	153	420
TOTAL	23,049	1,117	20,027	47,598

Autonomous Communities by the end of 2016, the total number of WFs, the total number of WTs, as well as the generated power in 2016. Castilla and Leon, Castilla-La Mancha, Andalusia and Galicia are the communities with the highest rate of WE development in Spain, accounting for around 70% of the total WE installed capacity in the country (Aee, 2017; CNMC, 2017; REE, 2017).

2.2. The EU's Renewable Energy Directive

Directive 2009/28/EC of the European Parliament and of the Council (European Parliament, 2009) defines a target of production from RES in all EU-28 countries for 2020. The goals to achieve are not the same for all countries, varying from 10% in Malta to 49% in Sweden. According to the data from Eurostat (Eurostat, 2017a) the share of RE in relation to GFCoE by the end of 2015 in Spain was 16.2%, 3.8% below the 2020 target. In addition to the 2020 national targets, the Renewable Energy Directive proposes an indicative trajectory in order to reach the final level of RES with the 2005 share as reference value. Therefore, a progressive growth is considered on the basis of the 2005 share, S_{2005}, for each country, as follows (D'Adamo and Rosa, 2016):

- S2005 + 0.20 ∗(S2020 − S2005) must be the average for the 2011-2012 period.
- S2005 + 0.30 ∗ (S2020 − S2005) must be achieved for the 2013-2014 period.
- S2005 + 0.45 ∗ (S2020 − S2005) must be achieved for the 2015-2016 period.
- S2005 + 0.65 ∗ (S2020 − S2005) must be achieved for the 2017-2018 period.

Based on this reference trajectory, the indicative values for Spain and EU-28 are shown in Table 2. According to this table, the average value of the share from RES in the 2015-2016 period was 16.2% in Spain, which coincided with the indicative trajectory proposed by the EC to reach the 2020 share.

1.2. The Spanish Renewable Energy Plans 2011-2020

In November 2011, the Spanish Government approved the Renewable Energy Plan 2011-2020 (REP) (Ministry of Industry, Tourism and Commerce, 2011), in order, firstly, to continue with the previous 2005-2010 REP and, secondly, to incorporate the new targets according to the Directive 2009/28/EC and the evolution of RES in Spain.

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Table 2: Indicative 2020 trajectory of energy share from RES (%) for EU-28 and Spain.

Country	2011-2012		2013-2014		2015-2016		2020 Target
	Forecast	Result	Forecast	Result	Forecast	Result	Forecast
EU-28	11.2	13.8	12.3	15.65	13.95	16.7	20
Spain	10.98	13.75	12.09	15.7	13.78	16.2	20

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As a consequence of the implementation of Directive 2009/28/EC, the EC required all EU-28 countries to draw up and approve national plans to commit to meeting the 2020 targets. Hence, in June 2010, the Spanish Government

Table 3: REP and NREAP 2020 goals (ktoe).

Goal	REP (2020)	NREAP (2020)
Gross final consumption of electricity from RES	12,455	12,907
Gross final consumption of heating and cooling from RES	5,357	5,641
Gross final consumption of transport from RES	3,216	4,308
Total gross final consumption of energy from RES	20,525	19,408
GFCoE	98,443	97,041
RES 2020 Share (%)	20.8	20.0

proposed the National Action Plan of Renewable Energy (NREAP) (Ministry of Industry, Tourism and Commerce, 2010). The NREAP was adjusted to the model of national action plans adopted by the EU.

The NREAP responded to the requirements and methodology of Directive 2009/28/EC and was adjusted to the model of national action plans adopted by the EC. The REP includes the essential elements of the NREAP and some additional analysis not added in the NREAP. In addition, the REP includes an extended analysis by sector, the technological evolution and the projection of costs. Table 3 shows the main 2020 goals included in the REP and NREAP.

2.4. 2.3. *Spanish Energy Plan 2015-2020*

In October 2015, the Spanish Government approved the Energy Plan 2015-2020 (2015-2020 EP) (Ministry of Industry, Energy and Tourism, 2015) covering also the electric grid development plan. The goal of this plan was to guarantee the electricity supply in the country taking into account the changes in the macroeconomic scenario, energy commitments until 2020 and the new regulatory framework. This plan defines a new forecast of energy demand considering the post-crisis scenario that had not been taken into account in the previous plans. This new scenario is based on a GFCoE in 2015 that was lower than the real demand in 2000.

The 2015-2020 EP provides a forecast of the GFCoE from 2015 to 2020

Table 4: Spanish Energy Plan 2015-2020, main 2020 indicators.

Indicator	EP (2020)
Gross inland energy consumption (ktoe)	130,306
GFCoE (ktoe)	90,788
RES installed capacity (MW)	56,804
Hydro installed capacity (MW)	17,492
WE installed capacity (MW)	29,479
Solar TE installed capacity (MW)	2,511
Solar PV installed capacity (MW)	6,030
Biomass, biogas and others (MW)	4,202

known as “prospective scenario”. This energy scenario proposes forward planning based on a yearly average growth of 0.9% until 2020, when a GFCoE of 90.788 ktoe could be reached. This approach considers the growth of the RE share, electricity and gas as final use, and a drop in oil dependence, although oil will continue to play a significant role in 2020 with a share of around 46%.

Table 4 shows the forecast of the main energy indicators by 2020. In terms of gross inland energy consumption, compliance with 2020 goals in the prospective scenario takes into account a less globally intensive Spanish economy (-1.4% yearly), an economy more intensive in primary consumption of natural gas (+0.1% yearly) and renewable energies (+0.7% yearly), and less intensive in oil consumption (-3.5% yearly) and nuclear energy (-1.7% yearly).

With regard to the evolution of the electric generation, the 2015-2020 EP considers different approaches depending on the energy source: coal, oil, natural gas, nuclear and RES. Concerning the RES, and with the commitment to reach the EU 2020 target of 20% in GFCoE, the prospective scenario requires a share of 36.6% of gross electric generation. Hence, new RE power was required, especially in the technologies proven to be more efficient and competitive: WE and photovoltaic (PV).

Based on these hypotheses, the 2015-2020 EP proposes an electricity gene-

Table 5: Spanish Energy Plan 2015-2020, electricity generation (GWh).

Indicator	EP (2020)
Electricity generation from coal	47,848
Electricity generation from oil	11,319
Electricity generation from natural gas	85,221
Electricity generation from nuclear	59,670
Electricity generation from RES	121,475
Gross electricity generation	331,355
Gross final consumption of electricity	267,336

ration forecast by 2020 as shown in Table 5. In relation with the electricity generation, the share of RES by 2020 should be 36.6% of the gross electricity generation and 45.4% of the final consumption of electricity.

Concerning the 2020 targets, in relation with the methodology proposed in Directive 2009/28/EC, the prospective scenario maintains the goal of 20% from RES and indicates a distribution as follows: 11.7% for electricity generation, 5.6% for heating and cooling and 2.7% in transport.

3. Data and methodology

This section is devoted to the analysis of the data and methodology used in this research. The methodology is developed in four stages as shown in Figure 2. The first stage focuses on the definition of a baseline scenario taking into account the information of all WFs in operation in Spain by the end of 2016, the determination of the RES quotas according to the 2020 targets, and the calculation of a forecast for the period 2017-2020 by means of the SHARES tool (Eurostat, 2017b). In the second stage, the character~~iz~~isation of the potential WE market to be repowered is assessed based on the information and data collection of the WFs anal~~yz~~ysed. Stage 3 focuses on the evaluation of the electricity production of repowered WFs in selected locations and using different types of WTs. Finally,

Table 6: Working assumptions for the proposed WE baseline scenario.

Target of energy from RES in GFCoE in 2020	20%
GFCoE in 2020	90,788 ktoe
Expected amount of energy from RES corresponding to the 2020 target	18,157.6 ktoe
Gross final consumption of electricity from RES	10,622.2 ktoe
Gross final consumption of heating and cooling from RES	5,084.1 ktoe
Gross final consumption of transport from RES	2,451.3 ktoe

stage 4 presents a sensitivity analysis of the main variables to better understand the impact of the uncertainties across the period anal~~yz~~ysed.

3.1. Stage 1. Definition of the WE baseline scenario

The WE baseline scenario is addressed on the basis of the information provided by the Spanish Energy Plan in Section 2.4. The working assumptions that have been considered to define the baseline scenario are shown in Table 6, where the gross final consumption of electricity corresponds to 11.4% of the total amount of energy from RES, the gross final consumption of heating and cooling corresponds to 5.6% and the gross final consumption of transport corresponds to 2.7%.

