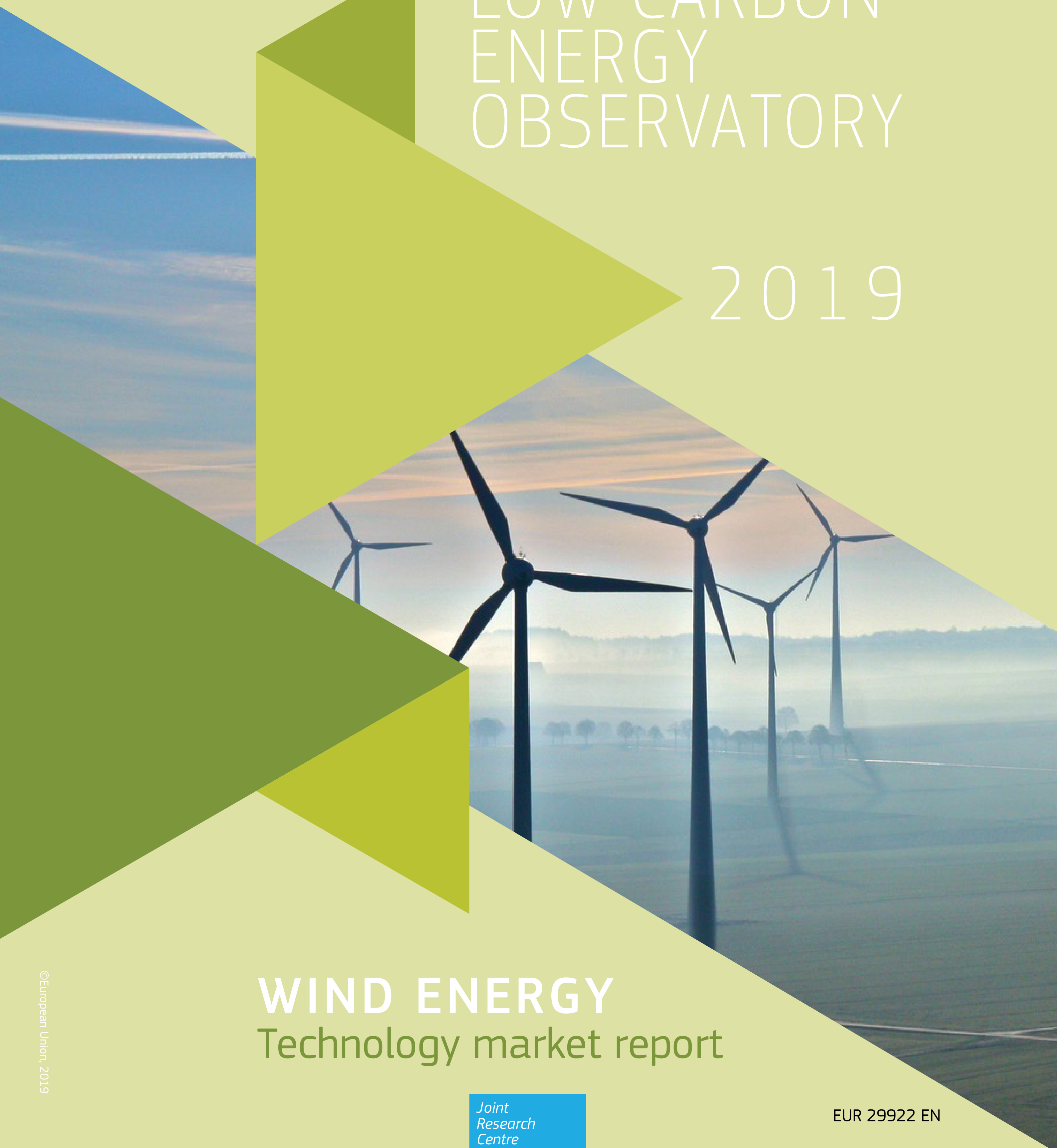
European Commission

LOW CARBON ENERGY OBSERVATORY

2019



WIND ENERGY
Technology market report

Joint Research Centre

EUR 29922 EN

Contact information
Name: Thomas TELSNIG
Address: Joint Research Centre, P.O. Box 2, 1755 ZG Petten, The Netherlands
Email: Thomas.TELSNIG@ec.europa.eu

Name: Matthijs SOEDE
Address: European Commission DG Research and Innovation, Brussels, Belgium
Email: Matthijs.SOEDE@ec.europa.eu

EU Science Hub
https://ec.europa.eu/jrc

JRC118314
EUR 29922 EN

PDF	ISBN 978-92-76-12569-3	ISSN 2600-0466 ISSN 1831-9424 (online collection)	doi:10.2760/223306
Print	ISBN 978-92-76-12570-9	ISSN 2600-0458 ISSN 1018-5593 (print collection)	doi:10.2760/260914

Luxembourg: Publications Office of the European Union, 2019

How to cite: TELSNIG T, VAZQUEZ HERNANDEZ C, Wind Energy Technology Market Report, EUR 29922 EN, European Commission, Luxemburg, 2019, ISBN 978-92-76-12569-3, doi:10.2760/223306, JRC118314.

TABLE OF CONTENTS

FOREWORD ON THE LOW CARBON ENERGY OBSERVATORY

The LCEO is an internal European Commission Administrative Arrangement being executed by the Joint Research Centre for Directorate General Research and Innovation. It aims to provide top-class data, analysis and intelligence on developments in low carbon energy supply technologies. Its reports give a neutral assessment on the state of the art, identification of development trends and market barriers, as well as best practices regarding use private and public funds and policy measures. The LCEO started in April 2015 and runs to 2020.

Which technologies are covered?

- Wind energy
- Photovoltaics
- Solar thermal electricity
- Solar thermal heating and cooling
- Ocean energy
- Geothermal energy
- Hydropower
- Heat and power from biomass
- Carbon capture, utilisation and storage
- Sustainable advanced biofuels
- Battery storage
- Advanced alternative fuels

How is the analysis done?

JRC experts use a broad range of sources to ensure a robust analysis. This includes data and results from EU-funded projects, from selected international, national and regional projects and from patents filings. External experts may also be contacted on specific topics. The project also uses the JRC-EU-TIMES energy system model to explore the impact of technology and market developments on future scenarios up to 2050.

What are the main outputs?

The project produces the following report series:

- Technology Development Reports for each technology sector
- Technology Market Reports for each technology sector
- Future and Emerging Technology Reports (as well as the FET Database).

How to access the reports

Commission staff can access all the internal LCEO reports on the Connected LCEO page. Public reports are available from the Publications Office, the EU Science Hub and the SETIS website.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the following JRC colleagues for providing data, reviewing inputs and results of this work:

Aliki Georgakaki, Johan Carlsson, Nigel Taylor, Wouter Nijs, Francesco Pasimeni, Pablo Ruiz Castello, Dalius Tarvydas, Ioannis Tsiropoulos, Roberto Lacal Arántegui, Sara André (design of front cover).

The authors also appreciate the useful feedback gained through exchanges and discussions with the following colleagues:

Nuno Quental (DG RTD), Matthijs Soede (DG RTD), Eric Lantz (NREL), Philipp Beiter (NREL), Alexander Vandenberghe (WindEurope).

1 INTRODUCTION

This report analyses the wind energy market with a special emphasis on technologies, the industry in Europe and its performance relative to the biggest competitors worldwide. Wherever possible, data coverage at least to the end of 2018.

Chapter 2 focuses on technology trends and prospects, elaborating in detail worldwide deployment trends for onshore and offshore wind, progress of MSs based on their commitment expressed in the national renewable energy action plans (NREAPs), efforts towards competitive support schemes as well as trends in R&D investment and patenting activity.

Chapter 3 gives a market overview of the main Original Equipment Manufacturers (OEMs) active in the wind energy sector, and analyses the reasons behind their latest financial performance and M&A activity. Moreover, this chapter aims to give an insight into the market of the most important wind energy components, and the presence of European component manufacturers in home and foreign markets. In order to provide an outlook on future developments this chapter also identifies emerging markets, players and trends.

Chapter 4 provides an overview on the mid- and long-term deployment of wind energy based on major energy system studies (IEA, Greenpeace, BNEF and the EC 2050 Long-term Strategy). Moreover, a detailed analysis on deployment, investment, and technical potential under different scenarios from the JRC-EU-TIMES model is presented. By performing a sensitivity analysis, results from JRC-EU-TIMES are used to estimate to which extent wind deployment and the associated market size change by 2050, depending on varying costs, fossil fuel prices, or energy policies. JRC-EU-TIMES scenarios are also used to identify the EU Member states with a high level of investment in wind and unused technical potential by 2050.

Finally selected conclusions are presented chapter 5.

2 TECHNOLOGY TRENDS AND PROSPECTS

2.1 Technology deployment and market trends

2.1.1 Deployment status

Within this decade, global wind energy deployment has continuously grown from 198 GW to about 591 GW in cumulative installed capacity [GWEC 2019a]. Since 2015, the majority of the global capacity installed is located in China (36 % in 2018) followed by the EU28 (30 %) and the US (16 %) (see Figure 1).

In 2018, annual capacity additions (51 GW) slightly fell as compared to the last three years, mainly because of the deployment rate in China, which seems to return to levels before experiencing the outlier year of 2015. Annual additions in the EU28 declined to about 10.1 GW (about 87 % of the European capacity additions) after the record year 2017 (15.9 GW; 93% of European countries) (see Figure **2**). Moreover, there was a strong performance in selected RoW markets (India: 2.2 GW; Brazil: 2.0 GW; Mexico: 0.9 GW).

The development in Europe is mainly associated with three markets (Germany, the United Kingdom and France), indicating an increasing market concentration until 2017 (see Figure **3**). Apart from the more established markets, new national records were established in Ireland and Croatia in 2017 as well as in Belgium in 2018.

The cumulated capacity growth rate in the EU28 dropped to about 6 % in 2018 after a period of stable growth at around 10 % since 2011. China seems to stabilize at about 12% in 2018, dropping from values ranging between 21 % and 39 % in the first half of the decade. The US market also shows stable cumulated growth rates between 8 % and 13 %, mainly driven by more certain regulatory incentives for wind energy.

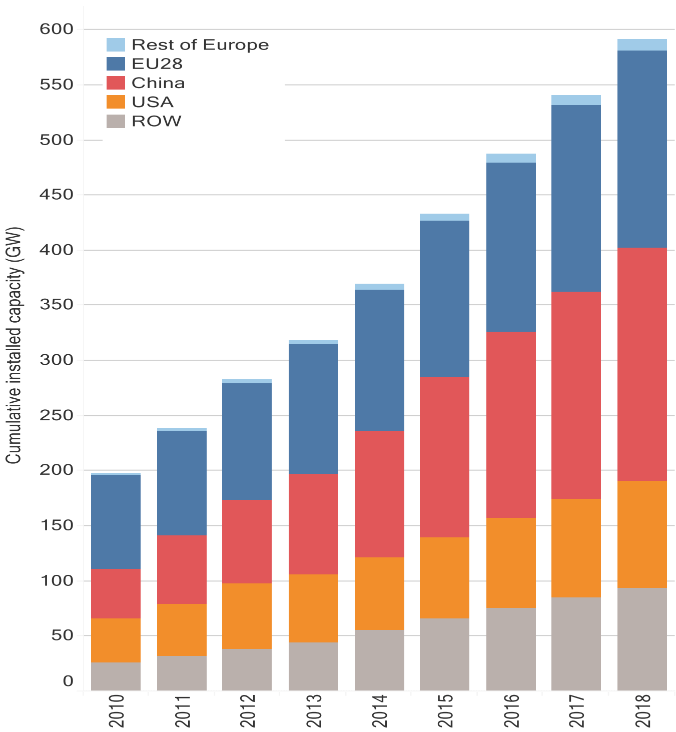


Figure 1 Cumulative installed capacity of wind energy worldwide

Source: JRC based on GWEC [GWEC 2019a]

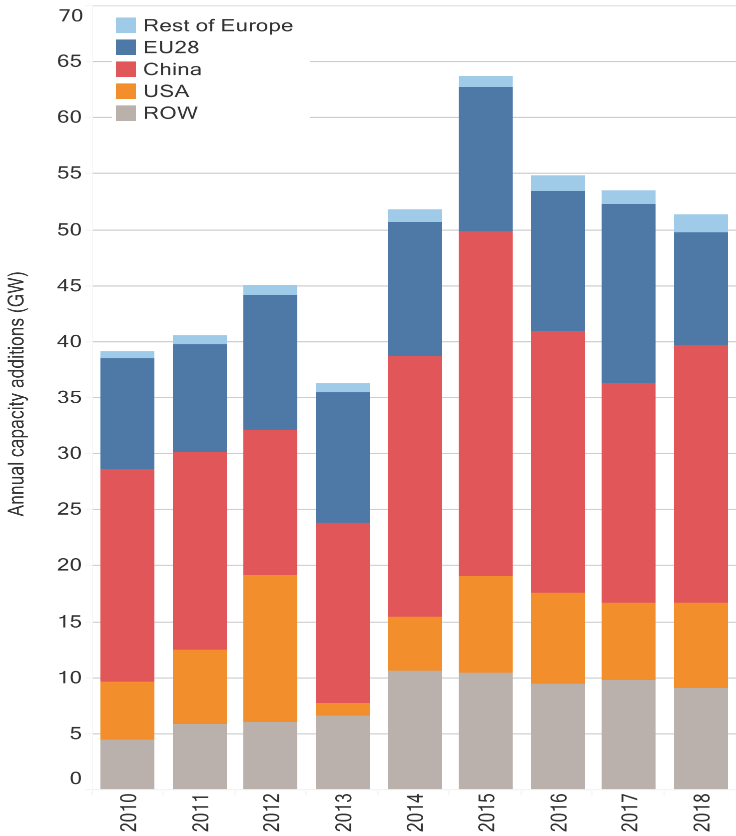


Figure 2 Annual capacity additions of wind energy worldwide
Source: JRC based on GWEC [GWEC 2019a]

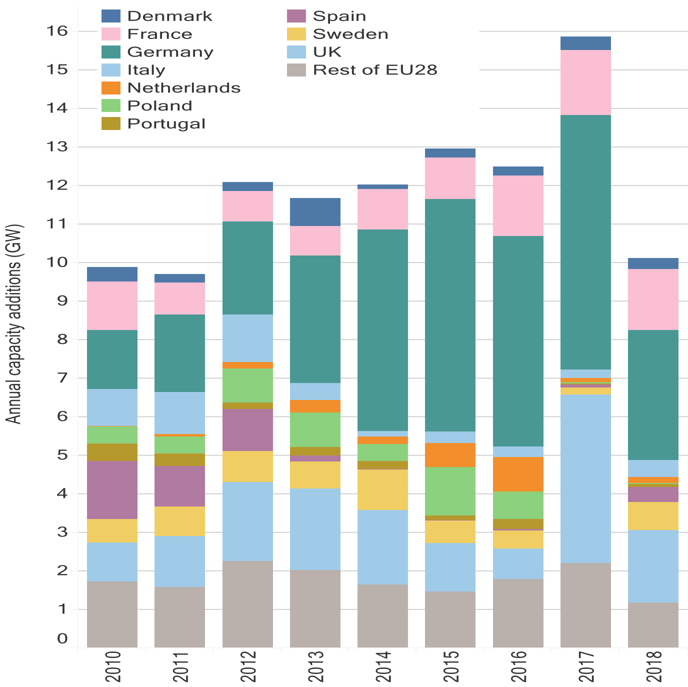


Figure 3 Annual capacity additions of wind energy for leading EU28 countries and the RoEU28
Source: JRC based on GWEC [GWEC 2019a])

2.1.2 Offshore wind deployment

The global offshore wind market grew further to a cumulated installed capacity of about 23.1 GW, of which 79 % are located in the EU28. In 2018, the United Kingdom and Germany were clearly leading cumulated offshore wind capacity with 8.0 GW (34 %) and 6.4 GW (28 %), respectively. Moreover, in recent years, significant capacity has been deployed in Belgium (1.2 GW), Denmark (1.3 GW) and the Netherlands (1.1 GW). With about 4.6 GW, China ranks third in total capacity installed (see Figure **4**). Today, 17 countries are hosting offshore wind projects, with an increasing number of new entrants stemming from non-European countries (Japan, South Korea, Taiwan, the United States, and Vietnam).

2018 was a record year in annual capacity additions. In total, 4.5 GW were added across all markets. The two leading countries, Germany and the United Kingdom accounted for about 51 % of the new capacity installed, with the latter having another strong year in capacity additions (1.3 GW). With a record year in capacity additions (1.8 GW), China experienced its fifth consecutive year in which its annual capacity additions increased substantially, resulting in cumulated capacity growth rates between 54 % and 71 % during 2014-2018. The remaining offshore capacity added in 2018 was installed in Belgium, Denmark, France, South Korea, Spain and Sweden. After two record years, offshore wind deployment in the Netherlands stagnated in the last two years, as planned competitive tenders are foreseen to be commissioned from 2019 onwards (see Figure **5**).

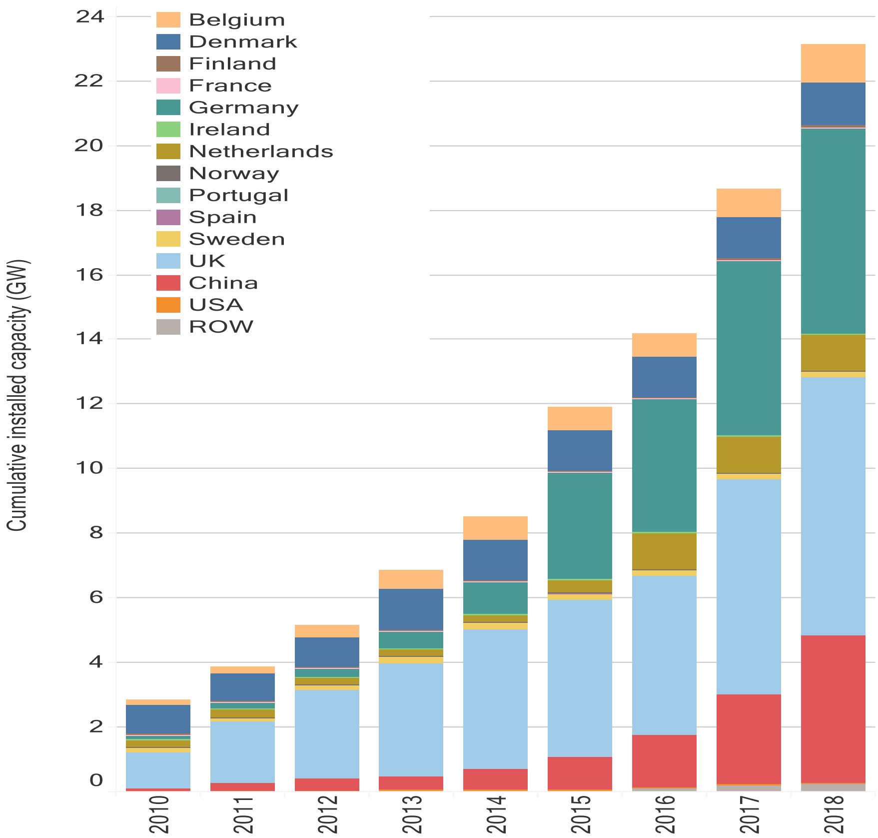


Figure 4 Cumulative installed capacity of offshore wind energy worldwide.
Source: JRC based on GWEC [GWEC 2019a])

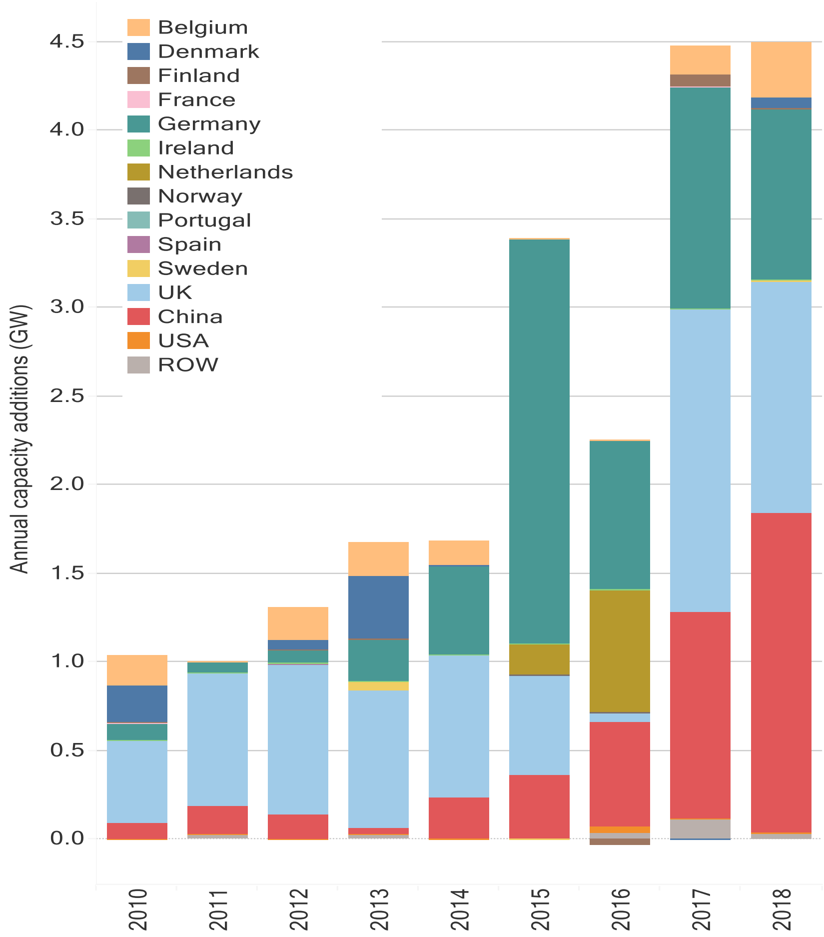


Figure 5 Annual capacity additions of offshore wind energy worldwide.
Source: JRC based on GWEC [GWEC 2019a])

In 2017, European waters saw the first multi-turbine floating offshore wind project (Hywind Scotland) with a capacity of 30 MW. This was followed by the Floatgen project, the first floating offshore wind farm in France, which aims to demonstrate the technology's capabilities under Atlantic deep water conditions. Until the mid-2020s future demonstration and pre-commercial projects are expected in France, the United Kingdom, Spain and Norway with a cumulated capacity of about 330 MW (see Table 1). Notably with WindFloat Atlantic, BALEA, VERTIMED and FLOCAN5 four upcoming multi-turbine floating offshore wind projects are funded by the EC's NER300 programme [EC 2019].

Outside Europe, Japan installed since 2013 three floating offshore wind demonstration projects with a cumulated capacity of 19 MW. Apart from Japan, the most promising future markets for floating offshore wind at commercial scale are expected in South Korea, Taiwan and the United States [GWEC 2018, OW 2019a].

Table 1 European floating offshore wind farms (announced and operational)

Project	Country	First Power	Capacity [MW]
Hywind Scotland	UK	2017 (operational)	30
Floatgen Project [1]	FR	2018 (operational)	2
WindFloat Atlantic (WFA)[2]	PT	2019	25
Kincardine Offshore Windfarm Project	UK	2020	50
BALEA[2]	ES	2020	26
DemoSATH - BIMEP	ES	2020	2
SeaTwirl S2 [3]	NO	2020	1
EolMed [4]	FR	2021	24.6
FWT Groix & Belle-Île	FR	2021	24
FWT Provence Grand Large/VERTIMED[2]	FR	2021	25.2
FWT Golfe du Lion	FR	2021	24
Nautilus Demonstration	ES	2021	5
Katanes Floating Energy Park - Pilot[5]	UK	2022	8
Hywind Tampen	NO	2022	88
FLOCAN 5[2]	ES	2024	25

[1] Funded by the EC's FP7 programme
[2] Funded by the EC's NER300 programme
[3] Received a €2.48 million grant from the European Innovation Council's SME instrument
[4] Co-financed by the European Investment Bank
[5] Combined wind-wave generator. Project will be further developed to 47MW

2.2 Targets

This section provides information on the EU targets on future wind energy deployment. Targets on EU Member States (MSs) level, stemming from the national renewable energy action plans (NREAPs), are compared with the wind energy generation as outlined in the MSs progress reports. This is complemented with the latest targets formulated by the EU wind industry and countries outside Europe.

2.2.1 Targets based on NREAPs

Wind energy is included in the NREAPs of all MSs. These plans include the foreseen trajectories on the installed capacities and electricity generation towards the binding 2020 targets to meet the countries' obligations under the Renewable Energy Directive [EP 2009]. The MSs report their progress towards the EU's 2020 renewable energy goals in biannual progress reports.

Figure 6 shows the progress of the MSs in electricity generation from wind energy in 2014 and 2016 based on the latest progress reports published in 2015 and 2017, respectively. As shown, MSs have increased their efforts towards reaching the EU NREAP target of 495 TWh/a in 2020. In 2016 the EU28 generated about 311 TWh of wind energy representing 62.7% of the overall EU wide 2020 NREAP target. This means an increase of 23 % over 2014.

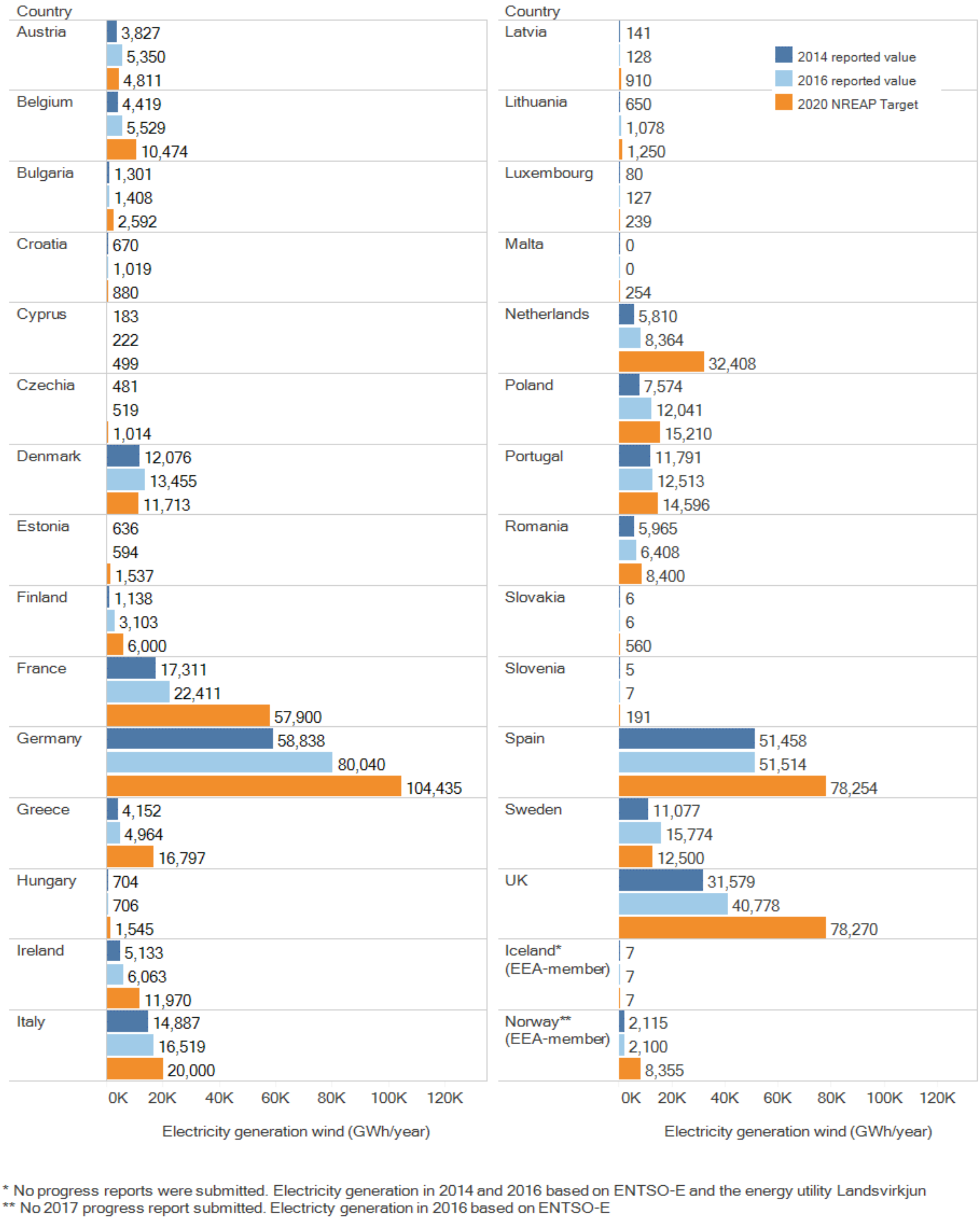


Figure 6 NREAP 2020 wind energy targets and MS progress in wind electricity generation
Source: JRC based on [EC 2018f, EC 2018e]

Compared to the initial NREAPs, four countries have already reached their 2020 targets on wind: Austria, Croatia, Denmark and Sweden. Germany, Italy, Lithuania, Poland, Portugal and Romania are very close to meeting their NREAP targets. Estonia, France, Greece, Latvia, Malta, the Netherlands, Slovakia and Slovenia are among the MSs trailing behind (less than 40 % of their NREAP targets). Apart from the EU28, EEA-members Iceland and Norway have also provided national action plans to the EC. Whereas Iceland plans to generate a relatively small amount of wind energy by 2020 (7 GWh from 2 MW wind capacity), a substantial generation target of 8.4 TWh was outlined by Norway. Based on data reported by ENTSO-E, and the energy utility Landsvirkjun, Island reached its target in 2013. Progress in Norway seems to have stagnated at about 25 % of the envisioned target [EC 2016, ENTSO-E 2017, ENTSO-E 2018, Landsvirkjun 2018].

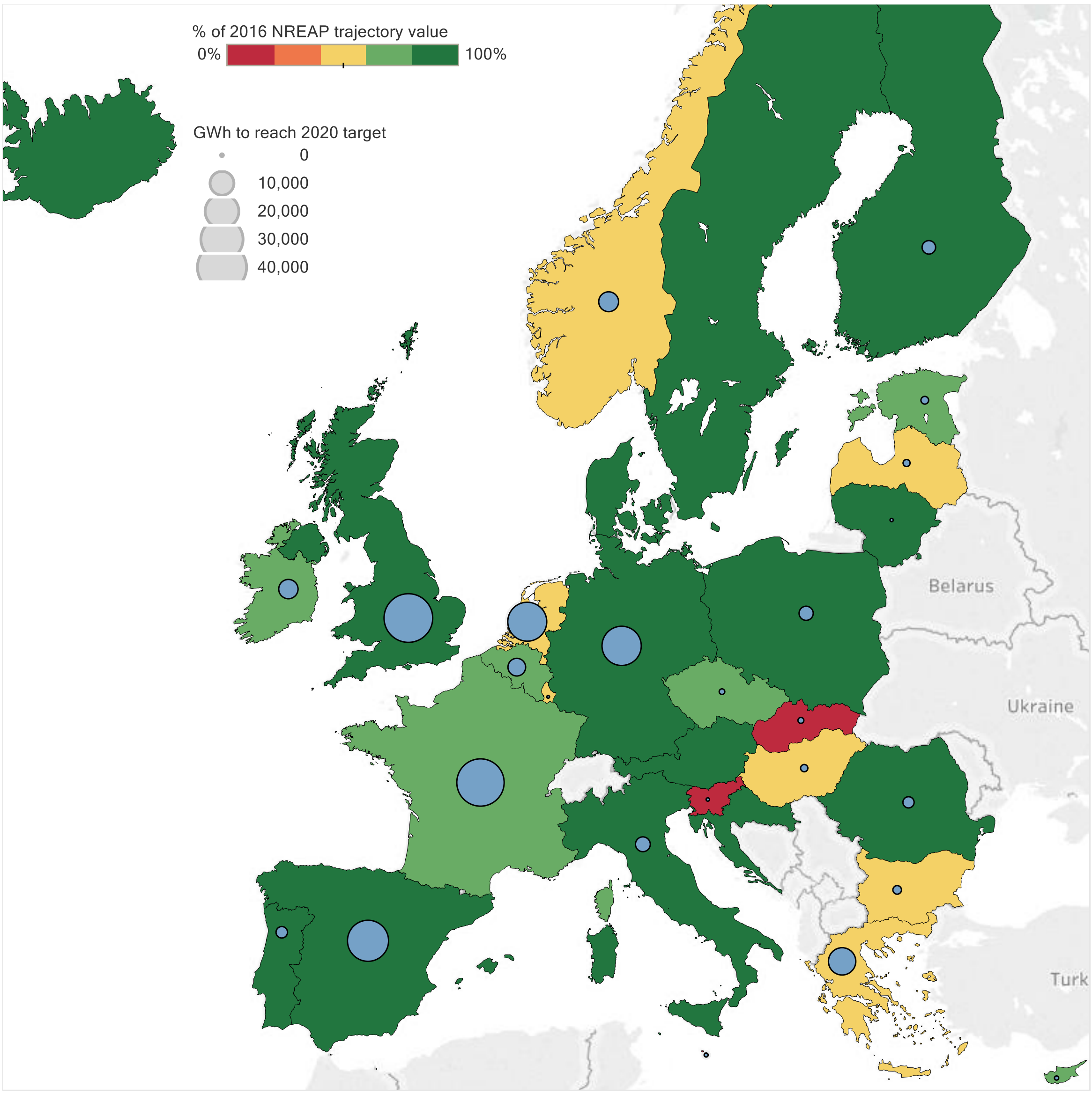
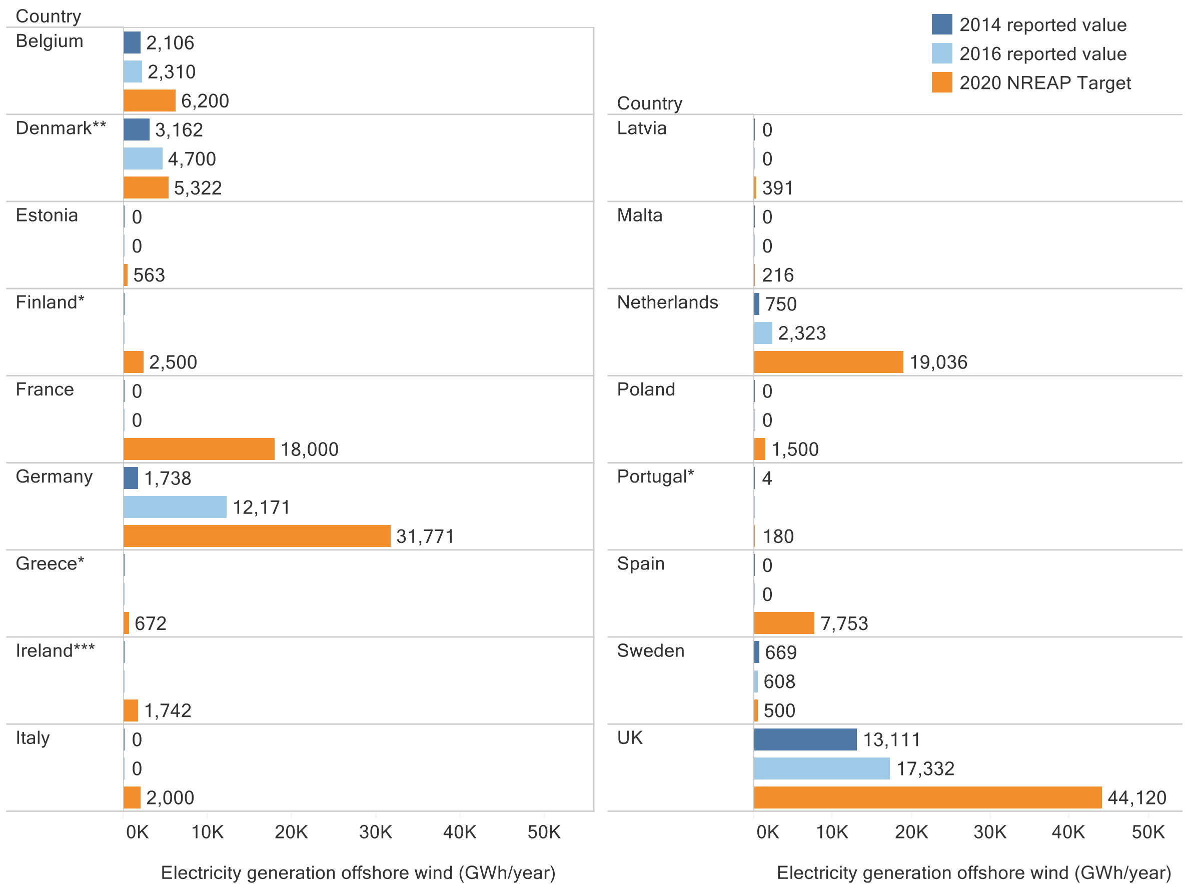


Figure 7 MS total wind electricity generation in 2016 against 2016 values of the NREAP trajectories (country colour) and remaining generation needed to reach the 2020 NREAP target (bubbles)
Source: JRC based on [EC 2018f, EC 2018e]



* No generation reported in 2014 and/or 2016
** 2016 data based on ENTSO-E
*** Wind generated electricity output not reported due to commercial sensitivity reasons, derived capacity for offshore wind (25MW) is equal to Arklow Bank Phase 1

Figure 8 NREAP 2020 offshore wind targets and MS progress in offshore wind electricity generation
Source: JRC based on [EC 2018f, EC 2018e]

Contrasting the situation in 2016 with the 2016-values of the NREAP trajectories, reveals the relative performance of each MS. Figure **7** shows that 13 MSs are on track based on their initial targets (meeting over 80 % of their target).

