Offshore wind energy

Patent insight report

November 2023

Europäisches Patentamt
European Patent Office
Office européen des brevets

years 1973 / 2023

IRENA
International Renewable Energy Agency

Contents

Executive summary

Offshore wind energy is a clean and renewable source of electricity generation. It helps to combat climate change (UN Sustainable Development Goal 13) by reducing greenhouse gas emissions, air pollution and the reliance on fossil fuels for electricity production, thus contributing to a more sustainable energy mix.

Offshore wind energy plays a significant role in supporting UN Sustainable Development Goal 7 (SDG 7), which aims to ensure access to affordable, reliable and sustainable energy for all by 2030.

In a collaborative effort by the European Patent Office (EPO) and the International Renewable Energy Agency (IRENA), this patent insight report examines the global evolution of patent filings published between 2002 and 2022 in the domain of offshore wind energy.

Patent filing statistics provide insightful indicators for measuring and examining innovation, commercialisation and knowledge transfer trends across international markets. They also provide meaningful information on changes in technology trends and make it easier to identify new players or consolidation efforts. All in all, this report aims to shed light on how key technological challenges are being addressed via innovation.

Using a proven EPO data analysis methodology, this report's findings consider information from roughly 17 000 patents (from the EPO's patent database). These patents cover inventions related to offshore wind energy, including key technology concept groupings such as: fixed and floating foundations, towers, mechanical power transmission, blades and rotors, hybrid systems, energy storage, and grids and submarine cables.

Policy insights

Patent data show a massive surge in global patent filings from 2006 to 2012, followed by a stagnation until 2017 when patent activity witnessed a resurgence. Floating foundations, transportation, and mechanical transmission accounted for the largest number of patents within the offshore wind area. Some key policy insights from the patent data are summarised below:

1. **Increased invention in offshore wind with dominance in Europa, Asia and USA emerging as future market.** In the ranking of the top ten countries in filed International Patent Families (IPFs), seven countries are European, with Germany and Denmark in the lead. The USA is third while China and Japan rank fourth and fifth respectively (the Republic of Korea ranks 11th). As for non-IPF patents mainly for domestic markets (i.e. not protected internationally), China leads, which reflects its reliance on a large local market for offshore wind.

2. **Floating foundation, logistics and green hydrogen attract invention activity.** Most inventions for offshore wind focus on three areas: floating foundations, transportation equipment, and the installation and erection of turbines. It is worth noting that a fourth area is rapidly scaling up in innovation activity, i.e. combining offshore wind and electrolysers, indicating great expectations of a large green-hydrogen economy as a value creation opportunity.

3. **Floating foundations pose to expand offshore wind markets.** Market trends indicate a growing interest in developing floating foundations given their potential for siting turbines in deeper waters with abundant wind potential. This is confirmed by patent data, which shows that industry players are innovating in this technology area.

4. **Tower and blade designs to reduce steel demand and enhance sustainability.** Players in the offshore wind sector are also looking into alternative designs for towers (i.e. concrete and lattice structures), which may reduce demand for steel. They are also exploring modular blade assembly options, as well as sustainable and recyclable blades, to promote circularity and address manufacturing and transportation challenges.

5. **Increased use of rare earth materials in drive trains.** Here the trend shows continued interest in direct-drive systems due to their effective cost-weight-power density ratio; however that trend would mean an increase in the utilisation of permanent synchronous magnet generators. The increase in the use of permanent magnets would, in turn, result in higher demand for rare earth materials needed to manufacture them.

6. **On-site energy storage and hydrogen production to balance power systems and create additional value.** There is a growing focus on flexible energy systems to counter the variability of renewable technologies. Patent data in offshore wind energy technologies also show a growing interest in energy storage options, especially in the combination of offshore wind parks and hydrogen production, which offer the added benefit of helping to decarbonize activities.

7. **Uptake of submarine electrical infrastructure.** The need for transmission infrastructure is also driving innovation activities and patent data reveals that there are many corresponding innovations in submarine cabling to connect supply and demand cost-effectively.

8. **Moderate interest in hybridising offshore wind with other energy generation sources.** To expand the potential of offshore wind solutions there are increasing efforts to combine offshore energy generation with other technologies such as PV or ocean energy. Insights from patents reveal that innovation activities remain steady since 2013. This can potentially be ascribed to the declining cost of offshore wind that acts as disincentivise given the complexity associated with the hybridisation of offshore wind with additional ocean technologies in terms of operation and maintenance.

Summary of patent data trends

Filing statistics:

— From 2002 to 2022, about 17 000 patent families related to offshore wind energy were published, reflecting an average annual increase of 18%. Between 2014 and 2017 filings stagnated, but this was followed by a steep increase.

— The top applicant country is China (52% of the total patent families), followed by the Republic of Korea (6%), Germany (5%), Japan (5%), USA (4%), and Denmark (4%).

— Twenty-seven percent of all offshore wind energy patent families are international patent families (IPFs) i.e. excluding single domestic filings. More specifically 79% of the total patent families developed by European countries are IPFs, as- are 64% by the United States of America. Four percent of Chinese patent families are international.

— Sixty-seven percent of all offshore wind energy IPFs include at least one granted patent application.

— For all granted EP applications, 68% are still in force in at least 1 member state. (10% more than the average).

Main actors:

— Vestas, Siemens, General Electric, Mitsubishi Heavy Industries and Hitachi are the top IPF applicants. In the last 5 years, RWE Renewables and Itrec have entered the top five, replacing Mitsubishi Heavy Industries and Hitachi.

— France has the highest number of patent families with international cooperation. The United States of America has the most diverse co-operation picture, pairing with 24 countries on a total of 81 patent families. Germany co-operates with 15 countries on a total of 79 patent families.

— From 2017 onwards, Chinese applications are increasingly more cited. Most citations come from other Chinese applications (and applicants), but also by applications from Germany, Denmark and USA, which indicates advances in patent quality.

- Until 2012, patent applicants who are natural persons used to file 50% of all patent applications, on a par with companies. Since then, that share has successively decreased to its current level of 6%.

- From 2013 onwards a consolidation across patent applicants can be seen, with mergers and acquisitions leading to fewer applicants, far fewer natural person applicants, but similar total numbers of patent applications are filed with the same grant rates, which suggests no reduction in the quality of applications.

Main technologies:

- Floating foundations lead in IPFs (49%), followed by transportation, installation and erection (26%).

- Combining offshore wind turbines and electrolysers is an emerging trend: the number of IPFs doubled between 2020 and 2021, with signs of this trend continuing in 2022.

1. Introduction

1.1 The role of offshore wind energy in energy transition

Climate change is already impacting the world's largest economies as well as emerging economies and, urges the decision makers and stakeholders to adopt corrective actions urgently to tackle the global climate emergency. IRENA's World Energy Transitions Outlook 2023 edition has once again shown that the renewables based energy transition is the solution to the fight against climate change and the pace of the transition is currently off-track[1].