Once the gross amounts of energy have been defined, the next step lies in the distribution of the gross final consumption of electricity among the different types of RES. These calculations have been performed by using the SHARES tool. The acronym SHARES stands for SHort Assessment of Renewable Energy Sources (Eurostat, 2017b). It is a tool designed to collect and present energy and information data and focuses on the harmon~~iz~~ised calculation of the share of energy from RES among EU-28. The basis for the methodology and imple- mentation of the SHARES tool comply with Directive 2009/28/EC. SHARES tool results for the proposed baseline scenario with the assessment of the RES quotas and their distribution are shown in Section 4.

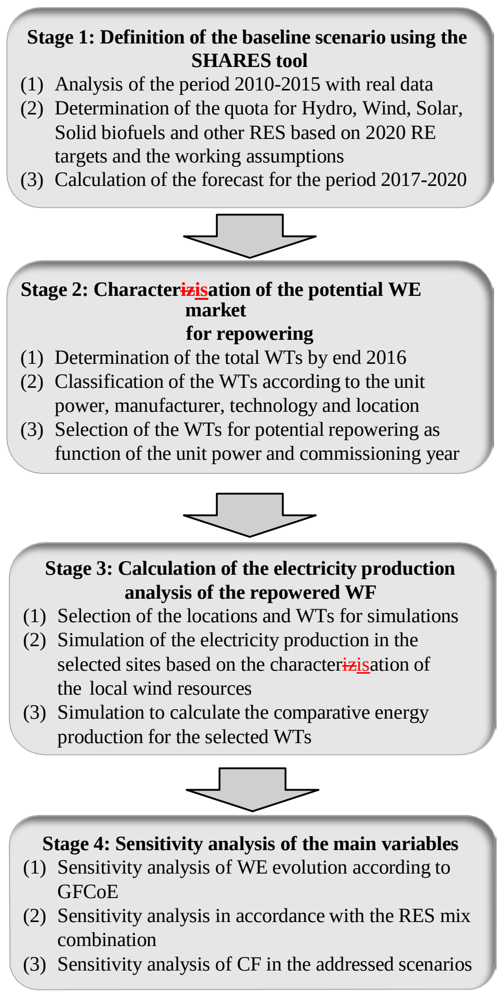

Figure 2: Overview of the four stages for optimal projection of WE by 2020 in Spain

3.2. Stage 2. Character~~iz~~isation of the potential WE market to repower

The total number of WTs in Spain was 20,027 by the end of 2016. The unit power of WTs ranges widely, from 5 kW to 5 MW. Figure 3 shows the number of WTs in Spain by the unit power at the end of 2016. The largest number of WTs corresponds to the 2 MW power type with 3,720 units, followed by 850 kW power with 3,639 units and 660 kW power with 3,556 units. It should be noted that the total number of installed WTs between 600 and 850 kW is 10,311 (red colour in Fig. 3), corresponding to 51.4% of the total number of WTs installed in Spain. This range of WTs was the first installed in Spain, and also in the most effective locations. Therefore, the WFs with these WTs are the most interesting from the perspective of potential repowering.

With regard to the distribution of the WFs by different locations, Figure 4 shows the distribution of WTs per in each Autonomous Community in Spain. It should be noted that the majority of WTs between 600 and 850 kW are installed in the autonomous communities where the WE development in Spain was first initiated: Galicia, Castilla and Leon, Castilla-La Mancha, Aragon, and Navarre. Just these five areas home to a total number of 8,819 units, 85.5% of the potential WT to be repowered.

In order to complete the extent analysis of the potential market to repower, Table 7 shows the total number of WTs in the range between 600 and 850 kW, Table 8 shows the total number of WTs between 600 and 850 kW per model and manufacturer, and Table 9 shows the potential WE market in Spain by autonomous community, with the total number of WFs, the total installed capacity and the total number of WTs suitable to be repowered. All this information refers to the end of 2016.

In order to character~~iz~~ise the total repowering market in Spain by the end of 2020, we must take into consideration the expected lifetime of the wind turbine (WT) and the payback period of the investment. According to IEC 61400-1 (IEC, 2005), the manufacturer must assure a lifetime of 20 years for the WT. The operation of the WT during this period is known to be with a loss in performance especially in the last 10 years (Colmenar-Santos et al., 2015).

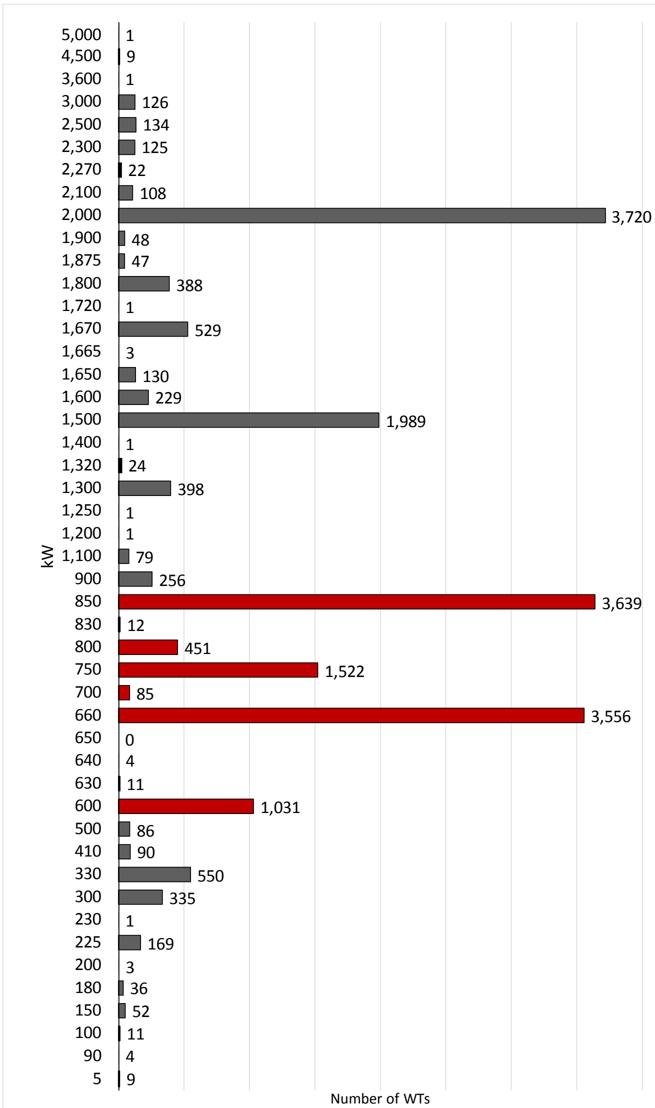

Figure 3: Number of WTs in Spain by the end of 2016 (according to the WT unit power, kW).

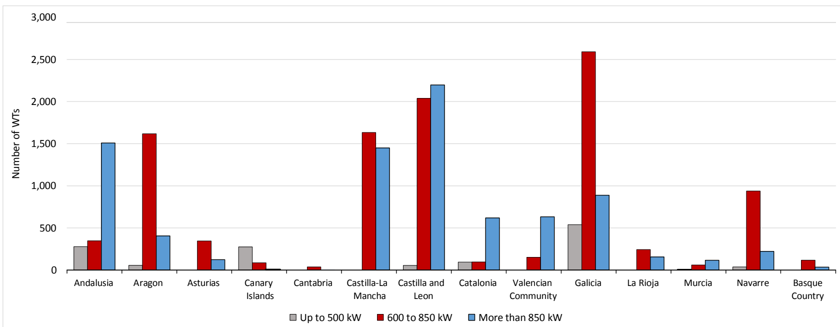

Figure 4: Wind turbines in the Spanish Autonomous Communities by the end of 2016.

Table 7: Total number of WTs between 600 kW and 850 kW by the end of 2016, per manufacturer.