In absolute terms significant deployment has to take place in Germany, France, Spain, the Netherlands and the UK, to fulfil the NREAP 2020 targets.

For offshore wind, most MSs will miss the initial NREAP 2020 target. Only Germany, Denmark and Sweden are on track in 2016, as compared to the 2016-values of the NREAP trajectories (see also Appendix A). Figure 8 shows the initial NREAP targets formulated and the wind generation for offshore wind, based on the last two progress reports[1]. Moreover, nine countries that formulated concrete offshore wind targets have no offshore wind capacity deployed so far.

2.2.2 Changes in MS targets

Since the initial submission of the NREAPs, several member states have modified their targets on national level (see Table 2). For some countries these changes arise from a very positive wind

[1] Not all progress reports submitted to the EC differentiate between onshore and offshore electricity generation (e.g. DK in its 2017 progress report). In these cases, ENTSO-E data is used. In 2016 the EU28 generated about 39.5 TWh of offshore wind energy or 28% of the overall EU-wide 2020 NREAP target. However, apart from Sweden and Denmark, all countries will miss their NREAP targets in 2020 as a consequence of the low deployment rate in the period 2017-2020, and changes in regulatory schemes in the leading offshore wind countries like Germany (see chapter 2.3).

energy development in the last years, while others modified their policies as the initial targets set were too optimistic or there was a change in the direction of national energy policies.

We identified four countries that increased their targets when compared to NREAP 2020: Austria, Belgium, Denmark and Lithuania. In Austria, the 2012 Green Electricity Act (GEA) formulated a long-term target of 3 GW of wind power capacity by 2020 (+422 MW as compared to its NREAP 2020 target). Although Austria is experiencing a downward trend in new installations since 2014, this target was already reached in 2018 [ÖSG 2012, IEA 2016a, IG Windkraft 2018, GWEC 2019a]. In Belgium, the region of Flanders increased its target for wind energy from 2.09 TWh to 3.03 TWh in 2020. This would translate to an additional 680 MW to 700 MW onshore capacity. By 2020, the total land-based installed capacity in Belgium should reach 3 GW, and an additional 2 292 MW is planned offshore (+292 MW as compared to NREAP target) [WPM 2017a]. In Denmark, a substantial expansion until 2020 of both onshore and offshore wind has been formulated through the Danish Energy Agreement for 2012-2020. It envisages new planning tools, encouraging the development of an additional 1.8 GW in onshore wind, and the construction of the offshore wind projects Kriegers Flak (600 MW), Horns Rev (400 MW), and an additional 500 MW of near the coast offshore wind [DM 2012, IEA/IRENA 2017a]. For Lithuania, a slight increase of 0.07 TWh, as compared to their initial NREAP target, is included in the country's 2018 National Energy Independence Strategy. Offshore wind in Lithuania is expected to take off after 2020 in the Baltic Sea, with the first auction for 250 MW wind capacity in 2019 (see Figure 12) [WindEurope 2018a] [MoELT 2018].

France is found among the countries that adopted new national wind targets that resulted in a decrease as compared to the NREAP 2020 target. The 2016-policy on Renewable Energy Developments Objectives foresees that France will only reache its NREAP target by 2023 [IEA/IRENA 2017b] [Legifrance 2016]. Similarly, the offshore wind target formulated in the German Renewable Energy Act (EEG 2014) foresees 3500 MW less than the 2020 NREAP target [BM 2014].

Table 2 Changes in national wind targets as compared to NREAP 2020
JRC based on [IDAE 2011, DM 2012, ÖSG 2012, EC 2013, SER 2013, BM 2014, IEA 2016a, Legifrance 2016, IEA/IRENA 2017b, IEA/IRENA 2017a, SEN 2017, WPM 2017a, IG Windkraft 2018, MoELT 2018, WindEurope 2018a]

Country	New national target	Change compared to NREAP 2020			Year	Policy/Source
		Total Wind	Onshore	Offshore		
AT	3000 MW by 2020		+422MW		2012	[ÖSG 2012]
BE	Onshore: 3000 MW by 2020 Offshore: 2,292 MW by 2020		+680MW	+292MW	2017	[IEA 2016a] [WPM 2017a]
DK	Onshore: additional 1800MW Offshore: additional 1500MW		+1800MW	+1500MW	2012	[DM 2012]
FR	Onshore: 15 GW by 2018, 21.8–26.0 GW by 2023 Offshore: 0.8GW in 2018 and 3–6GW in 2023		Decrease: new high target equals NREAP but only in 2023		2016	[Legifrance 2016]
DE	Offshore: 6500MW in 2020 and 15000MW in 2030			-3500MW	2014	[BM 2014]
IT	Total Wind: Base Scenario - 17TWh in 2020, 25TWh in 2030 SEN Scenario - 18TWh in 2020, 40TWh in 2030	-2 TWh (BS) -1 TWh (SENS)			2017	[SEN 2017]
LT	2020: the share of wind energy reach up to 44% (1.32TWh)	+0.07 TWh			2018	[MoELT 2018]
NL	Offshore: 4,450 MW of offshore wind by 2023			-728MW in 2023	2013	[SER 2013]
PT	Total wind: 5300 MW by 2020 Offshore wind: 27 MW by 2020		-1527MW	-48MW	2013	[EC 2013]
ES	Offshore Wind: 750MW/1845 GWh by 2020			-2250MW	2011	[IDAE 2011]

In Italy, the Strategia Energetica Nazionale 2017 (SEN) called for wind generation to rise to 40 TWh until 2030. Nevertheless, both scenarios presented in this strategy miss the binding 2020 target by 1 to 2 TWh [SEN 2017].

In its 2013 Agreement on Energy for Sustainable Growth, the Netherlands established a target of 4,450 MW of offshore wind by 2023 (-728 MW in 2023 as compared to the 2020 NREAP target) [SER 2013].

In the same year, the Portuguese Government established the national targets for renewable energy through the National Energy Efficiency Action Plan 2013–2020. The targets constitute a decrease in on- and offshore wind targets of 1527 MW and 48 MW, respectively [EC 2013].

In Spain, the electricity sector reform in 2012 led to a dramatic reduction in new wind projects, however no concrete change in onshore wind policies compared to the initial NREAP 2020 target could be witnessed in its Plan de Energías Renovables 2011-2020. On the contrary, this policy sets the national offshore wind target significantly lower (-2250 MW) than in the binding 2020 targets [IDAE 2011].

2.2.3 New trends in meeting MS targets

MSs can make use of so-called cooperation mechanisms under the Renewable Energy Directive (2009/28/EC)[2] in order to fulfil their mandatory national targets for the share of renewable energy. 2017 saw two cooperation agreements in the form of statistical transfers of renewable energy amounts: between Lithuania and Luxembourg, and between Estonia and Luxembourg [EC 2017a] [EC 2017b]. In both cases an amount of wind energy is deducted from one country's progress towards its target (Lithuania/Estonia) and added to another one (Luxembourg). As such, on the one hand it provides an incentive to countries to exceed their targets, and obtain a payment for energy transferred to others. On the other hand, it allows countries with less cost-effective renewable energy sources, or limited wind potential (e.g. offshore wind for landlocked countries), to achieve their targets at a lower cost [EC 2018a].

Through the cooperation mechanism 'joint projects' MSs can co-fund a renewable energy project and allocate their respective share towards their targets. In 2017, the company NERO Renewables announced its plans to develop 1 GW of wind energy in Romania by the end of 2020. NERO Renewables offered the Dutch Government the option to co-fund its project under the 'joint project' mechanism, which would reduce the countries' gap to meet its national renewable energy target by 30 % [WPM 2017b].

2.2.4 Comparison with international policy targets

Outside Europe several countries implemented policies and measures quantifying to which extent wind energy should help to meet their climate targets. As outlined in the NREAPs targets, the EU28 together with the reporting EEA member countries Norway and Iceland envisage installing 217 GW of wind capacity until 2020. At a comparable scale China's 13th Five-Year Energy Plan aims for 210 GW of wind capacity by 2020 [NRDC 2016]. With 60 GW a substantial contribution is planned to come from wind energy in India's 175 GW Renewable Energy Target for 2022 [MNRE 2015]. In the United States, the third biggest market worldwide, no comparable national capacity target is in place as targets are introduced at federal or local level [IEA/IRENA 2019]. Yet based on the current capacity installed and the projections of the next years, a total wind capacity of about 118 GW can be expected by 2020 [Wiser & Bolinger 2018, GWEC 2019a]. Most policies in other markets imple-

---

[2] Article 6-11 of the Renewable Energy Directive (2009/28/EC) specifies three cooperation mechanisms: Statistical transfers, joint projects and joint support schemes [EP 2009]

ment wind targets that foresee an uptake in wind deployment in the period 2020 – 2030 (see Table 3 and chapter 3.3.3 on emerging markets

Table 3 Selected international wind energy deployment targets
JRC based on [MNRE 2015, NRDC 2016, MoE 2017, EC 2018e, GWEC 2018, GWEC 2019a, IEA/IRENA 2019]

Country	Policy/Measure	Total Wind Capacity Target (GW)	Offshore Wind Capacity Target (GW)	Target year
EU28 + Norway + Iceland	NREAP 2020	217	44	2020
China	13th Five-Year Energy Plan	210	5	2020
India	India 175 GW Renewable Energy Target for 2022	60		2022
United States		No national wind energy target		
Brazil	2010-2019 Decennial Plan for Energy Expansion	6.0		2019
		28.5		2026
Japan	Long-term Energy Supply and Demand Outlook (Energy Mix Plan) 2015	10.0		2030
Taiwan	Four-Year Plan of Promotion for Wind Power		0.5	2020
			5.5	2025
			10 to 17	2030
Russia	Regulatory framework for RES support (2017 Governmental Decree No. 610)	3.3		2024
Saudi Arabia	National Renewable Energy program	10.0		2025
Vietnam	National Power Development Plan VII (PDP7, released in 2011 and revised in 2016)	0.8		2020
		2.0		2025
		6.0		2030
Thailand	Alternative Energy Development Plan (AEDP)	3.0		2036
Philippines	Renewable Energy Act in 2008	2.3		2030
Indonesia	Electricity Plan (Ministry of Energy and Mineral Resources (MEMR))	1.8		2025

2.2.5 Industry targets

Representing the European wind energy industry, the association WindEurope regularly formulates scenarios for future wind energy deployment, based on market intelligence from their members. In 2017, WindEurope published its outlook towards 2020 and defined three scenarios (low, central, high) (see Table **4**).

More recently, WindEurope's market outlook towards 2022 describes the same three scenarios, having revised all three scenario trajectories upwards compared to WindEurope's outlook in 2017. It foresees that the NREAP target is met by all scenarios in 2020, and estimates the total wind capacity installed by 2022 ranging from 248 GW (low scenario) to 264 GW (high scenario). In its central scenario, WindEurope expects a total installed wind capacity of 258 GW, with annual deployment rates of 15 GW to 20 GW between 2018 and 2022. The European market shows a stronger diversification, with increasing capacity additions in Southern Europe, France, the Nordic countries and non-EU countries. Germany is expected to remain the largest onshore market. With an average 3.3 GW/year, offshore wind will represent about 19 % of the total market in the period until 2022. The UK, Germany, the Netherlands, France, Belgium and Denmark will lead this development. In the mid-term, WindEurope identifies permitting issues (e.g. German citizen projects without permits; longer permitting times in France or Sweden) as one of the major obstacles [WindEurope 2018b]. Similarly, GWEC sees Europe on track regarding its 2020 targets; they expect a total of 254 GW of wind energy installed by the end of 2022 [GWEC 2018].

In order to assess the impacts of European policies until 2050, WindEurope commissioned DNV GL to perform an energy system study. Two scenarios have been modelled ('Accelerated Electrification' and 'Paris-compatible') aiming for either a prompt implementation of current policies or, more ambitiously, ensuring global temperature rises below 2 degrees to meet the Paris agreement. In order to fulfil these boundary conditions, both scenarios foresee significant electrification rates of the main energy sectors (51% to 62%) and builds on significant deployment of wind energy totalling to between 649 GW and 842 GW until 2050 (Table **5**) [WindEurope 2018c].

Table 4 WindEurope wind energy outlook towards 2020, 2022 and NREAP 2020 target.
Source: [WindEurope 2017][WindEurope 2018b]

Scenario	Total wind capacity 2020	Total wind capacity 2022	Unit
LOW	195	248	GW
CENTRAL	204	258	GW
HIGH	217	264	GW
NREAP-2020 target	217		GW

Table 5 WindEurope long-term scenarios towards 2050
Source: [WindEurope 2018c]

Scenario	Total wind capacity 2030	Total wind capacity 2050	Unit
Accelerated Electrification	325	649	GW
Paris-compatible	343	842	GW

Following the first pre-commercial projects floating offshore wind seems to become a viable option for countries lacking shallower offshore wind sites. As such WindEurope (2018d) estimates about 4 GW of floating offshore wind installed by 2030 in Europe given cost reduction is addressed at national and European level.

Equinor, the international energy company behind the Hywind Scotland project, assumes a floating offshore capacity of 12 GW in 2030 on a global level, of which about 6 GW can be expected in European waters [Equinor 2019]. Given further cost reduction and upscaling of project size are achieved; main European markets are seen in Norway, France, the United Kingdom, and Spain. On a lower level, capacity deployment might happen in Portugal, Greece and Ireland. Outside Europe the most promising markets until 2030 can be expected in the United States (California, Maine and Hawaii) and in Asia (South Korea, Japan, China and Taiwan).

2.3 Policy support

This section presents an overview of the policy support for onshore and offshore wind energy projects in the EU28. An overview of the support schemes in place[3], the results of the competitive tender processes held in the recent years, and the upcoming tenders is presented.

2.3.1 Support schemes

The State Aid Guidelines for Environmental protection and Energy (EEAG) 2014-2020 (applicable from 1 July 2014), have promoted a gradual move towards market-based support schemes for renewable energy technologies in the EU Member States (MSs) [European Commission 2014]. These guidelines have required RES support schemes to be adapted, in order to reach greater cost effectiveness and minimise distortions of competition in the Single Market. Thus, some MSs have had to reform their support schemes replacing feed-in tariffs (FITs) by market-based support schemes from January 2016, and setting up competitive bidding processes to determine the level of support to all new installations from January 2017.

As illustrated in Figure 9, as result of these regulatory changes the current support schemes for new wind projects at utility-scale in the EU28 are the following:

- For onshore wind energy, 14 MSs have a competitive tendering scheme in place. In particular: a tender-based feed-in premium (FIP) is the most common support scheme, in place in ten MSs (Germany, Denmark, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, and the Netherlands); followed by a contract for difference (CfD)[4] implemented in two MSs (Poland and the United Kingdom); a capacity payment[5] in Spain; and a tender-based FIT in Lithuania. Estonia and Slovenia) still have a FIP not allocated through a competitive tendering procedure in force, and five MSs (Austria, Bulgaria, Cyprus, Luxembourg, and Slovakia) grant FITs which are not affected by market signals, since they are administratively determined. Three MSs (Belgium, Romania, and Sweden) have tradable green certificates (TGC) in force.
- For offshore wind energy, twelve MSs have implemented support schemes. Like in onshore wind, tender-based FIP is the most common support scheme for new projects. Ten out of twelve MSs (Denmark, Finland France, Germany, Greece, Ireland, Italy, the Netherlands, Poland and the United Kingdom) have a competitive bidding scheme in force. Belgium and Sweden grant TGC. Unlike onshore wind, no EU MS grants any FIT or FIP determined administratively.

[3] The section presents the support schemes for onshore and offshore wind in force as of July 2019.

[4] Some publications consider CfD as a kind of sliding FIP. Eligible generators receive a "strike price", previously defined-by auction, and are required to participate in the wholesale market. If the market price is lower than the "strike price", the difference is covered by a CfD counterparty. On the contrary, if the market price rises above the strike price, the generators are required to pay back the difference between the guaranteed price and the wholesale price to the CfD counterparty.

[5] The capacity payment or "investment incentive" is a particularity of the design of the Spanish auctions, since wind energy does not receive any "operation incentive" under the "specific retributive regime" defined in Spain. Wind energy projects receive the market price, plus a remuneration for the initial investment based on the "reasonable profitability" that a "reference standard facility" would obtain, i.e. the remuneration is calculated based on what profitability a well-managed facility would obtain, considering theoretical incomes and construction and operating costs. Thus, bidders offer a discount on the standard value of the initial investment of the reference standard facility (Royal Decree 413/2014).

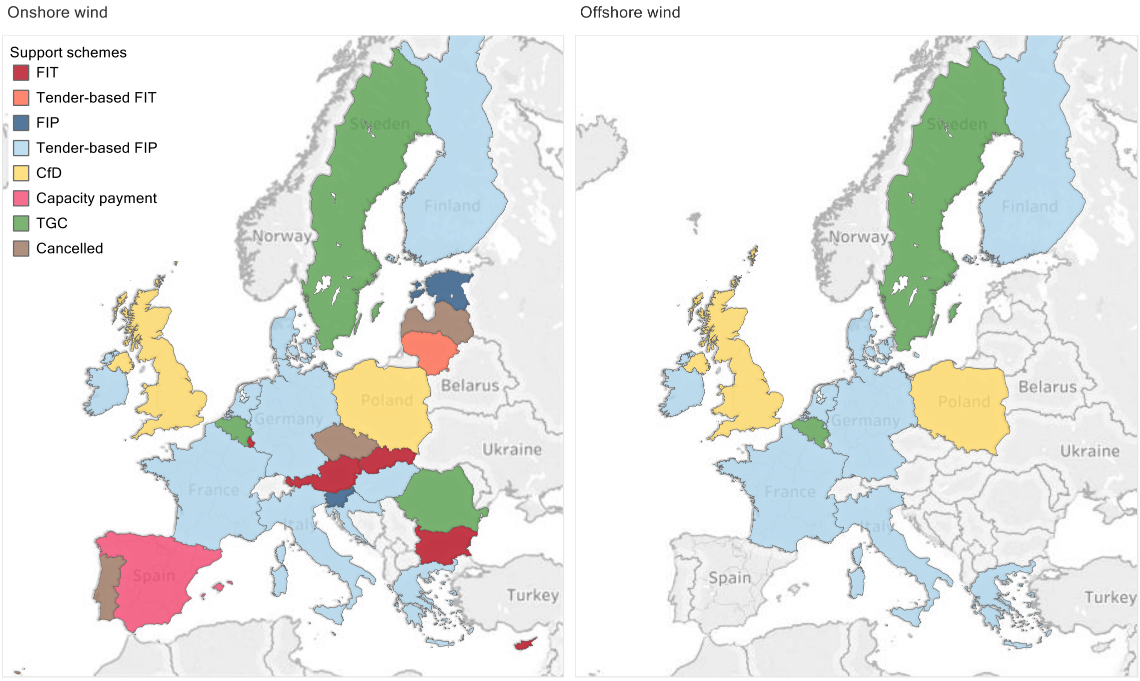


Figure 9 Overview of support schemes for new onshore and offshore wind energy projects (at utility-scale) in the EU28 (in force in July 2019)
Source: JRC
Note: Only support schemes for new projects are shown. Some MSs have other support schemes for smaller wind projects based on the exceptions contained in the EEAG as follows:
(1) In Germany onshore wind projects with capacity higher than 750 kW are supported by a FIP determined in a tendering process; however, projects with capacity between 100 kW and 750 kW, and smaller than 100 kW, are supported by a FIP and a FIT respectively. Similarly, Hungary and Italy support onshore wind projects through a FIP tender-based and smaller projects through FIT or FIP. In particular, in Hungary the small projects with capacity lower than 0.5 MW, and up to 1 MW, are supported by a FIT and a FIP respectively. In Italy, the small projects with capacity lower than 0.5 MW and up to 5 MW are supported by a FIT and a FIP respectively.
(2) In Greece the sliding FIP is determined by a competitive bidding process; however, wind farms with an installed capacity lower than 3 MW, the existing wind projects that entered into a power purchase agreement with the market operator before 1 January 2016, the wind projects placed in non-interconnected Greek islands, and demonstration projects, may either choose to switch to the new FIP or continue the previous FIT.
(5) In Poland and the United Kingdom, the onshore wind projects are supported by a tender-based CfD mechanism; however, small projects (lower than 500 kW in Poland and 5 MW in the UK) are supported by a FIT.

It is important to note that the EEAG contains some exceptions. Among others, FIP schemes are not required for wind energy projects with an installed capacity below 3 MW, or with three generation units. Additionally, the level of support is not required to be granted via competitive bidding processes for wind energy projects with an installed capacity below 6 MW, or six generation units. Consequently, some MSs have reformed their support schemes based on such exceptions, as further explained in the note of Figure 9.

According to the EEAG, competitive bidding procedures should, in principle, be technology-neutral (i.e. open to all RES generators), although they can be designed to be technology-specific, if bidding processes may lead to suboptimal results due to network constraints or diversification needs (among others). So far, most MSs[6] have implemented technology-neutral tenders, with Poland and Spain having exclusively technology-neutral RES tenders. In Hungary the legislation for technology-

[6] In addition to technology-specific tenders, Germany, France and Greece have organised some rounds of technology-neutral tenders for onshore wind and solar PV.

neutral tenders has been passed [CEER 2018]. Most recently, the new EU Renewable Energy Directive allows MSs to make use of technology-specific tender procedures.
Some MSs are on track for adapting their current support schemes according to the EEAG requirements[7]. In particular, Slovakia (FIT) is collecting information to implement auctions for RES support although no draft has been published yet. Lithuania (tender-based FIT) is in the process of amending its RES Act to implement a new support scheme for offshore wind projects expected to start commissioning after 2020 [WPM 2018a].

2.3.2 Onshore auctions

An overview of the results of onshore wind tenders in the MSs in recent years is displayed in Figure 10. In general, the outcome of these tendering procedures was a reference price level per kWh, either as a basis for a FIT (Lithuania), a FIP (Germany, Italy, France, the Netherlands, and Greece), a CfD (The United Kingdom and Poland), or a capacity payment (Spain). Some characteristics of these tenders can be highlighted. Firstly, a minimum participation size was defined for most of the tenders. Onshore wind projects must have a capacity of at least 750 kW in Germany, 10 kW in Lithuania, 5 MW in Italy, 3 MW in Greece, 500 kW in Poland, 5 MW in the UK. In France, only projects with at least 7 wind turbines, or with at least one wind turbine with an installed capacity larger than 3 MW could participate. Secondly, even though most MSs set a ceiling price to avoid the risk of overcompensation, Italy has defined a minimum bid price (60 % of the base tariff) [CEER 2018]. Thirdly, in Germany, France, Italy, Poland and Greece the support is guaranteed for 20 years starting from the date on which the wind farm is in operation. However, shorter supporting periods are granted in the United Kingdom and the Netherlands (15 years), Lithuania (12 years) and Spain (10 years).

The price level has been reduced or has even reached unexpected low results in some onshore wind tenders implemented so far. Spain allocated more than 4.6 GW to onshore wind projects in three tender rounds held in 2016 and 2017 (more than 8.7 GW considering all RES projects) resulting in no subsidy for the winners. The three tender rounds had different design elements. Only the second round was technology-neutral; the first round was specific for wind and biomass, and the third round focused on wind and solar PV. The first round was considerably oversubscribed, resulting in a 100 % discount[8] for all winning bidders. The capacity auctioned for wind energy (500 MW) was very low, because Spain had a moratorium of subsidies for four years. 2.5 GW participated in the auction, 10 GW were in the pipeline and still more capacity must be built to meet the 2020 target for RES [del Río 2017]. In the second round, the Government limited the maximum discount to 51.22 % for solar PV and 63.43 % for onshore wind, and introduced a new rule by establishing that if both installations offered the maximum discount, the capacity would be allocated to wind energy, since it offers more operating hours. As a consequence, 99 % of the auctioned capacity (2 979 MW) was allocated to wind energy and only 1 MW to solar PV [PV Magazine 2018]. Winners will not receive any subsidy on wholesale power prices, unless the latter fall below an annual average price of EUR 34.5/MWh. This guaranteed minimum price partially addresses the risk of wholesale price volatility. In the third round, the Government removed the 3 GW quota during bidding, and allowed unsuccessful bidders from the second round to compete. This resulted in 3.9 GW being awarded to solar PV and 1.1 GW to onshore wind, at the maximum discounts of

[7] As of July 2019, there are no concrete plans for introducing competitive tenders in the short term in Austria (FIT), Bulgaria (FIT), Czech Republic (cancelled), Cyprus (FIT), Latvia (cancelled), Romania (TGC), Slovenia (FIP), Sweden (TGC), Finland (FIP), and Luxembourg (FIT).

[8] In the Spanish auction system participants bid a percentage reduction of the country's regulated investment return policy. The policy establishes that projects will have their return level guaranteed at "300 basis points above the yield on 10-year government bonds over the last 10 years", which will amount to around 7.5 % pre-tax. This only applies during a 6-year "regulatory period". Nevertheless, the government reserves the right to decrease the guaranteed rate of return every 6 years.

69.88 % and 87.08 % respectively. There is no remuneration for all winning bids unless wholesale power prices fall below an annual average price of EUR 25/MWh [Bloomberg 2017]. All projects must be in operation by December 2019. Otherwise the developers will lose the bank guarantees as penalty.

In Germany the winning bid price decreased by 33 % within three technology-specific tendering rounds in 2017. In the Renewable Energy Sources Act (EEG), Germany introduced specific rules for citizen's energy companies, which were allowed to place a bid without holding a building and noise-emission permit (by only providing a wind location analysis) and benefit from a pay-as-cleared price awarding mechanism instead of a pay-as-bid[9] applied to commercial developers. In addition, if successful in the tender, the community energy companies had an additional 2 years to build their projects compared to other participants. Under these favourable conditions, over 95 % of the successful bidders in the three tendering rounds in 2017 were citizen's energy companies [CEER 2018]. The large decrease in price between the first and the last round in 2017 could be explained by the fact that these companies were able to bid at lower prices compared to other participants, since they could count on a further cost decrease for wind turbines in the additional 2 years. The German Government subsequently suspended some advantages, making building permits a compulsory requirement for all bidders. As a result, in the first tender for onshore wind in 2018 (EEG Wind Auction 2018 Round 1 in Figure 10), the average winning price level increased compared to the last round in 2017, and the participation of community projects was dramatically reduced (23 %) [WindEurope 2018e].

Even though the German Government improved the design of tenders by requiring a building permit to bid, the process to get this permit has become longer: up to 700 days instead of around 300 days as 2 years ago. Furthermore, when the project developer gets a permit it is also exposed to legal challenge because the regional siting plans are not as robust. As a result, the four onshore-specific rounds held in 2018 resulted in increasing weighted average prices and round 4 held in October 2018 experienced undersubscription. Over 900 MW of projects were pre-approved for the tender and had a building permit however only 363 MW actually bid and won a contract out of the 670 MW offered. The remaining projects feared legal consequences because of the regional siting plans and did not want to be exposed to penalties for non-delivery [WindEurope 2018f].

Permitting delays also resulted in an unsubscribed onshore tender in France in September 2018. Only 118 MW, out of the 500 MW available, were successfully allocated [WPM 2018b].

In Greece, the two rounds of onshore tenders held in 2018 were oversubscribed. This high level of competition resulted in favourable prices that became even lower in the second round [Wind Europe 2018a], [Wind Europe 2018b]. In spite of these results, the wind industry claims that the cost of obtaining a building permit in Greece is still high and the permitting procedure needs to be simplified [Wind Europe 2018b].

Germany, France and Greece have held some joint wind and solar PV tenders in 2018 and 2019 with negative results for wind energy as all capacity was assigned to solar PV–in the three joint tenders held up to now in Germany and the test joint tender held in France in 2018. This is a sign that both technologies are complementary and should not compete according to some members of wind and solar industry [TaiyangNews 2019a], [WPM 2018c]. The first joint tender in Greece was oversubscribed however only one wind energy project with 66.6 MW was awarded out of 600 MW offered while almost 438 MW were allocated to solar PV projects [TaiyangNews 2019b]. On the contrary, the second Greek joint tender offered 300 MW of wind energy and 300 MW of solar PV separately. Yet it remained undersubscribed allocating 261.75 MW of wind energy [TaiyangNews 2019c]

[9] In a pay-as-bid payment arrangement, each winning bidder receives the price they have offered, while in a pay-as-clear mechanism all winners receive the marginal price, i.e. the price set by the most expensive bid accepted.

The first onshore tender in Poland resulted in very competitive prices ranging between 37 EUR/MWh and 50 EUR/MWh for 1 GW of capacity allocated. They were lower than the previous tenders held in Germany and France in 2018 [Wind Europe 2018c]. In spite of these favourable results, Poland keeps its strict law on set-back distances for onshore wind turbines and plans to almost phase out this technology in its new energy strategy towards 2040. In particular, Poland plans to build 10 GW of offshore wind by 2040 but no onshore additions are planned beyond the volumes envisaged in their current tender process. Consequently, the onshore wind capacity in Poland could dramatically fall from 7 GW in 2025 to just 800 MW in 2040 [Wind Europe 2018d].

In Italy, the average winning price decreased by 44 % within four rounds held from 2013 to 2016, while the capacity allocated nearly doubled. Even though Italy originally scheduled additional rounds in 2018, they have been delayed after June 2019 [PV Magazine 2019]. Finland launched its market-based support scheme at the beginning of 2019. The first tender offered 1.4 TWh of electricity generation from wind power, solar PV, wave power and biomass, however only wind energy projects were awarded contracts with an average FIP of 2.49 EUR/MWh in addition to a 30 EUR/MWh market price for 12 years [WPM 2019].

2.3.3 Offshore auctions and tenders

An overview of the results of offshore wind tenders in the MSs in recent years is displayed in Figure 11. By mid-2019, ten MSs (Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Poland and the UK) had introduced competitive tendering procedures for offshore wind projects, although no tender has been held in Finland, Greece, Ireland, Italy and Poland for the time being.

All tendering schemes follow a single price-based principle, except for the United Kingdom that considers the project quality as a second criterion of selection. Like onshore wind, the MSs set ceiling prices for participation in order to avoid the risk of overcompensation, except for the UK. Only Italy defines a minimum bid price (60 % of the base tariff) [CEER 2018]. Most MSs implement tender procedures with predefined number and volume of rounds, whereas the Netherlands SDE+ scheme is reviewed every year to add rounds and increase the budget [Noothout & Winkel 2016]. In Germany, the support is guaranteed for 20 years. In the United Kingdom and the Netherlands, the guarantee is up to 15 years, and in Denmark only 12 years.

The shift from FITs to tender-based support schemes promoted by the EEAG has resulted in highly competitive price bidding from mid-2016 onwards. So far, more than 3.1 GW of offshore capacities have been allocated under zero-subsidy bids in Germany and the Netherlands, and bid prices have decreased by 65 % in tenders held in Denmark from 2010 to 2016 and in the United Kingdom from 2013 to 2017.

The first German offshore tender in April 2017 awarded three zero-bids for the first time in Europe. The winning projects are expected to be commissioned by 2024-2025, when the next generation of offshore wind turbines (13-15 MW) could be commercially available. One year later, the second offshore tender in Germany also resulted in four zero-bids for projects which will be allowed to extend their operational lifetime from 25 up to 30 years. Zero-subsidy bids were strengthened by not only the installation of the next generation offshore wind turbines and the extended operational lifetime but also a super-shallow grid connection approach in Germany. Following the results of the first tender in Germany, the Netherlands successfully held the first non-subsidy tender for offshore wind projects in the world in March 2018. 725 MW were allocated in the Hollandse Kust Zuid I&II offshore wind zones.

Even though zero-subsidy bids are only possible under specific conditions in a few markets and to certain players, bid prices are coming down as a consequence of the following cost drivers [JRC 2017a]:

- Technology advances through larger and more reliable wind turbines, as well as optimised electrical systems and optimised installation, logistics and service concepts;
- Reduced financing costs as a result of a lower cost of capital, as well as a reduced debt interest and return on equity rates;
- Ultra-shallow and super-shallow grid connection approaches in Denmark, the Netherlands and Germany; and
- Scalability towards larger wind farms, clusters of projects, and operating synergies, as well as more mature industrialisation and standardisation.

Technology advances, scalability, and competition will likely be reinforced in future tendering procedures, driving the bid prices down. However other cost drivers such as availability of good locations, and favourable market factors may not prevail.

More recently France has announced that the tender to build 600 MW offshore wind off the coast of Dunkirk resulted in a strike price of 44 EUR/MWh. [WindEurope 2019a] This result have prompted France to increase its offshore wind tendering target to 1 GW per year until 2028 as further explained in section 2.3.4 [OffshoreWIND.biz 2019a].