Limiting global warming to 1.5°C will require cutting carbon dioxide (CO_2) emissions by around 37 gigatonnes (Gt) from 2022 levels to achieve a net zero scenario in the energy sector by 2050. This will require a profound transformation of energy systems, including a massive deployment of renewable generation capacity. In 2022, IRENA's statistics show that renewables accounted for 83% of new annual generation capacity additions, with an additional 295 gigawatts (GW), reaching 40% of the total global installed capacity[2]. Under IRENA's 1.5°C scenario, renewable generating capacity will need to reach above 33 000 GW by 2050.[3]

By 2050, wind (onshore and offshore) would significantly increase from the current 900 GW up to more than 10 000 GW, representing almost one-third of the total installed capacity from renewable sources. In terms of offshore wind, the global installed capacity would reach almost 2 500 GW by 2050. This entails a 40 times increase from today's level (63 GW by 2022) and makes offshore wind one of the leading technologies in the bid to achieve global climate targets within the next three decades.

Yet the deployment of offshore wind comes with its own challenges. Even though the technology itself has experienced sharp cost reductions — a fall of 59% in the levelised cost of electricity (LCOE) [4] between 2010-2022, current commodity price inflation and higher interest rates are proving a challenging environment. In addition, aspects such as integrating this technology into the energy system via new interconnections, supply chain bottlenecks and logistical challenges, the demand for critical materials and recycling or the need for larger turbines and more robust foundations, among other factors, require further efforts, if we are to accelerate the sectors to the energy transition. Today, the offshore wind market remains smaller than the onshore wind market, with total installed capacities reaching 63 GW by 2022. Considering the current plans and targets set by countries as per IRENA's Planned Energy Scenario (PES), the global cumulative offshore wind capacity is expected to reach 275 GW by 2030 and close to 1 200 GW by 2050 respectively. This still falls behind of the 494 GW and 2 465 GW targets by 2030 and 2050 respectively in IRENA's 1.5°C Scenario.[5]

1 IRENA (2023), World Energy Transitions Outlook 2023: 1.5°C Pathway, Volume 1, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/Publications/2023/Jun/World-Energy-Transitions-Outlook-2023

2 https://www.irena.org/Publications/2023/Jul/Renewable-energy-statistics-2023

3 IRENA (2023), World Energy Transitions Outlook 2023: 1.5°C Pathway, Volume 1, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/Publications/2023/Jun/World-Energy-Transitions-Outlook-2023

4 IRENA (2023), Renewable Power Generation Costs in 2022, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022

5 IRENA (2023), World Energy Transitions Outlook: 1.5°C Pathway, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/Publications/2023/Jun/World-Energy-Transitions-Outlook-2023

Box 1: The cost-competitiveness of offshore wind

Due to its offshore location, its high energy output per square metre and its ability to be built up quickly at gigawatt-scale, offshore wind is a valuable option to provide electricity to densely populated coastal areas in a cost-effective manner.[6] Given its potential, offshore wind is expected to play a key role in the energy transition towards 2050.

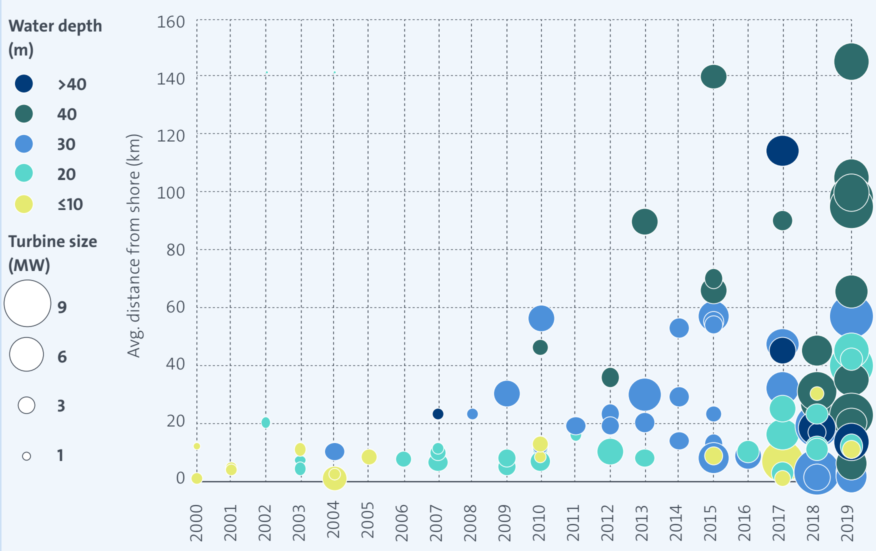
The period from 2010 to 2022 witnessed a massive deployment of offshore wind installed capacity, from 3.1 GW in 2010 up to 63.2 GW in 2022 — a twentyfold increase. During the same period, global weighted-average total installed costs fell 34%, from USD 5 217/kilowatt (kW) to USD 3 461/kW. At its peak in 2011, the global weighted-average total installed cost was USD 5 975/kW – 1.7 times higher than its 2022 value[7].

In addition, technology improvements related to larger turbines with longer blades, higher hub heights, and new locations further away from shorelines where wind resource increases are resulting in higher estimated lifetime capacity factors (for newly commissioned projects) that increased from 38% in 2010 to 45% in 2017 and then dropped to 42% in 2022.

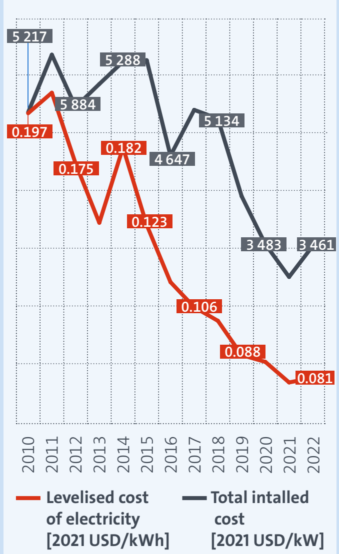
These trends underscore the potential for significant advancements through the process of learning via research and development, leading to technological enhancements. Initially, offshore wind farms were situated closer to shore and at shallow depths (see the bubble chart[8] below). However, thanks to stronger and more consistent wind resources, research, development and demonstration (RD&D) initiatives have prompted a shift of wind farms to greater distances from the coast and into deeper waters.

The technical potential that can be realised in waters of depths beyond 50 metres, mainly via the utilisation of floating offshore platforms, represents an opportunity for countries and regions with substantial seabed drops, such as Japan, China, the United States and Europe, to position wind farms significantly farther from the coastline. Yet, the geographical distribution of offshore wind projects remained consistent, led by Europe (including the United Kingdom, Denmark, and Germany) and Asia (represented by China and Japan).

Offshore wind turbine development trend



Levelised cost of electricity



All the above technology improvements and the growing maturity of the industry have resulted in a 59% decline of the weighted-average levelised cost for the period 2010-2022, from USD 0.197/kilowatt hour (kWh) to USD 0.081/kWh. 2021 alone saw a decline of 13% year-on-year (see trend lines[9]). Yet, in 2022, a 2% increase was observed.[6]

6 IRENA (2021), Offshore renewables. An action agenda for deployment A contribution to the G20 presidency https://www.irena.org/publications/2021/Jul/Offshore-Renewables-An-Action-Agenda-for-Deployment

7 IRENA (2023), Renewable Power Generation Costs in 2022, International Renewable Energy Agency, Abu Dhabi.

8 Source: IRENA (2022), Renewable Technology Innovation Indicators: Mapping progress in costs, patents and standards, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2022/Mar/Renewable-Technology-Innovation-Indicators

9 IRENA Renewable Cost Database

1.2 About the study

The objective of this study is to examine the global evolution of patent filings to identify major trends in the field of offshore wind energy and pinpoint market and technology gaps as well as opportunities relevant to the contribution of offshore wind to the energy transition.