Manufacturer	WT 600-850 kW (units)
ALSTOM-ECOTECNIA	630
DESA	1
ENERCON	66
GAMESA	6,599
GE	115
LAGERWEY	50
MADE	1,321
NORDEX	25
SIEMENS	342
VESTAS	1,162
Total	10,311

Table 8: Total number of 600 kW-850 kW WT per model and manufacturer, by the end of 2016 (units)

Model	Unit power (kW)	Manufacturer	WT 600-850 kW (units)
G-47	660	GAMESA	2,702
G-58	850	GAMESA	1,875
G-52	850	GAMESA	1,757
AE 46	660	MADE	823
NM 48	750	VESTAS	446
NM 44	750	VESTAS	464
IZAR MK-IV	600	SIEMENS	341
ECO48	750	ALSTOM-ECOTECNIA	299
ECO44	600	ALSTOM-ECOTECNIA	265
AE 52	800	MADE	212
G-42	600	GAMESA	199
AE 56	800	MADE	184
GE 750	750	GE	115
AE 59	800	MADE	102
NTK 600/43	600	VESTAS	83
ECO47	750	ALSTOM-ECOTECNIA	66
G-44	600	GAMESA	66
E-40	600	ENERCON	61
Multipower 52	750	VESTAS	53
V52	850	VESTAS	49
V600	600	VESTAS	40
LW50	750	LAGERWEY	32
V42	600	VESTAS	27
N43	600	NORDEX	25
LW52	750	LAGERWEY	18
E-48	800	ENERCON	5
1.3	750	SIEMENS	1
A600	600	DESA	1
Total			10,311

Table 9: Potential Spanish Wind Energy market to be repowered, by autonomous community

Autonomous Community	Wind farms (u.)	Installed power (MW)	Wind turbines (u.)
Andalusia	26	275.7	347
Aragon	52	1,201.8	1,618
Asturias	11	269.0	346
Balearic Islands	1	3.2	4
Canary Islands	17	60.0	87
Cantabria	2	32.3	38
Castilla-La Mancha	43	1,230.1	1,633
Castilla and Leon	88	1,597.0	2,038
Catalonia	3	63.4	96
Valencian Community	6	128.4	152
Galicia	83	1,819.1	2,591
La Rioja	6	186.1	244
Murcia	5	47.8	60
Navarre	29	633.1	939
Basque Country	5	93.3	118
Total	377	7,640.3	10,311

Table 10: WE market to by repowered by 2020

Total installed WE power	7,640.3 MW
Total number of WTs	10,311 units
Range of WT unit power	600-850 kW
Commissioning year	< 2005

In addition, the payback period of the investments concerning the first WFs installed in Spain before 2012 was less than 10 years, mainly because these WFs received high levels of support from the government in form of feed-in-tariffs (FiT). Even so, this study considers a lifetime period of 15 years for the WT to be repowered. Other authors consider a lifetime period of 13 years (Colmenar-Santos et al., 2015).

Therefore, and based on this analysis, by the end of 2020 all WFs installed before 2005 are apt to be repowered. Due to all WTs between 600 and 850 kW, and operating by the end of 2016, were installed before 2005, this is the potential WE market to be repowered, as summar~~iz~~ises in Table 10.

3.3. Stage 3. WE production analysis

This stage focuses on the analysis of the potential electricity production of the repowered WFs in relation to the current status. This subsection also describes the selection of both the WTs and the locations for the simulations.

For wind resource assessment, the output energy of a WT may be estimated based on the statistical characteristics of the wind speed by adding the energy corresponding to all possible wind speeds in a period of time (one year in the present study) (Pishgar-Komleh et al., 2015). The mathematical representation of the wind speed distribution in the WF may be adjusted by means of several probability functions. Due to the acceptable fit of the Weibull distribution to measured wind speed data, it is one of the most commonly used in the wind energy sector (Ayodele et al., 2016; Chang and Tu, 2007; Drew et al., 2013; Laiola and Giungato, 2017; Pishgar-Komleh et al., 2015; Ramadan, 2017;

Seguro and Lambert, 2000). In line with these authors, the Weibull distribution is adopted in this paper for wind speed modelling purposes. It is a two parameter distribution that takes the general form as follows:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left(-\left(\frac{v}{c}\right)^{k}\right) \quad (1)$$

where $f(v)$ is the probability of observing wind speed v, c is the Weibull scale parameter (with units equal to the wind speed units, i.e. m/s) and k is the Weibull shape parameter (dimensionless).

Once the Weibull parameters are estimated for a specific location, the cumulative probability function $F(v)$, which represents the probability that the wind speed is lower than v, is expressed as:

$$F(v) = 1 - exp\left(-\left(\frac{v}{c}\right)^{k}\right) \quad (2)$$

The AEP of a WT is calculated by combining the WT power output (from the WT manufacturer power curve) with the Weibull probability density function for the specific location (Drew et al., 2013). This AEP may be estimated by considering several wind speed groups (commonly known as bins), i, Eq. (3) —in case of not leap years—.

$$AEP = 8760 \int_{0}^{inf} P_{WT}(v)f(v) \approx 8760 \sum_{i=1}^{N} P_{WT,i}(v)(F(v_{i+1}) - F(v_i)) \quad (3)$$

Finally, the analysis of the AEP of the repowered WT is assessed by means of the capacity factor (CF), as shown in Eq. (4), where P_{WT} is the rated power of the WT. The CF of a WT is a currently a widely used metric to determine the techno-economic viability of a WT at a given site (Ayodele et al., 2016).

$$CF = \frac{AEP}{8760 P_{WT}} \quad (4)$$

3.3.1. Selection of WTs for the simulations

Several types of WTs have been selected for the simulations. Two of them correspond to WTs currently in operation, representing the potential WE mar-

Table 11: Selected WTs for simulations

WT model	IEC Class	Rated power (kW)	Rotor diameter (m)	Power density (W/m2)	Hub height (m)
G47	II	660	47	380.4	40-55
G58	II	850	58	400.2	44-74
G80	IA	2,000	80	397.9	60-100
G114	IIIA	2,000	114	195.9	60-100
V90	IA/IIA	3,000	90	471.5	65-105

ket to be repowered, and the other three to those currently offered by the manufacturers. The first of the selected WTs to be repowered is a 660 kW power manufactured by GAMESA, model G-47. It was one of the most widely installed WTs in Spain between 1994 and 2005, and this is also the power rate with the highest number of installed WTs, 2,702 units, which accounts for 26.02% of the total WTs to be repowered. The second WT considered for the calculations is the G-58 model, also manufactured by GAMESA. It is the second most widely installed type of WT in Spain, accounting for 18.18% of the total market to be repowered.

Regarding the new types of WTs to be considered in the calculations, two 2 MW models manufactured by GAMESA —G-80 and G-114—, and one 3 MW power manufactured by VESTAS (V90) have been selected. The G-114 model is a new generation of WT with improves WE generation in areas with low wind levels. Table 11 shows the main characteristics of the five WTs considered in the calculations and Figure 5 shows their power curves.

3.3.2. Selection of the locations for the simulations

Three locations were selected for the simulations, one in each of the three Autonomous Communities with the highest WE installed capacity in Spain: Galicia, Castilla and Leon, and Castilla-La Mancha. The three WFs were selected taking into account the location, the commissioning year, the type of WT

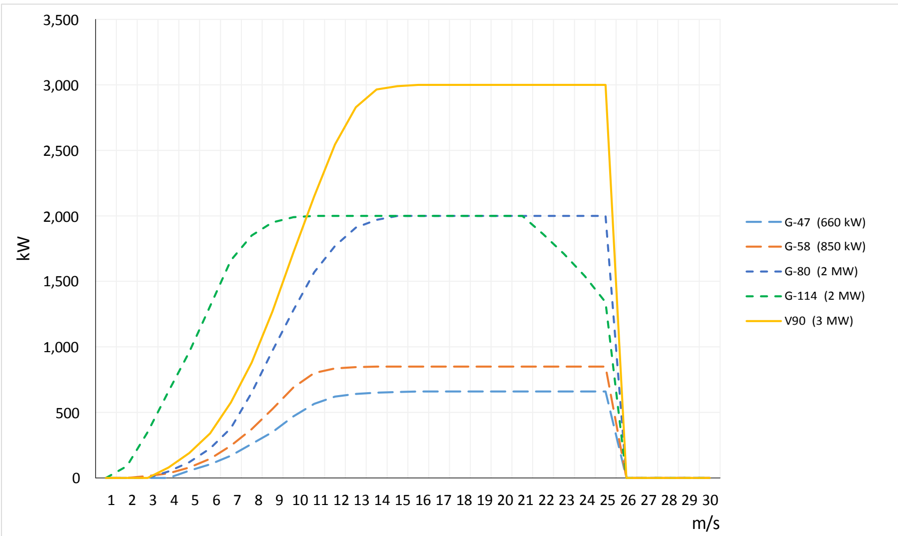

Figure 5: Power curves for the selected WTs.

Table 12: Selected sites for simulations

	WF-1	WF-2	WF-3
WF name	Fonsagrada	Altos de Cartagena	Malefatón
Autonomous Community	Galicia	Castilla y León	Castilla-La Mancha
Location	A Fonsagrada, Castroverde, Baleira, Ribeira de Piquín y Pol	Las Navas del Marqués	Higueruela
WT power rate	660 kW	660 kW	660 kW
WT number	69	32	75
Installed power rate (MW)	45.54	21.12	49.50
Latitude	43º 5' N	40º 37' N	38º 58' N
Longitude	7º 17' O	4º 20' O	1º 25' O
Altitude (m)	962	1,599	1,109
Commissioning year	2004	2002	1999

installed and the total WF power installed. Table 12 shows the main information about the WFs, coordinates and altitude of the selected sites, and commissioning year. Fig. 6 shows the location of the selected WFs in the Spanish wind resource map (IDAE, 2017).