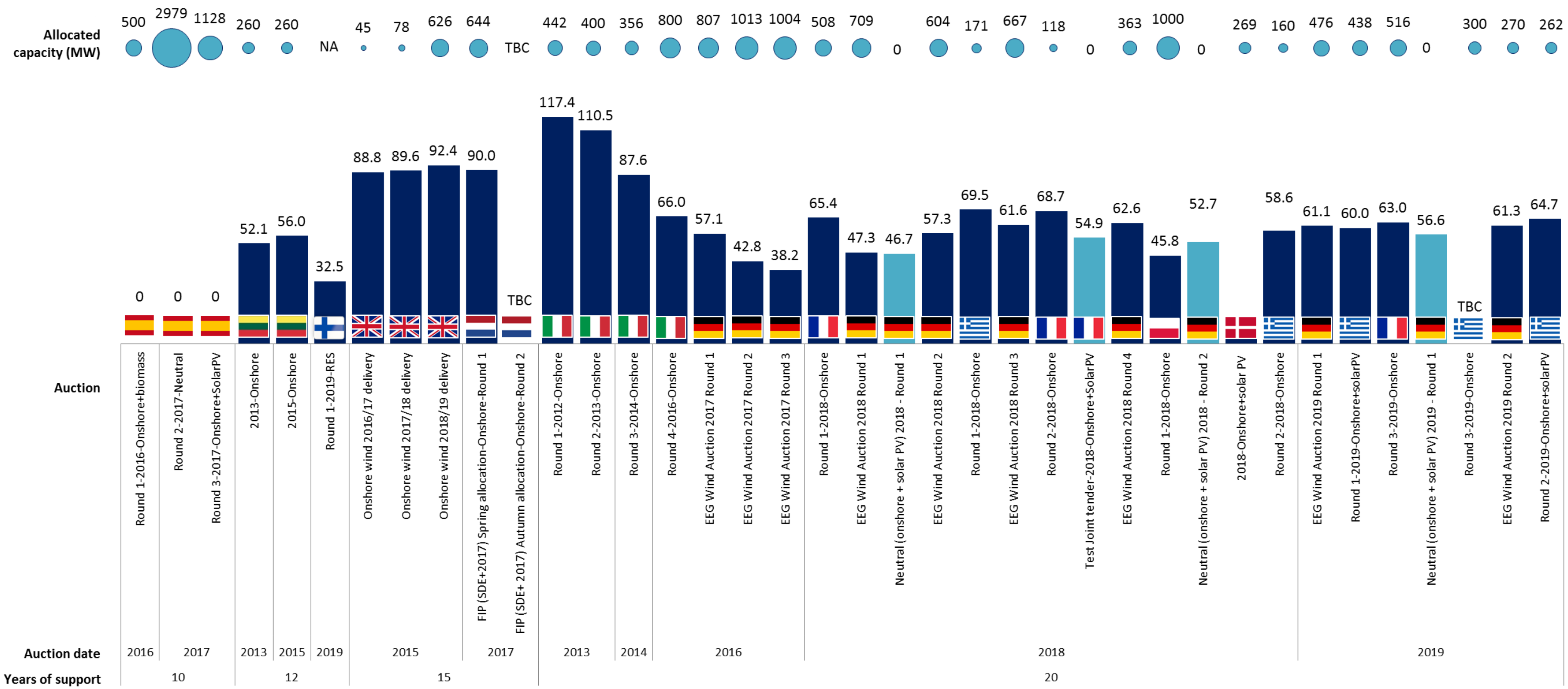


Figure 10 Results of onshore wind tendering procedures in the MSs (2013-July 2019)
Note: TBC means "to be confirmed". Bars highlighted in light blue refer to those joint tenders hold in Germany and France where no capacity was allocated to onshore wind. All capacity was allocated to solar PV projects
Source: JRC

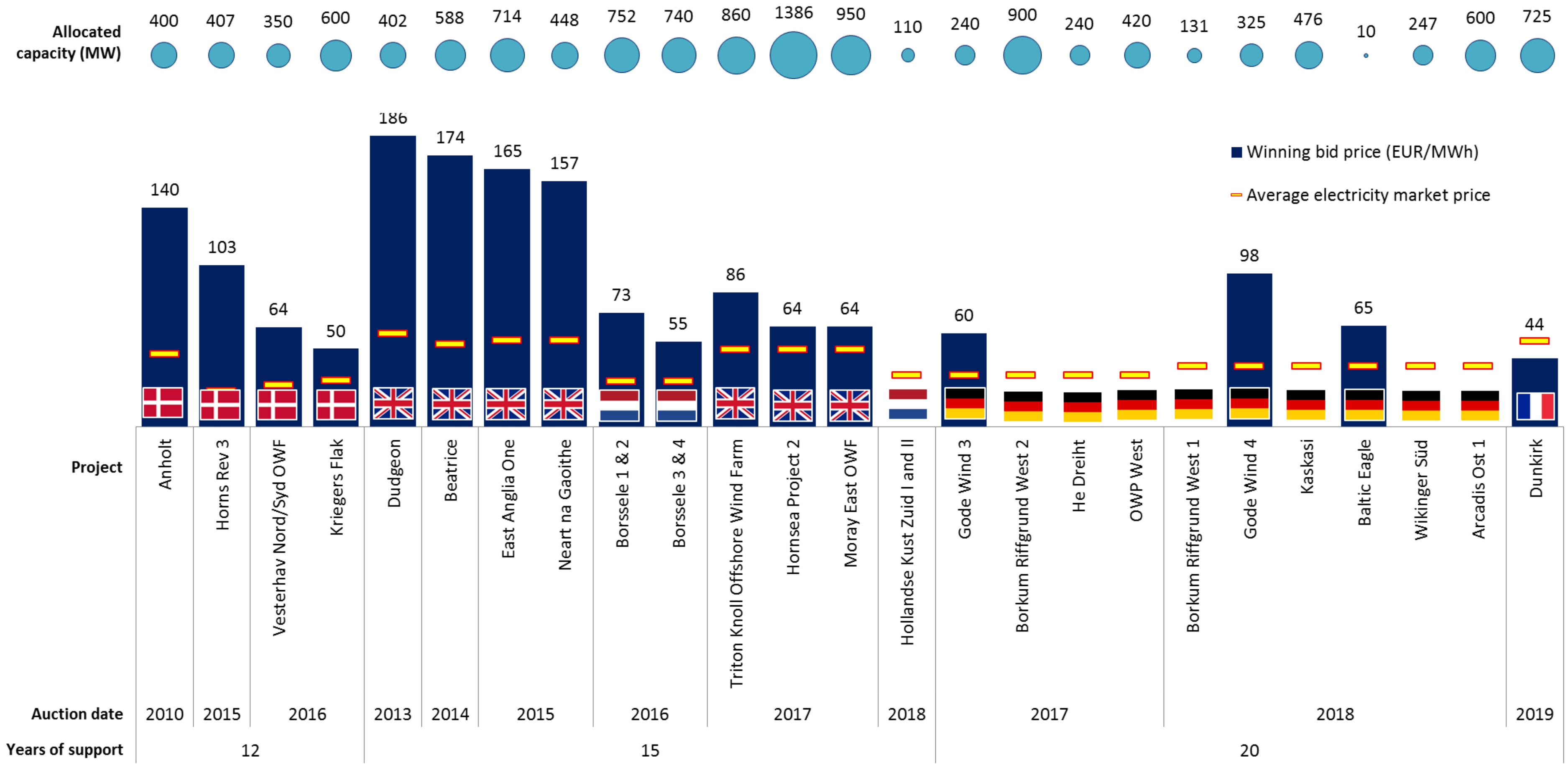


Figure 11 Results of offshore wind tendering procedures in the MSs (2010-July 2019)
Source: JRC

2.3.4 Upcoming competitive tenders

Figure 12 shows a timeline of upcoming tenders announced by MSs.

The Netherlands plans technology-neutral tenders, allocating an annual budget of EUR 6 billion for onshore wind up to 2020 under the SDE+ scheme [WindEurope 2018b]. In offshore wind, the applications to build two wind farms with 342 MW and 380 MW in Hollandse Kust (zuid) III and IV are being assessed. A final decision on whether to declare a winner of the subsidy-free round or to move the tender to the second, subsidized, round is expected to be made by mid-September 2019 [OffshoreWIND.biz 2019b].

Germany will hold technology-specific tenders for onshore wind, with a capacity of 2.8 GW in 2019 and 2.9 GW annually from 2020 onwards [BMJV 2017a]. Joint tenders of 400 MW of onshore wind and solar PV will also be auctioned in 2019 and 2020 [Bundesnetzagentur 2018]. In addition, at the end of 2018 the CDU/CSU/SPD coalition reached a political agreement of 4 GW of additional onshore wind auctions in 2019-2021 (1 GW in 2019, 1.4 GW in 2020 and 1.6 GW in 2021) [Wind Europe 2018e]. Starting from 2021, the Federal Network Agency will hold a tender of 700 to 900 MW of offshore wind per year [BMJV 2017b].

France will auction 3 GW onshore wind up to 2020 (one single window in 2017 and 2020 and two in 2018 and 2019) [WPM 2018b] The next offshore auction is foreseen to take place in December 2019 [WindEurope 2018b]. Moreover for 2020 and 2021 the Government plans to tender for 250 MW each of floating offshore wind capacity off the coast of Brittany and the Mediterranean [4COffshore 2019, OW 2019b].

The UK announced new CfD rounds to take place in May 2019 and 2021 mostly for offshore wind, although onshore wind projects in remote islands will also be eligible. The budget will be up to £ 557 million per round (around EUR 618 million). The awarded capacity could reach up to 7 GW of offshore wind per round including water depths up to 60 m. [WPO 2018a].

Italy approved a new auction system for RES projects with a capacity of higher than 1 MW (6 MW for wind energy) at the end 2018 [PV Magazine 2018].. Seven rounds were initially scheduled starting from 31th January 2019 until 31th January 2021 but they have been delayed after June 2019. 4.7 GW of renewable energy capacity will be contracted through tenders in the next 30 months. The capacity allocated will progressively increase from 500 MW in the first two rounds, to 700 MW for the third to fifth, and to 800 MW for the last two rounds. Additional tenders will be realized for renewable energy projects with a capacity of between 20 kW and 1 MW. The first round will be devoted to solar and wind projects and will have a total capacity of 650 MW [PV Magazine 2019].

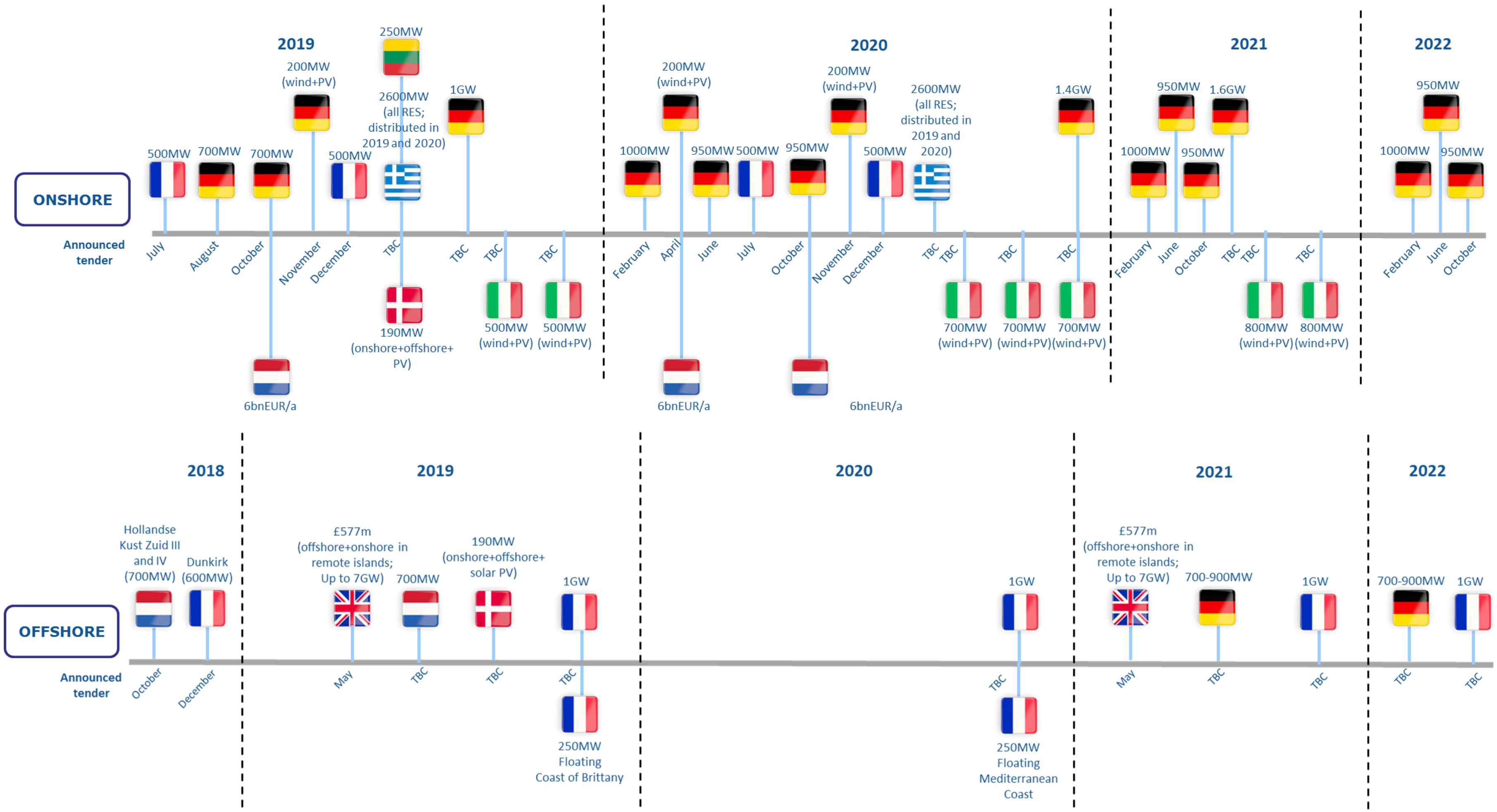


Figure 12 Upcoming competitive tenders of onshore and offshore wind in the EU28 (as of July 2019)
Source: JRC

2.4 R&D investment

In general terms, around 90 % of R&D funding in wind energy comes from the corporate sector which sets the relative position of the MSs in terms of absolute contribution to R&D activity (Figure 13).

Private R&D funding is highly concentrated in Germany, Denmark and Spain where the leading European OEMs concentrate their industry and value chain as shown below in sections 3.1.1 and 3.2. In 2014, the private R&D investment from these three MS reached 77 % and 69 % of EU corporate and total R&D funding respectively. In relative terms, their private R&D investment has remained relatively constant in the last years representing over 70 % and 65 % of EU corporate and total R&D funding annually over the period 2003-2014 (Figure 14). Nevertheless, German companies were responsible of almost 50 % of EU private R&D investment over the period 2003-2014.

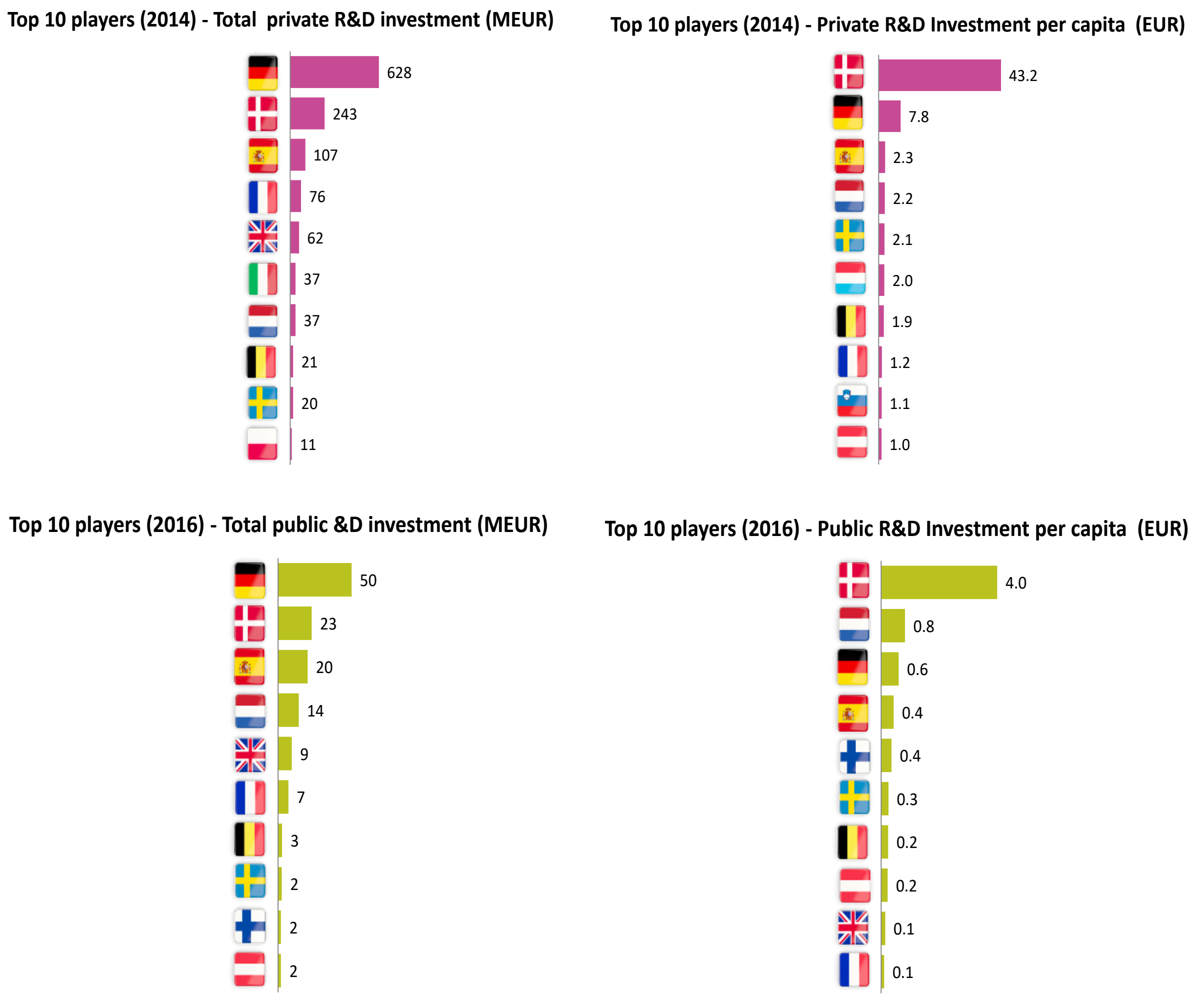


Figure 13 Top 10 players in private (top) and public (down) R&D investment. Total R&D investment (left) and R&D investment per capita (right)
Source: JRC; private R&D estimates according to Fiorini et al, Pasimeni et al; public R&D based on IEA. Population data based on Eurostat
Note: 2014 and 2016 are the last data available for private and public R&D investment respectively. Methodology to

Denmark, Germany and Spain also lead the private R&D funding per capita with Denmark reaching around 43 EUR of R&D investment per capita, followed far by Germany (almost 8 EUR per capita). Nevertheless, smaller MSs such as the Netherlands, Luxembourg , Slovenia and Austria displace bigger MSs such as the United Kingdom and Italy from the top 10 ranking in private R&D investment per capita (Figure 13).

Similarly to private R&D funding, Germany, Denmark and Spain have led the ranking of public R&D investments, although the United Kingdom have overcome Denmark and Spain in cumulative public R&D investment over the period 2003-2016 (Figure 14). Most of MSs have retained their position in the top10 private and public R&D investors over the last years.

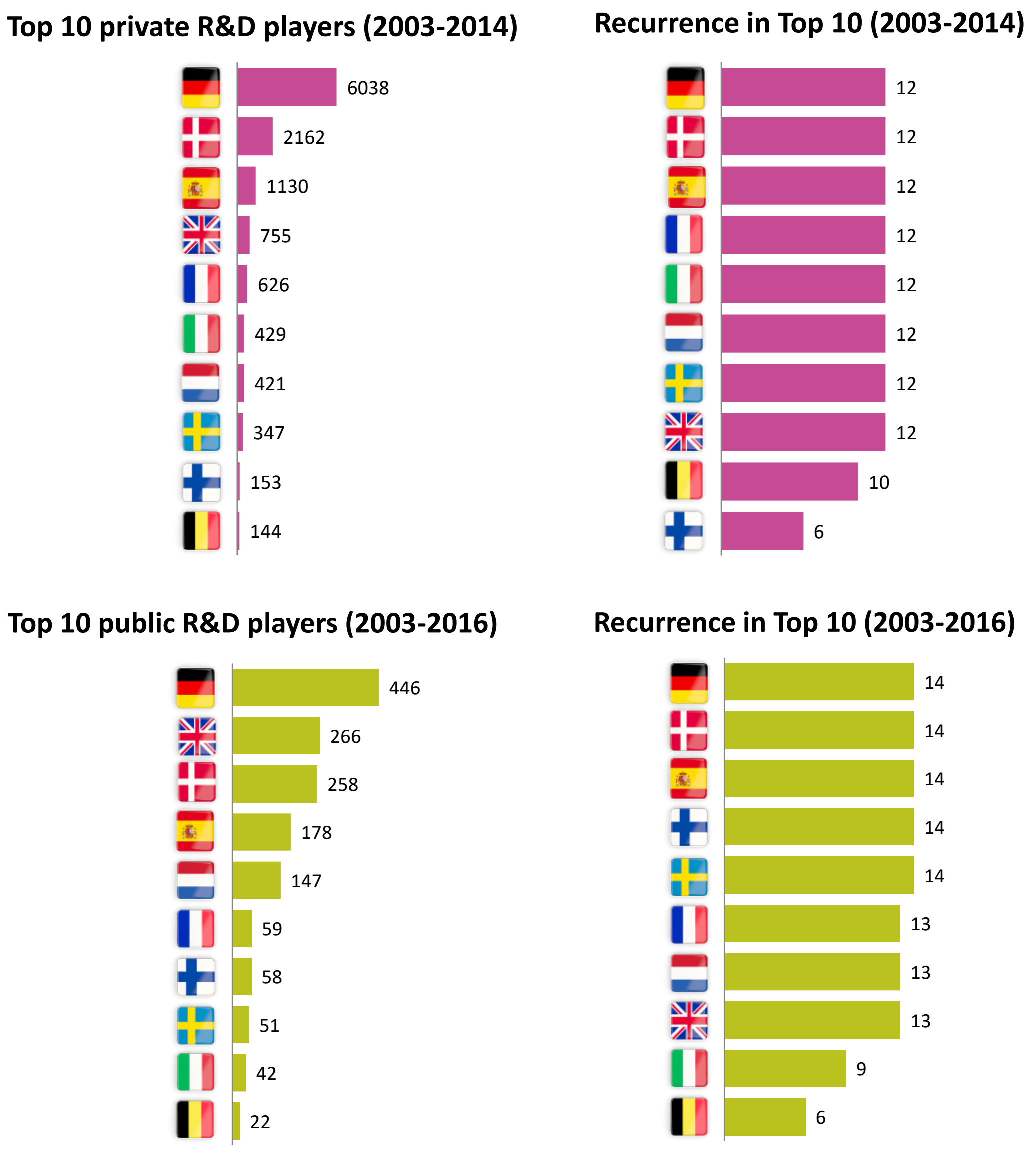
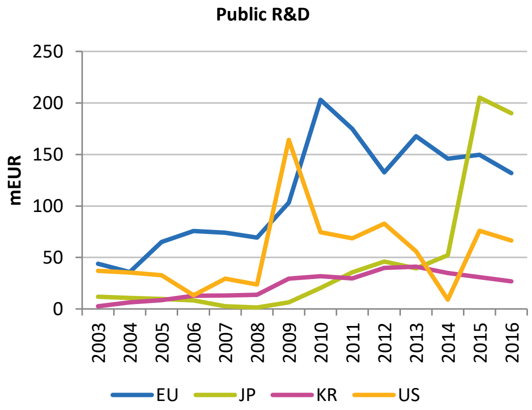
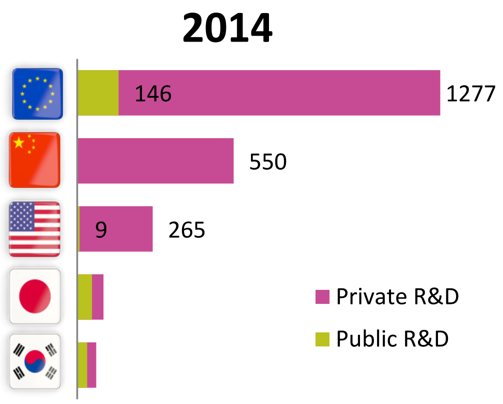


Figure 14 Top 10 players in private (top) and public (down) R&D investment and their recurrence in the top 10 ranking (EUR million)

Source: JRC; private R&D estimates according to Fiorini et al, Pasimeni et al; public R&D based on IEA
Note: 2014 and 2016 are the last data available for private and public R&D investment respectively



(i)



(ii)

Figure 15 International comparison of public R&D investment in the period 2003-2016 (i) and private and public R&D investment in 2014 (ii)

Data source: JRC; private R&D estimates according to Fiorini et al, Pasimeni et al; public R&D based on IEA

Note: 2014 and 2016 are the last data available for private and public R&D investment respectively

Looking ahead, the leading EU countries in R&D investment are also at the forefront in defining and committing to the R&D priority actions of the SET-Plan implementation plan for Offshore Wind in order to meet the SET-Plan targets for offshore wind energy. The implementation plan estimates an overall investment need of EUR 1090 million until 2026 (41 % from the private sector, 34 % from national programmes and 25 % from EU funds) in order to ensures future competitiveness in offshore wind [EC 2018b].

Regarding the international competitors, Europe has remained at the forefront in public R&D investments in wind energy (Figure 15). However, since 2008 Japan has strongly increased public R&D investment, overtaking Europe in 2015. Europe was also estimated to lead private R&D investments in 2014, leading China and the US by a long margin.

2.5 Patents

This section describes the patenting activity in wind energy technologies in the period 2000-2014, identifying main trends and players, and describing the market strategy in terms of patent protection and international flow[10].

With a compound annual growth rate of 57 % in the period 2000-2014, China currently ranks first in wind energy inventions[11] after overtaking the EU in 2012, who had been the world leader since 2006 (Figure **16**).

Even though China has the strongest patenting activity, it is aimed for protection in the national market. As shown in Figure 18, in the period 2000-2014 more than 50 % of inventions in the wind energy technologies were granted but only around 3 % were high value inventions, i.e. protected in other patent offices. Korea shows a similar trend, with more than 60 % of inventions granted, but

[10] Patent data are based on PATSTAT database 2018 spring version. The methodology behind the indicators is provided in [JRC 2017d].

[11] Inventions or patent families include all documents relevant to a distinct invention (e.g. applications to multiple authorities), thus preventing multiple counting. A fraction of the family is allocated to each applicant and relevant technology.

only 4 % considered as high-value inventions. In contrast, around 60 % of inventions in Europe and the United States were protected in other countries

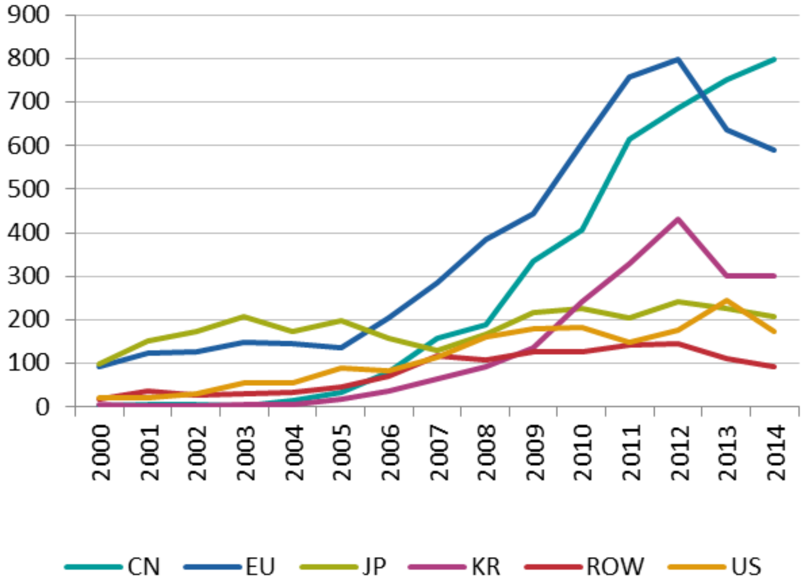


Figure 16 International comparison of the evolution of inventions in wind energy
Source: JRC based on EPO data

Nevertheless, Europe has the highest specialisation index[12] (indicating the patenting intensity) in wind energy compared to the rest of the world (Figure **17**).

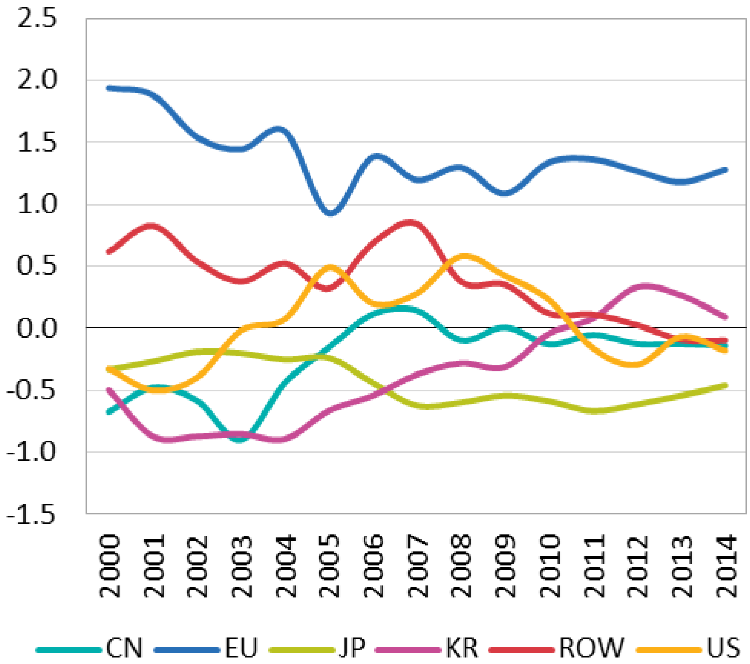


Figure 17 Specialisation index of the total inventions in wind energy
Source: JRC based EPO data

[12] For each country: SI = 0, patent intensity equal to the world; SI < 0, intensity lower than the world; SI > 0, intensity higher than the world. For more information please refer to [JRC 2017e]

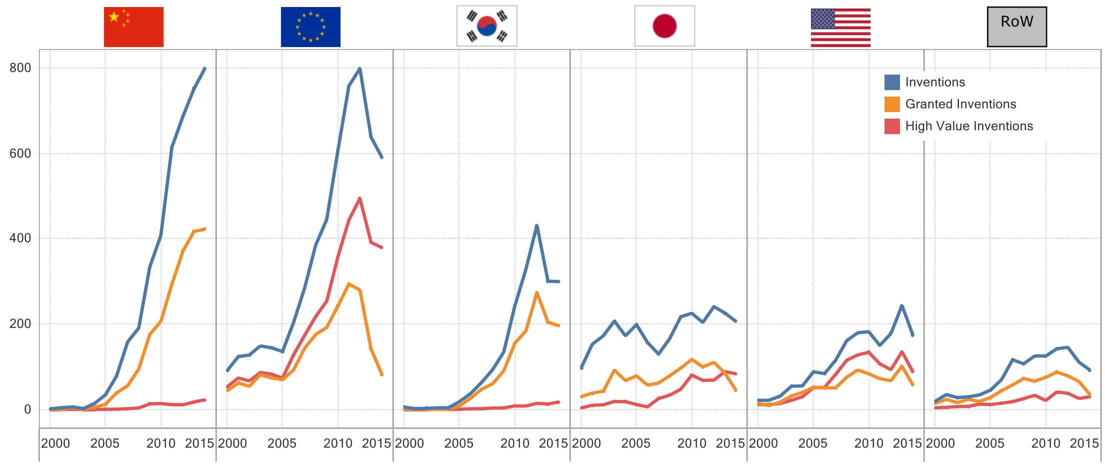


Figure 18 International comparison of the inventions filed, inventions granted and high value inventions in wind energy technologies
Source: JRC based on EPO data

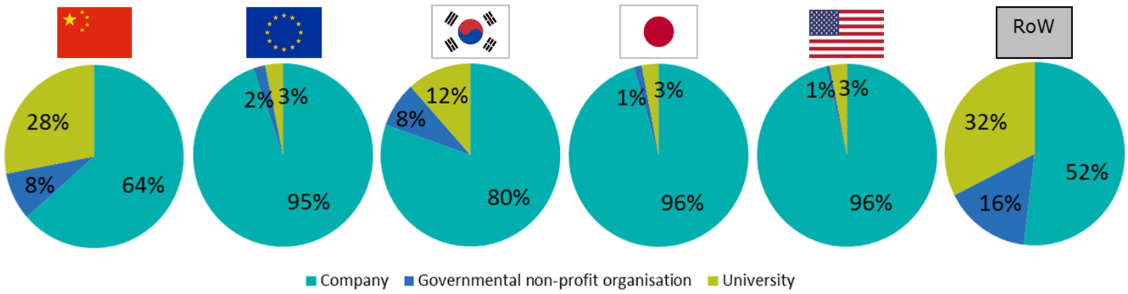


Figure 19 International comparison of the sector activity of the applicants
Source: JRC based on EPO data

.

Regarding the sector activity, more than 90 % of applicants were companies in the period 2000-2014, with the exception of China, where around 30 % of inventions were protected by universities (Figure 19). The inventions from Chinese and Korean governmental non-profit organisations have also been increasing slightly in the last years, but still only represent a marginal share of the total.

The parent companies of some of the leading OEMs in terms of capacity installed (see section 3.1.1) rank among the top players in patenting activity. As shown in Figure 20, in 2014, Siemens AG was the leading company in number of wind energy inventions, representing 5.8 % of global inventions, followed by General Electric (4.4 %) and Samsung Heavy Industry KK (3.3 %). Three out of the top 10 patenting entities were European companies (Siemens AG, Vestas Wind Systems A/S, and Enercon GMBH), covering altogether around 10 % of wind energy innovations. Almost all of the top 10 in 2014 have a long standing presence in wind patenting activity since they also rank among the top 10 in terms of total inventions in the period 2000-2014. State Grid Corporation of China and Doosan Heavy Industries and Construction are the only two exceptions, emerging in the top 10 since 2013.

Figure **21** displays the evolution of the share of inventions protected in the major patent offices including national and international applicants. China is the most targeted market, with around 40 % of inventions in wind energy protected in the Chinese patent office in 2014, and showing a strong increase in recent years. This trend seems to be driven by China's amendment of its patent legislation in 2000, more Chinese companies protecting their inventions, a growing domestic wind energy market, and the filing for protection of innovations by Chinese subsidiaries of foreign companies. The strong influence of domestic applications in China is visible when Figure **21** is compared with Figure 22. China is overcome by the US as the most targeted market when only international applicants are considered.

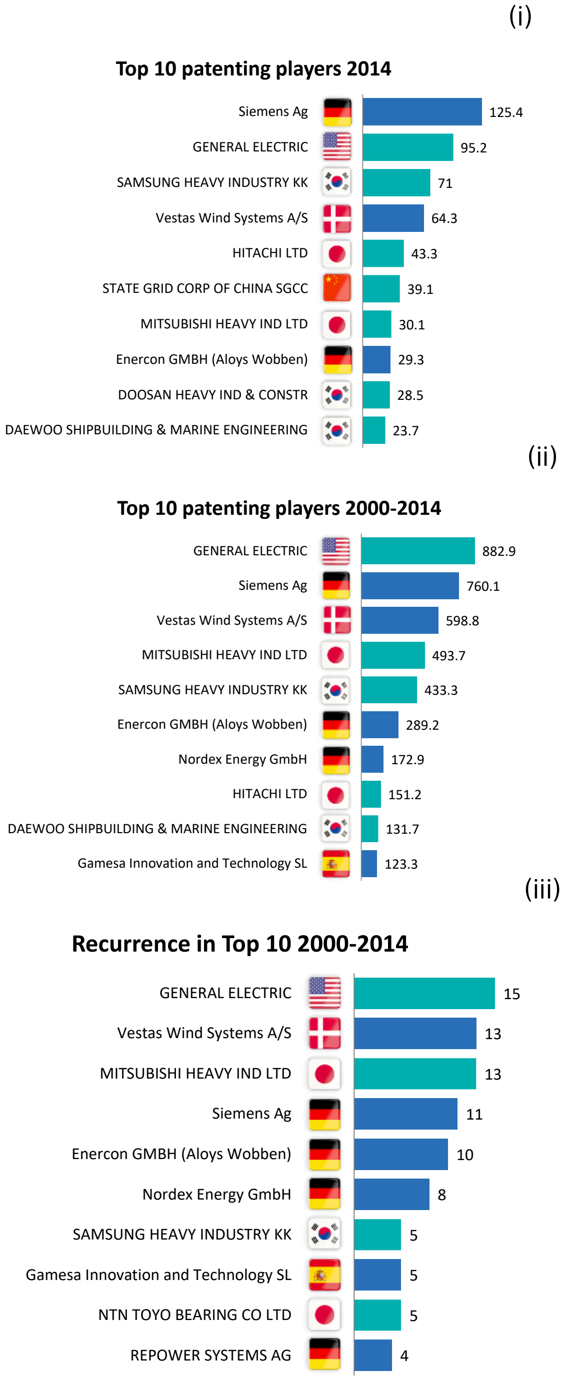


Figure 20 Top 10 patenting players in 2014 (i), in the period 2000-2014 (ii) and recurrence in the period 2000-2014
Source: JRC based on EPO data
Note: European players highlighted with dark blue

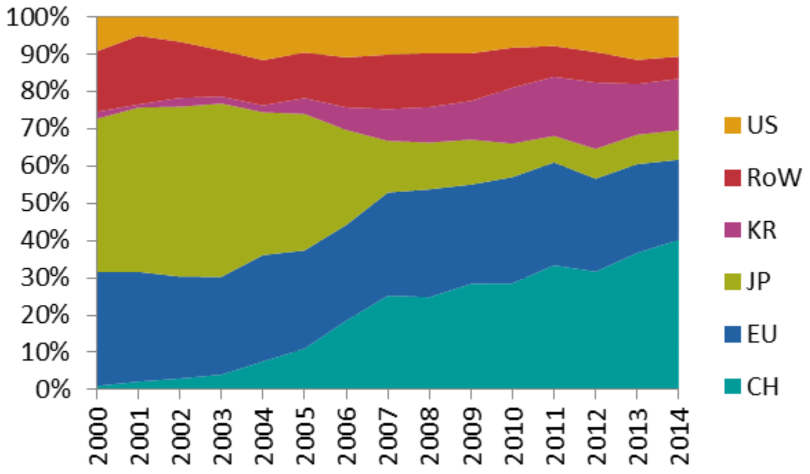


Figure 21 Evolution of the share of inventions protected in the major patent offices (including national and international applicants)
Data source: JRC based on EPO data

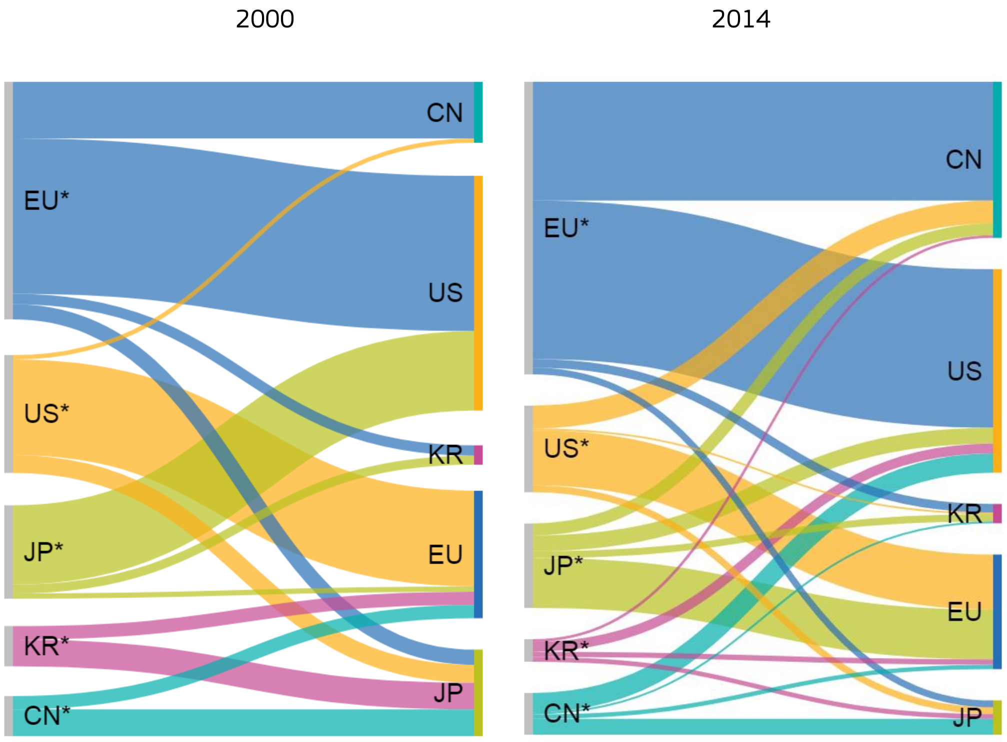


Figure 22 Comparison of the flow of inventions among the main patent offices (2000 vs 2014)
Source: JRC based on EPO data

The Korean patent office is also becoming a targeted destination but to a lesser extent than China. The European market receives a relatively constant share with around 20 % of total inventions in wind energy protected in the European patent office. The share of inventions protected in Japan has reduced significantly over the years.