The report aims to provide useful insights for interested players in the field and policymakers to leverage actions and initiatives for further developing and deploying offshore wind-related technologies, thereby enabling offshore wind energy in the energy system. The study uses various resources for this purpose, including EPO patent databases and registers and other public reports available. It also benefits from the technical expertise in the field of both IRENA and the EPO.

According to their respective missions and activities, the EPO and IRENA share a common interest in the study of patent filing statistics to improve understanding of trends affecting the transition to a sustainable energy future using renewable energy sources. In 2023, IRENA and the EPO extended their memorandum of understanding on bilateral cooperation to promote innovation in the field of renewable energy technologies[10], and committed to publish regular patent landscape reports focusing on specific technological areas.[11]

Building on this long-standing EPO-IRENA collaboration, the present insight report assesses patent filing statistics in the offshore wind energy domain. The growing political interest around the globe in climate-neutral energy production, energy storage technologies and the promise that offshore wind energy offers is the driving force behind a great momentum for innovation and spin-off activities.

Offshore wind energy, which can be considered a key technology for the energy transition, requires continuous improvement to harness its full potential and benefit not only the energy domain, but also economies and societies. In this sense, the growth of offshore wind energy has brought new business opportunities for the energy industry and changed the dynamics of the energy market. Among other benefits, its technological progress has led to the development of new solutions such as larger turbines, better transmission systems and special ships to install the turbines, while also creating jobs in the renewable energy sector. Overall, offshore wind energy is disrupting the energy industry by providing a new and sustainable source of energy that has the potential to meet the world's growing energy needs.

Even though patent filings show a steep increase in the last 10 years, major innovations in offshore wind energy technology are still needed to realise its full potential.

10 EPO and IRENA enhance co-operation on patent information about renewable energy technologies.

11 In 2022, EPO and IRENA published a patent insight report on innovation trends in electrolysers for hydrogen production, which you can download at: https://www.epo.org/news-events/news/2022/20220512.html

2. Methodology

This section introduces the main sources of information as well as the approach adopted to extract relevant information from the various datasets. Key patent-related concepts are explained as well as the rationale followed to select the seven technology concept groupings related to offshore wind energy technologies. Hence, the aim of the section is to provide the framework for understanding the results presented in this report.

2.1 Using patent information

Patents are exclusive rights that can only be granted for inventions that are novel and inventive.[12] High-quality patents are assets which can help attract investment, secure licensing deals and provide market exclusivity. Patent owners pay annual fees to maintain patents in those countries that are of commercial value to them and protect their inventions from being used by competitors, for example. In exchange for these exclusive rights, all patent applications are published, revealing the technical details of the protected inventions. This allows other researchers to build on the published inventions of other inventors and avoid the mistake of investing in developing a solution for a problem that has already been solved by others.

Patent databases contain a wealth of technical information, much of which cannot be found in any other source. The EPO's free Espacenet[13] database contains more than 140 million documents from over 100 countries. Patent filing statistics provide interesting indicators to measure and examine innovation, commercialisation and knowledge transfer trends. They also provide a means of observing changes in technology trends as well as identifying new players or consolidation efforts. This can reveal new insights into trends in the offshore wind energy sector and help support informed decision-making processes.

2.2 Patent search

This patent insight report provides a snapshot of the patent situation of offshore wind energy technologies. Although some technologies are equally applicable to onshore and offshore, this report defines the patent search strategies for most of the concepts and sub-concepts so that there would be a specific "offshore aspect" mentioned in the patent text or covered by the patent classification codes.

As for previous EPO patent insight reports, the approach to this work begins with a state-of-the-art search for the relevant technology in selected patent databases. A search strategy is developed with an expert examiner in the field, and search results are then analysed to answer specific questions about patterns of patenting activity or innovation. The results are presented visually to assist understanding and allow conclusions to be reached and recommendations to be made based on the empirical evidence.

The information, data and analysis provided in this report are primarily based on a targeted utilisation of EPO patent databases (PATSTAT, Espacenet, EP register and other dedicated patent examiner sources). Only relevant patent publications in the period from 2002 to 2022 (earliest publication year within the patent family) were considered. The identification of the relevant areas of technology and the creation of the technology-specific search strategies were undertaken by an EPO examiner expert in the offshore wind energy field and by IRENA experts. All search queries (summarised in Figure 2.2) were adapted as well[14] as possible to the free Espacenet tool. Detailed search queries based on the EPO's free Espacenet tool are provided in a separate excel document. This allows the reader to monitor future changes in the covered technologies.[15] An automatic and manual data harmonisation process has been implemented to enhance the accuracy and completeness of the final dataset.[16]

Each query is identifiable via a different label (QA, QB, etc.) and these correspond to concepts and sub-concepts related to offshore wind energy technologies. Not all documented queries have been used for the study in this report. Although the report strongly centres on the technology used for offshore wind energy (Q0), other concepts or detail views have not been limited to

12 epo.org/learning/materials/inventors-handbook/novelty.html.

13 https://worldwide.espacenet.com/.

14 Internal EPO systems allow more complex searches than the ESPACENET tool.

15 IPC and CPC patent classification codes as well as the keywords used may change when a technology matures.

16 Pasimeni, F. (2019). SQL query to increase data accuracy and completeness in PATSTAT. World Patent Information, 57, 1-7. https://doi.org/10.1016/j.wpi.2019.02.001

offshore or wind energy. For instance, (QL) submarine cables (conductors), (QL1) protection and (QM) recycling have not been limited to offshore or wind energy because the technology used in submarine cables is the same as what is used to transport electricity between countries divided by water. Equally, the technology used for recycling turbine blades is not limited to turbine blades for offshore use.

The total number of patent families used in this report (extracted via concepts QA to QL and published between 2002 and 2022) is about 17 000 (covering 33 000 unique applications).[17]

As illustrated in Figure 2.2, this report defines seven technology concept groupings relevant to offshore energy, following this rationale:

- Fixed and floating foundations
  - Rationale: With the arrival of ever bigger turbines to improve efficiency, floating platforms have made it possible to harness wind energy in deeper waters. This however comes with its own challenges such as anchoring, stabilisation and maintenance.

- Towers
  - Rationale: Tower structures have to fulfil multiple requirements regarding cost-effectiveness, weight, durability, strength, and ease of installation. Depending on the environmental conditions, different concepts or combinations of concepts can be considered.

- Mechanical power transmission
  - Rationale: Two competing types of drive systems share the focus of current lines of development and innovation. The gearbox approach transforms slow speed and high torque to higher speeds required by the generator. In direct-drive approach, the wind turbines directly power a synchronous generator.

- Blades and rotors
  - Rationale: Unique harsh operating conditions and the need for larger blades to capture more energy require adaptations in design using advanced composites and special monitoring techniques.

- Hybrid systems
  - Rationale: Hybrid systems combine offshore wind energy with other sources of energy to produce electricity; typically wave or solar energy.