3.4. Stage 4. Sensitivity analysis

The model performs a sensitivity analysis of the main variables for the proposed scenarios, considering the development of WE according to progress in GFCoE, the evolution of other RES in the energy mix, and the CF. The results are shown in Section 4.

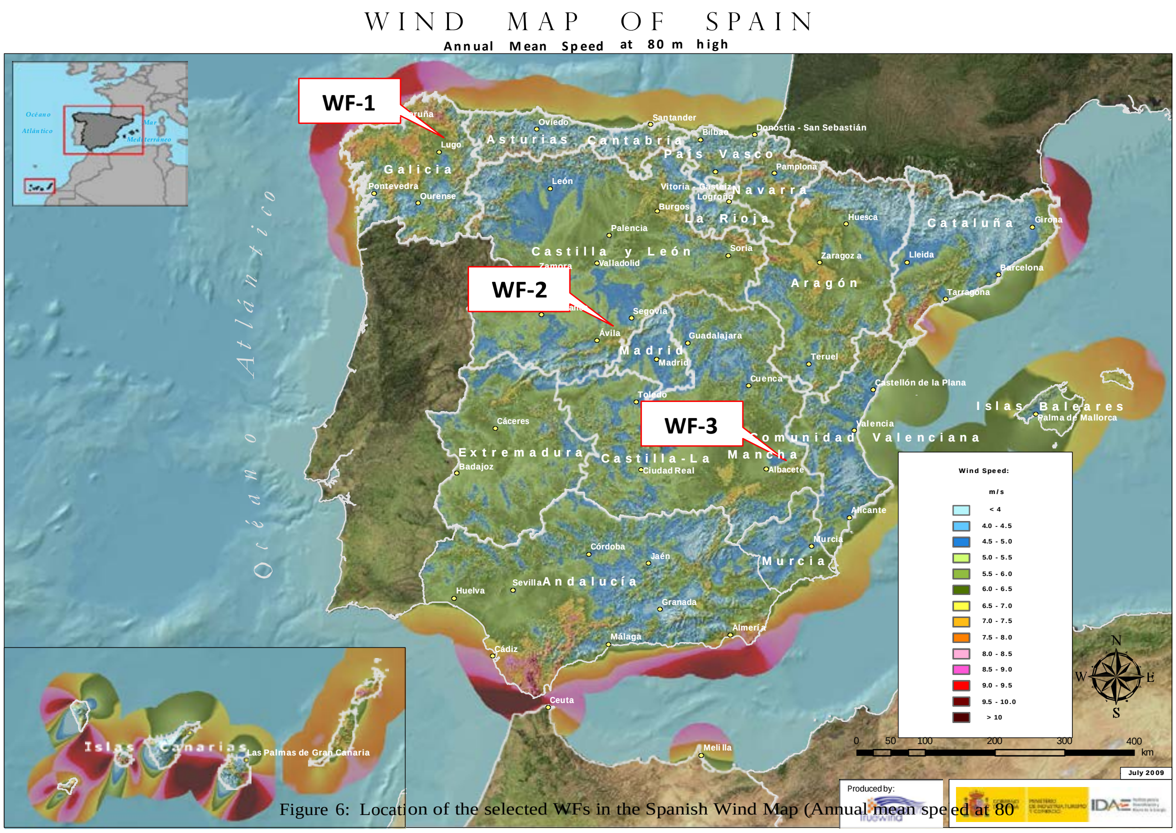

Figure 6: Location of the selected WFs in the Spanish Wind Map (Annual mean speed at 80 m high).

4. Results and discussion

In this section, we present and discuss the results, providing the key outcomes related to the deployment of wind energy until 2020. Several operative scenarios have been considered in the simulations in order to forecast both the impact of repowered WFs with the commissioning of new ones, and the evolution of WE in the energy mix, as follows:

- *Baseline scenario (SC-BL).* This scenario is based on the results provided by the SHARES Tool (Eurostat, 2016) using the working assumptions presented in Table 6 and considering that all RES achieve the 2020 goals according to the 2015-2020 EP (Ministry of Industry, Energy and Tourism, 2015).

- *Scenario A1 (SC-A1).* In this scenario, a growth of GFCoE of 10% over the baseline scenario entirely accounted for by WE is considered, maintaining the 2020 targets for hydro, solar, solid biofuels and other RES.

- *Scenario A2 (SC-A2).* This scenario considers a growth of GFCoE of 20% over the baseline scenario, that is entirely accounted for by WE, maintaining the 2020 targets for hydro, solar, solid biofuels and other RES.

- *Scenario A3 (SC-A3).* In this scenario, a growth of the GFCoE of 20% over the baseline scenario is considered, but without growth for the other RES, maintaining the installed capacity by the end of 2016. The new addition of demanded energy must be entirely accounted for by WE.

- *Scenario B1 (SC-B1).* This scenario is based on SC-BL but without growth for the all other RES that maintain the installed capacity by the end of 2016. WE accounts entirely for the increase in generated energy to reach the 2020 targets.

- *Scenario B2 (SC-B2).* It is based on the SC-BL, with a growth of 25% for solar, solid biofuels and other RES. Hydro maintains installed capacity by end of 2016 and WE accounts the remaining growth.

- *Scenario B3 (SC-B3).* This scenario is similar to SC-B2 but with a growth of 50% for solar, biofuels and other RES.

4.1. Baseline scenario results

The baseline scenario is assessed with the SHARES Tool (Eurostat, 2016) and the results are shown in Table 13. The calculations consider the real data of RES at the end of 2016, and perform a forecast from 2017 to 2020 based on the following assumptions:

(i) Hydro is normal~~iz~~ised and pumping is excluded. In addition, and as hydro- power is not expected to increase in Spain, the electricity generation from hydro has been forecast from 2016 to 2020 based on the average value of the last 10 years.

(ii) Wind is normal~~iz~~ised. The forecast value for 2017 has been determined as the average value of the 2014-2016 period as no new addition of WE is expected in 2017. For the next years, a growth of the electricity generation from wind sources has been considered as follows: 5% in 2018, 7.5% in 2019 and 12% in 2020 when the target for electricity generation from wind energy should be reached.

(iii) Solar includes solar PV and concentrating solar power (CSP). Due to there being no new additions of PV power in Spain in the 2013-2016 period (Ramírez et al., 2017), this work does not consider improvements in electricity generation from solar energy in 2017. The forecast value for the 2017 year has been determined as the average value of the 2014-2016 period. For the next years, a growth of the electricity generation from solar sources has been considered as follows: 5% in 2018, 5% in 2019 and 8.5% in 2020 when the target for electricity generation from solar energy should be reached.

(iv) A moderate growth of electricity generation from solid biofuels until 892.3 ktoe in 2020 has been considered. Furthermore, for the other RES, including electricity generation from gaseous and liquid biofuels, renewable municipal waste, geothermal, and tide, wave and ocean, a growth to 300.2 ktoe in 2020 has been estimated.

(v) The calculation of the final GFCoE from RES considers that the electricity used in transport is included in transport and is not included in electricity.

(vi) Aviation adjustment, according with the Article 5 (6) of the SHARE tool, is considered equal to zero for the period 2016 to 2020.

In accordance with the calculations using the SHARES tool, the WE 2020 targets for the baseline scenario are defined as shown in Table 14.

4.2. Simulation results of repowered WFs

Having defined the 2020 targets for all RES, this subsection focuses on the presentation of the results concerning the simulations of the repowered WFs considered in the Subsection 3.3.

The calculations have been performed using the five selected WTs (Table 11) in the three locations *WF-1, WF-2* and *WF-3* (Table 12). The results are presented in Table 15 and some findings can be highlighted, as follows:

- First, the AEP values in the three locations confirm the selected WFs are a representative sample of the existing WFs in operation before 2005 (potential market to be repowered). The AEP brings values from 1,207.33 to 1,648.59 MWh/year considering the G-47 type, and from 1,745.98 to 2,320.58 MWh/year with the G-58.

- Secondly, concerning the CF values with these WTs, the results range from 20.88 to 28.51% with the G-47, and from 23.45 to 31.17% with the G-58. Comparing these results with the evolution of the global CF from 1998 to 2016 in the WFs in operation in Spain (see Fig. 7, where the red colour bars correspond to the CF of the potential market to be repowered, and Fig. 8) we can affirm that the simulation results are consistent with the anal~~yz~~ysed evolution, with an average value of CF equal to 22.7% in the whole period and 23.9% in the last 10 years. Furthermore, more than 70%

Table 13: SHARES tool results 2016-2020 for the proposed baseline scenario (ktoe).