Figure 22 shows the flow of inventions from the main players in terms of number of patents to the main patent offices. This flow has diversified mainly towards China, the United States and Korea in the last years. European applicants keep the highest share of inventions protected in the United States and China in 2014 although they have doubled the number of patents protected in China compared to 2004. The European patent office has become the main target of the Japanese applicants who protected more than half of inventions in Europe in 2014. The number of inventions from American applicants has reduced almost half since more and more are address the Chinese patent office. Korean and Chinese applicants have drastically reduced the number of inventions protected in Europe since the American patent office has become their main target.

3 MARKET OVERVIEW

3.1 Wind turbine market

3.1.1 Turbine manufacture market

The European Original Equipment Manufacturers (OEMs) in the wind energy sector have held a leading position in the last few years although their market share has decreased in 2018 mainly in favour of the Chinese OEMs. Among the top 10 OEMs in 2018, European OEMs led with 43 % of market share, followed by the Chinese (32 %) and North American (10 %) companies.

As shown in Figure 23, Vestas (DK) retained as the world's largest turbine supplier in 2018 due to its wide geographic diversification strategy and high performance in the American market. Goldwind (CN) moved up to second position as a result of higher installations in its domestic market and Siemens Gamesa Renewable Energy (DE-ES) fell up to third place due to lower market share in the United Kingdom, Germany and India in 2018. GE Renewable Energy (US) held the fourth position thanks to its leading position in the US market.

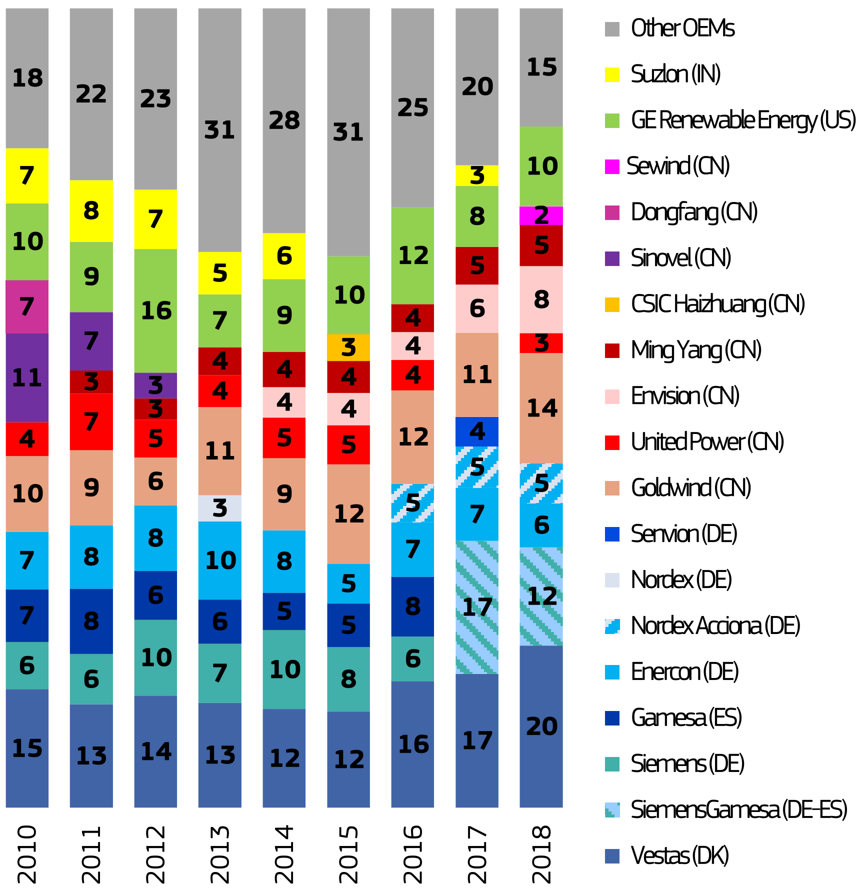


Figure 23 Market share of the top 10 OEMs over the period 2010 – 2018
Note: Since April 2016 Nordex and Acciona WindPower have merged, becoming Nordex Acciona. In April 2017, Siemens Wind Power and Gamesa also merged becoming Siemens Gamesa Renewable Energy.
Source: JRC, FTI Consulting and GWEC

Envision (CN) replaced Enercon (DE) in fifth position, mainly as a consequence of its increasing market share in the Chinese market. Enercon moved down to sixth place due to a strong drop of installations its home market.

Chinese suppliers Mingyang, United Power and Sewind reached seventh, ninth and tenth placed respectively, mainly due to stable performances in their domestic markets. In 2018 Suzlon (IN) dropped out of the top 10 ranking, primarily due to a strong decrease of installations in the Indian market [GWEC 2019b].

In the offshore wind market, Siemens Gamesa Renewable Energy (DE-ES) maintained its market leadership in 2018, with around 62 % of new global capacity installed. MHI Vestas ranked the second largest offshore wind turbine supplier with around 33 % of new installations. GE Renewable Energy (US) reached the third position with 5% of market share after connecting the Haliade 150-6 MW turbine for the first time in Europe. Siemens Gamesa Renewable Energy, MHI Vestas and Senvion (DE) represent 98 % of the total offshore capacity installed in Europe with 69%, 24% and 5% of market share respectively [WindEurope 2019b].

3.1.2 OEM financial situation

The OEMs financial situation is analysed based on the revenues and operating profit (EBIT[13]) as declared by the companies in their annual reports. As such only the listed companies of the Top10 OEMs in 2017 (see Figure 23) are taken into account. Wind activities within GE Renewables (US) are not individually reported.

After a very strong 2016 in both revenues and profit, the market leader Vestas (DK) is found again among the top OEM players in 2017 at an operating profit and EBIT margin of about 1.2 bn EUR and 12.4 %, respectively (see Figure 24 and Figure 25). The drop, as compared to 2016-levels, can be attributed to a decline in turbine delivery and falling turbine prices. In 2018, Vestas experienced a rise in turbine orders and revenue, so it could reach the previously formulated revenue target of 10 to 11 bn EUR. Nonetheless, increasing competition led to shrinking profits and an orientation towards new emerging markets resulted in job cuts in northern and central Europe [Vestas 2018a] [WPM 2018d] [WPM 2018e].

Since the acquisition of Acciona WindPower in 2016 and thus increased restructuring expenses, Nordex Acciona (DE) shows stagnating EBIT margins between 1.4 % and 5 %. Moreover the companies' revenues from service contracts are substantially lower than those of their competitors. By September 2018 revenues were 24 % lower than for the same period in 2017, yet turbine orders almost tripled in the same period, the increase stemming from the markets in Latin America and Europe [WPM 2018f].

The merger between Siemens Wind Power and Gamesa as SiemensGamesa Renewable Energy (SGRE) (ES/DE) started in April 2017. A significant drop in EBIT margin from 10.4 % to 5.3 % at the end of 2017 can be seen as consequence of integrating the two entities, and the volatility in some of the main onshore markets (India and the United States). Restructuring included massive job cuts in Europe and the United States [WPM 2017c, WPM 2017d]. Latest figures for 2018 show a further drop in revenues by 17 % due to a decline in turbine prices despite an increase in orders for both onshore and offshore turbines (e.g. UK and Taiwan) [WPM 2018g].

In the last years Goldwind (CN) saw a constantly growing EBIT margin above 10 %. However, its main focus on the home market (in 2017 it supplied 30 % of the Chinese market) resulted in high volatility in turbine sales and a decrease in revenues in 2017. As such, Goldwind sought new markets as reflected through turbine orders of 704.5 MW in Uzbekistan, Turkey, Kazakhstan, the Philippines, Argentina and Brazil [WPM 2018h].

[13] Earnings before interest and taxes

After recovering from a difficult period of falling revenues and margins between 2011 and 2013 (due to increased administrative, selling and distribution, and R&D expenses and a slowdown in the Chinese market) Ming Yang (CN) showed positive market figures from 2014 onwards. In 2016 Ming Yang became privately owned by a consortium of investors led by its former CEO [WPM 2012, WPM 2014, WPM 2016a].

In order to cut expenses Senvion (DE) implemented a cost reduction programme including job cuts and closing of factories mainly in Germany and outsourcing of components to India and China. Still operating profit has been decreasing since 2015. 2018 saw margins even more affected by increasing costs, in order to expand to emerging markets, and installation delays in Australia and Chile. Nonetheless, there was a growing number of turbine orders coming from emerging markets [WPM 2017e, WPM 2018i].

Suzlon (IN) is highly reliant on its domestic market, which was undergoing a transition to an auction system regime. This put the company's margins under pressure, as auctions have been delayed, and project execution time increased from nine to 18 months. Despite that, a recovery in revenues and operating profits since 2015 brought Suzlon back into the Top10 OEMs in 2017 allowing the company to plan re-entering into foreign markets (most probably into Europe and the United States) [WPM 2018j, WPM 2018k, WPM 2018l].

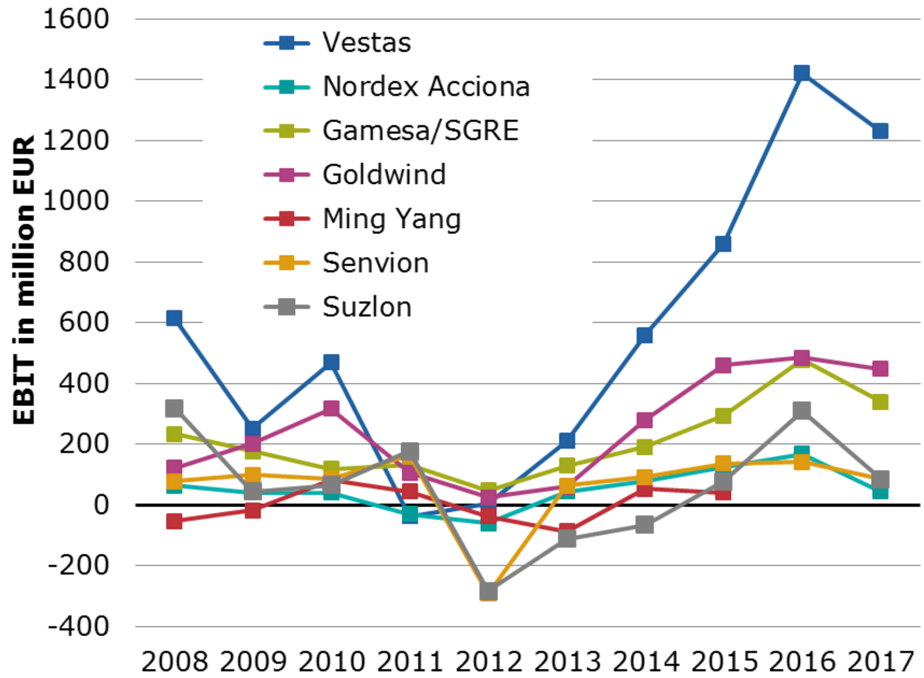


Figure 24 Operating profit (EBIT) of the leading listed OEMs
Source: JRC based on [Vestas 2018a][Nordex 2018][SiemensGamesa 2018] [Goldwind 2018] [Senvion 2018] [Suzlon 2018] and companies' earlier annual reports.

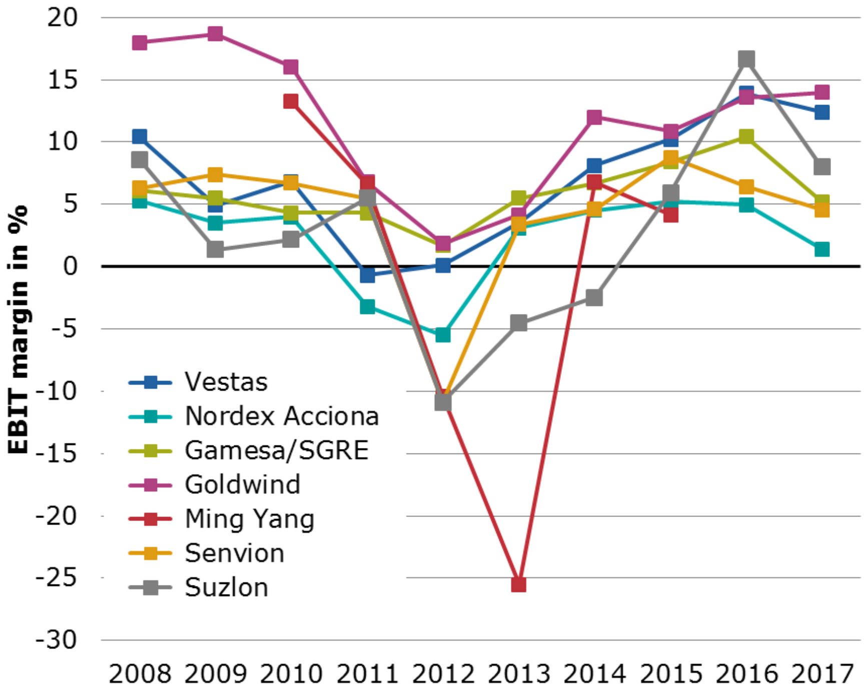


Figure 25 EBIT margin (Operating profit/Revenues) of the leading listed OEMs
Source: JRC based on [Vestas 2018a][Nordex 2018][SiemensGamesa 2018] [Goldwind 2018] [Senvion 2018] [Suzlon 2018] and companies' earlier annual reports.

3.1.3 Mergers & acquisitions in the wind energy sector

The globalisation of the wind energy sector has brought an increasing number of M&A deals over the last few years. These transactions are usually driven by a desire of wind players to consolidate their position in the market by increasing their market share and economies of scale, creating synergies (higher revenues and lower overall cost of capital and expenses), and lowering risk (for example aligning R&D resources), compared to individually developing new technologies and products. M&A activity also reduces trade barriers and competition, and increases the competitiveness of the wind energy sector against other technologies.

Table 6 displays the main transactions in the wind energy sector since 2010. At least 58 M&A have been identified, with 26 operations between European companies. Twelve European firms were acquired by foreign players (six American firms, four Chinese and two Japanese), while only seven foreign firms (six American and one Indian) were acquired by European players. It is interesting to note that six out of the ten joint ventures since 2010 were created between European and foreign firms.

The most relevant mergers between European OEMs were Nordex (DE) - Acciona Wind Power (ES) and Siemens Wind Power (DE) - Gamesa (ES). After the merger with Acciona's turbine business, Nordex returned to the top 10 OEMs in 2016, and expanded business in some growing markets including Spain and Brazil [FTI Consulting 2018]. The transaction between Siemens Wind Power and Gamesa combined Siemens' strength in offshore wind energy and Gamesa's strong presence in emerging markets such as India, Mexico, and Brazil thus creating a world leader in wind turbine manufacturing [Energia16 2016].

As mentioned before, some foreign firms have targeted leading European OEMs and independent suppliers. In 2014 the industrial conglomerate General Electric Co (US) acquired Alstom Wind (FR).

Even though the principal driver of this deal was Alstom's power generation business, GE fully acquired Alstom's onshore wind business and created a 50/50 joint venture for offshore wind. In 2018 General Electric Co acquired the remaining 50 % of the joint venture becoming the sole owner [RN 2018]. The acquisition of the onshore business has given GE a small increase in market share in Europe, where so far it had limited success, mostly in Germany. The joint venture and subsequent acquisition has allowed GE to enter the offshore wind market without committing its own R&D to bring a commercial turbine to market [Renewable Energy World 2015]. In 2016, General Electric Co (US) also acquired LM Wind Power (DK), the world's largest independent wind blade manufacturer in terms of blade capacity installed and turbine supplier relationships. Before the acquisition GE outsourced 100 % of blade production, with LM Wind Power as its largest supplier. Bringing production in-house has ensured supply of a critical wind turbine component, although GE operates LM Wind Power as a standalone company retaining all of its previous customer relationships [NavigantResearch 2016]. Last, the joint venture MHI Vestas (50 % owned by the Danish OEM Vestas Wind Systems A/S and 50 % by the Japanese firm Mitsubishi Heavy Industries) in 2013 turned the company into the second largest turbine supplier in the offshore wind market.

The search for technological differentiation to achieve a competitive advantage in the different stages of the supply chain has led to respective acquisitions of technology and intellectual property assets, as well as data services providers. In 2015 GE (US) acquired the UK-based technology company Blade Dynamics, specialising in the development of modular blades with a high degree of carbon fibre, making them the lightest in its class [NavigantResearch 2016]. In the same year Vestas Wind Systems A/S (DK) acquired the technology and Intellectual Property of the US-based start-up Modular Wind Energy (Modwind). In 2015, Vestas Wind Systems A/S acquired UpWind Solutions, the largest independent service provider in North America. This year the OEM has acquired Utopus Insights, Inc. for energy analytics and digital solutions although it operates as a stand-alone entity under Vestas service [Vestas 2018b].

The consolidation of the wind energy market is also visible among some independent component suppliers. In 2015 ZF Wind Power (DE) took over the industrial gears and wind turbine gearbox segments of Bosch Rexroth AG (DE) becoming the leading gearbox supplier in Europe. The Japanese firms Yaskawa and Nidec Corporation acquired the European generator manufacturers The Switch (FI) and Leroy-Somer (FR), respectively [FTI-Consulting 2017] [Nidec 2017].

M&A activity has also increased in the offshore wind installation business, thus strengthening positions in a growing market. Numerous examples are found such as the acquisition of 80 % of the Germany-based WindMW by China Three Gorges with the purpose to keep penetrating the European offshore wind market, or the acquisition of Bilfinger Marine & Offshore Systems (DE) by Van Oord (NL) to expand its business towards the German offshore wind market. Last year, the developer Ørsted (DK) acquired the American offshore wind farm developer Deepwater Wind further cementing its position in the U.S, one of Ørsted's strategic growth markets [WPM 2018m]. The company has even re-entered the onshore wind market[14] by acquiring the American firm Lincoln Clean Energy [WPM 2018n]. In May 2019 the developers EDP and Engie signed a memorandum of understanding to form a new joint venture and become a "top-five global player" in the offshore wind sector [WPO 2019].

Last but not least, some pension funds and infrastructure investors are increasingly considering wind energy as a viable long-term investment. In Europe, some utilities are selling wind projects or stakes in wind energy portfolios to financial investors, in order to reduce debt and fund expansion into growing markets. In the US market, and to a lesser extend in Europe (see chapter 3.3), operating wind projects with long-term power purchase agreements (PPAs) are becoming a highly attractive investment, since they generate stable dividends for investors [WPM 2015].

[14] In December 2014, Ørsted (then Dong Energy) ended its involvement in onshore wind with the divestment of its final share-holdings.

Table 6 Mergers, acquisitions and joint ventures in the wind energy sector since 2010

Note: A refers to Acquisition, M to Merger and JV to Joint Venture.
Rows highlighted in red correspond to European firms acquired by a foreign company. Rows highlighted in blue represent acquisitions of foreign companies by European players. Rows highlighted in green correspond to joint ventures between European and foreign firms.

Announcement year	Transaction	Company 1_ Buyer		Company 1_ Business/component	Company 2_ Target		Company 2_ Business/component
2010	A	Areva	FR	OEM	Multibrid (remaining 49%)	DE	OEM
2011	A	General Electric Co	US	Industrial conglomerate	Converteam	UK	Generator & converter manufacturer
2011	A	Clyde Blowers Capital	UK	Industrial engineering group	Moventas	FI	Gearbox manufacturer
2011	A	Toshiba Corporation	JP	OEM	Unison Co., Ltd. (40%)	KR	OEM
2012	JV	TPI Composites, Inc.	US	Blades manufacturer	ALKE INSAAT	TU	Blade manufacturer
2012	A	Prysmian	IT	Cable supplier	Global Marine Systems Energy (GME)	UK	Offshore cable installation
2012	A	Hitachi	JP	OEM	Fuji Heavy Industries (wind-turbine business)	JP	OEM
2012	A	MingYang (China Ming Yang Wind Power Group Ltd)	CN	OEM	GWPL (Global Wind Power Limited)	IN	OEM
2012	A	Titan Wind Energy (Suzhou) Co. Ltd.	CN	Tower manufacturer	Vestas (Tower business in DK)	DK	OEM
2013	A	Eiffage Group	FR	Construction group/Foundation supplier	Smulders, Lemants, Willems, Spomasz (Smulders Group)	NL	Offshore foundation and tower manufacturer
2013	A	Moventas	FI	Gearbox manufacturer	David Brown (gearbox business)	UK	Gear systems manufacturer
2013	JV	Vestas Wind Systems A/S (50%)	DK	OEM	Mitsubishi Heavy Industries (MHI) 50%	JP	OEM
2013	A	Toshiba Corporation	JP	OEM	Sigma Power Janex Co., Ltd.	JP	Developer/Operator
2014	JV	Gamesa (50%)	ES	OEM	Areva (50%)	FR	OEM
2014	JV	Bladt Industries	DK	Offshore foundation manufacturer	EEW Special Pipe Constructions GmbH (EEW SPC)	DE	Offshore foundation manufacturer
2014	A	Van Oord	NL	Offshore installation	Ballast Nedam	NL	Offshore installation
2014	A	GeoSea (DEME group)	BE	Offshore installation	HOCHTIEF (offshore assets)	DE	Construction group
2014	A	General Electric Co	US	OEM	Alstom Wind (power and grid business)	FR	OEM
2014	JV	General Electric Co (50%)	US	OEM	Alstom Wind (offshore wind business) 50%	FR	OEM
2014	A	Yaskawa	JP	Motion control and robotics	The Switch	FI	Generator manufacturer

Source: JRC M&A-Wind energy database (last update in July 2019)

Table 6 Mergers, acquisitions and joint ventures in the wind energy sector since 2010 (continued)

Note: A refers to Acquisition, M to Merger and JV to Joint Venture.
Rows highlighted in red correspond to European firms acquired by a foreign company. Rows highlighted in blue represent acquisitions of foreign companies by European players. Rows highlighted in green correspond to joint ventures between European and foreign firms.

Announcement year	Transaction	Company 1_ Buyer		Company 1_ Business/component	Company 2_ Target		Company 2_ Business/component
2015	A	Centerbridge Partners, L.P.	US	Investment firm	Senvion SE	DE	OEM
2015	A	ZF Wind Power	DE	Gearbox manufacturer	Bosch Rexroth AG (industrial gears and wind turbine gearbox segments)	DE	Manufacturer and assembler of hydraulics, electric drives and controls, gear technologies
2015	M	CSR Qishuyan Institute	CN	Gearbox manufacturer	CNR (named as CRRC Wind Power (Shandong) after the merger)	CN	Gearbox manufacturer
2015	A	GE Renewable Energy	US	OEM	Blade Dynamics	UK	Blade Manufacturer
2015	M	Nordex	DE	OEM	Acciona Windpower	ES	OEM
2015	A	Vestas Wind Systems A/S	DK	OEM	UpWind Solutions	US	Independent Service Provider
2015	A	Cheung Kong Infrastructure Holdings (CKI) and Power Assets Holdings	CN	Developer/Operator	Iberwind	PT	Developer/Operator
2015	A	CSR Times Electric	CN	Industrial conglomerate	Soil Machine Dynamics	UK	Advanced underwater machines
2015	A	Vestas Wind Systems A/S	DK	OEM	Modular Wind Energy, Inc. (ModWind)	US	Blade manufacturer
2016	JV	DEME Group	BE	Offshore installation	COSCO Shipping	CN	Offshore installation
2016	M	Siemens Wind Power	DE	OEM	Gamesa	ES	OEM
2016	A	Royal Boskalis Westminster N.V. (Boskalis)	NL	Offshore installation	VolkerWessels (offshore business consisting of VBMS, Stemat and VSI)	NL	Offshore cable installation vessels and foundations
2016	A	Nidec Corporation	JP	Generator manufacturer	Leroy-Somer	FR	Generator manufacturer
2016	A	Van Oord	NL	Offshore installation	Bilfinger Marine & Offshore Systems	DE	Offshore foundation installation
2016	A	NKT Cables	DK	Export cables	ABB (High voltage export cable business)	CH	Technology firm
2016	A	Siemens Gamesa	DE -ES	OEM	Adwen (50% Areva share)	DE	OEM
2016	A	General Electric Co	US	OEM	LM Wind Power Holding A/S	DK	Blade manufacturer
2016	A	Senvion SE	DE	OEM	Euros Group	DE	Blade Manufacturer
2016	A	China Three Gorges	CN	Developer/Operator	WindMW (80%)	DE	Developer
2016	A	Envision Energy	CN	OEM	ViveEnergia (portfolio of 600MW of projects)	MX	Developer

Source: JRC M&A-Wind energy database (last update in July 2019)

Table 6 Mergers, acquisitions and joint ventures in the wind energy sector since 2010 (continued)

Note: A refers to Acquisition, M to Merger and JV to Joint Venture.
Rows highlighted in red correspond to European firms acquired by a foreign company. Rows highlighted in blue represent acquisitions of foreign companies by European players. Rows highlighted in green correspond to joint ventures between European and foreign firms.

Announcement year	Transaction	Company 1_ Buyer		Company 1_ Business/component	Company 2_ Target		Company 2_ Business/component
2016	A	Senvion SE	DE	OEM	Kenersys India Pvt Ltd	IN	OEM
2016	A	Vestas Wind Systems A/S	DK	OEM	Availon	DE	Independent Service Provider
2017	A	China State Grid group	CN	Developer/Operator	CPFL Energias Renovaveis	BR	Operator
2017	A	Nordex	DE	OEM	SSP Technology	DK	Blade Manufacturer
2017	A	GeoSea (DEME group)	BE	Offshore installation	A2Sea (owned by DONG Energy and Siemens)	DK	Offshore installation
2017	M	Fred Olsen Windcarrier AS	DK	Offshore installation	Global Wind Service, Natural Power and Zephir Lidar	DK/UK/UK	Independent Service Providers
2017	A	EEW Special Pipe Constructions GmbH (EEW SPC)	DE	Offshore foundation manufacturer	Offshore Structures Britain Ltd. (OSB) (Bladt Industries' share)	UK	Offshore foundation manufacturer
2017	A	Enercon	DE	OEM	Lagerwey	NL	OEM
2018	A	Vestas Wind Systems A/S	DK	OEM	Utopus Insights, Inc.	US	Energy analytics and digital solutions
2018	A	General Electric Co	US	OEM	Alstom Wind (remaining 50% of the joint venture for offshore wind)	FR	OEM
2018	JV	Cwind (Global Marine Group)	UK	Cabling provider and asset management services	International Ocean Vessel Technical Consultant (IOVTEC)	TWN	Survey and crew transfer vessel (CTV) service provider
2018	A	Ørsted	DK	Offshore wind developer	Deepwater Wind	US	Offshore wind developer
2018	A	Ørsted	DK	Offshore wind developer	Lincoln Clean Energy	US	Onshore wind and solar PV developer
2019	JV	Taaleri Energia	FI	Developer and fund manager	Masdar	AUH	Utility/Developer
2019	A	Enel Green Power	IT	Developer/Operator	Tradewind Energy	US	Developer/Operator
2019	A	Fred Olsen Ocean	NO	Marine services company	United Wind Logistics (UWL)	DE	Offshore logistics (50%)
2019	JV	EDP (offshore wind business)	PT	Developer/Operator	Engie (offshore wind business)	FR	Developer/Operator
2019	JV	Fortum	FI	Developer/Operator	Nordkraft	NO	Developer/Operator

Source: JRC M&A-Wind energy database (last update in July 2019)

3.2 Component manufacture market

The European manufacturers capture around 35 % of the global wind turbine value chain (Figure 26), only superseded by Chinese players who dominate the global manufacturing of components with almost 50 %. The European wind industry has high manufacturing capabilities in components with a high value in wind turbine cost (towers, gearboxes and blades), as well as in components with synergies to other industrial sectors (generators, power converters and control systems).

Additionally, the European manufacturers show overcapacities in all key wind turbine components, when compared to the present and future European demand, at deployment rates between 12.1 and 22.7 GW/year. Expected deployment rates at global level also suggest an additional market potential for European manufacturers outside the EU [Magagna et al. 2017].

As shown in Figure 27, most of the European manufacturing facilities are in Germany, Spain (the MSs with the largest installed wind power capacity) and Denmark (the MS with the largest share of wind energy in its electricity demand). The highest number of facilities is estimated to assemble nacelle components followed by blade and tower manufacturing facilities.

In Europe, the main vendors usually locate their manufacturing facilities not only in vicinity of their headquarters, but also in those countries where they supply wind turbine components and services. In this sense, the German and Danish OEMs have expanded to other European markets. Nordex SE, Enercon GmbH, Senvion SE and Siemens AG have spread their manufacturing facilities to big markets such as Spain, the United Kingdom, and France, among others, but also to smaller markets such as Portugal, Sweden, Belgium, and Romania. The Danish wind turbine manufacturer Vestas Wind Systems and blade supplier LM Wind Power A/S have also installed facilities not only in Denmark, but also in Spain, Germany, and the United Kingdom, among others.

Although showing strong presence on a worldwide level, European activities of Spanish vendors are more concentrated in their national market, where they have installed most of their manufacturing facilities. Similarly, smaller OEMs (such as Eólica del Zenete SL and Gestamp Wind Steel SL) tend to locate their facilities around their headquarters.

Some of the leading non-EU OEMs have located part of their manufacturing facilities close to their supply areas in Europe (Goldwind (located in Germany), GE Wind Energy (the UK) and Suzlon (Spain)) (see Figure 28).

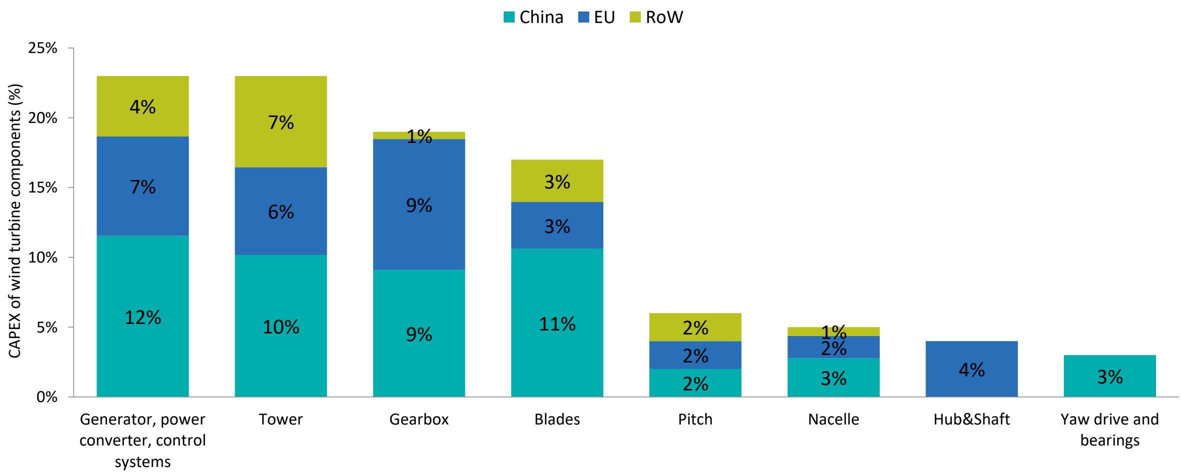
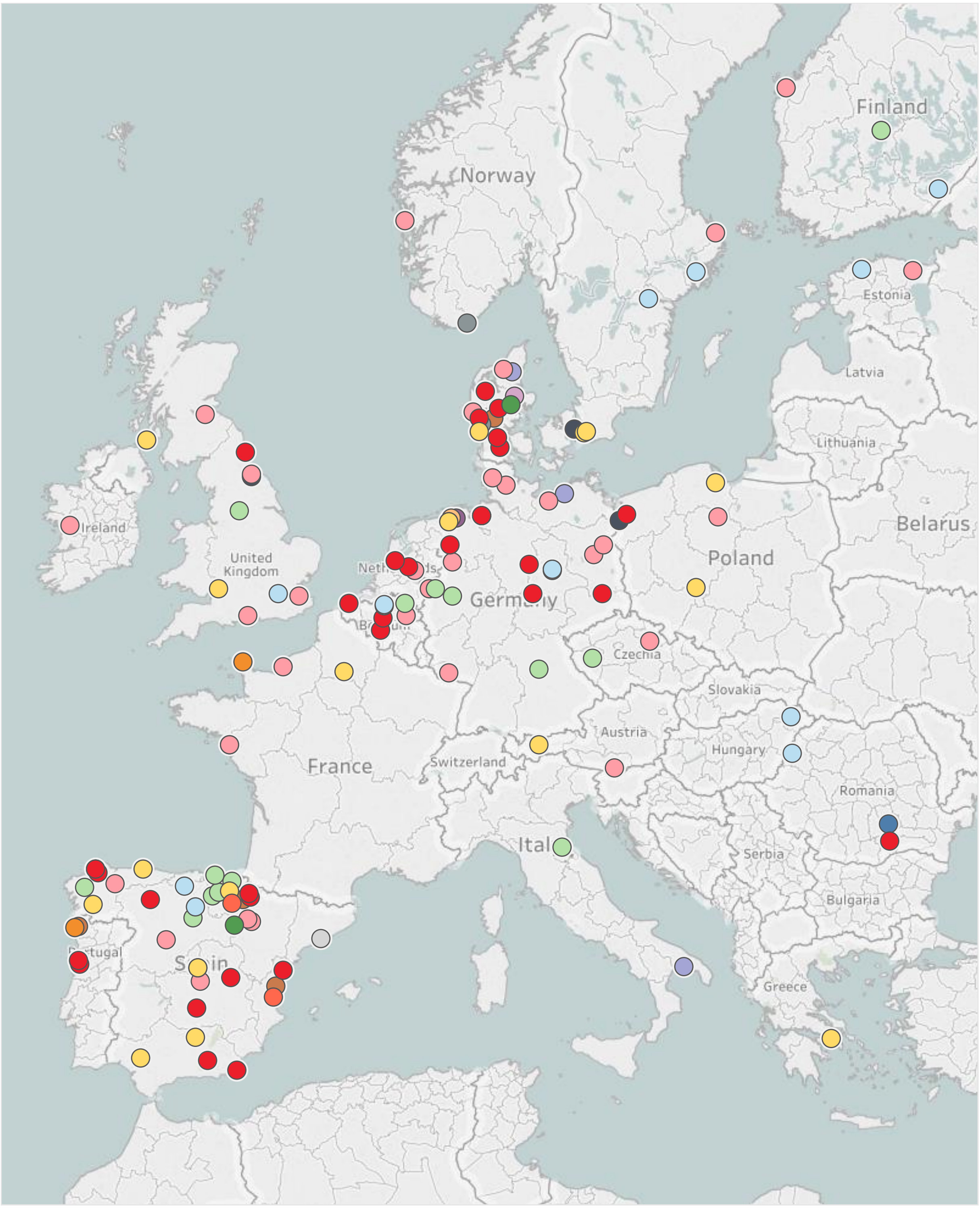


Figure 26 Manufacturing capabilities (MW) of European and Chinese manufacturers for each wind turbine component based on their CAPEX. **Note**: The location considered corresponds to the country where the headquarters of the manufacturer is placed. If the manufacturer is a subsidiary, the country of the subsidiary is considered instead of the country of the headquarters of the parent company.
Source: JRC Wind Manufacturing Facilities Database 2018. CapEx data based on [NREL 2017]



WIND TURBINE COMPONENTS

- Generators
- Power converters
- Control systems
- Towers
- Gearboxes
- Blades
- Nacelle Assembly
- Hubs & Shafts
- Bearings
- Foundations
- Foundry
- Blades & Generators
- Blades & Towers
- Blades & Nacelle Assembly
- Generators & Nacelle Assembly
- Hubs & Shafts & Nacelle Assembly
- Spare Parts & Repair
- Spare Parts & Repair & Nacelle Assembly

Figure 27 Manufacturing facilities of wind OEMs in the EU28 according to wind turbine component produced
Source: JRC Wind Manufacturing Facilities Database 2018

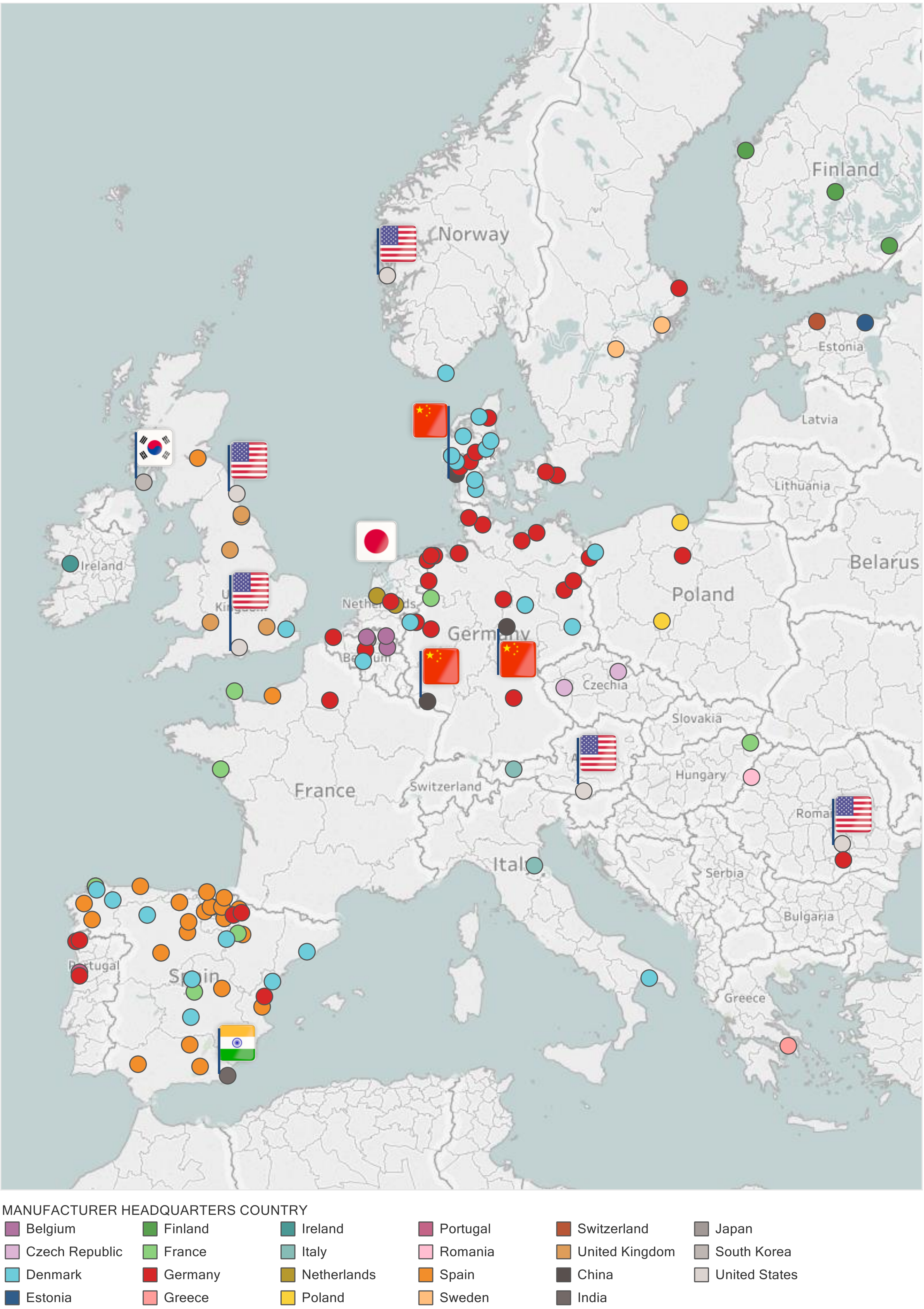


Figure 28 Manufacturing facilities of wind OEMs in the EU28 based on their country of origin
Note: The location considered corresponds to the country where the headquarters of the manufacturer is placed. If the manufacturer is a subsidiary, the country of the subsidiary is considered instead of the country of the headquarters of the parent company. Non-EU facilities are marked with flags.
Source: JRC Wind Manufacturing Facilities Database 2018

In the following subsections the markets on wind components holding the highest value (generator, tower, gearbox and blades) and the markets on offshore specific components are analysed. For each of the main components the market activity of companies inside and outside their home market is analysed.