- Energy storage
  - Rationale: Renewable energy, be it produced by wind, solar or ocean energy, is often dictated by weather conditions. Innovative solutions are needed to capture and store the produced energy when there is an oversupply and release it when demand peaks.

- Grid, submarine cables and protections
  - Rationale: Submarine cables are needed to transport the electricity to the consumers on shore. Harsh conditions shorten their lifespan and they require complex repairs when needed. Extra measures need to be taken to protect submarine cables against damage.

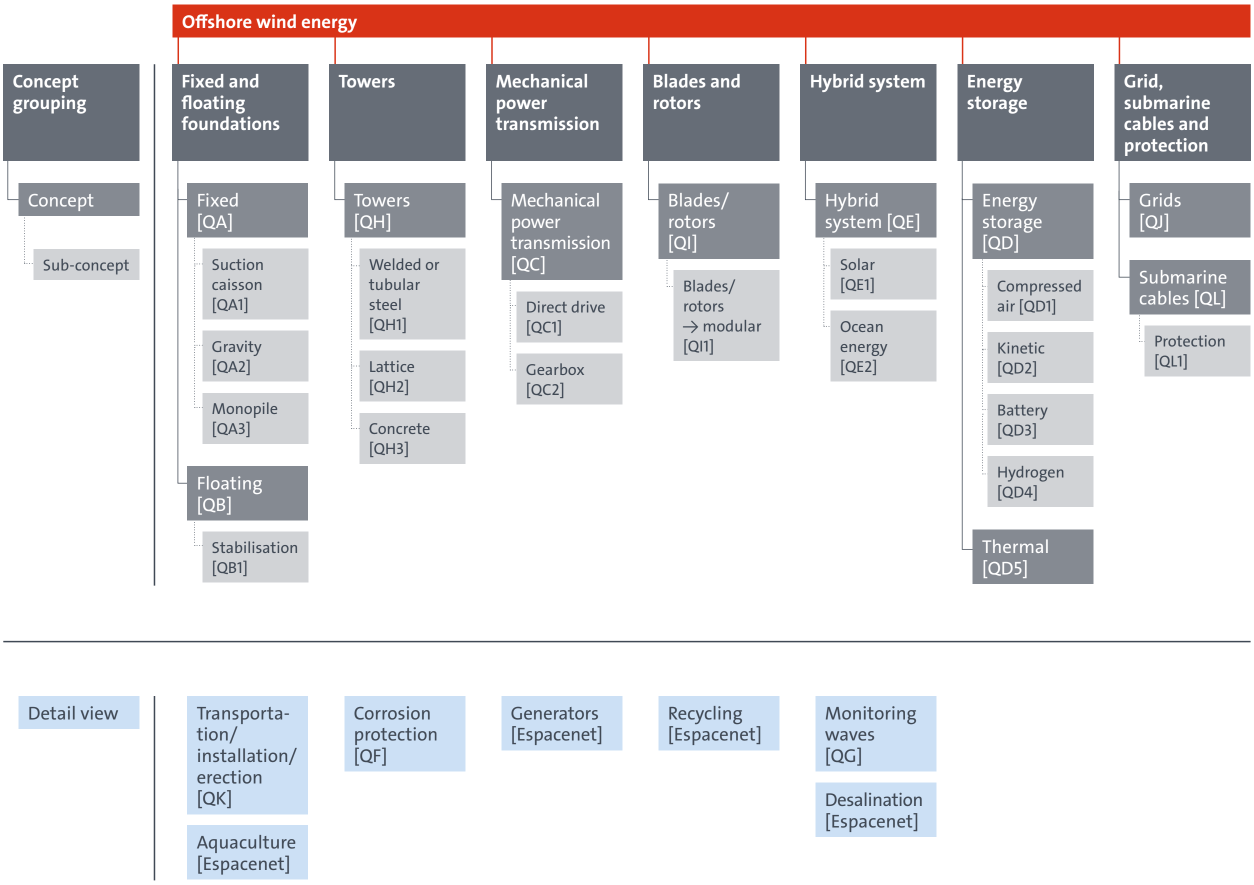
Throughout the report, detailed views are also provided in the “blue boxes” that focus on other relevant areas touching upon offshore wind energy technology. These relate to transportation, installation and erection of wind turbines, aquaculture, desalination, corrosion protection, generators, recycling, and patents for monitoring waves.

17 The total number of patent families in the dataset is around 26 000, meaning that about 9 000 patent families are not being considered for this report. Those patent families left out cover technical areas such as: monitoring, testing, controlling, diagnostics, AC/DC circuit arrangements, and hydraulic engineering.

Figure 2.2:

This figure shows a summary of the technology concepts analysed in this report.

The Q-codes within the square brackets indicate the corresponding query or the EPO patent databases from which data are sourced.



When using IPC and CPC classification codes to extract patents for statistical analysis, readers must bear in mind that it is in the patent applicant's interest to get the broadest possible scope of protection for the invention. Therefore, a patent will not be restricted to the combination of elements in which the applicant is developing its technology. As a result, some aspects may be inaccurately attributed to a patent application in the sense that a particular technical aspect may be developed for a specific technology without being explicitly indicated in the patent application or reflected in the patent classification. The patents extracted and grouped under (QL) *submarine cables (conductors)* provide an example of this aspect. Just over 2% of *submarine cables* patent families are also classified specifically for offshore wind energy.

Data mining (optimising search queries) and curation were conducted by the EPO in line with existing best practices of EPO experts and patent examiners. A challenge in this report was defining the boundaries for the various datasets of patents. This leads to quite large overlaps between the different technology concepts and the relevant patent families. Keywords were often used to create a better separation of the various concepts.

Throughout the report, patent filing statistics are addressed at different levels of aggregation whenever appropriate. Patent numbers are quantified by the distinct count of patent families.[18] In addressing the patent filing data through the lens of origin of innovation, it is important to note that different filing strategies by stakeholders from different countries can have an

18 epo.org/searching-for-patents/helpful-resources/first-time-here/patent-families.html.

impact on the overall statistics and on the conclusions. For instance, Chinese applicants choose predominantly domestic filings and do not file for patents on a comparable scale internationally.[19] In addition, Chinese applicants often file utility models as well as patents on the same or similar inventions, which increases Chinese filing numbers when simply counting patent filings or even families.

This report uses a stricter concept of patent families called international patent families (IPFs). This concept excludes all single national patent families that have only been filed in the country of the applicant[20]. Patent families with applications having applicants or inventors from different countries were also considered to be international patent families. EP and WO filings[21] as well as any other regional office filings are by default IPFs. Of the about 17 000 patent families used in this report (extracted within concepts from QA to QL and published between 2002 and 2022), 4 657 are IPFs (about 27%), grouping a total of 20 165 unique patent applications.

The fact that patent families can belong to different concepts will lead to a statistical double counting in some of the graphs because the patent family will be considered relevant for each of the concepts. A similar double counting occurs at the country (applicant, patent office) level analysis when an application has applicants from different countries, or when patent family members are filed at multiple patent authorities.