	2016	2017 (F)	2018 (F)	2019 (F)	2020 (F)
(a) Electricity					
Hydro	2,710.6	2,711.3	2,708.6	2,707.8	2,710.7
Wind	4,390.2	4,400.3	4,620.3	4,966.9	5,562.4
Solar	1,164.5	1,177.3	1,236.2	1,298.0	1,410.4
Solid biofuels	406.1	477.8	562.2	661.4	892.3
All other renewables	159.3	168.7	178.6	189.1	300.2
Total (RES-E share numerator)	8,830.7	8,935.4	9,305.9	9,823.1	10,876.0
RE electricity in transport	199.3	207.4	220.7	235.9	253.5
Article 5: GFCoE from RES					
(a) electricity	8,631.4	8,728.0	9,085.2	9,587.2	10,622.6
(b) heating and cooling	4,744.5	4,827.5	4,912.0	4,997.9	5,084.1
(c) transport	319.2	531.4	884.6	1,472.5	2,451.3
(a) + (b) + (c)	13,695.0	14,086.9	14,881.8	16,057.7	18,158.0
Article 2 (f):					
GFCoE	92,256.6	86,306.3	87,770.0	89,258.6	90,788.0
Article 5 (6): Aviation adjustment					
Total before adjustment	84,866.9	86,306.3	87,770.0	89,258.6	90,788.0
Total (RES-E share denominator)	84,866.9	86,306.3	87,770.0	89,258.6	90,788.0
RES-E share [%]	16.69%	17.15%	17.78%	17.99%	20.00%

(F: Forecast)

Table 14: WE baseline scenario

Baseline scenario parameters	2020 Target
Electricity generation from WE	5,562.4 ktoe
WE share in RES-E	51.2%
Indicative installed WE power capacity	29,479 MW

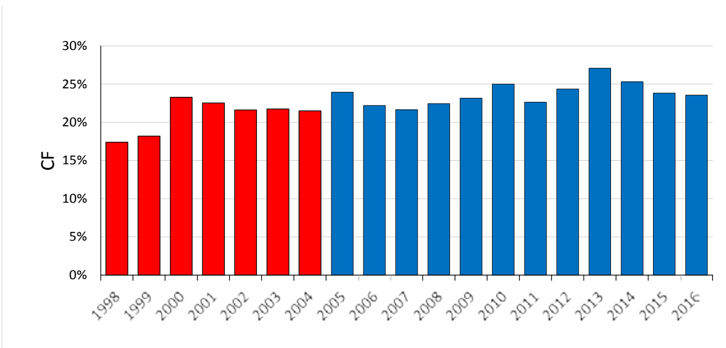

Figure 7: CF evolution of wind farms in operation, 1998-2016

of the years in the whole period the CF value has been between 20.4 and 26.4% (Fig. 8).

- Regarding the results of the simulations with the WTs currently being manufactured, it can be observed that the best AEP and CF values are obtained with the new generation G-114, with AEP values from 7,890.97 to 8,878.26 MWh/year and CF values from 45.04 to 50.68%. In relation to the improvements in the CF that could be obtained in the selected locations with the replacement of old WTs for the new 2 and 3 MW models, the results show significant enhancements with the G-114 type (19.51 to 24.16%), followed by the G-80 (7.42 to 14.16%) and V90 (5.39 to 11.24%) types. Comparing these results with the other research works and the information from the manufacturers, these are consistent with the estimations made by Colmenar-Santos et al. (2015) with regard to the G-80 and V90 types, and the information provided by GAMESA in relation with the G-114 type, stating that this new generation of WT increases the AEP in more than 20% due to its capacity to operates with low levels of wind speed (Siemens Gamesa RE, 2017).

Figure 8: Pareto diagram of CF evolution in the period 1998-2016

Table 15: Simulation results for the considered repowered WFs

Wind Farm	WT type	AEP (MWh/year)	CF	CF improvement with (3)	CF improvement with (4)	CF improvement with (5)
WF-1	**(1) G-47 660 kW**	1,509.40	0.261	0.102	0.236	0.082
	(2) G-58 850 kW	2,150.67	0.289	0.074	0.208	0.054
	(3) G-80 2 MW	6,360.42	0.363			
	(4) G-114 2 MW	8,706.92	0.497			
	(5) V90 3 MW	9,006.55	0.343			
WF-2	**(1) G-47 660 kW**	1,648.59	0.285	0.108	0.222	0.082
	(2) G-58 850 kW	2,320.58	0.312	0.081	0.195	0.055
	(3) G-80 2 MW	6,882.02	0.393			
	(4) G-114 2 MW	8,878.26	0.507			
	(5) V90 3 MW	9,635.89	0.367			
WF-2	**(1) G-47 660 kW**	1,207.33	0.209	0.142	0.242	0.112
	(2) G-58 850 kW	1,745.98	0.234	0.116	0.216	0.087
	(3) G-80 2 MW	6,138.77	0.350			
	(4) G-114 2 MW	7,890.97	0.450			
	(5) V90 3 MW	8,441.04	0.321			

4.3. Sensitivity analysis of WE evolution as function of the GFCoE

This subsection focuses on the presentation of the results concerning the sensitivity analysis of the evolution in WE according to GFCoE. Based on the results obtained in the previous chapters and the information provided by the state of the art, certain factors have been taken into account, as follows:

- The total installed power capacity in a repowered WF does not vary in relation to the author~~iz~~ised power of the initial WF.
- For the WFs in operation and commissioned since 2005, a CF value of 24% is assumed, based on the analysis of the CF evolution in Spain from 2005 to 2016 as shown in Fig 7.
- A CF value of 35% for the new WFs installed from 2017 is assumed, according to the data provided in the last WE auction in Spain (Ministry of Energy, Tourism and the Digital Agenda, 2017) and the information from WT manufacturers.
- Based on the simulation results, a CF value of 45% is assumed for the repowered WFs. This value is consistent with the work by Colmenar-Santos et al. (2015), where a CF of 40% is considered, and taking into account the performance improvement of the new generation of WTs in the recent years.

Fig. 9 shows the results for the sensitivity analysis of the WE evolution considering the combination of the repowering of WFs in operation before 2005 with the commissioning of new WFs. The different alternatives by repowering level —from 0% to 100%— of the total market to be repowered are presented. In this figure, the use of the current WE capacity that is not repowered is represented as WE-C, the repowered capacity as WE-R, and the new required WE installed capacity as a function of the addressed scenarios is depicted as WE-N-BL, WE-N-A1, WE-N-A2, and WE-N-A3 for the named baseline, A1, A2 and A3 scenarios.

The following findings are deduced from Fig. 9, as follows:

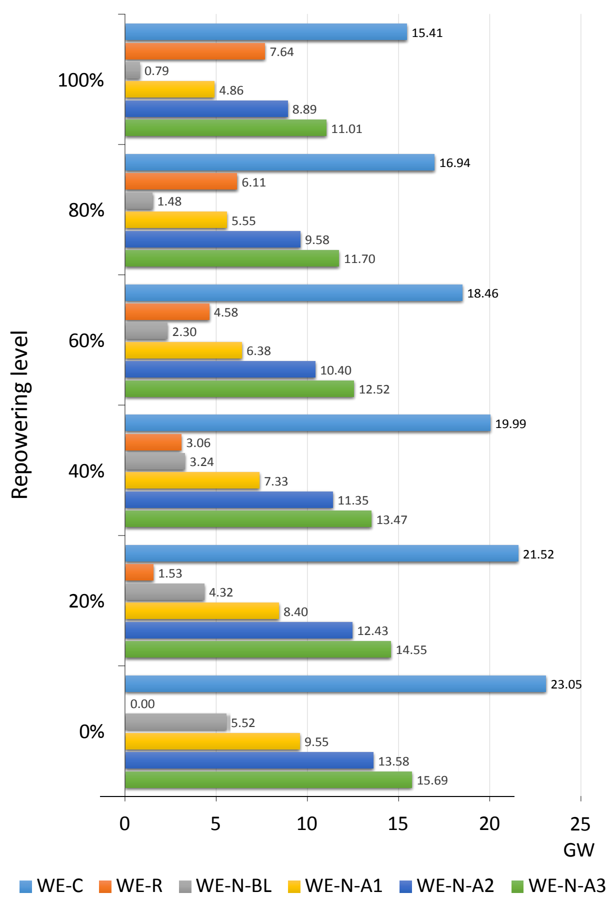

Figure 9: WE combination as function of the repowering level

- Considering the baseline scenario, where the value of GFCoE corresponds to the forecasting of the 2015-2020 EP, the new required installed capacity ranges from 5.52 GW (0% of repowering level) to 0.79 GW (100% of repowering level). This means that, on the one hand, the recent auction launched by the Spanish government of 3GW would not be enough to reach the 2020 goals if a repowered level of 46% is not achieved and, on the other hand, with the repowering of all existing WFs only 1 GW of new WE capacity would be necessary to reach the 2020 targets. This also assumes that solar, solid biofuels and other RES also achieve the 2020 goals.