3.2.1 Generator, power converter, control systems

Geared-wind turbines with DFIGs (Doubly-Fed Induction Generators) dominate the worldwide market representing around 42 % of cumulative capacity installed by 2017, followed by EESGs (Electrically Excited Synchronous Generators) with around 30 %.

Although most leading OEMs manufacture power generators in-house, independent generator suppliers supply more than one third of the market.

Most generator companies originate from China and the EU28, with the latter being present in China, the United States and the rest of world-markets (mainly India, Brazil) abroad. Similarly, US manufacturers (GE and TECO Westinghouse) seek opportunities outside their home market (Figure 29).

The offshore wind generator market is currently dominated by geared-wind turbines with SCIGs (Squirrel Cage Induction Generators) and full power converters (Siemens), as well as geared-wind turbines with DFIG (Siemens, MHI Vestas and Senvion). However, next generation turbines are expected to increase the penetration of configurations with PMSGs (Permanent Magnet Synchronous Generators), since more and more powerful generators with a reduced size and weight will be demanded [JRC 2017b]. EU companies are ahead of their competitors in providing offshore generators of all power ranges, due to a well-established European offshore market, and the larger average size of newly installed turbines (see Figure 30).

Some European manufactures are already working on 10 MW and 12 MW designs. MHI Vestas has already unveiled the world's first 10 MW offshore wind turbine, with first deliverables expected in 2021 and SGRE expects to unveil the first 12 MW-plus design within a year [RECHARGE 2018a, WPO 2018b]. Senvion is developing a 12MW-plus platform under an EC H2020-supported research project (ReaLCoE) and plans to install a prototype onshore around mid-2020, followed by an offshore demo in 2021.

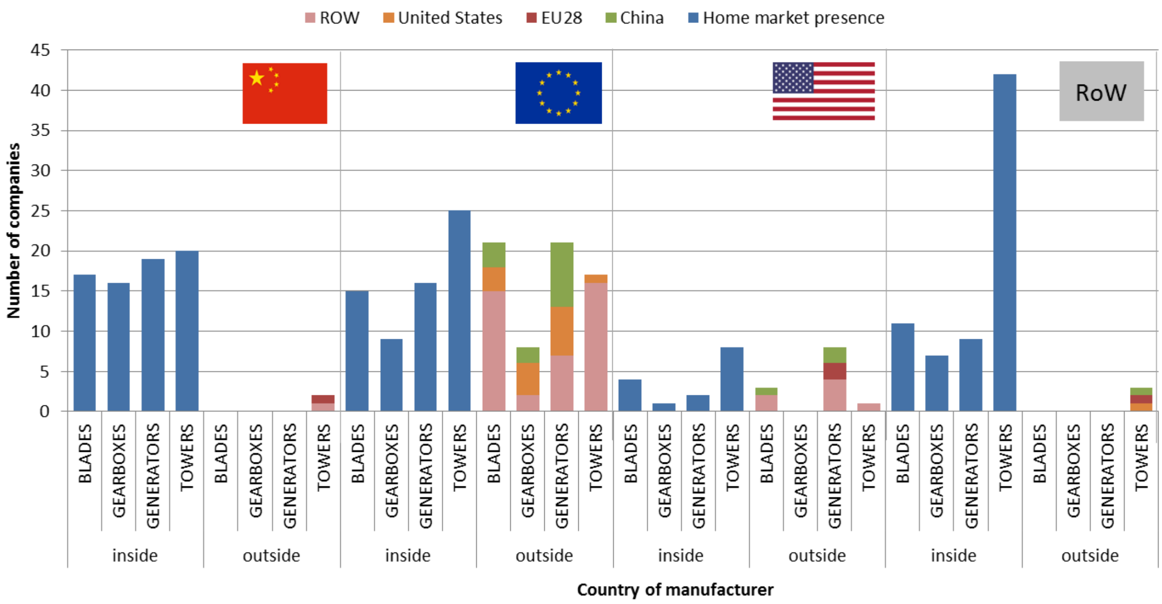


Figure 29 Number of companies manufacturing main wind energy components and their market presence within their home market and abroad. Note: If one company has multiple presences in one foreign market, its presence in that market is counted as one. Source: JRC

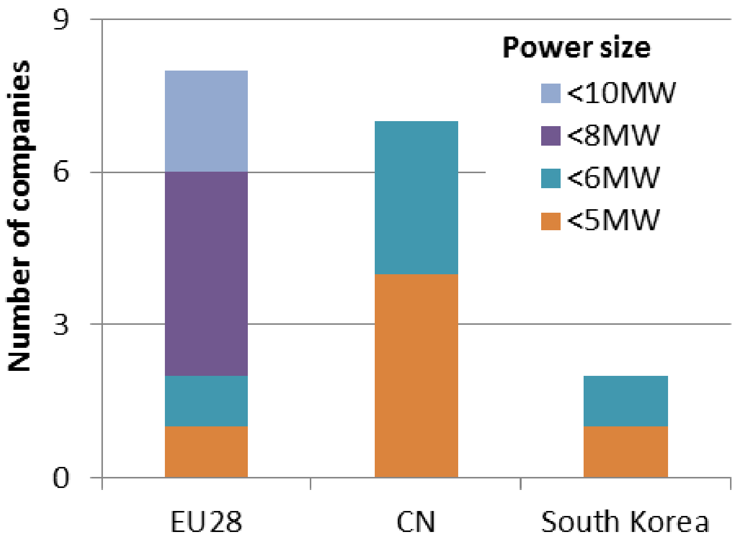


Figure 30 Number of offshore generator companies and range of provided generator sizes.
Source: JRC and [FTI Consulting 2016a].

US and Chinese players do not want to fall behind. GE aims to supply its first Haliade-X 12 MW nacelle for demonstration in 2019, and the leading Chinese wind turbine generator maker, CRRC Yongji, has revealed that it is developing a 10 MW offshore wind turbine, which will be launched by the end of 2019, becoming the largest offshore wind generator produced in Asia to date [RECHARGE 2018b, Renews 2018, WPO 2018c].

Apart from Envision (CN), the top 10 turbine OEMs (see chapter 3.1.1) have manufacturing capabilities of power converters in-house. Additionally, there are approximately 25 independent suppliers based in Asia Pacific, 11 in Europe (e.g. ABB (CH) and Ingeteam (ES)) and six in North- and South-America. Power converters for the offshore wind market are predominantly manufactured in-house by the market leaders Vestas (DK) and Siemens (DE). Only 25 % of the offshore market is supplied by independent manufacturers [FTI Consulting 2016a].

Control systems are predominantly manufactured in-house, since OEMs tend to protect the Intellectual Property of this component.

3.2.2 Towers

Currently the global tower market is facing overcapacities, a trend that is expected to continue in the short-term for European and Chinese markets (Figure 31). Being a low-tech component, manufacturing is mostly sourced locally following wind energy deployment.

In offshore wind only a limited number of tower manufacturers exist, due to high technical requirements (anti-corrosion techniques and O&M solutions). Again, the component is sourced locally, with European manufacturers being based in the main offshore wind markets (Denmark, Germany), or emerging markets (China, Indonesia, South Korea, Taiwan). Notably in Taiwan manufacturers, such as MHI Vestas or SGRE, have signed agreements to source towers locally, in order to meet the Taiwanese Government's demands for local cooperation [WPO 2018d, WPO 2018e].

3.2.1 Gearbox

The Top 10 OEMs use geared drive trains, with the exception of Enercon and Goldwind, who manufacture direct drive turbines, and SGRE offshore turbines which are also gearless. Within the gearbox market all major OEMs outsource gearbox production, with the exception of SGRE. An increasing number of M&As and a shift in the Chinese market to higher quality products led to consolidation of the gearbox market, with about 24 independent suppliers today [FTI Consulting 2016c].

In 2015, a record year for the Chinese market, the world's largest gearbox supplier, in terms of delivery, was the Chinese firm NGC. The European market is led by the German supplier ZF. The main strategy of the gearbox suppliers consists of achieving higher torque densities, in order to drive down gearbox unit mass and cost. In this context, ZF has recently presented the Shift 6k gearbox platform, which holds the wind industry's torque density record at 175 Nm/kg [WPM 2018o].

Similarly to generators, European manufacturers (SGRE, ZF, Winergy, Moventas OY) are present in the markets of China, the United States and India (see Figure 29).

The offshore wind energy market could become challenging for gearbox suppliers, as direct drive configurations are gaining momentum (e.g. Siemens using the direct drive PM for its offshore platforms) [FTI-Consulting 2017, SiemensGamesa 2019].

As shown in Figure **32**, European companies are leading in number and offered product range, as offshore deployment mostly occurs in European waters. However, new entrants are emerging especially in the Asian markets (China, India, Japan).

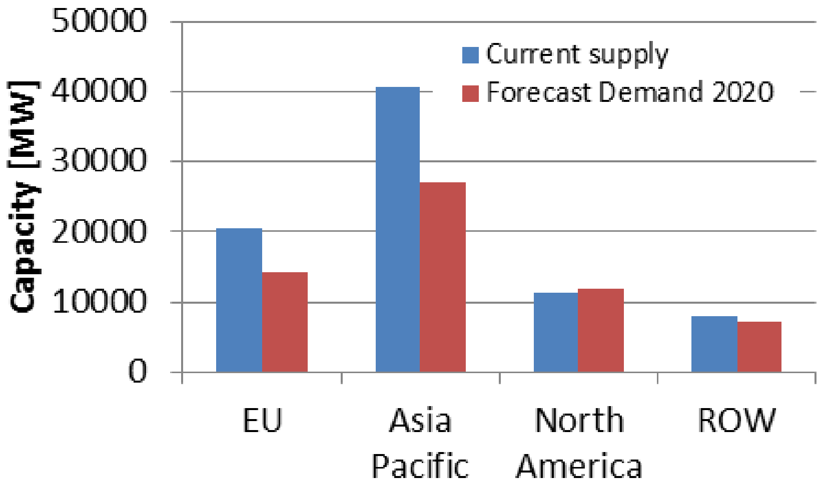


Figure 31 Current tower supply and forecasted demand for 2020.
Source: JRC and [FTI Consulting 2016b].

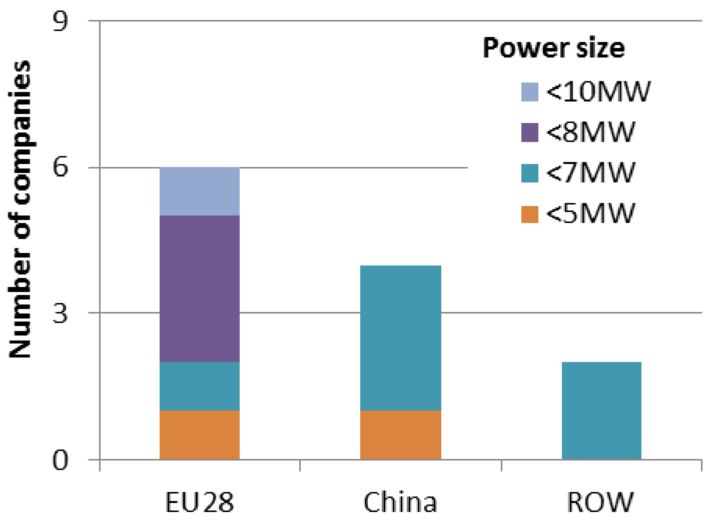


Figure 32 Number of offshore gearbox companies and range of provided gearbox sizes.
Source: JRC and [FTI Consulting 2016c]

3.2.2 Blades

Currently there are about 20 OEMs in the world manufacturing blades in-house and supplying around half of the global demand for blades. Vestas, SGRE, Enercon and Senvion are the in-house manufacturers with the strongest global presence. Around 30 independent blade manufacturers meet the remaining demand with LM Wind Power (DK), Sinoma Wind (CN) and TPI Composites (US) being ahead [FTI Consulting 2016d].

More than half of the independent suppliers are Chinese, focusing on the supply of their domestic market (Figure 29). However, there is evidence that suggests that China is also seeking emerging markets abroad, such as the OEM Dongfang aiming to build a blade factory in Russia [WPM 2018p]. European blade manufacturers have a larger presence in the foreign market, with manufacturing facilities installed in all major markets, and LM Wind Power (DK) being the world's largest independent supplier.

Within the market of blades, there is a trend towards outsourcing (as a consequence of the market growth in China) and market consolidation (e.g. GE's acquisition of LM Wind Power) [WPM 2018q]. Outsourcing can be performed in dedicated collaborative supplier models (e.g TPI Composites) in which blade suppliers dedicate capacities at their facilities (with specific precision moulds) to OEMs in exchange for their commitment to purchase minimum annual volumes [TPI 2019].

3.2.3 Offshore wind – Main components

Europe's offshore wind industry is leading the sector, driven by a strong home market that accounts for about 91 % of the worldwide offshore capacity fully commissioned by mid2016.

Foundations

As shown in Figure 33, monopile foundations dominate the European market (74 % of total capacity installed), followed by other concepts such as tripods, tripiles and jacket structures. Leading European foundation suppliers (e.g. EEW, Bladt Industries, SIF Group, Eiffage Group) are located in the North Sea and Baltic Sea countries, and stay abreast of the ongoing trend towards next generation turbines by providing XL monopiles (diameter up to 10 m and 120 m length) to the market. Currently China mainly applies monopiles and other piled foundations (e.g. high-rise pile caps) at its offshore wind projects. In recent years, China saw a strong increase in the number of foundation suppliers, with ZPMC and Jiangsu Haili in the lead.

Due to the increased number of projects being installed in deeper waters, and farther away from shore, jacket foundations and gravity base foundations are becoming more popular. In Europe, 19 projects with jacket foundations were being developed or under construction since 2013. So far only a few gravity based foundations are installed at smaller and demonstration projects (e.g. Blyth Demonstrator project [OW 2017a]).

Substations

Offshore wind substations, transforming the power generated to grid voltage, mainly use HVAC as the benefits of current HVDC technology (i.e. minimized losses) are displaced by higher costs and system complexity, such as construction of substation topsides. European manufacturers (CGSD, Siemens PTS, ABB, GE Grid Solutions[15]) lead the worldwide market of the main electrical components of HVAC and HVDC. Shortage in supply might only come from unforeseen increased demand from other sectors. About 55 % of offshore wind substations use jacket foundations. Manufacturing of substation foundations is outsourced to the aforementioned foundation suppliers.

[15] GE Grid Solutions (FR) formerly AlstomGrid

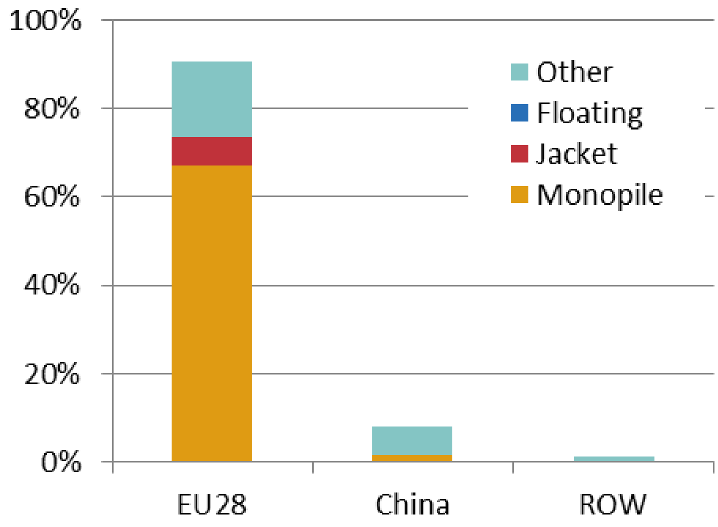


Figure 33 Market share by capacity in offshore wind and foundation type installed by mid-2016. Source: JRC

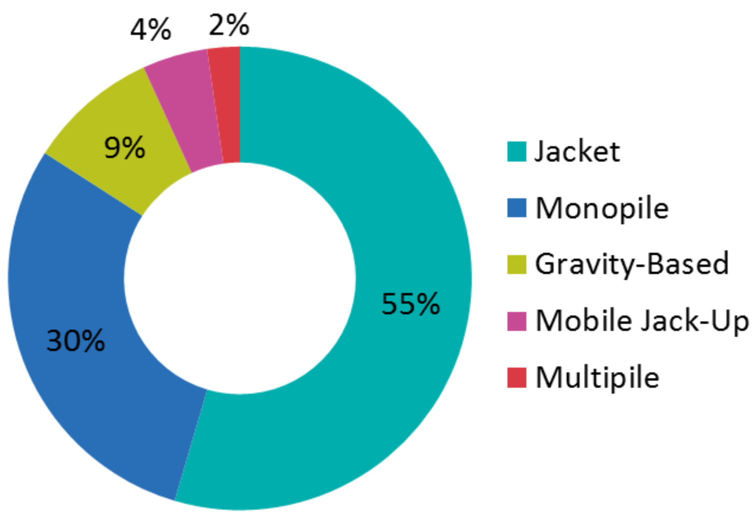


Figure 34 Share of substation support structures (commissioned projects by 2017). Source: JRC

Offshore wind cables

The demand for cables includes array cabling connecting wind turbines, as well as export cables connecting wind parks to the shore. For both sub-technologies more than 10 European cable manufacturers supply products and have recently increased their capacities to meet EU demand. Outside Europe, Asian suppliers from China, South Korea and Japan show capabilities in offshore wind cabling.

With respect to export cables the European manufacturers ABB (CH), Nexans (NO) and Prysmian (IT) are the global market leaders. The smaller HVDC export cable market is supplied by two manufacturers only: Prysmian and NSW (DE).

Array cabling currently undergoes a shift from 33 kV towards 66 kV cabling. Most companies seem capable to undertake this shift; however, lengthy processes towards product commercialisation might result in bottlenecks.

Notably, some of the Asian manufacturers also entered other markets such as LS Cable & System (KR) providing the array cabling to the Kriegers Flak OWF (DK) and the Block Island OWF (US).

Offshore wind installation vessels

The offshore wind industry uses jack-up vessels and heavy-lift vessels to install wind turbines, foundations, transition pieces and substations. The move towards wind turbines with higher capacity, longer blades, higher towers, and XL foundations capable to operate at deeper waters, resulted in a significant increase of the vessels' weight and size, a trend that is expected to continue in the mid-term. The decisive figures of a vessel are its size and crane capacity, with the latter being currently upgraded at more and more vessels. Compared to crane capacities in 2010 of about 800 t, current crane standard capacities range between 900 t to 1 500 t. In the short term industry expects crane sizes of 1 800 t to be the norm [NEU 2016]. At the same time, the downturn of the oil industry made more vessels available for the offshore wind market (e.g. vessels from Jumbo Offshore), which led to disinvestments of first-generation vessels.

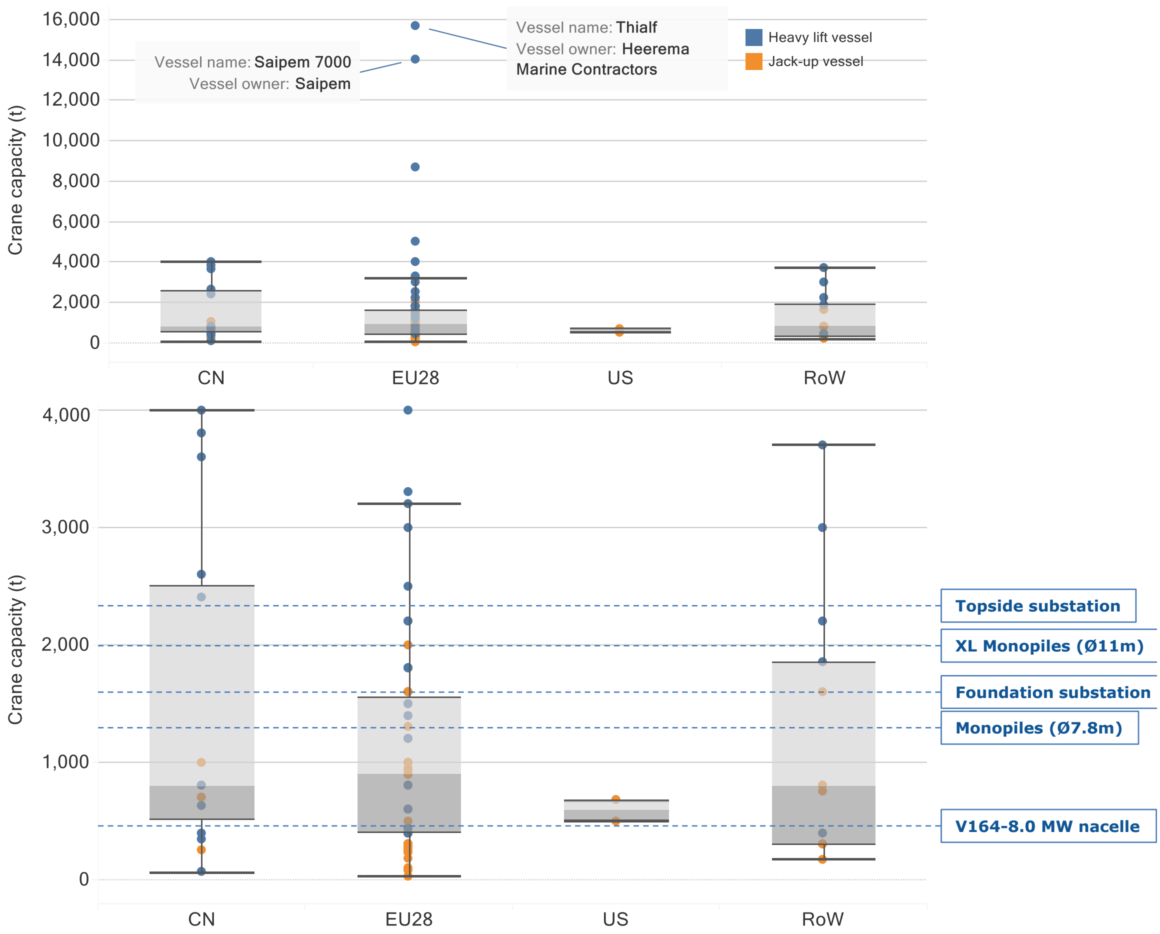


Figure 35 Crane capacity of offshore wind installation vessels (jack-up and heavy lift vessels) (top) and comparison against weight of main offshore wind components (bottom).
Note: Substation numbers based on Nordsee 1 substation. Note: Boxplots represent crane capacity range; blue dotted lines indicate the weight of standard offshore components.
Source: JRC and [FTI Consulting 2016e]

The market for installation vessels is clearly dominated by European companies, being home to more than 80 vessels also covering the broadest crane capacity range. This includes the heavy-lift vessels with the highest crane capacity Saipem 7000[16] (14 000 t) and Heerema's Thialf (15 652 t). In Europe, but also globally, increased crane capabilities will especially be needed in the area of

[16] The first move of the fossil-fuel player Saipem into the offshore wind turbine installation market was at the Hywind project in Scotland for Equinor [WPM 2018ae].

foundations, where current monopiles (ranging at about 1 200 t) are already reaching the limits of most vessels. Future XL monopiles weighing 2 000 t are already in the pipeline, and could lead to bottlenecks in vessel availability [OW 2017b]. Similarly, the installation of weighty offshore substations (foundations and topsides) requires heavy-lift vessels with significant crane capacity (Figure 35).

No bottlenecks are expected in the Chinese market, although a future surge in offshore wind installations might be challenging with respect to skilled workforce.

The US have about 12.5 GW offshore capacity in the pipeline. As such, a significant number of installation vessels will be needed (see Figure 35) which have to be compliant with the Jones Act[17] [Douglas-Westwood 2013] [DWW 2015] [GWEC 2018]. Currently, US-based Aeolus Energy and Ulstein Design & Solutions (NL) plan to build an US fleet of jack-up vessels capable of carrying the next generation of 10-12 MW turbines, cable-laying ships, and service and crew transfer boats [WPO 2018f, WPO 2018g].

In the RoW, Japan and Taiwan are finding themselves in challenging positions with respect to offshore wind installation vessels. Japan's shortage in installation vessels led to the construction of a multi-purpose self-elevating platform vessel being built by Japan Marine United Corporation (JMU) for Penta-Ocean Construction. The vessel will operate with an 800 t pedestal mounted crane (PMC) delivered by Huisman Equipment (NL) [OW 2016] and is expected to be completed at the end of 2018. In Taiwan the absence of installation vessels resulted in A2SEA becoming the first European installer in the Asian offshore wind market [WPO 2015].

3.3 Emerging players, markets & trends

3.3.1 Corporate power purchase agreements (PPAs)

With wind energy becoming increasingly competitive as compared to electricity wholesale market prices, more and more industrial consumers make use of power purchase agreements (PPAs)[18] to cover their energy demand with renewable electricity (see Figure 36). For project developers PPAs can be seen as a vehicle for additional investments with predictable income flows.

The latest proposal for a revised Renewable Energy Directive, encourages MSs to remove administrative barriers to long-term corporate power purchase agreements to finance renewables and facilitate their uptake. Moreover it further highlights the importance of Guarantees of Origin (GO)[19] making PPA traceable [EC 2017c] [EC 2018c].

In Europe, the majority of the corporate PPA capacity signed can be found in Norway, Sweden, the Netherlands and the United Kingdom. Among the identified buyers signing wind-PPAs, industry corporations, associations as well as companies from various high-tech sectors (e.g. biotech, telecommunication, social media, IT, automotive and healthcare, among others) can be found. In total 4.8 GW of wind-PPAs have been signed since 2000, peaking in the last three years with power deals above 1 GW annually [BNEF 2018]. 2018 could bring a new record in wind-PPAs, mainly driven by the long term agreements (up to 29 years) of Norsk Hydro (DK) and Alcoa (US), both major aluminium producers. [WPM 2018r, WPM 2018s, WPM 2018t]

---

[17] The Jones Act (also Merchant Marine Act) requires any vessel transporting cargo between U.S. ports be built and flagged in the U.S. [US Statutes 1920]. Foreign-flagged installation vessels will have to be supported by various Jones Act-compliant feeder barges and other support vessels when operating on US wind farm projects [GMSC 2017].

[18] PPA means a contract under which a legal person agrees to purchase renewable electricity directly from an energy generator.

[19] The GO-instrument labels electricity from renewable sources, to provide information to electricity customers on the source of their energy.

With three companies among the Top10, leading players from the digital economy are seeking wind-PPAs to decrease their electricity costs and carbon emissions. Google LLC, who aimed to cover 100 % of its energy demand with renewable energy by 2017, has signed wind-PPAs in four European countries (FI, NL, NO, SE) including the latest deal on the 81 MW Hedet wind farm to power its datacentre in Hamina/Finland [WPM 2018u]. Similarly, Facebook has chosen PPAs as an instrument to power its datacentres in Ireland and Norway, involving deals with a capacity of 150 MW and 294 MW respectively [RN 2016, WPM 2018v]. Furthermore, Microsoft signed wind PPAs in the Netherlands and Ireland with a combined capacity of 217 MW [RN 2017, WPM 2017f].

In offshore wind, PPAs concentrate in Denmark and the Netherlands. In Denmark wind energy from the Horns Rev and Vattenfall's Kriegers Flak project was sold under a PPA to Norsk Hydro (DK) and the biotech company Novozymes (DK) [OW 2018a]. In the Netherlands, the university TU Delft, Unilever and the railway association Vivens secured offshore wind PPAs stemming from the Luchterduinen and Westermeerwind project [OW 2017c] [NS 2018].

A substantial increase of PPAs can be expected from markets with an ageing wind fleet. Wind farms leaving a national support scheme will either have to be decommissioned or forced to seek alternative ways to sell their electricity. Some examples of PPAs with wind farms leaving a support scheme can be found in Germany, such as the deals signed by Greenpeace Energy (9 MW) and Statkraft (41 MW). Both companies signed PPAs with citizen wind projects leaving 20-year support system of the renewable energy act (EEG) from 2020 onwards [WPM 2018w].

3.3.2 Digitalisation

Digitalisation in wind energy encompasses data-based services and tools that facilitate system integration, improve forecasting, or aim at reducing the costs of wind energy along the value chain.

Digitalisation in manufacturing especially targets the traceability of data in production processes to optimise the assembly of wind turbines. Based on already established truck-manufacturing processes, SiemensGamesa Renewable Energy (SGRE) implemented Cuxhaven factory a just-in-sequence system to minimise production failures in its nacelle assembly. Moreover, a transport-logistics solution was implemented involving remotely controlled self-propelled modular transporters (SPMTs) capable to move complete pre-commissioned nacelles from the end of the assembly line into specialised "roll-on/roll-off" (ro-ro) vessels [PEI 2018, WPM 2018x].

Automated inspection techniques are becoming increasingly attractive in order to decrease O&M costs and preventive maintenance planning. It is estimated that the market for automated drone inspection in wind could become USD 1 billion (around EUR 878 million) industry [WPM 2016b]. As a consequence of the increasing market for automated inspection vehicles, SGRE decided to bundle its activities in a dedicated drone platform. First developments include an inspection drone and a service robot capable to monitor, clean, and repair blades. SGRE formed cooperation with Skyspecs Drones, a company offering fully automated drone solutions, including a cloud-based software solution. On the blade service robot SGRE formed a cooperation with Rope Robotics, a company launched by former SGRE employees [OW 2018b, WPM 2018y]. With respect to offshore wind, a consortium of robotics companies (Perceptual Robotics/ASV Global/Vulcan UAV) was awared a EUR 1.35 million UK grant to further develop their inspection drones towards extreme working environments [WPM 2017g, PR 2018]. Likewise, below sea level autonomous vehicles are an option to decrease O&M costs and increase safety. Blueye Robotics, a spin-off from NTNU, developed an underwater drone for cable inspection of wind arrays capable to operate in depths up to 150 m [WPO 2017].

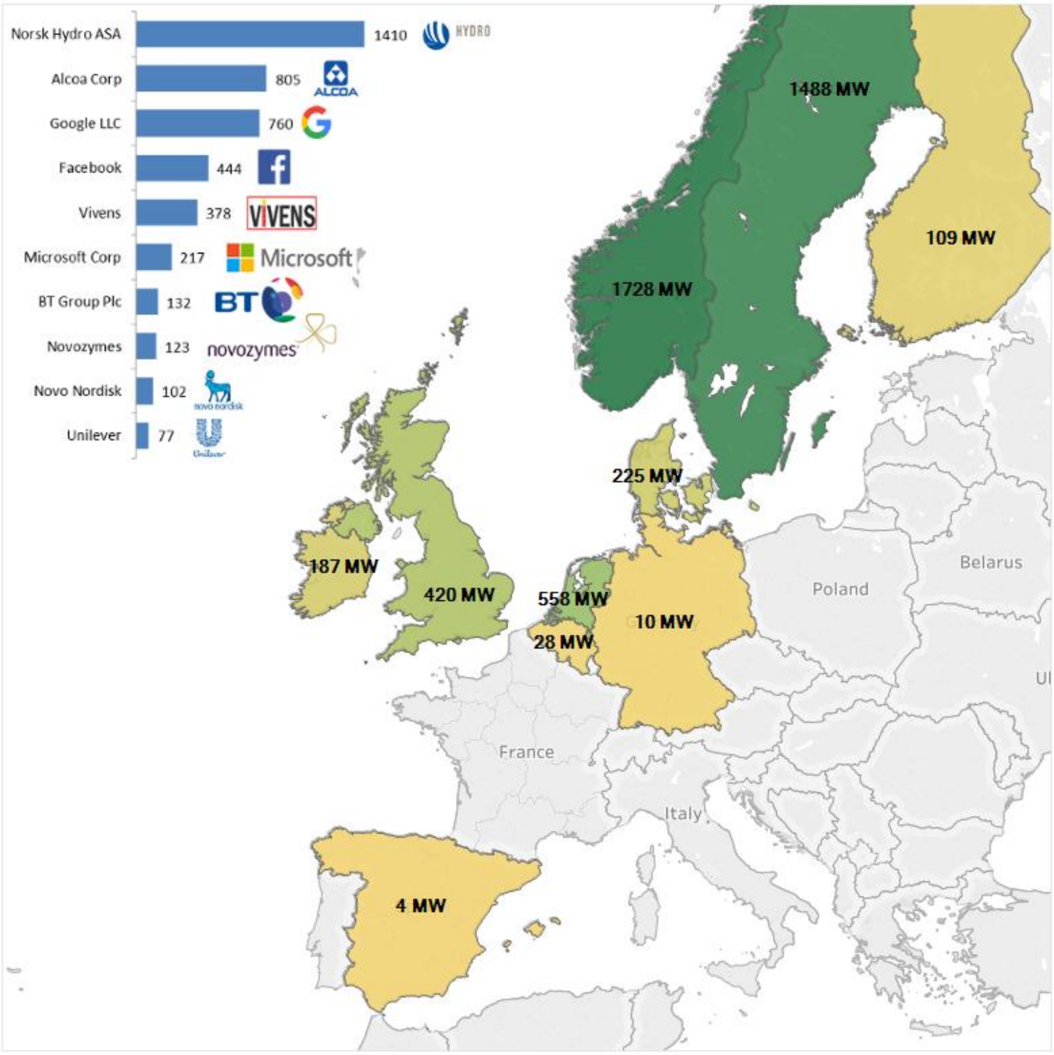


Figure 36 Signed capacity of corporate wind power purchase agreements (PPA) in Europe and Top10 buyers (end of 2018). Source: JRC

In trading, first initiatives of blockchain technology allow wind turbine operators to sell energy directly to their customers. In Germany, a trading platform (Tal.Markt) owned by a public energy company allows customers to buy local wind energy from projects that left the EEG support scheme. Similarly, Statkraft and the service provider Esforin bypassed intraday wholesale trading platforms in its blockchain project 'Enerchain' by selling wind electricity to a customer. Large consumers might benefit from blockchain trading, as it allows them to react on short term price signals from the intraday market [WPM 2017h, WPM 2018z, WSW 2018].