19 Pasimeni, F., Fiorini, A., & Georgakaki, A. (2021). International landscape of the inventive activity on climate change mitigation technologies. A patent analysis. Energy Strategy Reviews, 36, 100677. https://doi.org/10.1016/j.esr.2021.100677

20 Applicant countries and filing authorities are abbreviated throughout the report according to WIPO STANDARD ST.3: https://www.wipo.int/standards/en/pdf/03-03-01.pdf

21 EP denotes filings at the European Patent Office and WO those at the World Intellectual Property Organization

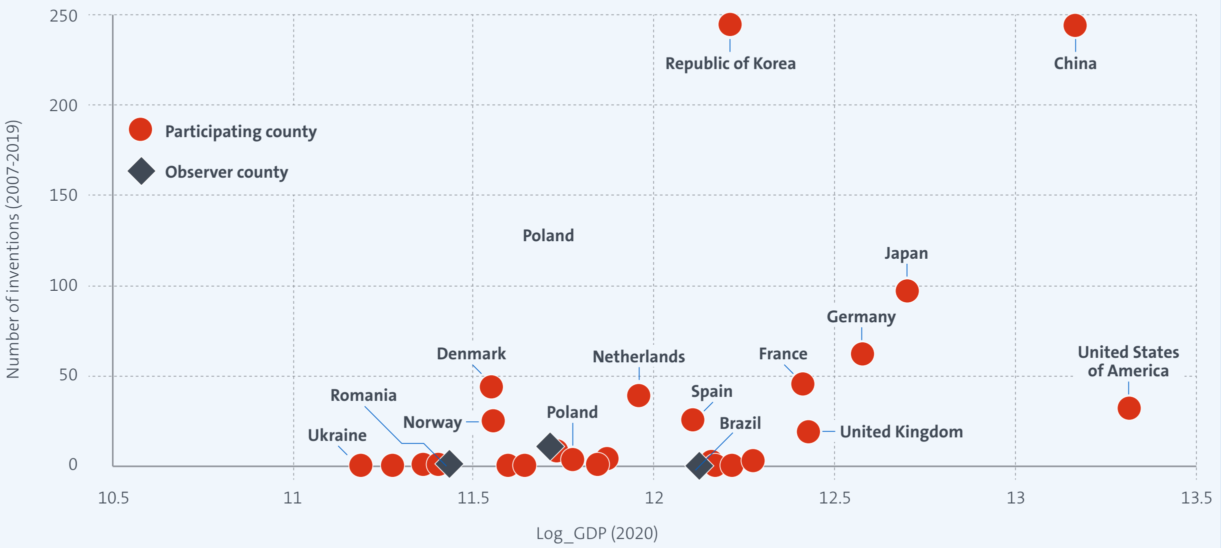
Box 2: International technical standardization of offshore wind[22]

The international standardisation of offshore wind technology encompasses various aspects, including design, production, safety, testing and analysis, aimed at optimising operations. From 2004 to 2020, a total of 33 international standards were established for wind energy technologies. Within this period, 26 standards were applicable to both onshore and offshore wind energy, with an additional 5 focusing solely on offshore or floating wind. Many of these standards emerged after 2012, indicating technology maturity and progression to commercialisation.

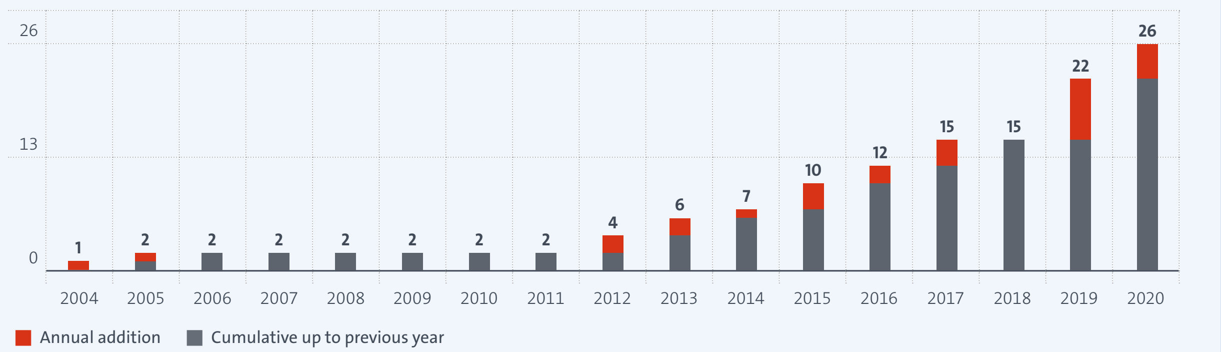
Offshore wind technology has gained global interest, with participation by various countries often tied to their intent to commercialise wind-related innovations. The number of participating member countries involved in developing international technical standards for wind energy covering both onshore and offshore domains grew steadily from 16 to 33 between 2004 and 2020. Taking observer countries into account, the total count reached 41 in 2020.

An observation emerges that wealthier economies are more actively engaged in this technological field compared to other economies, as most observer countries in the wind technical committee count among the latter category. To ensure the widespread dissemination of offshore wind technologies, it is crucial for less developed economies to play a role in the standardisation process. International standardisation bodies should facilitate increased participation from developing nations or professionals from countries with limited technical expertise.

Countries in technical committee on wind energy



Standard developed



22 Source: IRENA (2022), Renewable Technology Innovation Indicators: Mapping progress in costs, patents and standards, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2022/Mar/Renewable-Technology-Innovation-Indicators

3. Results

This section presents the key results, including technology insights and interpretations. First, in section 3.1, results are presented by looking at all the queries run to identify relevant areas related to offshore wind energy technologies. Then, in section 3.2., the focus of the analysis moves to the seven technology concept groupings, each of which are analysed in a dedicated sub-section. All results are presented based on the following structure: global patenting trends are shown first, then the analysis moves to countries of the applicants, and concludes by focusing on the top patent applicants. Further detailed views and observations are provided in the "blue boxes".

3.1 Patent trends in offshore wind energy technologies

The following sub-sections present the insights on offshore wind energy technologies by focusing on six specific patent metrics. The first of these sub-sections, 3.1.1, illustrates the main patenting trends, followed by insights related to both top patenting countries (section 3.1.2) and top patent offices (section 3.1.3), each focusing on countries where IPFs are developed and on countries where IPFs are legally protected by national patent authorities. Top patent applicants are presented in section 3.1.4, while section 3.1.5 focuses on patent citations. Section 3.1.6 introduces the maturity map, which summarises the main phases of patent development related to offshore wind energy technologies.