- In the assessment of scenario A1, which assumes a growth of 10% over the forecast GFCoE, a new addition of 9.55 GW would be required to reach the 2020 goals if none of the existing WFs is repowered, or 4.86 GW of new capacity if 100% of the potential repowering is completed. With this hypothesis, a new auction of minimum 2.86 GW would be required to reach the 2020 targets in addition to complete a repowering level of 100%.

- In the analysis of the results for the A3 and A4 scenarios, a new addition of installed capacity would be required, from 13.58 to 15.69 GW if the repowering level is absent or from 8.89 to 11.01 GW if the repowering level reaches 100%. Although these scenarios are, in principle, improbable, they are not impossible, firstly because of the positive situation of the Spanish economy in the recent years, and secondly because WE promoters have established the most competitive prices in the last RE auctions in 2015 and 2017, at the expense of solar and other RES.

4.4. Sensitivity analysis results in accordance with the RES mix combination

This subsection focuses on the analysis of the combination of WE with other RES in the scenarios addressed, according to the repowering level. Due to the limit in the length of the paper, only the results for a repowering level of 25% (Fig. 10) and 75% (Fig. 11) are presented here. These calculations also consider

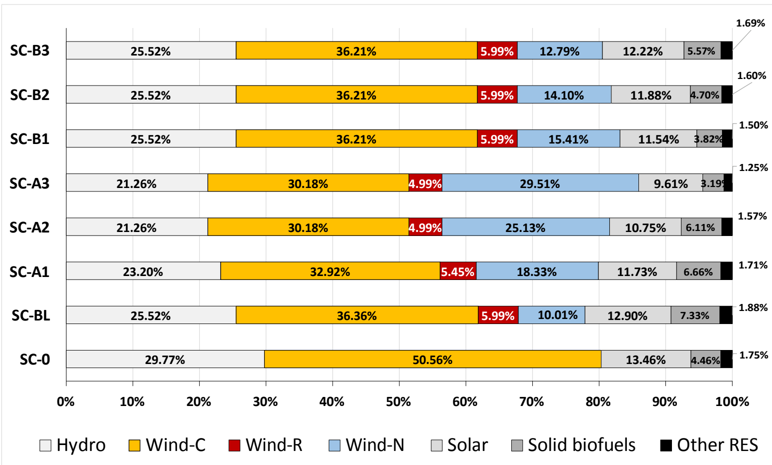

Figure 10: AEP (in percentage) for the energy mix in the scenarios addressed, with a WE repowering level of 25%

the scenario SC-0, which corresponds to the AEP in the energy mix by end of 2016.

The analysis of these figures provides the following findings:

- Hydro reduces its participation in all scenarios, from 29.77% at the end of 2016 to 21.26% in SC-A2 and SC-A3. This is logical due to the projection of the RES targets until 2020 not considering the growth of hydro.
- WE is the RES with the highest value of participation in the energy mix, with 50.56% in SC-0. This value gradually increases in the scenarios considered, reaching 64.68% in SC-A3.
- Concerning the new additions of installed WE capacity (Wind-N) the results show a wide range of values according to the scenarios considered and the repowering level. With a repowering level of 25%, a new addition of WE from 10.01% for SC-BL to 29.51% in the SC-A3 would be required. Analyzysing the results with a repowering level of 75%, the new AEP re-

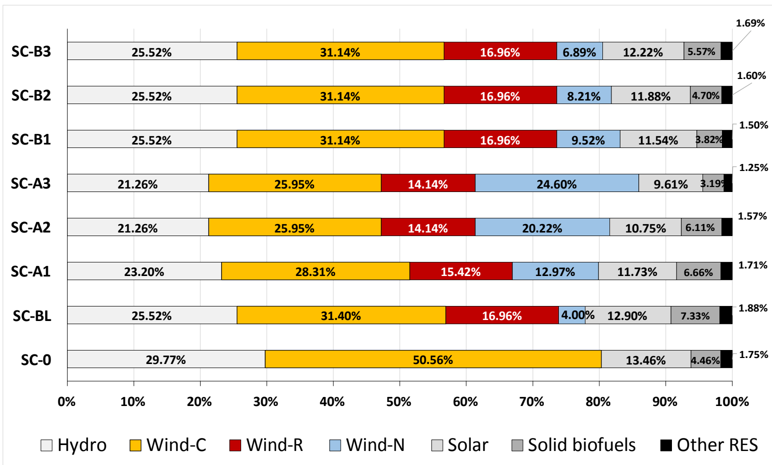

Figure 11: AEP (in percentage) for the energy mix in the scenarios addressed, with a WE repowering level of 75%

quired from WE is logically lower, ranging from 4% in SC-BL to 24.6% in SC-A3.

- Solar energy had a participation in the AEP energy mix equal to 13.46% at the end of 2016. Although the profitability of this RES in Spain is well documented (Ramírez et al., 2017), solar energy has reduced its participation in the latest auctions in Spain in favor of WE. In this study, and based on the scenarios anal~~yz~~ysed, which consider achievement of the 2020 targets in SC-BL, SC-A1, SC-A2 and SC-A3, solar energy ranges from 12.9% in SC-BL to 9.61% in SC-A3, decreasing its quota in favor of WE.

- Solid biofuels and other RES have a minor participation in the energy mix and this situation is unlike to change in the 2017-2020 period. Biofuels had a quota of 4.46% of AEP at the end of 2016, which could increase to 7.33% in SC-BL. This value will be reduced in all scenarios in benefit of WE, and according to the growth considered.

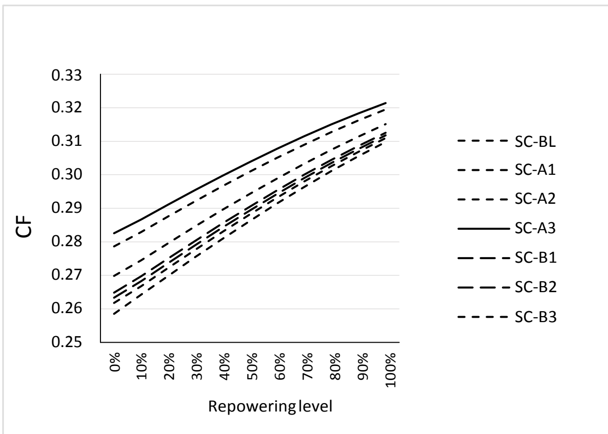

Figure 12: Evolution of CF according to the repowering level. CAMBIAR LEYENDA

4.5. Sensitivity analysis of CF in the assessed scenarios

Finally, Fig. 12 shows the results of the sensitivity analysis for the evolution of CF according to the repowering level for the seven scenarios considered. The figure reveals the best CF performance in SC-A3, with values ranging from 28.3 to 32.1%, followed by SC-A2, SC-A1, SC-B1, SC-B2 and SC-B3. Finally, SC-BL would have the lowest values ranging from 25.8 to 30.9%.

5. Conclusions

We have broadly assessed combining ~~repowered~~ repowering WFs with ~~the~~ commissioning ~~of~~ new ones in order to reach the desired quota of 20% of GFCoE from RES in Spain by 2020. Production of WE plays a key role in the Spanish energy mix and repowering emerges as a feasible and suitable approach to increase the current RES generation share. This work presents a novel model to assess the optimal projection of the WE sources until 2020 combining the repowering of WFs commissioned before 2005, with the remaining WFs currently in operation, and the commissioning of new ones. First~~ly~~, the research carries out an extensive analysis of the WE sector in Spain, identifying the potential WE market to be repowered. ~~Secondly~~Then, the work defines a baseline scenario based on Directive 2009/28/EC, the National Plans of Renewable Energy, and the Spanish 2015-2020 Energy

Plan. ~~Third~~Finally, the designed model is used to simulate several scenarios to better explain how WE can be deployed and which level of repower~~–~~ing must be performed to reach the 2020 targets. The model calculations have been performed in different locations and considering different types of WTs representing the current WE market to be repowered in order to evaluate the repowering performances. In addition, sensitivity results have been presented ~~considering~~taking into account the repowering level in the energy mix combination, measuring the impact in the evolution of hydro, solar, solid biofuels and other RES. The results obtained from the study show that a minimum level of repowering of 46% is required if the forecast GCFoE by 2020 is to be achieved, and 3 GW in new installed capacity when the last auction is fulfilled. In the event that solar and other RES do not increase the current share due mainly to WE winning the next announced auction of 4 GW, the repowering level could be greater. Furthermore, this scenario becomes more difficult if GCFoE grows to 10% due to the favourable evolution of the gross domestic product (GDP). In this scenario, a repowering level close to 100% would be required, together with the addition of 9 GW in new WE installed capacity.

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This research may help promoters, manufacturers and the Spanish government to make efficient decisions in relation to the development of WE production in Spain up to 2020. In addition, the sensitivity analysis performed in this work could help to steer future decisions in relation to utilising the current WE potential to maximise the resources as regards future deployment.