Blockchain technology might also become relevant in future financing of wind assets. The start-up Datawatt Energy sees advantages in blockchain financing, especially in saving the fees associated with conventional financing and PPA fees. This could lead to a reduction in financing and development cost of about 20 %. Yet, as blockchain is still barely regulated, potential risks would be borne by the investor [WPM 2018aa].

More and more major industrial players and companies from the digital economy are interconnecting their industrial processes with digital services in so-called IIoT[20] platforms. Especially leading IT

[20] IIoT (Industrial Internet of Things): A system comprising networked smart objects, cyber-physical assets, associated generic information technologies and optional cloud or edge computing platforms, which enable

companies such as Amazon, Cisco, IBM, Microsoft and SAP are building their industrial internet platforms in which wind energy will be integrated. The specific capabilities of these platforms are hard to assess from the outside. Within the wind industry, GE and Siemens are cooperating with software companies for IIoT platforms (see Table 7), allowing them to deliver customised wind turbines including analytical solutions [WPM 2016c]. In China, the wind OEM Envision introduced its IIoT platform 'EnOS' to operate, connect and integrate all types of energy infrastructure and its wind analytics platform 'EnSight' offering data, analytics, and control of wind farms. Moreover, the Chinese turbine OEM has formed the 'Energy IoT and Smart City Technology Alliance', a cooperation with Microsoft, Arm Limited and Accenture which provide their integration services in terms of cloud computing and enterprise solutions. Goldwind, another Chinese OEM, was involved in the development of an IIoT platform for the Qinghai province in which wind energy plays an integral part. The so-called 'Qinghai New Energy Big Data Innovation Platform' is used to maximise renewable energy production, while minimising labour costs and turbine health monitoring. The independent supplier Empolis (DE) provides an industrial analytics platform focussing on service-diagnostics applications for wind energy. Among others this IIoT platform uses root-cause analysis, error prevention, data aggregation from multiple sources, text mining to interpret technicians' service reports in different languages and visual interaction to optimise in turbine service [WPM 2016c, Envision 2017, WPM 2017i, WPM 2018ab].

Table 7 Recent examples of digitalisation in the wind energy sector and wind energy in the digital economy. Source: JRC

Organisation	**Product/Service/Type of digitalisation**
Blueye Robotics	Autonomous underwater drone for cable inspection
Datawatt Energy	Blockchain financing of assets
Empolis Information Management GmbH	Industrial analytics platform
Envision Energy	IIoT platform 'EnOS' and 'EnSight energy analytics'
Facebook	Wind-PPA to power datacenters
GE & PTC Thingswork	Wind power integrated into an IIoT platform
Goldwind State Grid Qinghai Electric Power Company Tsinghua University	IIoT platform "Qinghai New Energy Big Data Innovation Platform"
Microsoft	Wind-PPA to power Microsoft cloud services
Perceptual Robotics ASV Global Vulcan UAV	Automated inspection drone for offshore wind
Siemens & Atos & RTI	Wind power integrated into an IIoT platform (Sinalytics)
SiemensGamesa RE	Traceability of data in the turbine assembly of production process (just-in-sequence materials flow system)
SiemensGamesa RE	Self-propelled modular transporters (SPMTs)
SiemensGamesa RE Rope Robotics	Automated blade-repair robot
SiemensGamesa RE Skyspecs Drones	Automated inspection drone
Soluna Brookstone Partners	Wind-PPA to power blockchain facilities for cryptocurrency mining
Statkraft Esforin	Blockchain-based trading platform 'Enerchain'
WSW Tal.Markt Axpo	Blockchain-based trading platform

real-time, intelligent, and autonomous access, collection, analysis, communications, and exchange of process, product and/or service information, within the industrial environment, so as to optimise overall production value. This value may include improving product or service delivery, boosting productivity, reducing labour costs, reducing energy consumption, and reducing the build-to-order cycle [Boyes et al. 2018].

In parallel to the digitalisation of the wind sector, wind energy is also seen as a preferential partner of the digital economy to provide competitive and low carbon energy. Examples of wind-PPAs between wind project owners and the digital economy cover agreements used to power datacentres for cloud computing services, data storage, social media or cryptocurrency mining (see also chapter 3.3.1) [RN 2016, RN 2017, WPM 2017f, WPM 2018ac, WPM 2018u, WPM 2018v].

3.3.3 Emerging markets

Wind power keeps spreading globally, with Russia, Saudi Arabia and Africa emerging as three of the largest potential new wind energy markets in the world.

Russia is the largest country in the world. It has huge areas with excellent wind resources, however, only a few megawatts have been developed so far due to a long process to develop a regulatory framework for RES support which was finally approved last year. Russia aims for 3.25 GW of wind energy to become online by 2024, with the Ulyanovsk region as the main territory for the development of wind power engineering in the country. Some European OEMs including Vestas, Siemens Gamesa Renewable Energy and Lagerwey have already located wind turbine production in the Russian market, in some cases thought joint ventures with local players [Ermolenko 2018], [WPM 2017j], [WPM 2018ad].

Saudi Arabia aims to develop its large wind and solar resources through their National Renewable Energy Program. Even though solar energy will get the largest share, the country has a wind energy technical potential higher than 200 GW with an average capacity factor of 35.2 % (higher than most global leading countries). Through this program, the Government aims to install 10 GW of wind energy by 2025 (700 MW already tendered) and to capture the full value chain [Almubarak 2018].

In the African continent, wind energy could play a key role to support its economic and social growth and to bring power to about 600 million Africans. To date Egypt, Morocco and South Africa are the most important players in wind energy. However, other very exciting markets opportunities are emerging across sub-Saharan African countries. The wind energy technical potential in Africa reaches 1 300 GW [IEA 2014]. IRENA estimates that around USD 70 billion/year will be needed to fill the energy capacity gap in Africa in the period 2015-2030 and around 2/3 of investments could come from RES. However, key challenges still impede a scale up of RES investments in Sub-Saharan Africa, including a lack of information on project profitability to encourage finance and bankability, slow administrative processes and lack of clear regulation, reliable payment mechanisms, a good market design and clear grid access rules [Marena 2018].

In offshore wind, Poland is seen as a promising and attractive market in Europe: it has up to 9 m/s average wind speed (similar to wind conditions in Denmark and Northern Germany) and the Polish offshore wind industry has high potential capabilities in heavy lift jack-up vessels, transformer topsides, cabling vessels, turbine towers, offshore cables and jackets foundations. The first Polish offshore wind farm is planned to be commissioned between 2022 and 2025. The Polish wind industry estimates that offshore wind capacity to be installed by 2030 could range between 2.2 and 6 GW (low and high scenarios), which will require EUR 7-20 billion investment from 2018 to 2030. An increase up to 12 GW is estimated by 2040 [PWEA 2018]. Unlike other MSs, some site permits have been issued before a support scheme for offshore wind was granted[21] [K&L Gates 2018].

Beyond Europe, East Asia and the United States have the potential to become major new markets for the offshore industry. Taiwan aims to build 5.5 GW by 2025, but both Japan and the US have the potential to be much larger markets in the medium to longer term.

[21] A technology-specific tender-based CfD scheme is expected to be announced in 2019.

Taiwan has become one of the most promising offshore wind markets in Asia. A strong political framework, with ambitious targets to promote clean energy industry, good wind resources and one of the highest FITs in the world are the main incentives to attract international offshore developers and OEMs. In particular, Taiwan has an offshore wind target of 5.5 GW by 2025 and 10-17 GW by 2030. Regarding the FIT, the developers can choose between two options: EUR 175/MWh for 20 years or EUR 198/MWh for the first 10 years and EUR 96/MWh for the following 10 years[22]. Taiwan also has good port infrastructures and will build the Southeast Asia's largest offshore wind port facility in Taichung [GWEC 2018]. Even though Taiwan is a promising offshore market, OEMs must meet local content requirements as well as strong technical requirements for typhoons [MHI Vestas Offshore Wind 2018].

Japan has abundant offshore wind potential and legislation is currently ongoing to set a framework for offshore wind expansion. So far the offshore wind sector has developed at slow pace, since the island has some grid issues which are expected to be eased at the electric power system reform by 2020. In particular, grid infrastructure will be improved and wind power priority areas will be selected. Japan currently has 65 MW in operation spread over 11 projects (including 2 floating offshore wind projects accounting for 16 MW) and around 12 GW in the pipeline. A FIT is currently in place, but the Government plans to move to an auction system only for fixed foundation offshore wind. The first auctions for offshore wind are likely to be held in 2019. The Japanese wind industry estimates that the country has more than 91 GW offshore wind power potential (only considering fixed-bottom foundations) and aims to install 10 GW by 2030. In spite of the ongoing grid infrastructure improvements and legislation, Japan is still lacking offshore construction work industries and the Japanese wind industry is currently looking for European cooperation [JWPA 2018].

Even though the United States currently only has 30 MW installed[23], the increased confidence in future market growth driven by the policy support from State Governments and the support of regulatory and financial institutions, along with continued cost reductions and an increased demand for offshore wind in the north-eastern United States, are seen as the main drivers of offshore wind development. Forecasts expect the US to install between 4 GW to 13 GW of offshore wind by 2025 and between 11 GW to 16 GW by 2030 [R. Wiser & Bolinger. 2017] [Musial et al. 2019].. The States at the forefront of offshore wind power development are located in the East Coast and include Rhode Island, New York, New Jersey and Massachusetts [GWEC 2018]. In spite of these ambitious targets, the wind industry still has some gaps in the supply chain, in particular in specialty vessels, nacelle and blade manufacturing, cables and skilled workforce for O&M [Burdock 2018].

Floating offshore wind technology deserves a special mention, since it is moving towards commercial viability with a growing market share in the coming years.

At the end of 2017 only 50 MW of floating wind power were installed globally (in Norway, Japan and the UK). Since 2009 different prototypes demonstrated the technological viability of single units until 2017 when the Hywind Scotland project demonstrated the first pre-commercial array deployment with larger wind turbines. Currently, there is a pipeline of pilot projects that could reach an installed capacity of around 200-260 MW by 2021; however, based on current market conditions, the first large scale projects are not expected to be installed before 2025 [CarbonTrust 2018].

Future scenarios of cumulative installed capacity vary widely. The wind industry has high aspirations for floating offshore wind technology, with ambitious targets reaching around 8 GW by 2025 and 30 GW by 2030. However, the Carbon Trust estimates that around 12 GW could be feasible by 2030. Most LCOE savings in floating offshore wind are expected to come from innovations shared

---

[22] Nevertheless, the Government plans to move to an auction system: only projects fitting into the first 3 GW will stay within the FIT scheme while the remaining 2.5 GW will have to compete in the tender process.

[23] Block Island Wind farm is online since 2016.

with fixed-bottom offshore wind, including increase in turbine size, as well as improvements in components and in blade dynamics, materials, and manufacture [InnoEnergy 2018].

Europe is expected to lead technology commercialisation and deployment of floating offshore wind technology, although East Asia and North America could show a strong growth in the long-term. France, the UK, Norway, and Portugal could dominate the early market to 2020, while Japan, China and Taiwan are expected to grow fast by 2025 and continue to 2030. The US could enter in mid 2020s and speed up to nearly equal other regions [CarbonTrust 2018].

The first array of floating wind turbines has been operational for several months and several pilot projects of few turbines are expected to be connected to the European grid in the coming years in France, Portugal, Spain and the United Kingdom. Large scale farms (hundreds of MW) are under serious development in South Korea, Taiwan and the US. New national plans for sites and regimes specific to floating offshore wind may soon be launched by France, Japan, Norway, the UK and the US [Dussillol 2018].

Standardisation aiming to harmonise technical development and safety levels in floating offshore wind has recently made some progress. Even though international floating wind standards such as the IEC 61400-3-2 are still under development, DNV GL has published the first international holistic standard package[24] that considers floating offshore wind technology as an integrated system and provides straight forward verification activities to ensure a safe and reliable development, design and operation of floating offshore wind technologies [Manjock et al. 2018].

[24] The new DNV GL service document package comprises the floating service specification DNVGL-SE-0422, the floating standard DNVGL-ST-0119 and the floating recommend practice DNVGL-RP-0286_DRAFT.

4 MARKET OUTLOOK

This chapter provides, in its first part, a review of future wind deployment based on main studies providing energy scenarios. This is followed by the scenario projections from the EC 2050 Long-term Strategy. Finally, scenario results from the JRC-EU-TIMES model on deployment, investment, technical potential are presented. The geographical reference of the analyses shown in this chapter is Europe.

4.1 Outlook for future developments – Main energy system studies

Studies providing detailed scenario trajectories for both onshore and offshore wind show a wide spread of trajectories towards 2050 (see Figure **37** and Figure **38**). At the lower bound, representing scenarios driven only by the policies currently in place (e.g. IEA ETP 6DS, IEA ETP RTS, GP-Ref), onshore wind would range between 265 GW and 420 GW in 2050, whereas offshore wind would grow moderately towards an installed capacity below 40 GW. More ambitious scenarios, striving to meet the Paris Agreement (IEA ETP 2DS), or even looking beyond this target (IEA ETP B2DS, GP-ER, GP-ADV), foresee onshore wind installations between 400 GW and 600 GW in 2050. An even stronger relative growth can be observed for offshore wind in these scenarios, ranging from about 70 GW to 240 GW installed in 2050. For both technologies, BNEF's reference scenario shows a strong increase towards 2030 and 2040, with the installed capacity subsequently dropping by 2050 to the 2030 levels. In both Greenpeace (GP) scenarios, ER and ADV, wind becomes the leading technology in electricity generation in Europe by 2030 [Greenpeace 2015, IEA 2016b, IEA 2017].

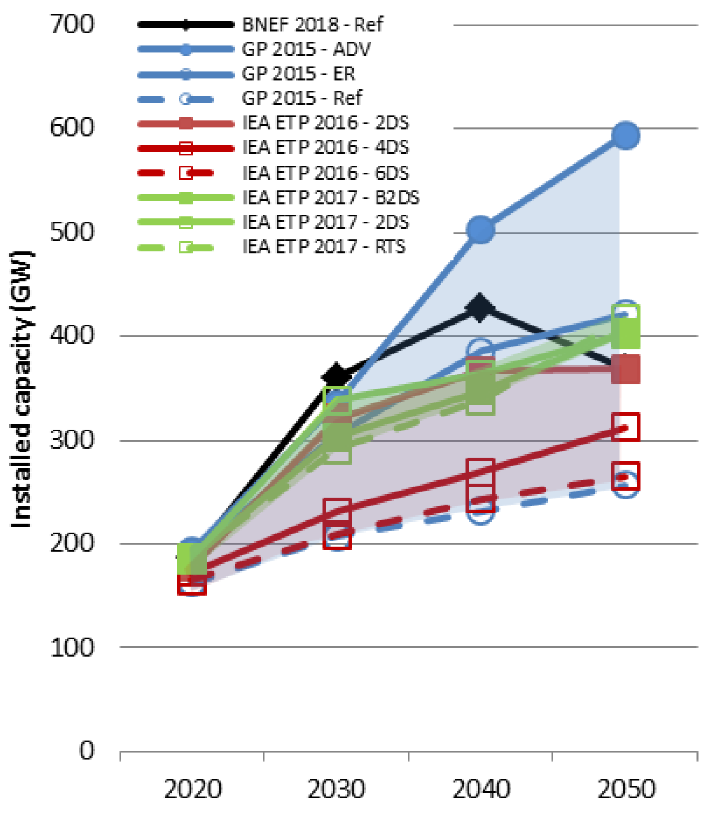


Figure 37 Scenario trajectories on installed onshore wind capacity.
Source: JRC

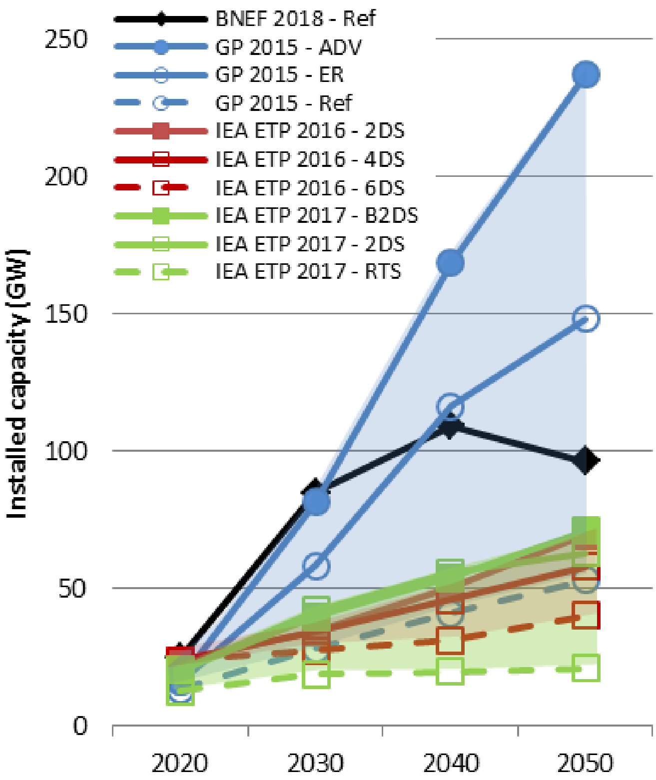


Figure 38 Scenario trajectories on installed offshore wind capacity.
Source: JRC

The aging wind fleet in Europe results in an increased number of wind farms that have to be replaced. Assuming an average lifetime of 25 years for onshore wind and 30 years for offshore wind, capacity additions vary significantly among the different scenarios (see Figure **39** and Figure **40**). In onshore wind, most of the more ambitious scenarios see a first wave of increased capacity additions in the period 2021-2030. The following periods show a decline followed by a rise in the period 2041-2050. In offshore wind, the IEA scenarios see a constant rate of capacity additions until 2040 followed by an increase in the last period.

Interestingly, for both onshore and offshore wind, the more recent and ambitious IEA ETP 2017 scenarios already show a stronger deployment rate in the period 2031-2040 than its predecessor ETP 2016. Moreover, capacity additions in the most ambitious GP ADV scenario surge until 2040, followed by a moderate decline in the period 2041-2050. According to BNEF, capacity additions drop significantly after 2030, which seems to be mainly caused by an increased investment in solar PV.

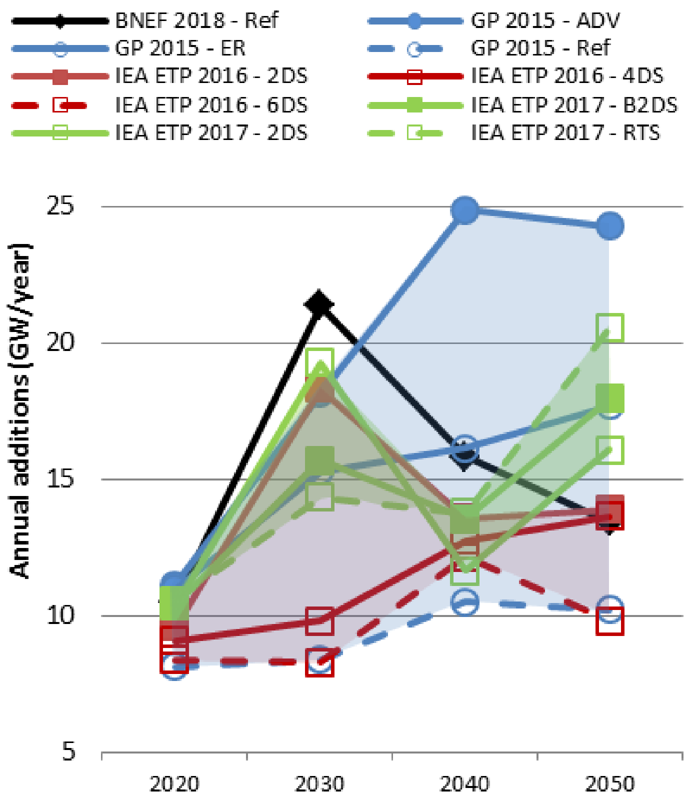


Figure 39 Scenario trajectories on annual capacity additions for onshore wind.
Source: JRC

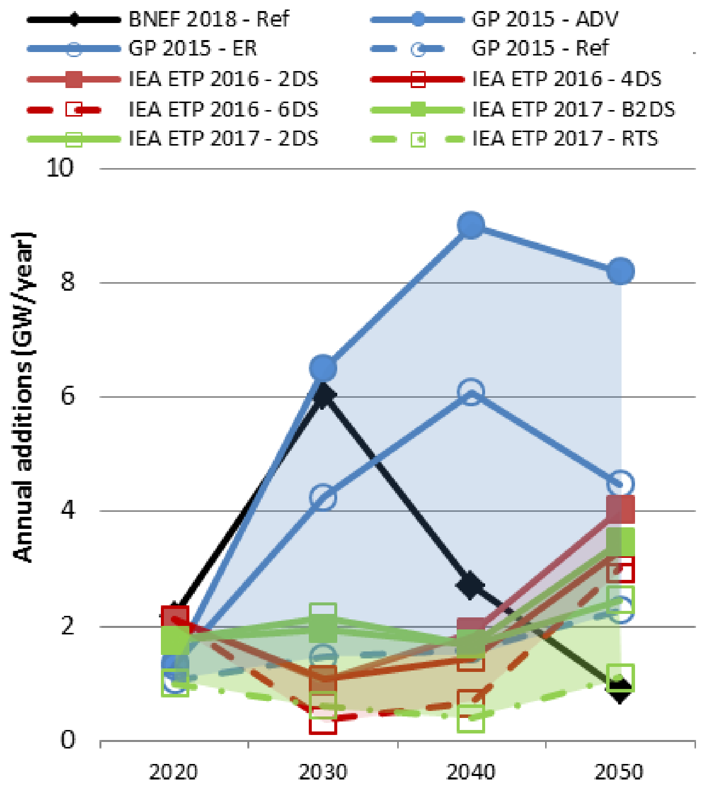


Figure 40 Scenario trajectories on annual capacity additions for offshore wind.
Source: JRC

4.2 Scenario projections of the EC 2050 Long-term strategy

The modelling projections within the EC long-term strategy 2050 find the installed wind capacity increasing from 140 GW in 2015 to values between 700 GW (EE-scenario) and about 1 200 GW (P2X-scenario and 1.5TECH scenario) by 2050 (see Figure 41). As a consequence, wind is leading with 51-56 % of the power production in 2050 in all decarbonisation scenarios. This translates into annual capacity additions ranging between 30 GW (EE-scenario) to over 50 GW (1.5TECH-scenario) between 2030 and 2050. Moreover, scenario results for 2050 show about two thirds of the capacity being installed onshore (92 % in 2015) [EC 2018d]. Apart from these studies defining a deployment trajectory until 2050, several studies (e.g. IRENA's EU Ref and EU REMAP scenarios [EU/IRENA 2018]) give the expected deployment for single point in time. However, these data points are not diverging from the presented scenario projections in this section.

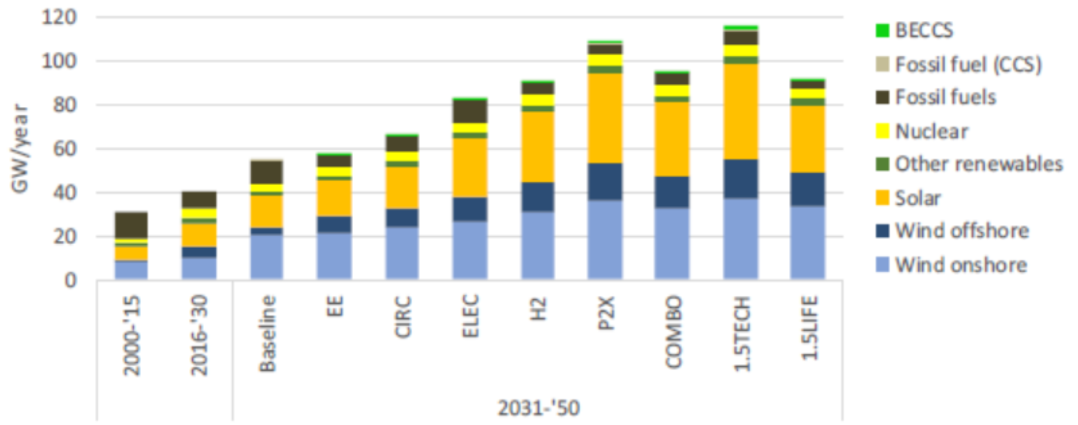


Figure 41 Newly installed power generation capacities of the modelling projections in the EC 2050 Long-term Strategy.
Source: PLATTS (2000-2015), PRIMES, as published in [EC 2018d]

4.3 Outlook for future developments – JRC-EU-TIMES model

4.3.1 Deployment under the main scenarios

The JRC-EU-TIMES model is used to calculate the contribution of wind energy to the overall EU energy system. JRC-EU-TIMES is a linear optimisation model providing cost efficient pathways for the EU to meet its climate targets [JRC 2018a]. The main storylines implemented in the model are following a scenario setting the reference (Baseline) and two scenarios (Diversified and ProRES) striving for fulfilling the CO_2 emission reduction target in 2050 (80 % as compared to 1990 levels). In addition, the even more ambitious 'NearZero'-scenario aims for 95 % CO_2 reduction by 2050. Table **8** describes the main assumptions met for each of the four main scenarios[25].

[25] Further description about the JRC-EU-TIMES model is available in the dedicated report produced under the LCEO project deliverable 4.7 [JRC 2018a]

Table 8 LCEO scenario assumptions.
Source: [JRC 2018a]

Scenario	Description
Baseline	Continuation of current trends; no ambitious carbon policy outside of Europe; only 48 % CO_2 reduction by 2050.
Diversified	Usage of all known supply, efficiency and mitigation options (including CCUS and new nuclear plants); 2050 CO_2 reduction target is achieved.
ProRES	80 % CO_2 reduction by 2050; no new nuclear; no CCUS.
NearZero	95 % CO_2 reduction by 2050; no new nuclear; no CCUS.

Table 9 Wind energy classes implemented in the JRC-EU-TIMES model.
Source: [JRC 2018b]

Implemented wind technologies (only major categories shown)
Onshore, low capacity factor (< 20%)
Onshore, medium capacity factor (20%-25%)
Onshore, high capacity factor (> 25%)
Offshore, monopile, medium distance to shore
Offshore, jacket, medium distance to shore
Offshore, floating, long distance to shore

With respect to wind energy the JRC-EU-TIMES model uses three different classes of onshore wind and three different classes of offshore wind technologies[26]. The main difference among onshore wind categories refers to the specific power of the turbine and the hub height. Offshore wind turbines are differentiated based on their distance from shore and the type of support structure used [JRC 2018b].

Results show that the installed wind energy capacity increases moderately to about 380 GW and 540 GW respectively, for the scenarios building on the continuation of current trends (Baseline) and those reaching the 80 % CO_2 reduction in 2050 by using all available technologies (Diversified). Significantly higher wind deployment can be witnessed for the scenarios not only aiming for CO_2 reduction, but also refraining from deploying new nuclear plants or CCUS technologies (ProRes and NearZero). To achieve the 80 % and the 95 % CO_2 reduction by 2050, wind installed capacities reach for about 1500 GW and 2100 GW, respectively. As the timeframe of the JRC-EU-TIMES model also covers the post-2050 period, the CO_2 reduction targets combined with restrictive nuclear and CCUS policies require significant additional wind capacity (see Figure **42**). After reaching the 2050 target, the incentive to build wind capacity as intensively as in the period 2030-2050 disappears, as there are no additional policies in place. Replacement of the ageing fleet still leads to an increasing market in terms of annual deployment from 2060 onwards, after the market "dip" that takes place when the power system is largely transformed.

Annual deployment surges after 2030. Within the decarbonisation scenarios 'Diversified', 'ProRes' and 'NearZero', in 2040, the wind market reaches annual deployment levels of 20 GW/year, 75 GW/year and 100 GW/year, respectively.

[26] Please see detailed cost trajectories for wind in Annex 2 of deliverable 4.7 [JRC 2018a]

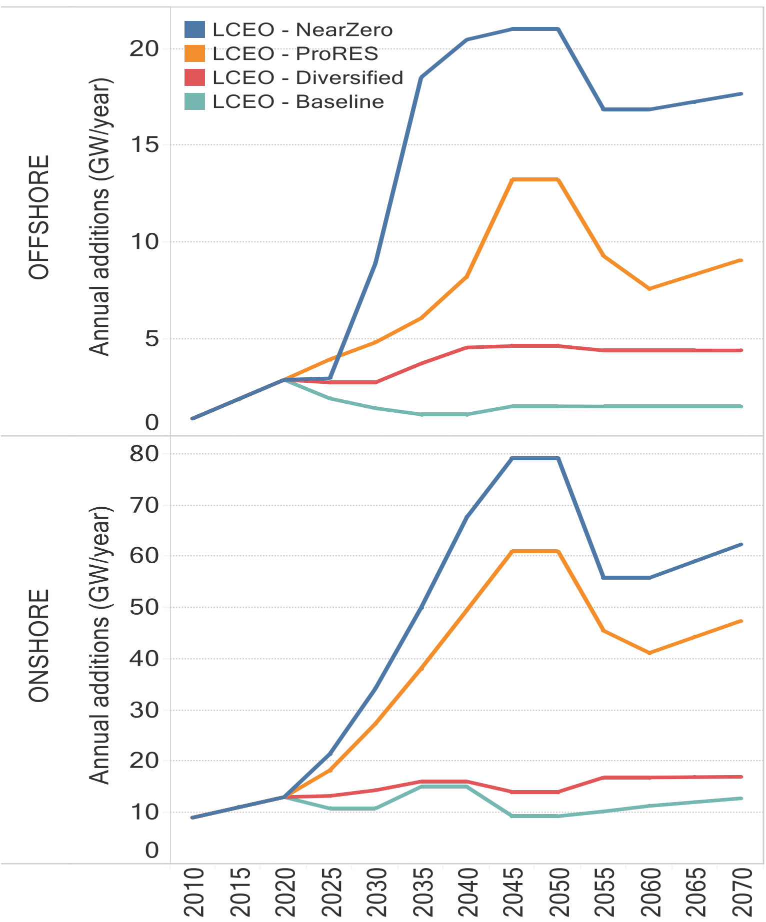


Figure 42 Annual capacity additions for onshore and offshore wind in the main LCEO scenarios
Source: JRC

The ageing wind fleet results in a growing market for wind farms being replaced or repowered. By assuming an average lifetime of 25 years for onshore wind farms and 30 years for offshore wind farms, JRC-EU-TIMES calculates the annual capacity to be replaced[27]. The scenarios 'Baseline' and 'Diversified' show significant replacement needs from 2035 onwards, ranging at about 30-35 % of installed capacity (see Figure **43**). Given the steeper increase of new deployment in the period 2020-2050 the 'ProRes' and 'NearZero' scenarios show comparable replacement rates as the 'Baseline' and 'Diversified' scenarios only by 2050, yet at much higher scale (21-27 GW/year). For all decarbonisation scenarios replacement reaches a share of 100 % between 2055 and 2060.

4.3.1 Sensitivity analysis

The wind energy deployment and associated annual investments are not only highly dependent on the techno-economic assumptions made (CAPEX, OPEX and capacity factor), but also on the technology's relative performance compared to other technologies, and policy or resource restrictions. To test the robustness of the results of the main storylines we performed a sensitivity analysis by:

- applying different technology learning rates (LR) on wind energy costs (high LR, low LR);
- considering variations in main commodities (cheaper fossil fuels); and
- implementing specific policy related restrictions (no CCS in the power sector

[27] Replacement does not refer to the specific location of the single wind farm but replacement of capacity in the overall system

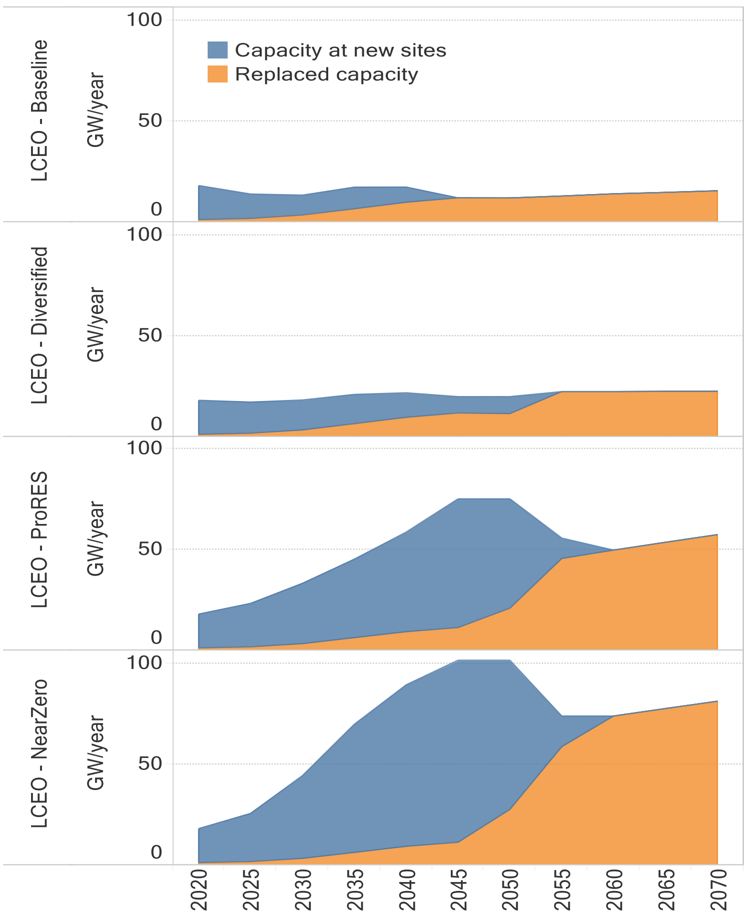


Figure 43 New capacity additions and replacement needs in the main LCEO scenarios
Source: JRC

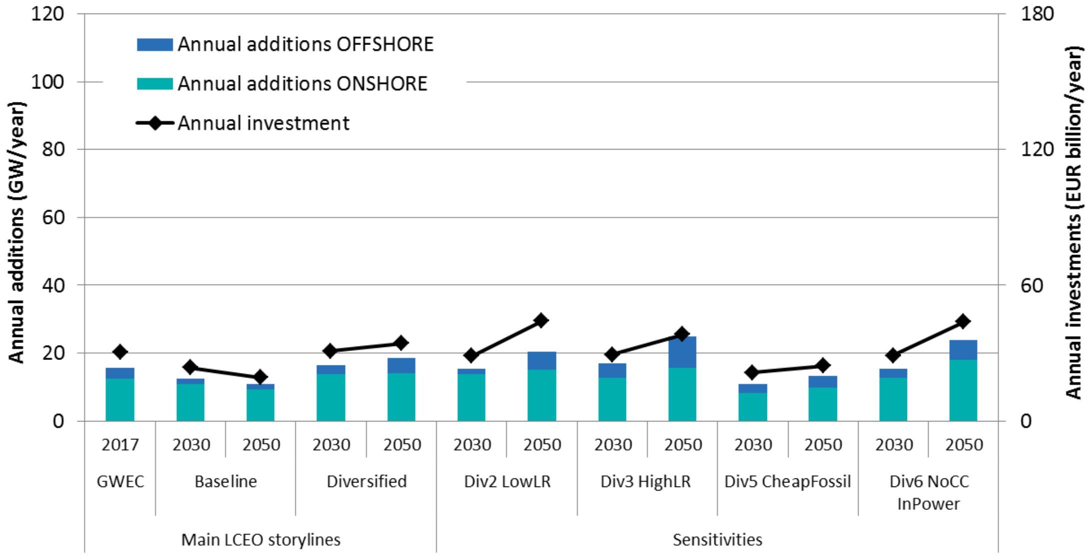


Figure 44 Mid- and long-term outlook on annual capacity additions and associated investments based on the JRC-EU-TIMES main storylines and sensitivities of the Diversified scenario.
Note: Investments 2017 estimated based on projects reaching final investment decision in 2017 [WindEurope 2018g]

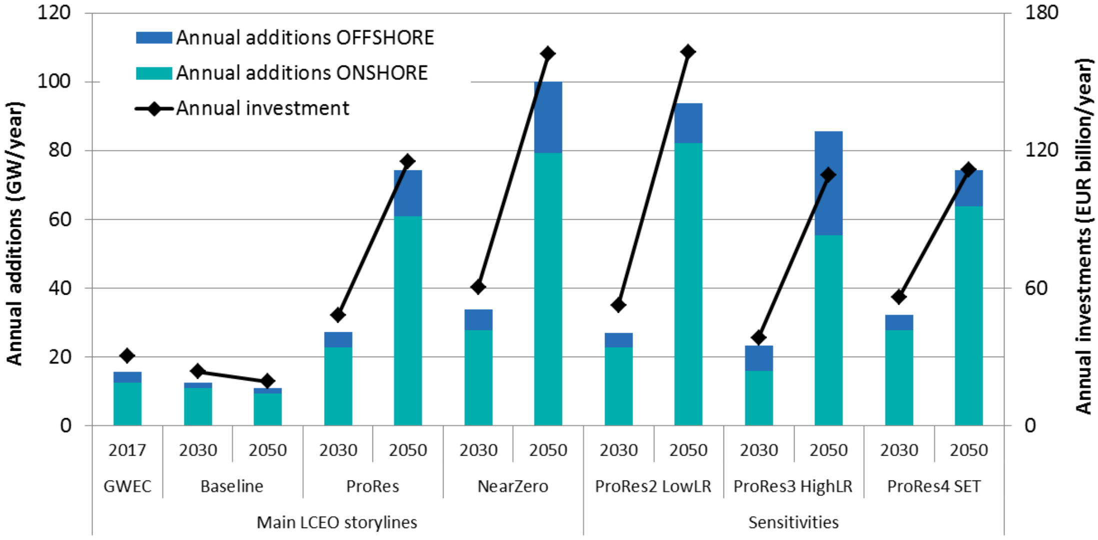


Figure 45 Mid- and long-term outlook on annual capacity additions and associated investments based on the JRC-EU-TIMES main storylines and sensitivities of the ProRes scenario.
Note: Investments 2017 estimated based on projects reaching final investment decision in 2017 [WindEurope 2018g]

The resulting annual additions and investments for onshore and offshore wind are analysed for the mid- (2030) and long-term (2050) and compared against the decarbonisation scenarios of the main storylines.