→ Interactive data in public Tableau workbook

3.1.1 Patent filings

Following an initial phase marked by limited patent filings, the patenting activity in offshore wind energy technologies experienced a notable surge starting in 2006. Subsequently, a period of consistent annual expansion persisted until 2012. As shown in Figure 3.1.1, the evolution of patenting activity presents a slight dip in the following years. Nevertheless, a new increasing trend emerges from 2017 onward, maintaining momentum up to the present moment. This trend is similar either when all patent families or only IPFs are plotted (in the top and bottom bar chart in Figure 3.1.1, respectively). These innovations led to cost reductions over the past decade, enabling the exploration of alternative offshore installation methods, including greater distances from the coast and deeper waters. As a result, these advancements have contributed to achieving the notably high installed offshore wind capacity.[23]

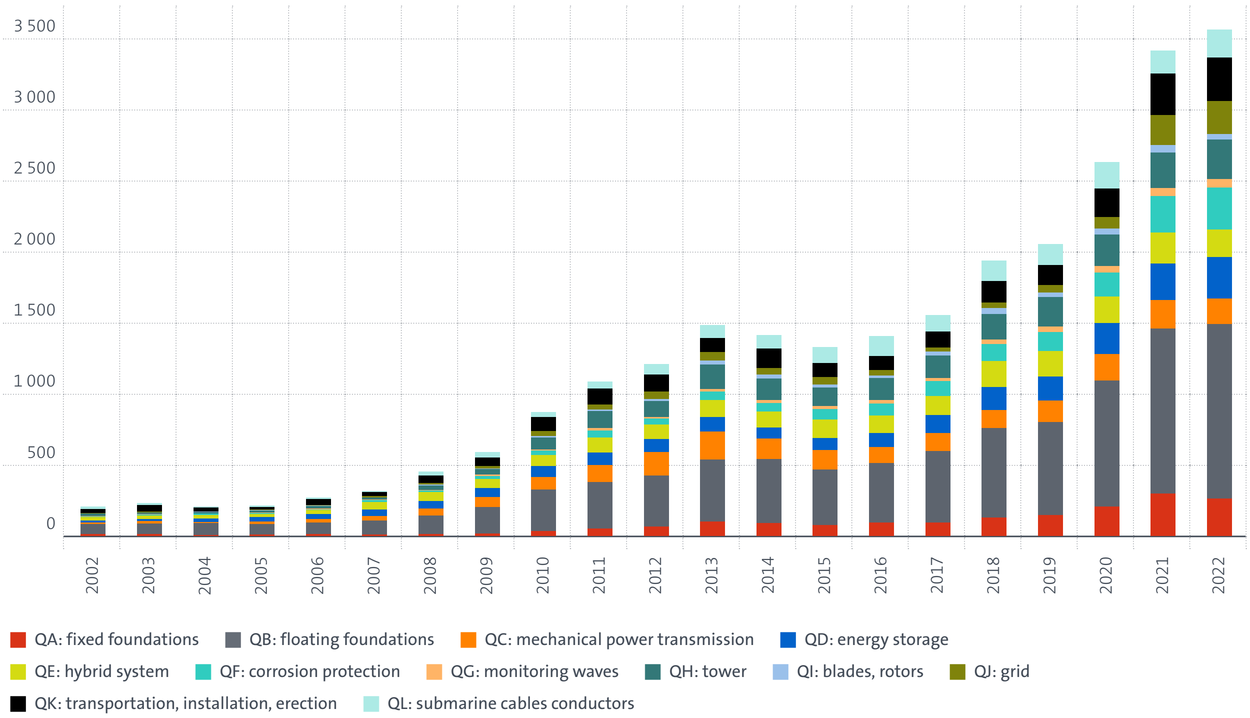
On annual average, IPFs account for about 40% of the total patent families (more on this later), and Figure 3.1.1 also indicates that the largest number of patent families concern QB floating, with these accounting for about 27% of the total number of IPFs, followed by QK transportation, installation and erection (14%) and QC mechanical power transmission (12%).

23 IRENA (2022), Renewable Technology Innovation Indicators: Mapping progress in costs, patents and standards, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2022/Mar/Renewable-Technology-Innovation-Indicators

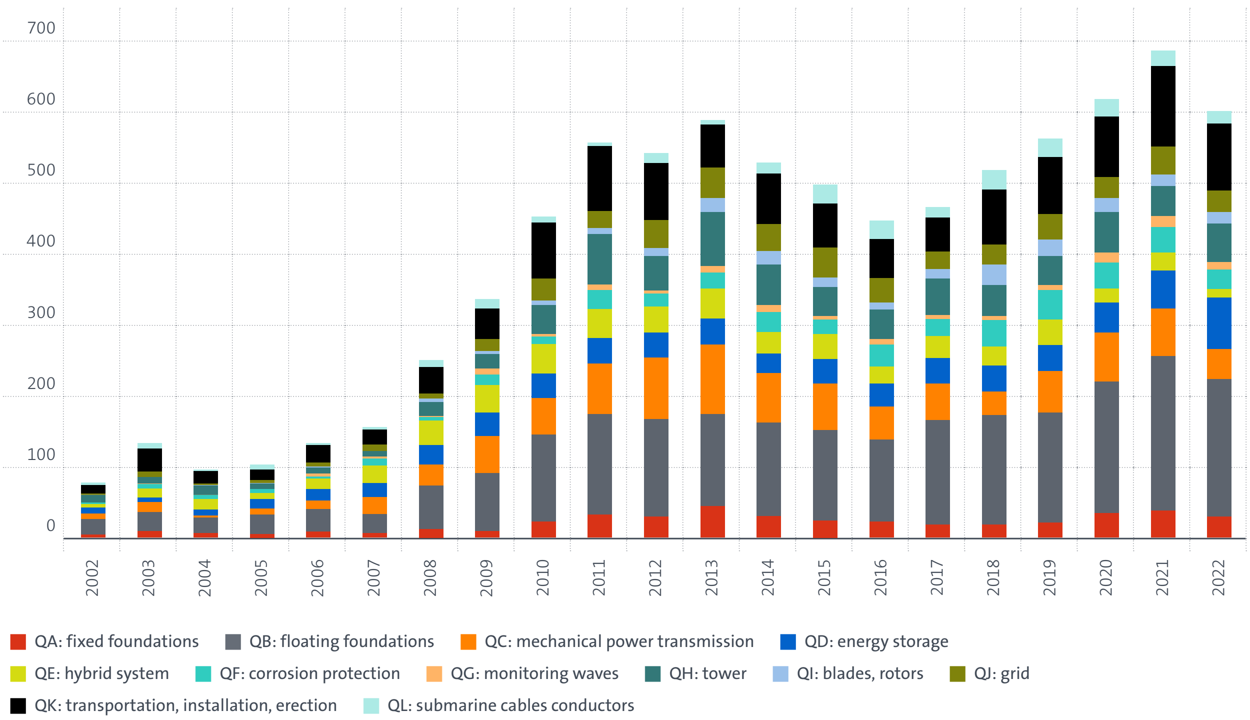
Figure 3.1.1:

Trend in all patent families (2002-2022)

All patent families



International patent families (IPF)



Trend in all patent families (top) and international patent families (bottom) between 2002 and 2022 for the 12 queries (QA to QL) run for this report.