Despite the fact that the economic analysis of repowering has been addressed by several authors who have proved that investment in the repowering of old WFs can be more profitable than investing in new ones (Castro-Santos et al., 2011, 2012; Colmenar-Santos et al., 2015; Filgueira et al., 2009; Himpler and Madlener, 2012; Prabu and Kottayil, 2015), further work could focus on the assessment of the scenarios analysed from an economic perspective. Furthermore, the model could be applied in other countries and also for the evaluation of other RES such as solar or solid biofuels. In addition, an analysis of the future projection of WE until 2030 in line with the EU 2030 targets might also be conducted.

Acknowledgments

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research stay of Dr F. Javier Ramirez at the College of Engineering and Physical Sciences, University of Birmingham, UK, in 2017.

Appendix

Abbreviation	Definition
AEP	Annual energy production
CF	Capacity factor
CSP	Concentrating solar power
EC	European Commission
EU	European Union
Eurostat	Statistical Office of the European Union FiT
	Feed-in tariff
GDP	Gross domestic product
GFCoE	Gross final consumption of energy NREAP National action plan of renewable energy
PV	Photovoltaic energy
RE	Renewable energy
REP	Renewable energy plan
RES	Renewable energy sources
TE	Solar thermal
U.N.	United Nations
WE	Wind energy
WF	Wind farm
WT	Wind turbine

References

Aee, 2017. Asociación Empresarial Eólica. Tech. rep. URL http://www.aeeolica.org/(accessed19.04.2017)

Ayodele, T., Ogunjuyigbe, A., Amusan, T., 2016. Wind power utilization assess- ment and economic analysis of wind turbines across fifteen locations in the six geographical zones of Nigeria. Journal of Cleaner Production 129, 341–349.

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~~to be repowered. Secondly, the work defines a baseline scenario based on Di- rective 2009/28/EC, the National Plans of Renewable Energy, and the Spanish 2015-2020 Energy Plan. Thirdly, the designed model is used to simulate several scenarios to better explain how WE can be deployed and which level of repower- ing must be performed to reach the 2020 targets. The model calculations have been performed in different locations and considering different types of WTs representing the current WE market to be repowered in order to evaluate the repowering performances. In addition, sensitivity results have been presented considering the repowering level in the energy mix combination, measuring the impact in the evolution of hydro, solar, solid biofuels and other RES.~~

~~The results obtained from the study show that a minimum level of repowering of 46% is required if the forecast GCFoE by 2020 is to be achieved, and 3 GW in new installed capacity as result of the last auction is fulfilled. In the event that solar and other RES do not increase the current share due mainly to WE winning the next announced auction of 4 GW, the repowering level could be greater. Furthermore, this scenario become more difficult if GCFoE grows to 10% due to the favorable evolution of the gross domestic product (GDP). In this scenario, a repowering level close to 100% would be required, together with the addition of 9 GW in new WE installed capacity.~~

~~This research may help promoters, manufacturers and governments to make efficient decisions in relation to the development of WE production in Spain until 2020. In addition, the sensitivity analysis performed in this work could help to steer future decisions in relation to utilize the current WE potential to maximize the resources as regards future deployment.~~

~~Despite the fact that the economic analysis of repowering has been addressed by several authors proving that investment in the repowering of old WFs can be more profitable than investing in new ones (Castro-Santos et al., 2011, 2012; Colmenar-Santos et al., 2015; Filgueira et al., 2009; Himpler and Madlener, 2012; Prabu and Kottayil, 2015), further work could focus on the assessment of the scenarios analyzed from an economic perspective. Furthermore, the model could be applied in other countries and also for the evaluation of other RES~~

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such as solar or solid biofuels. In addition, an analysis of the future projection of WE until 2030 in line with the EU 2030 targets might also be conducted.

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Appendix

Abbreviation	Definition
AEP	Annual energy production
CF	Capacity factor
CSP	Concentrating solar power
EC	European Commission
EU	European Union
Eurostat	Statistical Office of the European Union
FiT	Feed-in tariff
GDP	Gross domestic product
GFCoE	Gross final consumption of energy
NREAP	National action plan of renewable energy
PV	Photovoltaic energy
RE	Renewable energy
REP	Renewable energy plan
RES	Renewable energy sources
TE	Solar thermal
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References

Aee, 2017. Asociación Empresarial Eólica. Tech. rep. URL http://www.aeeolica.org/(accessed19.04.2017)

Ayodele, T., Ogunjuyigbe, A., Amusan, T., 2016. Wind power utilization assessment and economic analysis of wind turbines across fifteen locations in the six geographical zones of Nigeria. Journal of Cleaner Production 129, 341–349.

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Calvo, A., Gomez, G. I., Rio, P. d., 2013. Analyzing the techno-economic determinants for the repowering of wind farms. The Engineering Economist 58 (4), 282–303.

Castro-Santos, L., Filgueira, A., Seijo, M. A., Muñoz, E., Piegiari, L., 2011. Is it economically possible repowering Wind Farms . A general analysis in Spain. Renewable Energy and Power Quality Journal 9 (9), 1–4.

Castro-Santos, L., Vizoso, A. F., Camacho, E. M., Piegiari, L., 2012. General Economic Analysis about the Wind Farms Repowering in Spain. Journal of Energy and Power Engineering 6 (7), 1158.

Chang, T.-J., Tu, Y.-L., 2007. Evaluation of monthly capacity factor of WECS using chronological and probabilistic wind speed data: A case study of Taiwan. Renewable Energy 32 (12), 1999 – 2010.

CNMC, 2017. Comisión Nacional de los Mercados y la Competencia. Tech. rep. URL https://www.cnmc.es/(accessed10.06.2017)

Colmenar-Santos, A., Campos Perez-Romero, S., Perez-Molina, C., Mur-Perez, F., 2015. Repowering: An actual possibility for wind energy in Spain in a new scenario without feed-in-tariffs. Renewable and Sustainable Energy Reviews 41, 319–337.

Del Río, P., Calvo Silvosa, A., Iglesias Gómez, G., 2011. Policies and design elements for the repowering of wind farms: A qualitative analysis of different options. Energy Policy 39 (4), 1897–1908.

Drew, D., Barlow, J., Cockerill, T., 2013. Estimating the potential yield of small wind turbines in urban areas: A case study for Greater London, UK. Journal of Wind Engineering and Industrial Aerodynamics 115, 104 – 111.

D'Adamo, I., Rosa, P., 2016. Current state of renewable energies performances in the European Union: A new reference framework. Energy Conversion and Management 121, 84–92.

Formatted: Body Text, Indent: Left: 1.68 cm, Hanging: 0.35 cm, Right: 1.71 cm, Space Before: 7.95 pt

European Council, 2016. International agreements on climate action. Tech. rep., European Union.
URL http://www.consilium.europa.eu/en/policies/climate-change/ (accessed9.06.2017)

European Parliament, 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. Tech. rep.

Eurostat, 2016. Harmonised Indices of Consumer Prices (HICP). Annual Data 2015.
URL http://appsso.eurostat.ec.europa.eu/(accessed16.07.05)

Eurostat, 2017a. Share of energy from renewable sources (last update: 14-03-2017). Tech. rep., European Commission.
URL http://appsso.eurostat.ec.europa.eu/(accessed6.04.2017)

Eurostat, 2017b. Short Assessment of Renewable Energy Sources (SHARES). Tech. rep., European Commission.
URL http://ec.europa.eu/eurostat/web/energy/data/shares(accessed10.04.2017)

Filgueira, A., Seijo, M. A., Muñoz, E., Castro-Santos, L., Piegiari, L., Munoz, E., Castro, L., Piegari, L., 2009. Technical and Economic Study of Two Re-powered Wind Farms in Bustelo and San Xoán , 24 . 7 MW and 15 . 84 MW respectively. 2009 International Conference on Clean Electrical Power, 545–549.

Himpler, S., Madlener, R., 2012. Repowering of Wind Turbines: Economics and Optimal Timing. Tech. Rep. 19.

IDAE, 2017. Wind Map of Spain. Tech. rep., Ministry of Energy, Tourism and the Digital Agenda.
URL http://atlaseolico.idae.es/(accesed7.04.2017)

IEC, 2005. IEC 61400-1. International Standard. Wind turbines - Part 1: Design requirements. Tech. rep., International Electrotechnical Commission.

Laiola, E., Giungato, P., 2017. Wind characterization in Taranto city as a basis for innovative sustainable urban development. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2017.05.111.