In 2017 the EU28 installed 15.6 GW of new wind capacity. Assuming the same specific investment as for projects reaching final investment decision in 2017 (EUR 22.3 billion for 11.5 GW [WindEurope 2018g]) this translates into an annual investment of EUR 30.3 billion. In the mid-term the 'Diversified'-scenario shows annual deployment figures at levels comparable to current values (16.5 GW/year in 2030), followed by an increase in deployment at rates between 19 GW/year and 21 GW/year (EUR 34 billion/year to EUR 38 billion/year) in the following decades, across all sensitivities. Notably, annual offshore wind deployment accounts for about 3 GW/year in 2030 and increases to 4.6 GW/year in 2050 (see Figure 44). Applying a variation to the LR[28] moderately changes the results in terms of annual deployment, but has more of an effect on the time of deployment. In the 'LowLR'-scenario annual deployment increases from about 15 GW/year to 20 GW/year (EUR 44 billion/year) in 2050. As compared to the 'Diversified'-scenario the model delays significant capacity towards 2050 to meet the emission reduction target. High LRs result in higher annual deployment (between 17 GW/year and 25 GW/year) but lower annual investments (EUR 30/year to EUR 38 billion/year). Moreover, the significant reduction in offshore costs results in an increase in offshore deployment between 2040 and 2050 (7 GW/year to 9 GW/year), whereas onshore deployment decreases during the same period. Reduction in fossil fuel (oil and gas) prices until 2050 cause a drop in deployment rates below 2017-level as conventional electricity technologies using CCS are more competitive in this scenario ('CheapFossil'-scenario). The 'NoCC InPower'-scenario excludes carbon capture from the power sector, which is the second biggest emitter of CO_2 after the transport sector. Total wind deployment in this scenario is similar to the sensitivity with high LRs, with annual deployment peaking at 25 GW/year (EUR 44 billion/year) in 2050, of which about 6 GW are installed offshore.

[28] Please see for detailed LR assumptions in [JRC 2018b]. Onshore wind: Reference LR: 5 %, Low LR 2 %, High LR: 10 %. Offshore wind: Reference LR: 11 % to 5 %, Low LR 5 % to 2 %, High LR: 20 % to10 %.

The results of the JRC-EU-TIMES model foresee a much more pronounced role for wind energy in the decarbonisation scenarios which exclude new nuclear deployment and the use of CCUS (see Figure 45). Annual deployment rates are increasing until 2050 to 74 GW/year and 100 GW/year in the 'ProRes' and 'NearZero'-scenario, respectively. An even stronger increase for the latter scenario can be observed in market size (EUR 115 billion/year versus EUR 162 billion/year in 2050) as a higher share of capacity is installed offshore.

Within the 'ProRes'-scenario wind energy becomes the dominant renewable energy technology by 2040 with respect to the electricity produced. In case of low technology learning ('ProRes2'), scenario results show an increase in wind additions, as the relative difference to the LR of the strongest technological competitor PV decreases in comparison to the reference case ('ProRes'). Similarly, the difference in the LR between wind and PV decreases in the high learning rate scenario ('ProRes3'), albeit to a lower extent. Annual additions increase compared to the 'ProRes'-scenario but at a lower level than in the 'ProRes2'-scenario, as more offshore capacity with a higher capacity factor and a more stable generation profile is added to the system. Although both LR-scenarios result in comparable deployment rates, the difference in technology learning leads to annual investments being 27 % lower in 2030 and 33 % lower by 2050 in the high LR scenario than in the low LR scenario.

The 'ProRes4'-sensitivity includes the same techno-economic assumptions for wind, because the default 'ProRes' already reflects EU technology innovation as foreseen in the SET plan. Even though other technologies have a higher learning rate (solar, ocean), very similar wind additions are installed in this scenario compared to the 'ProRes'-scenario.

4.3.2 Investments per MS

Figure 46 presents the EU Member States with the highest level of investment in low carbon energy technologies up to 2050 according to the JRC-EU-TIMES scenarios. As shown, the investment in new capacity increases as more ambitious carbon policies aiming at higher CO_2 reduction by 2050 are implemented. Thus, achieving 95 % CO_2 reduction by 2050 without new nuclear and CCUS ("NearZero'-scenario), would lead to the highest investments up to 2050 in all MSs.

In the period 2020-2050, France, Germany and the United Kingdom are the MSs with the highest level of investment in new capacity in LCETs in all JRC-EU-TIMES scenarios.

Achieving at least 80 % CO_2 reduction by 2050 without new nuclear and CCUS ('ProRes' and 'NearZero'-scenario), would lead to a strong increase of wind power capacity, making it the low carbon energy technology with the highest investment in the majority of the MSs. As an example, this investment would reach more than EUR 700 billion in France and the United Kingdom. Italy and Spain are the exception, with most of capacity additions in solar energy, namely solar PV in Italy and solar thermal electricity in Spain.

4.3.1 Technical potential

The wind energy potential is determined by the land availability. The maximum technical potential in the MSs has been estimated based on a hypothetical scenario, where the exclusion of surfaces for wind converges in all countries to a low level. In general terms, the restrictions considered are the following: (1) a minimum allowed setback distance from settlements of 400 m in onshore wind and (2) a minimum distance to shore of 12 NM in offshore wind, as well as the inclusion of floating offshore wind (at depths higher than 50 meters), the assumption of low buffer zones and a shipping density lower than 5000 ships per year. The assumptions behind these restrictions are further explained in [JRC 2017c].

Figure **48** and Figure 47 display the maximum potential wind capacity in the EUMSs under the most optimistic JRC-EU-TIMES scenarios (ProRES and NearZero).

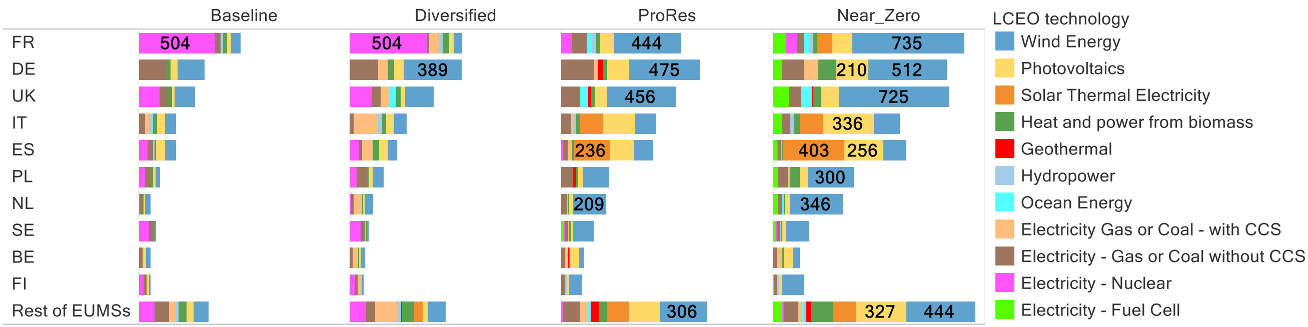


Figure 46 Top 10 Member States in terms of investments in capacity additions (BEUR) up to 2050 according to the JRC-EU-TIMES scenarios
Source: JRC

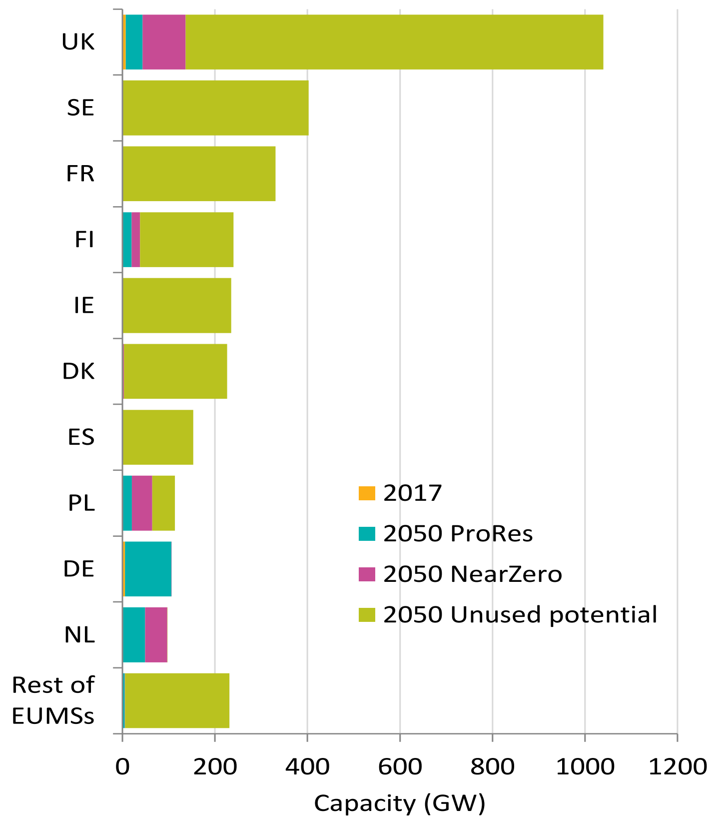


Figure 47 Top 10 Member States in terms of unused offshore technology potential by 2050. Comparison with cumulative capacity by 2050 in ProRes and NearZero JRC-EU-TIMES scenarios and current installed capacity
Source: JRC

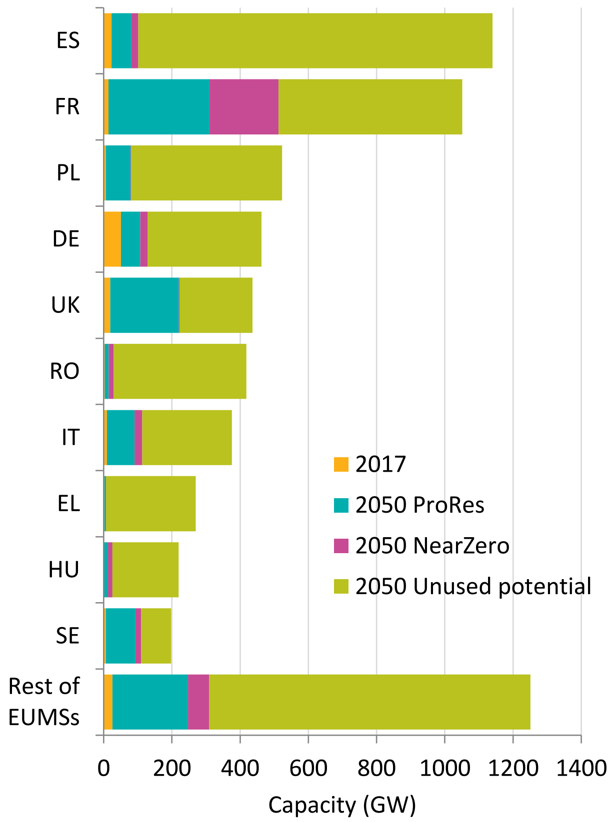


Figure 48 Top 10 Member States in terms of unused onshore technology potential by 2050. Comparison with cumulative capacity by 2050 in ProRes and NearZero JRC-EU-TIMES scenarios and current installed capacity
Source: JRC

With a low level of restrictions, Spain, France, Poland, Germany and the United Kingdom are estimated to have the highest potential onshore wind capacity. Some MSs such as France, the UK and Sweden use around half of their potential by 2050 according to the most optimistic JRC-EU-TIMES scenarios. In Germany and Spain, currently the leading MSs in terms of installed wind power capacity, the cumulative capacity by 2050 would only reach around 30 % and 10 % of the full potential respectively.

In offshore wind, the highest potential with a low level of restrictions is found in the waters of the United Kingdom, reaching more than 1000 GW. Interestingly, Germany and the Netherlands could deploy their full technical potential by 2050, if the aforementioned restrictions were implemented and according to the deployment in the 'ProRes' and the 'NearZero' scenarios respectively.

5 CONCLUSIONS

In 2018, the EU wind energy market declined to about 10.1 GW in annual capacity additions (about 87 % of the European capacity additions) after experiencing a record year 2017 (15.9 GW; 93% EU28-share). Still 2018 was a record year in annual offshore wind capacity additions with 4.5 GW installed globally across all markets. On a global level the majority of cumulative capacity installed is located in China (36 %) followed by the EU28 (30 %) and the US (16 %).

In 2016 (the most recent year reported in the MSs' progress reports towards the EU's 2020 renewable energy goals) only ten EU MSs were on track to meet their 2020 NREAP targets. In total the EU28 generated 311 TWh/year of wind energy (or 62.7 % of the overall EU wide 2020 NREAP target).

The EC's State Aid Guidelines for Environmental protection and Energy 2014-2020 have promoted the competitive tender-schemes for new onshore and offshore wind projects, which have now become the most common support scheme in place. These market-based schemes have resulted in a lower level of support for new projects in some EU MSs in recent years.

In terms of competitiveness, the EU has a pivotal role in wind energy. R&D is dominated by corporate funding. As such the EU MSs hosting the global market leaders in wind energy are leading (DE, ES, DK). In patenting activity, the EU ranks second behind China, however, patents filed by EU-based entities have a higher impact, as the average EU wind patent is filed in multiple patent offices worldwide, whereas their Chinese counterparts aim for protection in their home market only.

Market shares of European Original Equipment Manufacturers (OEMs) in the wind energy sector show a positive trend in the last years. Among the top 10 OEMs in 2017 European OEMs led with 49 % of the market share followed by the leading Chinese (21 %) and North American (8 %) companies. The European OEMs show overcapacities in all key wind turbine components, when compared to the present and future European demand. Expected deployment rates at global level suggest an additional market potential for European manufacturers outside the EU. EU companies already show a significantly higher market presence in foreign markets than their competitors from China and the US.

The globalisation of the wind energy sector has brought an increasing number of mergers and acquisitions deals over the last few years. These transactions have consolidated the market, with wind players increasing their market share and economies of scale, creating synergies, and lowering risk. Although this restructuring led to stable operating profits, the industry also witnessed significant job cuts in the recent years.

With wind energy becoming increasingly competitive among renewable energy technologies even in emerging markets, latest developments see new ways to participate in the wind market from the consumer side (corporate PPAs) as well as in the form of new products originating from broader technological trends (digitalisation).

Scenarios from the main energy system models, suggest that wind energy will play a substantial role in the European electricity mix in the mid- to long-term, in the context of decarbonisation. However, the sensitivities performed using the JRC-EU-TIMES model show that the market could increase by 4-5 times as compared to current levels if, along with decarbonisation, future policies exclude the usage of CCUS or new nuclear power plants.

6 REFERENCES

[4COffshore 2019] 4COffshore: Events on France - 2020 Tender (Floating). Accessed: 07/01/2019. URL: https://www.4coffshore.com/windfarms/project-dates-for-france---2020-tender-(floating)-fr70.html

[Almubarak 2018] Almubarak A: Saudi Arabia - What opportunities lie ahead for wind - Conference Presentation. WindEurope 2018 Conference at the Global Wind Summit, Hamburg

[Bloomberg 2017] Bloomberg: Spain Auctions - Policy Overview (Limited distribution)

[BM 2014] Bundesministerium: Gesetz für den Ausbau erneuerbarer Energien (Erneuerbare - Energien - Gesetz - EEG 2014)

[BMJV 2017a] Bundesministerium der Justiz und für Verbraucherschutz: Gesetz für den Ausbau erneuerbarer Energien (Erneuerbare-Energien-Gesetz - EEG 2017). Available at: https://www.gesetze-im-internet.de/eeg_2014/BJNR106610014.html

[BMJV 2017b] Bundesministerium der Justiz und für Verbraucherschutz: Gesetz zur Entwicklung und Förderung der Windenergie auf See (Windenergie-auf-See-Gesetz - WindSeeG) § 17 Ausschreibungsvolumen. Available at: http://www.gesetze-im-internet.de/windseeg/__17.html

[BNEF 2018] Bloomberg New Energy Finance: 2H 2018 Corporate Energy Market Outlook

[Boyes et al. 2018] Boyes H, Hallaq B, Cunningham J and Watson T: The industrial internet of things (IIoT): An analysis framework. Computers in Industry 101 (1–12). DOI:10.1016/j.compind.2018.04.015

[Bundesnetzagentur 2018] Bundesnetzagentur: Gebotstermin 1. November 2018 Bekanntmachung der Ausschreibung. Available at: https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Ausschreibungen/Technologieuebergreifend/Gebotstermin_01_11_2018/gebotstermin_01_11_2018_node.html

[Burdock 2018] Burdock L: OffshoreWindUS.org: US Offshore wind market overview - Conference Presentation. WindEurope 2018 Conference at the Global Wind Summit

[CarbonTrust 2018] James R, Weng W, Spradbery C, Jones J, Matha D, Mitzlaff A, Ahilan R, Frampton M and Lopes M: Floating Wind Joint Industry Project. Phase I Summary Report. Key findings from Electrical Systems, Mooring Systems, and Infrastructure & Logistics studies. Available at: https://www.carbontrust.com/media/675868/flw-jip-summaryreport-phase1.pdf

[CEER 2018] Council of European Energy Regulators: Tendering procedures for RES in Europe: State of play and first lessons learnt (C17-SD-60-03). Available at: https://www.ceer.eu/documents/104400/-/-/167af87c-5472-230b-4a19-f68042d58ea8

[del Río 2017] del Río P: Assessing the design elements in the Spanish renewable electricity auction: an international comparison. Available at: http://www.realinstitutoelcano.org/wps/wcm/connect/d7a44509-e2be-403e-8bab-2ed188e398c3/DT6-2017-DelRio-Design-Spanish-renewable-electricity-auction.pdf?MOD=AJPERES&CACHEID=d7a44509-e2be-403e-8bab-2ed188e398c3

[DM 2012] Danish Ministry of Climate Energy and Building: Accelerating green energy towards 2020 - The Danish Energy Agreement of March 2012. Available at: https://ens.dk/sites/ens.dk/files/EnergiKlimapolitik/accelerating_green_energy_towards_2020.pdf

[Douglas-Westwood 2013] Douglas-Westwood: Assessment of Vessel Requirements for the U.S. Offshore Wind Sector. Available at: https://www.energy.gov/sites/prod/files/2013/12/f5/assessment_vessel_requirements_US_offshore_wind_exec_summary.pdf

[Dussillol 2018] Dussillol A: Financing floating offshore wind projects - Conference presentation. WindEurope 2018 Conference at the Global Summit

[DWW 2015] DeepWaterWind: Historic milestone for America's first offshore wind farm. URL: http://dwwind.com/press/block-island-wind-farm-completes-first-steel-in-the-water/

[EC 2013] European Commission: National Energy Efficiency Action Plan (NEEAP) - Council of Ministers Resolution No 20/2013. URL: https://ec.europa.eu/energy/sites/ener/files/documents/Portugal_NEEAP_en.pdf

[EC 2016] European Commission: 3rd progress report from EFTA country Norway (reference year 2013-2014). URL: https://ec.europa.eu/energy/sites/ener/files/documents/Progress Report-Norway-ENversion.pdf

[EC 2017a] European Commission: Agreement on statistical transfers of renewable energy amounts between Lithuania and Luxembourg. URL: https://ec.europa.eu/info/news/agreement-statistical-transfers-renewable-energy-amounts-between-lithuania-and-luxembourg-2017-oct-26_en

[EC 2017b] European Commission: Second agreement on statistical transfers of renewable energy amounts between Estonia and Luxembourg. URL: https://ec.europa.eu/info/news/second-agreement-statistical-transfers-renewable-energy-amounts-between-estonia-and-luxembourg-2017-nov-13_en

[EC 2017c] European Commission: Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the promotion of the use of energy from renewable sources (recast). EUR-Lex COM(2016) (1–116)

[EC 2018a] European Commission: Cooperation mechanisms. URL: https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive/cooperation-mechanisms

[EC 2018b] EC: SET-Plan Offshore Wind Implementation Plan. Available at: https://setis.ec.europa.eu/system/files/setplan_wind_implementationplan_0.pdf.

[EC 2018c] European Commission: EC - Statement: Europe leads the global clean energy transition: Commission welcomes ambitious agreement on further renewable energy development in the EU, 14 June 2018. URL: http://europa.eu/rapid/press-release_STATEMENT-18-4155_en.htm

[EC 2018d] European Commission: IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773 A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. Available at: https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

[EC 2018e] European Commission: National action plans. Accessed: 08/23/2018. URL: https://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans

[EC 2018f] European Commission: Progress reports. Accessed: 08/23/2018. URL: https://ec.europa.eu/energy/en/topics/renewable-energy/progress-reports

[EC 2019] European Commission: NER 300 programme. URL: https://ec.europa.eu/clima/policies/innovation-fund/ner300_en

[Energia16 2016] Energia16: Siemens and Gamesa merger to create a world leader in wind power. Accessed: 12/07/2018. URL: https://www.energia16.com/siemens-and-gamesa-merger-to-create-a-world-leader-in-wind-power/?lang=en

[ENTSO-E 2017] ENTSO-E: Statistical Factsheet 2016. Available at: https://docstore.entsoe.eu/Documents/Publications/Statistics/Factsheet/entsoe_sfs_2016_web.pdf

[ENTSO-E 2018] ENTSO-E: Statistical Factsheet 2017. Available at: https://docstore.entsoe.eu/Documents/Publications/Statistics/Factsheet/entsoe_sfs_2017.pdf

[Envision 2017] Envision: Envision Energy Announces New Strategic Renewable Energy Forecasting Partnership. Accessed: 08/20/2018. URL: http://www.envision-energy.com/2017/12/11/envision-energy-announces-new-strategic-renewable-energy-forecasting-partnership/

[EP 2009] European Parliament: Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. Official Journal of the European Union 140 (16–62). DOI:10.3000/17252555.L_2009.140.eng

[Equinor 2019] Equinor: The market outlook for floating offshore wind. Accessed: 07/01/2019. URL: https://www.equinor.com/en/what-we-do/hywind-where-the-wind-takes-us/the-market-outlook-for-floating-offshore-wind.html

[Ermolenko 2018] Ermolenko G: What’s all the hype about the Russian wind market? - Conference presentation. WindEurope 2018 Conference at the Global Wind Summit

[EU/IRENA 2018] EU/IRENA: Renewable Energy Prospects for the European Union - Based on REmap analysis conducted by the International Renewable Energy Agency in co-operation with the European Commission. Available at: https://www.irena.org/publications/2018/Feb/Renewable-energy-prospects-for-the-EU

[European Commission 2014] European Commission: Communication from the Commission — Guidelines on State aid for environmental protection and energy 2014-2020, OJ C 200, 28.6.2014

[FTI-Consulting 2017] FTI Consulting: Global Wind Supply Chain Update 2016

[FTI Consulting 2016a] FTI Consulting: Global Wind Supply Chain Update 2016 - Generators

[FTI Consulting 2016b] FTI Consulting: Global Wind Supply Chain Update 2016 – Towers

[FTI Consulting 2016c] FTI Consulting: Global Wind Supply Chain Update 2016 - Gearboxes

[FTI Consulting 2016d] FTI Consulting: Global Wind Supply Chain Update 2016 – Blades

[FTI Consulting 2016e] FTI Consulting: Global Wind Supply Chain Update 2016 – Offshore Balance of Plant

[FTI Consulting 2018] Zhao F, Karcanias A, Clover R, LeWand C and Ramakrishnan G: Global Wind Market Update – Demand & Supply 2017

[GMSC 2017] GustoMSC: U.S. Jones Act Compliant Offshore Wind Turbine Installation Vessel Study. Available at: https://www.northeastwindcenter.org/wp-content/uploads/US_Jones_Act_Compliant_Offshore_Wind_Study.pdf

[Goldwind 2018] Goldwind: Annual report 2017. Available at: http://106.38.64.54:8080/goldwind-en/upload/files/20180507100622AuveIkp6.pdf

[Greenpeace 2015] Greenpeace: Energy [R] Evolution - A sustainable world energy outlook 2015. Available at: https://elib.dlr.de/98314/

[GWEC 2018] GWEC: Global Wind Report - Annual Market Update 2017. Available at: http://files.gwec.net/files/GWR2017.pdf

[GWEC 2019a] GWEC: GWEC - Global Wind report 2018. Available at: www.gwec.net

[GWEC 2019b] GWEC: GWEC: 1 in 5 wind turbines installed by Vestas in 2018, according to new market intelligence report. URL: https://gwec.net/gwec:-1-in-5-wind-turbines-are-installed-by-vestas,-according-to-new-market-intelligence-report/

[IDAE 2011] IDAE: Plan de Energias Renovables 2011 2020. Accessed: 08/20/2018. URL: http://www.idae.es/tecnologias/energias-renovables/plan-de-energias-renovables-2011-2020

[IEA/IRENA 2017a] IEA/IRENA: IEA/IRENA Joint Policies and Measures database - Danish Energy Agreement for 2010-2020. Accessed: 09/13/2018. URL: https://www.iea.org/policiesandmeasures/pams/denmark/name-42441-en.php?s=dHlwZT1yZSZzdGF0dXM9T2s,&return=PG5hdiBpZD0iYnJlYWRjcnVtYiI-PGEgaHJlZj0iLyI-SG9tZTwvYT4gJnJhcXVvOyA8YSBocmVmPSIvcG9saWNpZXNhbmRtZWFzdXJlcy8iPlBvbGljaWVzIGFuZCBNZWFzdXJlczwvYT4gJnJhcX

[IEA/IRENA 2017b] IEA/IRENA: IEA/IRENA Joint Policies and Measures database - Decree of 24 of April 2016 on renewable energy developments objectives (Arrêté du 24 avril 2016 relatif aux objectifs de développement des énergies renouvelables). URL: https://www.iea.org/policiesandmeasures/pams/france/name-162564-en.php?s=dHlwZT1yZSZzdGF0dXM9T2s,&return=PG5hdiBpZD0iYnJlYWRjcnVtYiI-PGEgaHJlZj0iLyI-SG9tZTwvYT4gJnJhcXVvOyA8YSBocmVmPSIvcG9saWNpZXNhbmRtZWFzdXJlcy8iPlBvbGljaWVzIGFuZCBNZWFzdXJlczwvYT4gJnJhcX

[IEA/IRENA 2019] IEA/IRENA: IEA/IRENA Joint Policies and measures database. Accessed: 06/26/2019. URL: https://www.iea.org/policiesandmeasures/renewableenergy/

[IEA 2014] IEA: Africa Energy Outlook. Available at: https://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf

[IEA 2016a] IEA: IEA wind TCP 2016 Annual Report

[IEA 2016b] IEA: Energy Technology Perspectives 2016. Available at: https://webstore.iea.org/energy-technology-perspectives-2016

[IEA 2017] IEA: Energy Technology Perspectives 2017. Available at: http://www.oecd-ilibrary.org/energy/energy-technology-perspectives-2017_energy_tech-2017-en

[IEA 2018] IEA: RD&D Statistics, Energy Technology RD&D Budgets Database © OECD/IEA. Available at: www.iea.org/statistics

[IG Windkraft 2018] IG Windkraft: Windkraft in Österreich - Jahresanfangspressekonferenz - Presentation. Available at: https://www.igwindkraft.at/mmedia/download/2015.06.25/1435239093942923.pdf

[InnoEnergy 2018] Floating offshore: 55 technology innovations that will have greater impact on reducing the cost of electricity from European floating offshore wind farms

[JRC 2017a] Telsnig T, Vazquez Hernandez C, Gonzalez Aparicio I and Uihlein A: Current offshore wind energy bid prices (JRC107775). Petten

[JRC 2017b] Vázquez Hernández C, Telsnig T, Villalba Pradas A, Vazquez Hernandez C, Telsnig T and Villalba Pradas A: JRC Wind Energy Status Report 2016 Edition. EUR 28530. Publications Office of the European Union, Luxembourg. Available at: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/jrc-wind-energy-status-report-2016-edition

[JRC 2017c] Dalla-Longa F, Kober T, Badger J, Volker P, Hoyer-Klick C, Hidalgo Gonzalez I, Medarac H, Nijs W, Polities S, Tarvydas D and Zucker A: Wind potentials for EU and neighbouring countries - Input datasets for the JRC-EU-TIMES Model, EUR 29083 EN,. Publications Office of the European Union, Luxembourg

[JRC 2017d] Fiorini A, Georgakaki A, Pasimeni F and Tzimas E: Monitoring R&I in Low-Carbon Energy Technologies

[JRC 2017e] Fiorini A, Georgakaki A, Jimenez Navarro J, Marmier A, Pasimeni F and Tzimas E: Energy R&I financing and patenting trends in the EU: Country dashboards 2017 edition. JRC Science for Policy Report EUR 29003. DOI:10.2760/519466

[JRC 2018a] Nijs W, Ruiz Castello P, Tarvydas D, Tsiropoulos I and Zucker A: Deployment scenarios for low carbon energy technologies Deliverable - D4.7 for the Low Carbon Energy Observatory (LCEO), JRC112915. Petten

[JRC 2018b] Tsiropoulos I, Tarvydas D and Zucker A: Cost development of low carbon energy technologies - Scenario-based cost trajectories to 2050, 2017 Edition, EUR 29034 EN, JRC109894. Luxembourg. Available at: https://ec.europa.eu/jrc/en/publication/cost-development-low-carbon-energy-technologies-scenario-based-cost-trajectories-2050-2017-edition

[JWPA 2018] Ueda Y: Offshore Wind Power in Japan - Present Status and Challenges - Conference presentation. WindEurope 2018 Conference at the Global Wind Summit

[K&L Gates 2018] Lasocki K: Offshore in Poland - Conference presentation. WindEurope 2018 Conference at the Global Wind Summit

[Landsvirkjun 2018] Landsvirkjun: Wind Power. Accessed: 08/21/2018. URL: https://www.landsvirkjun.com/ResearchDevelopment/Research/WindPower/

[Legifrance 2016] Legifrance: Decree of 24 of April 2016 on renewable energy developments objectives (Arrêté du 24 avril 2016 relatif aux objectifs de développement des énergies renouvelables). Accessed: 09/03/2018. URL: https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000032452174&categorieLien=id

[Magagna et al. 2017] Magagna D, Telsnig T, Uihlein A, Shortall R and Vázquez Hernández C: Supply chain of renewable energy technologies in Europe : An analysis for wind , geothermal and ocean energy. Publications Office of the European Union, Luxembourg. Available at: http://publications.jrc.ec.europa.eu/repository/handle/JRC108106

[Manjock et al. 2018] Manjock A, Argyriadis K, Hopstad A and Nguyen N: New Standard Development for Floating Wind Turbines - Conference Proceedings. WindEurope 2018 Conference at the Global Summit

[Marena 2018] Marena L: Challenges and opportunities for renewable energy investments in Sub-Saharan Africa - Conference presentation. WindEurope 2018 Conference at the Global Wind Summit

[MHI Vestas Offshore Wind 2018] Zachlod D: Offshore wind developments in Taiwan -Conference presentation. WindEurope 2018 Conference at the Global Wind Summit

[MNRE 2015] Government of India - Ministry of new and renewable energy: Tentative State-wise break-up of Renewable Power target to be achieved by the year 2022. Accessed: 06/26/2019. URL: https://mnre.gov.in/file-manager/UserFiles/Tentative-State-wise-break-up-of-Renewable-Power-by-2022.pdf

[MoE 2017] Ministry of Energy Bureau of Economic Affairs: Four-Year Plan of Promotion for Wind Power

[MoELT 2018] Ministry of Energy Lithuania: Rep. of Lithuania - National Energy Independence Strategy - ENERGY FOR LITHUANIA' FUTURE. Available at: https://enmin.lrv.lt/uploads/enmin/documents/files/National_energy_independence_strategy_2018(1).pdf

[Musial et al. 2019] Musial W, Beiter P, Spitsen P and Nunemaker J: 2018 Offshore Wind Technologies Market Report (forthcoming)

[NavigantResearch 2016] NavigantResearch: What GE's LM Wind Power Acquisition Means for the Wind Industry. Accessed: 11/13/2018. URL: https://www.navigantresearch.com/news-and-views/what-ges-lm-wind-power-acquisition-means-for-the-wind-industry

[NEU 2016] NewEnergyUpdate: Offshore wind installation vessel capacity to tighten after 2020. Accessed: 11/22/2018. URL: http://newenergyupdate.com/wind-energy-update/offshore-wind-installation-vessel-capacity-tighten-after-2020

[Nidec 2017] Nidec: Nidec Corporation Completes Acquisition of Leroy-Somer and Control Techniques. Accessed: 11/29/2018. URL: http://acim.nidec.com/motors/news-and-media/press-releases/2017/nidec-corporation-completes-acquisition-leroy-somer-and-control-techniques

[Noothout & Winkel 2016] Noothout P and Winkel T: Auctions for Renewable Energy Support in the Netherlands: Instruments and lessons learnt. Available at: http://auresproject.eu/sites/aures.eu/files/media/countryreports/pdf_netherlands.pdf

[Nordex 2018] Nordex-Acciona: Annual Report 2017. Available at: https://www.ccamatil.com/-/media/Cca/Corporate/Files/Annual-Reports/2017/CCA181-Annual-Report-2016-low-resolution.ashx

[NRDC 2016] National Development and Reforms Commission: Policy release (2016/12/07), 13TH FIVE-YEAR PLAN FOR ECONOMIC AND SOCIAL DEVELOPMENT OF THE PEOPLE'S REPUBLIC OF CHINA 2016–2020, Translated by the Compilation and Translation Bureau. Beijing, China. Available at: http://en.ndrc.gov.cn/newsrelease/201612/P020161207645765233498.pdf

[NREL 2017] Moné C, Hand M, Bolinger M, Rand J, Heimiller D and Ho J: 2015 Cost of Wind Energy Review