Box 3: Granted patent applications in IPF for offshore wind energy

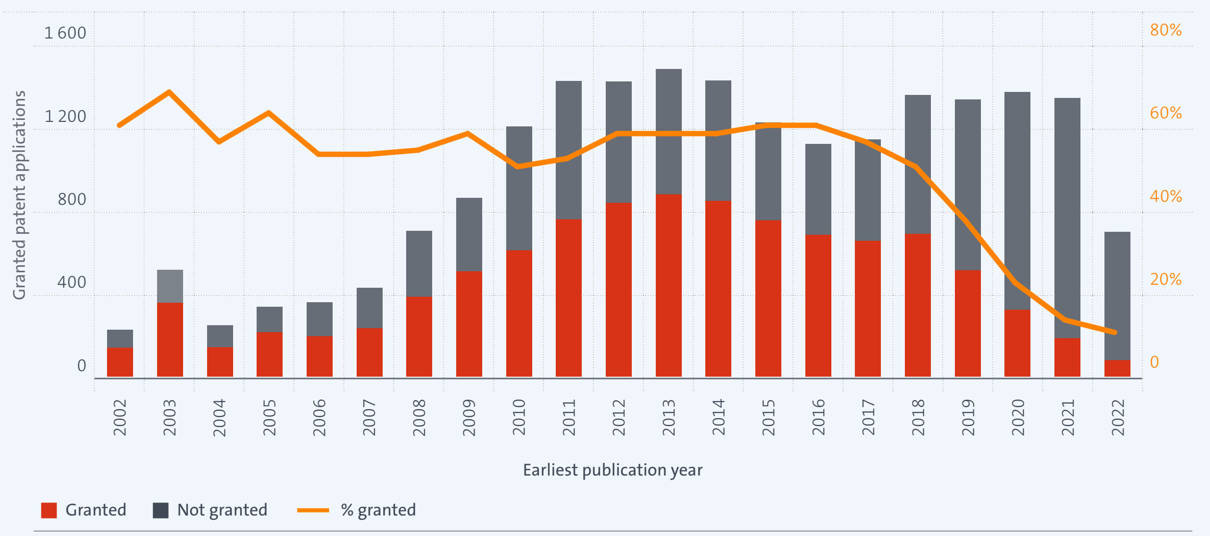
The number of granted patents is a good measure of innovative quality and economic importance. Granted patent applications are usually considered to be a better indicator of the quality of the patents because only patents fulfilling all the requirements of patentability[24] will effectively be granted.

A growing number of granted patent applications indicates the willingness of patent owners to invest resources to protect the market share where the invention might be used to generate income. The bar chart below shows the trend of the net number of granted patent applications (dark blue) in comparison to patent applications that were not granted (light blue) in international patent families (IPF).

In fact, an IPF is composed by one or more patent applications, and these might be (or might be not) granted. In the chart, the horizontal axis indicates the earliest publication year of the family.

A sustained increase in the number of granted patents is seen up to 2013 (about 60% on annual average), which indicates a general increase in the capacities acquired for the development of new offshore wind technology. In subsequent years, the share of granted applications decreases, also due to the time needed for a patent to be granted after its application has been filed (which is about 38 months for EPO applications). Please also note that data for 2022 are incomplete because there are delays on data deliveries, which is the reason for the lower total in that year.

Granted patent applications (2002-2022)



24 At the EPO this means that the inventions are new, involve an inventive step and are susceptible of industrial application (see Article 52 EPC).

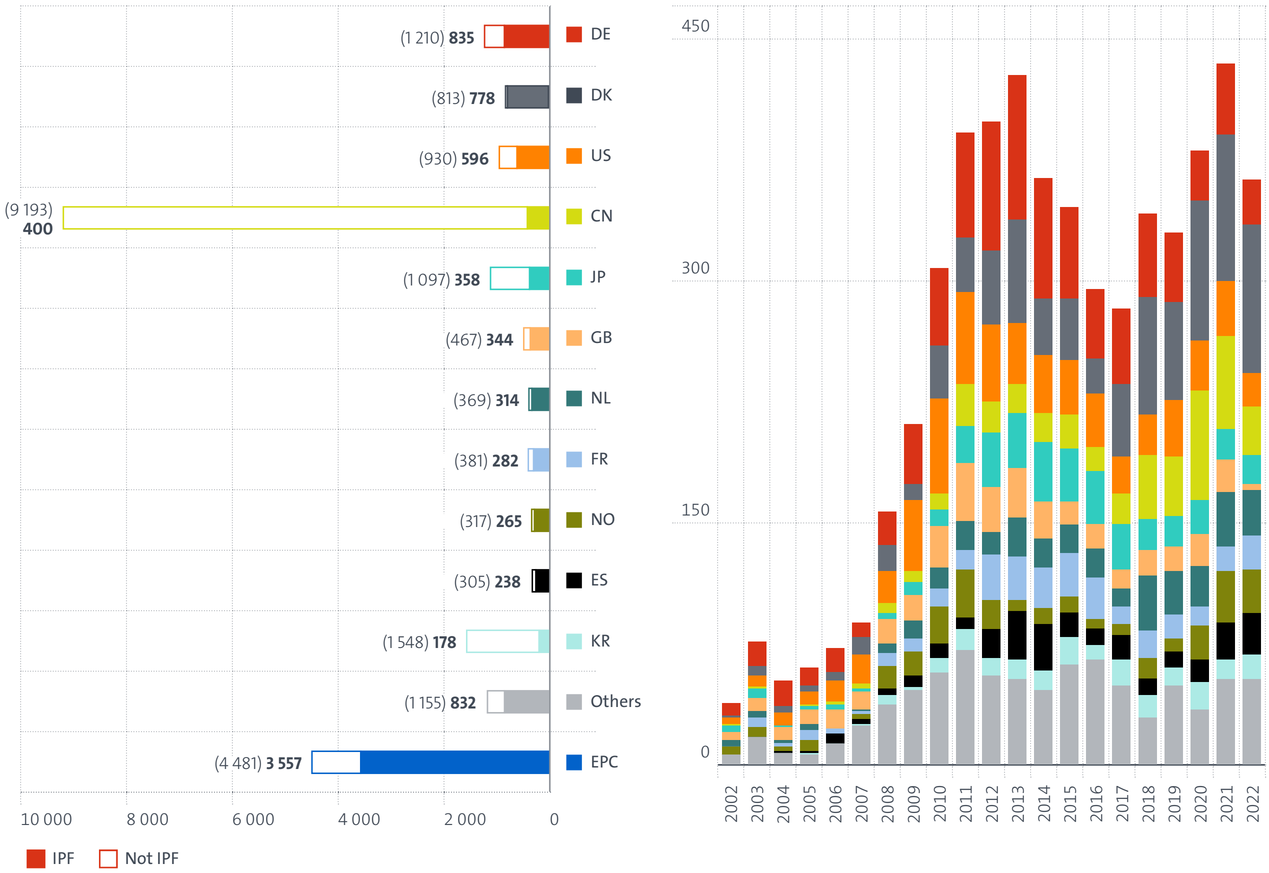
3.1.2 Top applicant countries

Looking at the patent filing data by origin of innovation (based on the country of business of the applicant), it is important to note that different filing strategies followed by stakeholders from different countries have an impact on the overall statistics. The main source of the general upswing trend and higher numbers on the left in Figure 3.1.1 is the number of patents filed in China, mostly by Chinese applicants. Chinese applicants have a high focus on the domestic market, as only 4% of patents filed by Chinese applicants are international (400 IPFs out of a total of 9193 applications; see the chart at left in Figure 3.1.2). A detailed analysis shows that patents filed in China are often utility models[25] that do not have any further patent filings in other patent jurisdictions. Moreover, Chinese applicants often file patents as well as utility models for the same or similar inventions, which increases overall filing numbers.

Despite its heavily domestic focus, Chinese applicants are still in fourth place in terms of international patent families. In addition, the EPC[26] countries as well as the United States of America follow a filing strategy that results in 79% and 64% of the applications, respectively, being flagged as international patent filings. Europe's position is an important finding in view of the strategic importance attributed to the "European Green Deal" (Figure 3.1.2).