Ministry of Energy, Tourism and the Digital Agenda, 2017. Royal Decree 359/2017. Tech. rep., Gobierno de España.
URL www.boe.es/(accessed19.06.17)

Ministry of Industry, Energy and Tourism, 2012. Royal Decree 1/2012. Tech. rep., Gobierno de España.
URL https://www.boe.es(accessed10.05.2017)

Ministry of Industry, Energy and Tourism, 2015. Planificación Energética. Plan de Desarrollo de la Red de Transporte de Energía Eléctrica 2015-2020. Tech. rep., Gobierno de España.

Ministry of Industry, Tourism and Commerce, 2010. Plan de Acción Nacional de Energías Renovables de España (PANER) 2011-2020. Tech. rep., Gobierno de España.

Ministry of Industry, Tourism and Commerce, 2011. Plan de Energías Renovables 2011-2020. Tech. rep., Gobierno de España.

Nivedh, B., Devi, R., Sreevalsan, E., 2013. Repowering of Wind Farms-a Case Study. Wind Engineering, 137–150.

Pishgar-Komleh, S., Keyhani, A., Sefeedpari, P., 2015. Wind speed and power density analysis based on weibull and rayleigh distributions (a case study: Firouzkooh county of iran). Renewable and Sustainable Energy Reviews 42, 313 – 322.

Prabu, T., Kottayil, S. K., 2015. Repowering a Windfarm – A Techno-Economic Approach. Wind Engineering 39 (4), 385–398.

Ramadan, H., 2017. Wind energy farm sizing and resource assessment for optimal energy yield in Sinai Peninsula, Egypt. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2017.01.120.

Ramírez, F. J., Honrubia-Escribano, A., Gómez-Lázaro, E., Pham, D. T., 2017. Combining feed-in tariffs and net-metering schemes to balance development in adoption of photovoltaic energy: Comparative economic assessment and policy implications for european countries. Energy Policy 102, 440 – 452.

REE, 2017. Red eléctrica española. Tech. rep.
URL http://www.ree.es/(accessed7.06.2017)

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Rodriguez, R., Rodríguez-monroy, C., Coruña, U. D., Coruña, A., Calvo, F., 2013. Analysis of Renewable Energy Policies Related to Repowering the Wind Energy Sector : the Spanish Case, 1–8.

Santos-Alamillos, F., Thomaidis, N., Usaola-García, J., Ruiz-Arias, J., Pozo-Vázquez, D., 2017. Exploring the mean-variance portfolio optimization approach for planning wind repowering actions in Spain. Renewable Energy 106, 335–342.

Seguro, J., Lambert, T., 2000. Modern estimation of the parameters of the weibull wind speed distribution for wind energy analysis. Journal of Wind Engineering and Industrial Aerodynamics 85 (1), 75 – 84.

Siemens Gamesa RE, 2017. G114-2.0 MW Greater energy produced from low and medium wind sites. Tech. rep.
URL http://www.gamesacorp.com/en/products-and-services/wind-turbines/(accessed5.06.2017)

U.N., 1994. United Nations Framework Convention on Climate Change. Tech. rep., United Nations.
URL http://unfccc.int/(accessed14.6.2017)

U.N., 1998. Kyoto Protocol To the United Nations Framework. Tech. rep., United Nations.
URL http://unfccc.int/(accessed16.05.12)

U.N., 2012. Doha amendment to the kyoto protocol. Tech. rep., United Nations.
URL http://www.unfccc.int/(accessed13.6.2017)

WindEurope, 2017. Wind in power. 2016 European Statistics. Tech. rep., WindEurope.
URL https://windeurope.org/(accessed5.06.2017)

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European Council, 2016. International agreements on climate action. Tech. rep., European Union.
URL http://www.consilium.europa.eu/en/policies/climate-change/ (accessed9.06.2017)
European Parliament, 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. Tech. rep.
Eurostat, 2016. Harmonised Indices of Consumer Prices (HICP). Annual Data 2015.
URL http://appsso.eurostat.ec.europa.eu/(accessed16.07.05)

Eurostat, 2017a. Share of energy from renewable sources (last update: 14-03- 2017). Tech. rep., European Commission.
URL http://appsso.eurostat.ec.europa.eu/(accessed6.04.2017)

Eurostat, 2017b. Short Assessment of Renewable Energy Sources (SHARES). Tech. rep., European Commission.
URL http://ec.europa.eu/eurostat/web/energy/data/ shares(accessed10.04.2017)
Filgueira, A., Seijo, M. A., Muñoz, E., Castro-Santos, L., Piegiari, L., Munoz, E., Castro, L., Piegari, L., 2009. Technical and Economic Study of Two Re- powered Wind Farms in Bustelo and San Xoán , 24 . 7 MW and 15 . 84 MW respectively. 2009 International Conference on Clean Electrical Power, 545–549.
Himpler, S., Madlener, R., 2012. Repowering of Wind Turbines: Economics and Optimal Timing. Tech. Rep. 19.
IDAE, 2017. Wind Map of Spain. Tech. rep., Ministry of Energy, Tourism and the Digital Agenda.
URL http://atlaseolico.idae.es/(accesed7.04.2017)

IEC, 2005. IEC 61400-1. International Standard. Wind turbines - Part 1: Design requirements. Tech. rep., International Electrotechnical Commission.

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Laiola, E., Giungato, P., 2017. Wind characterization in Taranto city as a basis for innovative sustainable urban development. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2017.05.111.
Ministry of Energy, Tourism and the Digital Agenda, 2017. Royal Decree 359/2017. Tech. rep., Gobierno de España.
URL www.boe.es/(accessed19.06.17)

Ministry of Industry, Energy and Tourism, 2012. Royal Decree 1/2012. Tech. rep., Gobierno de España.
URL https://www.boe.es(accessed10.05.2017)

Ministry of Industry, Energy and Tourism, 2015. Planificación Energética. Plan de Desarrollo de la Red de Transporte de Energía Eléctrica 2015-2020. Tech. rep., Gobierno de España.
Ministry of Industry, Tourism and Commerce, 2010. Plan de Acción Nacional de Energías Renovables de España (PANER) 2011-2020. Tech. rep., Gobierno de España.
Ministry of Industry, Tourism and Commerce, 2011. Plan de Energías Renov- ables 2011-2020. Tech. rep., Gobierno de España.
Nivedh, B., Devi, R., Sreevalsan, E., 2013. Repowering of Wind Farms-a Case Study. Wind Engineering, 137–150.
Pishgar-Komleh, S., Keyhani, A., Sefeedpari, P., 2015. Wind speed and power density analysis based on weibull and rayleigh distributions (a case study: Firouzkooh county of iran). Renewable and Sustainable Energy Reviews 42, 313 – 322.
Prabu, T., Kottayil, S. K., 2015. Repowering a Windfarm — A Techno-Economic Approach. Wind Engineering 39 (4), 385–398.
Ramadan, H., 2017. Wind energy farm sizing and resource assessment for op- timal energy yield in Sinai Peninsula, Egypt. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2017.01.120.

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Ramírez, F. J., Honrubia-Escribano, A., Gómez-Lázaro, E., Pham, D. T., 2017. Combining feed-in tariffs and net-metering schemes to balance development in adoption of photovoltaic energy: Comparative economic assessment and policy implications for european countries. Energy Policy 102, 440 – 452.
REE, 2017. Red eléctrica española. Tech. rep.
URL http://www.ree.es/(accessed7.06.2017)

Rodriguez, R., Rodríguez-monroy, C., Coruña, U. D., Coruña, A., Calvo, F., 2013. Analysis of Renewable Energy Policies Related to Repowering the Wind Energy Sector : the Spanish Case, 1–8.
Santos-Alamillos, F., Thomaidis, N., Usaola-García, J., Ruiz-Arias, J., Pozo-Vázquez, D., 2017. Exploring the mean-variance portfolio optimization ap- proach for planning wind repowering actions in Spain. Renewable Energy 106, 335–342.
Seguro, J., Lambert, T., 2000. Modern estimation of the parameters of the weibull wind speed distribution for wind energy analysis. Journal of Wind Engineering and Industrial Aerodynamics 85 (1), 75 – 84.
Siemens Gamesa RE, 2017. G114-2.0 MW Greater energy produced from low and medium wind sites. Tech. rep.
URL http://www.gamesacorp.com/en/products-and-services/ wind-turbines/(accessed5.06.2017)
U.N., 1994. United Nations Framework Convention on Climate Change. Tech. rep., United Nations.
URL http://unfccc.int/(accessed14.6.2017)

U.N., 1998. Kyoto Protocol To the United Nations Framework. Tech. rep., United Nations.
URL http://unfccc.int/(accessed16.05.12)

U.N., 2012. Doha amendment to the kyoto protocol. Tech. rep., United Nations. URL http://www.unfccc.int/(accessed13.6.2017)

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~~WindEurope, 2017. Wind in power. 2016 European Statistics. Tech. rep., WindEurope.~~
~~URL https://windeurope.org/(accessed5.06.2017)~~

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