[NS 2018] NS: Sustainable Energy at Nederlandse Spoorwegen (NS). Accessed: 09/07/2018. URL: https://www.ns.nl/en/about-ns/sustainability/energy/sustainable-energy.html

[OffshoreWIND.biz 2019a] OffshoreWIND.biz: Dunkirk Strike Price Is EUR 44/MWh. URL: https://www.offshorewind.biz/2019/06/20/dunkirk-strike-price-is-eur-44-mwh/

[OffshoreWIND.biz 2019b] OffshoreWIND.biz: Dutch Extend Offshore Wind Tender Decision Deadline. URL: https://www.offshorewind.biz/2019/06/17/dutch-extend-offshore-wind-tender-decision-deadline/

[ÖSG 2012] ÖSG: Bundesgesetz über die Förderung der Elektrizitätserzeugung aus erneuerbaren Energieträgern (Ökostromgesetz 2012 – ÖSG 2012). Available at: https://www.ris.bka.gv.at/GeltendeFassung/Bundesnormen/20007386/ÖSG 2012%2C Fassung vom 17.09.2018.pdf

[OW 2016] OffshoreWIND.biz: Huisman Muscle for First Japanese-Built Wind Turbine Installation Vessel. Accessed: 11/22/2018. URL: https://www.offshorewind.biz/2016/10/25/huisman-muscle-for-first-japanese-built-wind-turbine-installation-vessel/

[OW 2017a] OffshoreWIND.biz: Jan De Nul Completes Turbine Installation at Blyth OWF. Accessed: 11/18/2018. URL: https://www.offshorewind.biz/2017/09/29/jan-de-nul-completes-turbine-installation-at-blyth-owf/

[OW 2017b] OffshoreWIND.biz: Installation Vessels: Reaching the Limit and Beyond. URL: https://www.offshorewind.biz/2017/03/27/installation-vessels-reaching-the-limit-and-beyond/

[OW 2017c] OffshoreWIND.biz: Unilever, TU Delft Powered by Eneco Luchterduinen OWF. Accessed: 08/07/2018. URL: https://www.offshorewind.biz/2017/01/31/unilever-tu-delft-powered-by-eneco-luchterduinen-owf/

[OW 2018a] OffshoreWIND.biz: Kriegers Flak to Power Healthcare Company and Bio Innovator. Accessed: 11/11/2018. URL: https://www.offshorewind.biz/2018/07/13/kriegers-flak-to-power-healthcare-company-and-bio-innovator/

[OW 2018b] OffshoreWIND.biz: Siemens Gamesa Automates Blade Inspections with SkySpecs Drones. Accessed: 11/14/2018. URL: https://www.offshorewind.biz/2018/09/26/siemens-gamesa-automates-blade-inspections-with-skyspecs-drones/

[OW 2019a] OffshoreWIND.biz: Japanese Floating Wind Turbine Put Into Operation. Accessed: 09/21/2019. URL: https://www.offshorewind.biz/2019/06/06/japanese-floating-wind-turbine-put-into-operation/

[OW 2019b] OffshoreWIND.biz: France to Tender Up to 6GW of Offshore Wind by 2028. Accessed: 06/05/2019. URL: https://www.offshorewind.biz/2019/01/28/france-tender-6gw-offshore-wind-2028/

[Pasimeni et al. 2018] Pasimeni F, Fiorini A and Georgakaki A: Patent-based Estimation Procedure of Private R&D: The Case of Climate Change and Mitigation Technologies in Europe. SPRU Working Paper Series (SWPS). Available at: http://www.sussex.ac.uk/spru/research/swps

[PEI 2018] Power Engineering International: Siemens opens $236m nacelle plant. URL: https://www.powerengineeringint.com/articles/2018/06/siemens-opens-236m-nacelle-plant.html

[PR 2018] Perpetual Robotics: Website Perceptual Robotics. Accessed: 11/12/2018. URL: https://www.perceptual-robotics.com/

[PV Magazine 2018] PV Magazine: Italy to hold first 500 MW wind-solar auction in January. Accessed: 10/14/2018. URL: https://www.pv-magazine.com/2018/09/07/italy-to-hold-first-500-mw-wind-solar-auction-in-january/

[PV Magazine 2019] PV Magazine: EU approves Italy's auction scheme for renewables. URL: https://www.pv-magazine.com/2019/06/14/eu-approves-italys-auction-scheme-for-renewables-incentives/

[PWEA 2018] Gajowiecki J: Polish wind is back in the spotlight - Conference presentation. WindEurope 2018 Conference at the Global Wind Summit

[R. Wiser & Bolinger. 2017] R. Wiser and Bolinger. M: 2011 Wind Technologies Market Report. Available at: https://emp.lbl.gov/sites/default/files/2017_wind_technologies_market_report.pdf

[RECHARGE 2018a] RECHARGE: Official Show Daily. Global Wind Summit 2018. Day four. Available at: https://windeurope.org/summit2018/files/media-and-press/GWS-2018-recharge-day-four.pdf

[RECHARGE 2018b] RECHARGE: Official Show Daily. Global Wind Summit 2018. Day three. Available at: https://windeurope.org/summit2018/files/media-and-press/GWS-2018-recharge-day-three.pdf

[Renewable Energy World 2015] Renewable Energy World: Wind Energy Implications of the Alstom and GE Deal. Accessed: 12/03/2017. URL: https://www.renewableenergyworld.com/ugc/articles/2015/09/wind-energy-implications-of-the-alstom-and-ge-deal.html

[Renews 2018] Renews: renews LIVE @ WindEnergy Hamburg

[RN 2016] RenewablesNow: Facebook to buy 150 MW of wind power in Ireland from Brookfield. Accessed: 09/24/2018. URL: https://renewablesnow.com/news/facebook-to-buy-150-mw-of-wind-power-in-ireland-from-brookfield-520006/

[RN 2017] RenewablesNow: Microsoft signs 37-MW wind PPA with GE in Ireland. Accessed: 09/24/2018. URL: https://renewablesnow.com/news/microsoft-signs-37-mw-wind-ppa-with-ge-in-ireland-586254/

[RN 2018] RenewablesNow: Alstom to offload stake in renewables JV with GE. URL: https://renewablesnow.com/news/alstom-to-offload-stake-in-renewables-jv-with-ge-612145/

[SEN 2017] SEN: Ministero dello Sviluppo Economico Ministero dell'Ambiente e della Tutela del Territorio e del Mare - Strategia Energetica Nazionale (SEN 2017). Available at: http://www.sviluppoeconomico.gov.it/index.php/it/198-notizie-stampa/2037347-strategia-energetica-nazionale-oggi-la-presentazione

[Senvion 2018] Senvion: Annual report 2017. Available at:

https://www.senvion.com/global/en/investors/publications/

[SER 2013] SER: Summary of the “Energy Agreement for sustainable Growth” in NL 1 (6–9). DOI:10.1017/CBO9781107415324.004

[SiemensGamesa 2018] SiemensGamesa: Annual report 2017. Available at: https://www.siemensgamesa.com/en-int/-/media/siemensgamesa/downloads/en/investors-and-shareholders/annual-reports/2017/annual-report-17-en.pdf

[SiemensGamesa 2019] SiemensGamesa: SiemensGamesa - Products and services - Offshore. Accessed: 03/18/2019. URL: https://www.siemensgamesa.com/en-int/products-and-services/offshore

[Suzlon 2018] Suzlon: Annual report 2017-18. Available at: https://www.suzlon.com/in-en/investor-relations/financial-reports-presentations

[TaiyangNews 2019a] TaiyangNews: Once More Solar Rules In German Tender. URL: http://taiyangnews.info/markets/once-more-solar-rules-in-german-tender/

[TaiyangNews 2019b] TaiyangNews: Greece Awards Over 437 MW In 600 MW RE Auction. URL: http://taiyangnews.info/markets/greece-awards-over-437-mw-in-600-mw-re-auction/

[TaiyangNews 2019c] TaiyangNews: Solar Undersubscribed In Greek 300 MW Tender. URL: http://taiyangnews.info/markets/solar-undersubscribed-in-greek-300-mw-tender/

[TPI 2019] TPI: TPI Composites 2108 Annual Report. Available at: http://www.tpicomposites.com/English/investors/Financial-Information/Annual-Report/default.aspx

[US Statutes 1920] US Statutes: Merchant Marine Act - Policy for development of an American merchant marine - SIXTY-SIXTH CONGRESS . Sess . II . Cli . 250 . - 1920. Legis Works, US. Available at: http://www.legisworks.org/congress/66/publaw-261.pdf

[Vestas 2018a] Vestas: Annual report 2017. Available at: https://www.vestas.com/~/media/vestas/investor/investor pdf/financial reports/2017/q4/2017_annual_report.pdf

[Vestas 2018b] Vestas: Vestas to acquire Utopus Insights, a leading energy analytics and digital solutions company. Accessed: 12/08/2018. URL: https://www.vestas.com/en/media/company-news?n=1679383#!grid_0_content_0_Container

[Wind Europe 2018a] Wind Europe: Competitive prices in first Greek onshore wind auction. URL: https://windeurope.org/newsroom/press-releases/competitive-prices-in-first-greek-onshore-wind-auction/

[Wind Europe 2018b] Wind Europe: Lower prices for onshore wind in second Greek renewables auction. URL: https://windeurope.org/newsroom/news/lower-prices-for-onshore-wind-in-second-greek-renewables-auction/

[Wind Europe 2018c] Wind Europe: Competitive prices in Polish onshore wind auction. URL: https://windeurope.org/newsroom/press-releases/competitive-prices-in-polish-onshore-wind-auction/

[Wind Europe 2018d] Wind Europe: Poland’s new energy strategy to almost phase out onshore wind. URL: https://windeurope.org/newsroom/press-releases/polands-new-energy-strategy-to-almost-phase-out-onshore-wind/

[Wind Europe 2018e] Wind Europe: Germany reaches political agreement on additional onshore wind volumes. URL: https://windeurope.org/newsroom/news/germany-reaches-political-agreement-on-additional-onshore-wind-volumes/

[WindEurope 2017] WindEurope: Wind energy in Europe: Outlook to 2020. Bruxelles. Available at: https://windeurope.org/about-wind/reports/wind-energy-in-europe-outlook-to-2020/

[WindEurope 2018a] WindEurope: Lithuania significantly steps up its wind energy ambitions with new National Energy Strategy. Accessed: 11/08/2018. URL: https://windeurope.org/newsroom/news/lithuania-significantly-steps-up-its-wind-energy-ambitions-with-new-national-energy-strategy/

[WindEurope 2018b] WindEurope: Wind energy in Europe: Outlook to 2022. Brussels. Available at: https://windeurope.org/about-wind/reports/wind-energy-in-europe-outlook-to-2022/

[WindEurope 2018c] WindEurope: Breaking new ground - Wind Energy and the Electrification of Europe’s

Energy System. Bruxelles

[WindEurope 2018d] WindEurope: FLOATING OFFSHORE WIND ENERGY - A POLICY BLUEPRINT FOR EUROPE. Accessed: 01/04/2019. URL: https://windeurope.org/wp-content/uploads/files/policy/position-papers/Floating-offshore-wind-energy-a-policy-blueprint-for-Europe.pdf

[WindEurope 2018e] WindEurope: First 2018 onshore wind auction in Germany: fair competition, low prices and community projects still among the winners. Accessed: 12/04/2018. URL: https://windeurope.org/newsroom/press-releases/first-2018-onshore-wind-auction-in-germany-fair-competition-low-prices-and-community-projects-still-among-the-winners/

[WindEurope 2018f] WindEurope: Permitting issues leave latest German onshore wind auction under-subscribed. URL: https://windeurope.org/newsroom/press-releases/permitting-issues-leave-latest-german-onshore-wind-auction-under-subscribed/

[WindEurope 2018g] WindEurope: Financing and investment trends The European wind industry in 2017. Available at: https://windeurope.org/about-wind/reports/financing-and-investment-trends-2017/

[WindEurope 2019a] WindEurope: Dunkirk auction result boosts the case for ambitious offshore wind volumes in France. URL: https://windeurope.org/newsroom/press-releases/dunkirk-auction-result-boosts-the-case-for-ambitious-offshore-wind-volumes-in-france/

[WindEurope 2019b] WindEurope: Offshore Wind in Europe - Key trends and statistics 2018

[Wiser & Bolinger 2018] Wiser R and Bolinger M: 2017 Wind Technologies Market Report

[WPM 2012] WPM: Ming Yang warns on 70% Q1 revenue fall. Accessed: 11/20/2018. URL: https://www.windpowermonthly.com/article/1134051/ming-yang-warns-70-q1-revenue-fall

[WPM 2014] WPM: Ming Yang profits slump again. Accessed: 11/28/2018. URL: https://www.windpowermonthly.com/article/1289284/ming-yang-profits-slump-again

[WPM 2015] Wind Power Monthly: Mergers and acquisitions -- Low risk, high returns. Accessed: 10/10/2018. URL: https://www.windpowermonthly.com/article/1344895/mergers-acquisitions-low-risk-high-returns

[WPM 2016a] WPM: Ming Yang board accepts privatisation bid. Accessed: 11/28/2018. URL: https://www.windpowermonthly.com/article/1382328/ming-yang-board-accepts-privatisation-bid

[WPM 2016b] WPM: Drones: gimmick or game-changer? Accessed: 08/07/2018. URL: https://www.windpowermonthly.com/article/1380741/drones-gimmick-game-changer

[WPM 2016c] WPM: Ramping up intelligence and interconnectivity. Accessed: 08/28/2018. URL: https://www.windpowermonthly.com/article/1416808/ramping-intelligence-interconnectivity

[WPM 2017a] WPM: Flanders raises 2020 wind target. Accessed: 10/01/2018. URL: https://www.windpowermonthly.com/article/1340362/market-status-belgium-long-term-prospects-better-offshore

[WPM 2017b] WPM: Romanian 1GW could help Netherlands reach targets. Accessed: 08/12/2018. URL: https://www.windpowermonthly.com/article/1449805/romanian-1gw-help-netherlands-reach-targets

[WPM 2017c] WPM: Siemens Gamesa cuts 600 further jobs at Aalborg. Accessed: 11/25/2018. URL: https://www.windpowermonthly.com/article/1442429/siemens-gamesa-cuts-600-further-jobs-aalborg

[WPM 2017d] WPM: SGRE cuts jobs at Iowa factory. Accessed: 11/20/2018. URL: https://www.windpowermonthly.com/article/1455686/sgre-cuts-jobs-iowa-factory

[WPM 2017e] WPM: Senvion factory closures force earnings down. Accessed: 11/20/2018. URL: https://www.windpowermonthly.com/article/1433202/senvion-factory-closures-force-earnings-down

[WPM 2017f] WPM: Microsoft buys power from Vattenfall's Wieringermeer. Accessed: 09/24/2018. URL: https://www.windpowermonthly.com/article/1449134/microsoft-buys-power-vattenfalls-wieringermeer

[WPM 2017g] WPM: Group wins grant to develop drone inspection system. Accessed: 09/05/2018. URL: https://www.windpoweroffshore.com/article/1450832/group-wins-grant-develop-drone-inspection-system

[WPM 2017h] WPM: Blockchain platform launched to market local wind power. Accessed: 11/29/2018. URL: https://www.windpowermonthly.com/article/1450798/blockchain-platform-launched-market-local-wind-power

[WPM 2017i] WPM: Envision Energy forms partnership with Microsoft. Accessed: 09/12/2018. URL: https://www.windpowermonthly.com/article/1439607/envision-energy-forms-partnership-microsoft

[WPM 2017j] Wind Power Monthly: Vestas signs Russian blade factory deal. Accessed: 09/09/2018. URL: https://www.windpowermonthly.com/article/1444081/vestas-signs-russian-blade-factory-deal

[WPM 2018a] Wind Power Monthly: Finland launches 1.4TWh auction. Accessed: 11/05/2018. URL: https://www.windpowermonthly.com/article/1499101/finland-launches-14twh-auction

[WPM 2018b] Wind Power Monthly: French onshore tender undersubscribed. Accessed: 11/20/2018. URL: https://www.windpowermonthly.com/article/1492187/french-onshore-tender-undersubscribed

[WPM 2018c] Wind Power Monthly: Wind takes a beating from solar. URL: https://www.windpowermonthly.com/article/1498432/wind-takes-beating-solar

[WPM 2018d] WPM: Vestas announces 400 job cuts. Accessed: 11/29/2018. URL: https://www.windpowermonthly.com/article/1494301/vestas-announces-400-job-cuts

[WPM 2018e] WPM: Vestas profits fall despite increase in orders. Accessed: 11/29/2018. URL: https://www.windpowermonthly.com/article/1498301/vestas-profits-fall-despite-increase-orders

[WPM 2018f] WPM: Nordex earnings still below 2017 levels. Accessed: 11/29/2018. URL: https://www.windpowermonthly.com/article/1498821/nordex-earnings-below-2017-levels

[WPM 2018g] WPM: Pricing pressures stunt SGRE recovery. Accessed: 11/29/2018. URL: https://www.windpowermonthly.com/article/1498131/pricing-pressures-stunt-sgre-recovery

[WPM 2018h] WPM: Goldwind revenue falls, but profit rises. Accessed: 11/29/2018. URL: https://www.windpowermonthly.com/article/1460336/goldwind-revenue-falls-profit-rises

[WPM 2018i] WPM: Senvion makes net loss in “challenging” environment. Accessed: 11/20/2018. URL: https://www.windpowermonthly.com/article/1498959/senvion-makes-net-loss-challenging-environment

[WPM 2018j] WPM: Suzlon CEO charts overseas re-entrance. Accessed: 11/25/2018. URL: https://www.windpowermonthly.com/article/1489492/suzlon-ceo-charts-overseas-re-entrance

[WPM 2018k] WPM: Suzlon’s earnings, installations hit by auction shift. Accessed: 11/30/2018. URL: https://www.windpowermonthly.com/article/1489653/suzlons-earnings-installations-hit-auction-shift

[WPM 2018l] WPM: Suzlon-backed developer acquires US cluster. Accessed: 11/30/2018. URL: https://www.windpowermonthly.com/article/1490462/suzlon-backed-developer-acquires-us-cluster

[WPM 2018m] WPM: Ørsted buys Deepwater Wind. URL: https://www.windpoweroffshore.com/article/1495252/orsted-buys-deepwater-wind

[WPM 2018n] WPM: Ørsted buys US firm Lincoln Clean Energy. URL: https://www.windpowermonthly.com/article/1489978/orsted-buys-us-firm-lincoln-clean-energy?_ga=2.99486622.1882253801.1561632884-1590187288.1542373200

[WPM 2018o] WPM: Reflections from WindEnergy Hamburg 2018. Accessed: 11/16/2018. URL: https://www.windpowermonthly.com/article/1497113/reflections-windenergy-hamburg-2018

[WPM 2018p] WPM: Dongfang to build blades in Russia. Accessed: 11/15/2018. URL: https://www.windpowermonthly.com/article/1409177/dongfang-build-blades-russia

[WPM 2018q] WPM: EC approves GE’s LM takeover. Accessed: 11/16/2018. URL: https://www.windpowermonthly.com/article/1427966/ec-approves-ges-lm-takeover

[WPM 2018r] WPM: Corporations driving renewables growth. Accessed: 09/12/2018. URL: https://www.windpowermonthly.com/article/1489816/corporations-driving-renewables-growth

[WPM 2018s] WPM: GIG finances 235MW Swedish project. Accessed: 11/03/2018. URL: https://www.windpowermonthly.com/article/1488273/gig-finances-235mw-swedish-project

[WPM 2018t] WPM: Alcoa to buy power from 330MW Norwegian site. Accessed: 11/30/2018. URL: https://www.windpowermonthly.com/article/1458948/alcoa-buy-power-330mw-norwegian-site

[WPM 2018u] WPM: Wind to power Google’s Finnish data centre. Accessed: 09/24/2018. URL:

https://www.windpowermonthly.com/article/1492443/wind-power-googles-finnish-data-centre

[WPM 2018v] WPM: Facebook buys Norwegian wind power. Accessed: 09/24/2018. URL: https://www.windpowermonthly.com/article/1465676/facebook-buys-norwegian-wind-power

[WPM 2018w] WPM: PPAs give old projects new lease of life - updated. Accessed: 11/30/2018. URL: https://www.windpowermonthly.com/article/1492488/ppas-give-old-projects-new-lease-life-updated

[WPM 2018x] WPM: Industrialising production and shipping. Accessed: 12/04/2018. URL: https://www.windpowermonthly.com/article/1462973/industrialising-production-shipping

[WPM 2018y] WPM: SGRE steps up offering with custom drone and robot. Accessed: 11/13/2018. URL: https://www.windpowermonthly.com/article/1462930/sgre-steps-offering-custom-drone-robot

[WPM 2018z] WPM: Statkraft and Esforin team-up for blockchain trading. Accessed: 12/05/2018. URL: https://www.windpowermonthly.com/article/1456138/statkraft-esforin-team-up-blockchain-trading

[WPM 2018aa] WPM: Startup promises to "bring wind power to the masses." Accessed: 12/07/2018. URL: https://www.windpowermonthly.com/article/1465716/startup-promises-bring-wind-power-masses

[WPM 2018ab] WPM: Chinese province runs on renewables for 216 hours. Accessed: 12/03/2018. URL: https://www.windpowermonthly.com/article/1489670/chinese-province-runs-renewables-216-hours

[WPM 2018ac] WPM: Blockchain facility to be powered by wind. Accessed: 09/05/2018. URL: https://www.windpowermonthly.com/article/1489552/blockchain-facility-powered-wind

[WPM 2018ad] Wind Power Monthly: Components produced in Russia for first time. Accessed: 09/04/2018. URL: https://www.windpowermonthly.com/article/1465417/components-produced-russia-first-time

[WPM 2018ae] WPM: Vessels go supersize. Accessed: 12/09/2018. URL: https://www.windpowermonthly.com/article/1465996/vessels-go-supersize

[WPM 2019] Wind Power Monthly: Clean sweep for wind in Finland's first tender. URL: https://www.windpowermonthly.com/article/1580274/clean-sweep-wind-finlands-first-tender

[WPO 2015] WPO: A2Sea to install Taiwan's Formosa 1. Accessed: 10/10/2018. URL: https://www.windpoweroffshore.com/article/1367658/a2sea-install-taiwans-formosa-1

[WPO 2017] Wind Power Offshore: New underwater drone for cable inspection launched. Accessed: 10/08/2018. URL: https://www.windpoweroffshore.com/article/1434069/new-underwater-drone-cable-inspection-launched

[WPO 2018a] WPO: Crown Estate upgrades UK round 4 to 7GW. URL: https://www.windpoweroffshore.com/article/1518786/crown-estate-upgrades-uk-round-4-7gw

[WPO 2018b] WPO: MHI Vestas unveils 10MW turbine. Accessed: 10/12/2018. URL: https://www.windpoweroffshore.com/article/1493924/mhi-vestas-unveils-10mw-turbine

[WPO 2018c] WPO: GE unveils 12MW offshore turbine - updated. Accessed: 10/10/2018. URL: https://www.windpoweroffshore.com/article/1458364/ge-unveils-12mw-offshore-turbine-updated

[WPO 2018d] WPO: MHI Vestas advances Taiwanese supply chain. Accessed: 11/15/2018. URL: https://www.windpoweroffshore.com/article/1497514/mhi-vestas-advances-taiwanese-supply-chain

[WPO 2018e] WPO: SGRE signs Taiwanese local supply agreements. Accessed: 11/15/2018. URL: https://www.windpoweroffshore.com/article/1494780/sgre-signs-taiwanese-local-supply-agreements

[WPO 2018f] WPO: US firm to build offshore vessels fleet. Accessed: 11/23/2018. URL: https://www.windpoweroffshore.com/article/1461086/us-firm-build-offshore-vessels-fleet

[WPO 2018g] WPO: US firm designing Jones Act-compliant vessel. Accessed: 11/20/2018. URL: https://www.windpoweroffshore.com/article/1496279/us-firm-designing-jones-act-compliant-vessel

[WPO 2019] WPO: EDP and Engie plan offshore JV. URL: https://www.windpoweroffshore.com/article/1585327/edp-engie-plan-offshore-jv

[WSW 2018] WSW: Tal.Markt. Accessed: 11/29/2018. URL: https://wsw-talmarkt.de/#/home

APPENDIX A

Table 10 NREAP trajectories for electricity generation from wind energy [EC 2018e]

Country	Technology	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
		GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
AT	Wind total	1343	2034	2460	2844	3189	3500	3780	4032	4258	4462	4646	4811
AT	Wind Onshore	1343	2034	2460	2844	3189	3500	3780	4032	4258	4462	4646	4811
AT	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0
BE	Wind total	319.6	990.5	1745.5	2866.2	4171.9	5281.5	6084.1	7402.5	8505	9286.3	9975.7	10474
BE	Wind Onshore	319.6	839.5	1110.5	1308.2	1505.9	1802.5	2100.1	2495.5	2891	3349.3	3812.7	4274
BE	Wind Offshore	0	151	635	1558	2666	3479	3984	4907	5614	5937	6163	6200
BG	Wind total	5	605	1008	1390	1764	2007	2293	2367	2466	2516	2556	2592
BG	Wind Onshore	5	605	1008	1390	1764	2007	2293	2367	2466	2516	2556	2592
BG	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0
CR	Wind total	9.5	139.1	287.3	347.6	495.8	644	880	880	880	880	880	880
CR	Wind Onshore	9.5	139.1	287.3	347.6	495.8	644	880	880	880	880	880	880
CR	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0
CY	Wind total	0	31.4	189	189	275	275	300	300	350	350	433	499
CY	Wind Onshore	0	31.4	189	189	275	275	300	300	350	350	433	499
CY	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0
CZ	Wind total	16	343	371	414	486	566	649	721	794	867	941	1014
CZ	Wind Onshore	16	343	371	414	486	566	649	721	794	867	941	1014
CZ	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0
DK	Wind total	11242	11667	11837	11832	11787	11713	11242	11667	11837	11832	11787	11713
DK	Wind Onshore	6322	6660	6728	6617	6471	6391	6322	6660	6728	6617	6471	6391
DK	Wind Offshore	4920	5007	5109	5215	5316	5322	4920	5007	5109	5215	5316	5322
EE	Wind total	54	337	355	432	757	855	981	974	1209	1320	1320	1537
EE	Wind Onshore	54	337	355	432	757	855	981	974	974	974	974	974
EE	Wind Offshore	0	0	0	0	0	0	0	0	235	346	346	563
FI	Wind total	150	360	590	820	1060	1290	1520	2440	3350	4260	5180	6000
FI	Wind Onshore	150	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3500
FI	Wind Offshore	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2500
FR	Wind total	1128	11638	14344	17956	21875	26101	30634	35473	40620	46073	51833	57900
FR	Wind Onshore	1128	11638	14344	15956	17875	20101	22634	25473	28620	32073	35833	39900
FR	Wind Offshore	0	0	0	2000	4000	6000	8000	10000	12000	14000	16000	18000
DE	Wind total	26658	44668	49420	53055	57314	63657	69994	76067	82466	89210	96359	104435
DE	Wind Onshore	26658	44397	48461	51152	54064	58420	61990	64583	66873	68913	70694	72664
DE	Wind Offshore	0	271	959	1903	3250	5237	8004	11484	15592	20297	25666	31771
EL	Wind total	1267	3129	4501	5838	7116	8427	9674	10532	11751	13152	15240	16797
EL	Wind Onshore	1267	3129	4501	5838	7116	8427	9674	10425	11538	12831	14790	16125
EL	Wind Offshore	0	0	0	0	0	0	0	107	213	321	450	672
HU	Wind total	NA	692	692	929	1150	1303	1377	1404	1450	1483	1504	1545
HU	Wind Onshore	NA	692	692	929	1150	1303	1377	1404	1450	1483	1504	1545
HU	Wind Offshore	NA	0	0	0	0	0	0	0	0	0	0	0
IE	Wind total	1588	4817	5965	6189	7478	7756	8339	8404	8985	10235	10258	11970
IE	Wind Onshore		4701	5848	6073	6663	6942	7525	7587	7639	8534	8553	10228
IE	Wind Offshore		116	116	117	815	814	814	817	1345	1702	1705	1742
IT	Wind total	2558	8398	9358	10318	11529	12575	13652	14769	15940	17184	18526	20000
IT	Wind Onshore	2558	8398	9358	10318	11279	12239	13199	14159	15119	16080	17040	18000
IT	Wind Offshore	0	0	0	0	250	336	453	610	820	1104	1486	2000
LV	Wind total	47	58	73	100	134	175	228	300	394	517	681	910
LV	Wind Onshore	47	58	73	100	134	175	228	234	264	297	395	519
LV	Wind Offshore	0	0	0	0	0	0	0	66	130	220	286	391
LT	Wind total	2	297	473	563	688	813	924	1111	1250	1250	1250	1250
LT	Wind Onshore	2	297	473	563	688	813	924	1111	1250	1250	1250	1250
LT	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0

LU	Wind total	52.4	60	71	98	130	163	192	213	226	234	238	239
LU	Wind Onshore	52.4	60	71	98	130	163	192	213	226	234	238	239
LU	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0
MT*	Wind total	NA	0	0	0	4.17	10.42	17.35	95.06	254.49	254.49	254.49	254.49
MT	Wind Onshore	NA	0	0	0	4.17	10.42	17.35	38.12	38.12	38.12	38.12	38.12
MT	Wind Offshore	NA	0	0	0	0	0	0	56.94	216.37	216.37	216.37	216.37
NL	Wind total	2067	4470	4472	6576	8322	11784	13655	17406	21157	24908	28657	32408
NL	Wind Onshore	2067	3667	3669	5773	6694	8475	9508	10281	11054	11827	12599	13372
NL	Wind Offshore	0	803	803	803	1628	3309	4147	7125	10103	13081	16058	19036
PL**	Wind total	136	2310	3255	4308	5327	6491	7541	8784	9860	11210	12315	15210
PL	Wind Onshore	136	2310	3255	4300	5268	6380	7370	8550	9563	10810	11845	13160
PL	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	1500
PT	Wind total	1773	10214	11334	12600	12600	12600	13480	13480	13480	14580	14476	14596
PT	Wind Onshore	1773	10214	11334	12600	12600	12600	13420	13420	13420	14520	14416	14416
PT	Wind Offshore	0	0	0	0	0	0	60	60	60	60	60	180
RO	Wind total	0.227	460	1997	3316	4634	5952	6614	7271	7668	8020	8230	8400
RO	Wind Onshore	0.227	460	1997	3316	4634	5952	6614	7271	7668	8020	8230	8400
RO	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0
SK	Wind total	7	7	8	120	240	240	480	480	480	560	560	560
SK	Wind Onshore	7	7	8	120	240	240	480	480	480	560	560	560
SK	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0
SI	Wind total	0	2	4	4	14	14	109	109	109	109	191	191
SI	Wind Onshore	0	2	4	4	14	14	109	109	109	109	191	191
SI	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0
ES	Wind total	20729	40978	43668	47312	50753	53981	57086	60573	64483	68652	73197	78254
ES	Wind Onshore	20729	40978	43668	47312	50753	53906	56786	59598	62238	64925	67619	70502
ES	Wind Offshore	0	0	0	0	0	75	300	975	2245	3727	5577	7753
SV***	Wind total	939	4793	5564	6334	7105	7876	8646	9417	10188	10959	11729	12500
SV	Wind Onshore	877	4585	5326	6068	6809	7551	8292	9034	9775	10517	11258	12000
SV	Wind Offshore	62	208	237	266	296	325	354	383	412	442	471	500
UK	Wind total	2904	14150	19130	23170	27790	33170	39430	46730	54800	63040	70320	78270
UK	Wind Onshore	2501	9520	12480	14200	15990	17970	20610	23460	26500	29690	31920	34150
UK	Wind Offshore	403	4630	6650	8970	11800	15200	18820	23270	28300	33350	38400	44120
IS	Wind total	0	0	0	0	7	7	7	7	7	7	7	7
IS	Wind Onshore	0	0	0	0	7	7	7	7	7	7	7	7
IS	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0
NO	Wind total	448	576	1177	1357	2040	3118	4029	4894	5760	6625	7490	8355
NO	Wind Onshore	448	576	1177	1357	2040	3118	4029	4894	5760	6625	7490	8355
NO	Wind Offshore	0	0	0	0	0	0	0	0	0	0	0	0

* Additionally the NREAP plan provides small scale wind. As this is only a minor capacity it is not included in the data shown here

** NREAP includes small wind installations, therefore the number of Wind Onshore and Wind total is not the same

Table 11 Electricity generation from wind energy based on the 3rd and 4th progress reports [EC 2018f]

		Progress reports 2015		Progress reports 2017			Progress reports 2015		Progress reports 2017	
Country	Technology	2013	2014	2015	2016	Country	2013	2014	2015	2016
		GWh	GWh	GWh	GWh		GWh	GWh	GWh	GWh
AT	Wind total	3012	3827	4679	5350	LV	120	141	147	128
AT	Wind Onshore	3012	3827	4679	5350	LV	120	141	147	128
AT	Wind Offshore	0	0	0	0	LV	0	0	0	0
BE	Wind total	3626	4419	5121	5529	LT	634	650	836	1078
BE	Wind Onshore	2059	2313	2820	3219	LT	634	650	836	1078
BE	Wind Offshore	1567	2106	2301	2310	LT	0	0	0	0
BG	Wind total	1220	1301	1366	1408	LU	83	80	91	127
BG*	Wind Onshore	1220	1301	NA	NA	LU	83	80	91	127
BG	Wind Offshore	0	0	NA	NA	LU	0	0	0	0
CR	Wind total	453	670	846	1019	MT	0	0	0	0
CR	Wind Onshore	453	670	846	1019	MT	0	0	0	0
CR	Wind Offshore	0	0	0	0	MT	0	0	0	0
CY	Wind total	231	183	205	222	NL	5368	5810	6917	8364
CY	Wind Onshore	231	183	205	222	NL	4632	5060	5882	6041
CY	Wind Offshore	0	0	0	0	NL	736	750	1035	2323
CZ	Wind total	460	481	521	519	PL	6133	7574	9688	12041
CZ	Wind Onshore	460	481	521	519	PL	6133	7574	9688	12041
CZ	Wind Offshore	0	0	0	0	PL	0	0	0	0
DK	Wind total	10585	12076	13065	13455	PT	11135	11791	12002	12513
DK**	Wind Onshore	8001	8914	NA	NA	PT	11130	11787	NA	NA
DK**	Wind Offshore	2584	3162	NA	NA	PT	5	4	NA	NA
EE	Wind total	565	636	715	594	RO	4233	5965	6566	6408
EE	Wind Onshore	565	636	715	594	RO	4233	5965	7063	6590
EE	Wind Offshore	0	0	0	0	RO	0	0	0	0
FI	Wind total	746	1138	1985	3103	SK	6	6	6	6
FI	Wind Onshore	NA	NA	NA	NA	SK	6	6	6	6
FI	Wind Offshore	NA	NA	NA	NA	SK	0	0	0	0
FR	Wind total	15751	17311	19936	22411	SI	4	5	6	7
FR	Wind Onshore	15751	17311	19936	22411	SI	4	5	6	7
FR	Wind Offshore	0	0	0	0	SI	0	0	0	0
DE	Wind total	52712	58838	71468	80040	ES	50706	51458	51055	51514
DE	Wind Onshore	51629	57193	66415	70980	ES	50706	51458	51055	51514
DE	Wind Offshore	1236	1738	7040	12171	ES	0	0	0	0
EL	Wind total	4053	4152	4497	4964	SV****	9184	11077	14117	15774
EL**	Wind Onshore	NA	NA	NA	NA	SV	9374	10566	15608	14871
EL**	Wind Offshore	NA	NA	NA	NA	SV	468	669	714	608
HU	Wind total	704	704	701	706	UK	25804	31579	37494	40778
HU	Wind Onshore	704	704	701	706	UK	15474	18468	21339	23446
HU	Wind Offshore	0	0	0	0	UK	10330	13111	16155	17332
IE***	Wind total	4607	5133	5133	6063					
IE	Wind Onshore	NA	NA	NA	NA					
IE	Wind Offshore	NA	NA	NA	NA					
IT	Wind total	14120	14887	15298	16519	NO	1872	2115		
IT	Wind Onshore	14120	14887	15298	16519	NO	1868	2107		
IT	Wind Offshore	0	0	0	0	NO	4	8		

*BG progress report 2015: assumed to be all onshore wind as in the NREAP

**DK progress report 2017: No differentiation between onshore and offshore wind

*** IE: Wind generated electricity output is not split between onshore and offshore for commercial sensitivity reasons

**** Unlike the total fields for wind power, the division of on-shore/off-shore wind power has not been normalised

KJ-BK-19-013-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

Publications Office of the European Union

doi:10.2760/223306

ISBN 978-92-76-12569-3