Figure 3.1.2:

Top applicant countries related to offshore wind energy in 2002-2022, including all 12 queries from QA to QL.



The chart on the left shows the top countries and the difference between IPFs and non-IPFs (number in brackets represents the total; number not in brackets refers to IPFs only). EPC countries are grouped together at the bottom of the chart to facilitate a comparison between Europe and major world players like China and USA. The figure on the right shows the trend in IPF for top applicant countries.

25 A utility model has a lower standard for inventive step than that for an invention patent. They are often issued without examination, and the right granted tends to be shorter than a patent. (10 years in China)

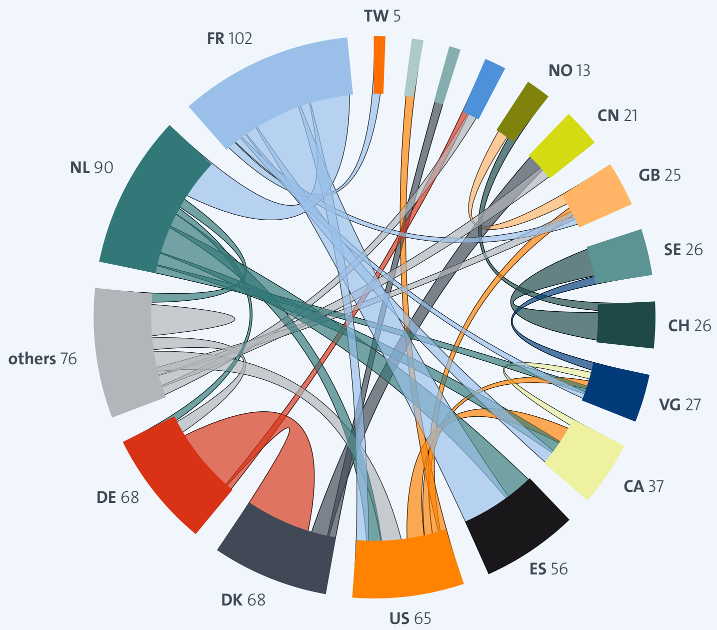
26 The group EPC represents applicants from the 39 Member States of the European Patent Organisation. Full list here: epo.org/about-us/foundation/member-states.html

Box 4: International patenting co-operation in offshore wind energy

The chord diagram in this box shows international collaboration of applicant countries with at least 5 shared patent families. The analysis of international collaboration is based on the location of the applicants. It shows that there is considerable involvement of the Member States of the European Patent Organisation[27] in cross-country developments and subsequent patent applications. Most prominently, this applies to France, the Kingdom of the Netherlands, Germany, Denmark and Spain. We can also observe relevant collaborations between: Canada with the United States of America, China with Denmark, the Kingdom of the Netherlands with the United States of America, and Canada with France.

France has the highest number of patent families with international co-operation. The United States of America has the most diverse co-operation picture, pairing with 24 countries on a total of 81 patent families. Germany cooperates with 15 countries on a total of 79 patent families. Co-operation with China is marked by co-applicant filings with mainly Denmark, Hong Kong (SAR), and Chinese Taipei. Overall, about 1.6% of all patent families show indicators of international co-operation between the patent applicants, which is less than the 3% for the entire population of all patent families available in the PATSTAT database.

International patenting co-operation



Note that a substantial part of the international co-operation is due to subsidiaries of the same parent company, hence filing patent via local entities.[28] For example: ABB Research [CH] and ABB (Asea Brown Boveri) [SE], Siemens [DE] and Siemens Gamesa Renewable Energy [DK], Envision Energy (DK) and Envision Energy (Jiangsu) Company [CN].

Examples of co-operation among entities without organisational ties are: Reinhold Cohn and Partners [IL] and University of Malta [MT], NKT HV Cables [SE] and ABB Technology [CH] (with a later acquisition by NKT of ABB HV activities), Universidad Politecnica de Cataluna [ES] and University of Stuttgart Public-Law Institution [DE], LM Wind Power [DK] and Blade Dynamics [GB], RWE Renewables [DE] and Stiesdal Offshore Technologies [DK], and Frontica Engineering [NO] with MH Wirth [DE].

27 Member States of the European Patent Organisation: epo.org/about-us/foundation/member-states.html.

28 Pasimeni, F., Fiorini, A., and Georgakaki, A. (2019). Assessing private R&D spending in Europe for climate change mitigation technologies via patent data. World Patent Information, 59, 101927. https://doi.org/10.1016/j.wpi.2019.101927

3.1.3 Top patent offices

The first reason for patent applicants to file a patent at a certain patent office is to obtain the right to prevent competitors from selling or using a technology that encompasses the invention. However, very often an applicant will first file a priority filing which is an easy and sometimes an economical filing strategy to buy time to decide whether more patents need to be filed in other patent jurisdictions.

The figures below represent those countries where the invention originates as well as where the inventions can obtain protection and what patent offices will have to do the work of searches and possibly examining and granting the patents. We can view this as a proxy for the patent office "workload". WO and EP are special cases because a patent filing at the EPO and WIPO can provide protection in multiple countries. We can observe that the top 10 countries cover 75% of all patent filings. Looking at this ranking, one should also keep in mind that once an EPO patent becomes granted, it can come into force in EPO Member States without this being reflected in this ranking. The fact that EPO Members States Denmark, Spain and Germany are in this list is a clear indication that European innovation happens in those countries. United States of America and China take the absolute lead in the number of filings, accounting for nearly 25% of all patent filings.

Figure 3.1.3a:

Top 10 patent offices, IPF (2002-2022)

Patent office ranking based on number of distinct patents filed retrieved by the queries for offshore wind energy (QA to QL) between 2002 and 2022.

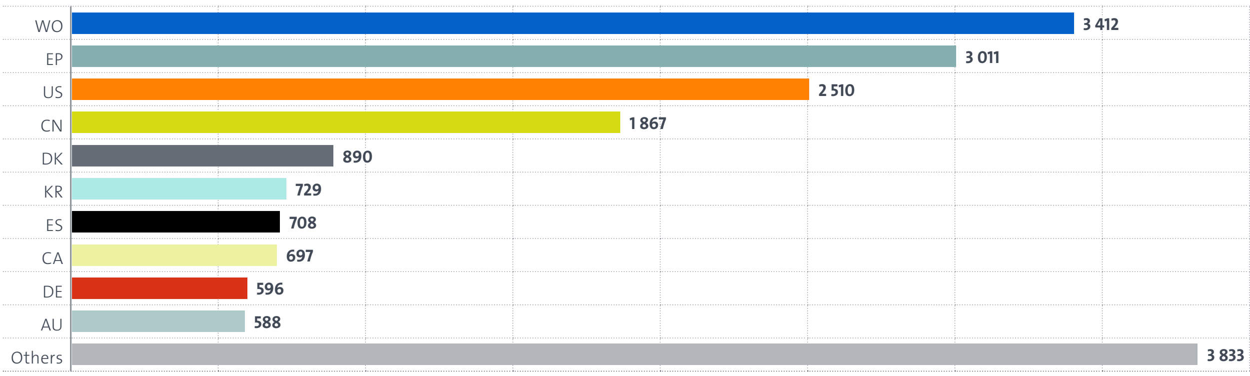
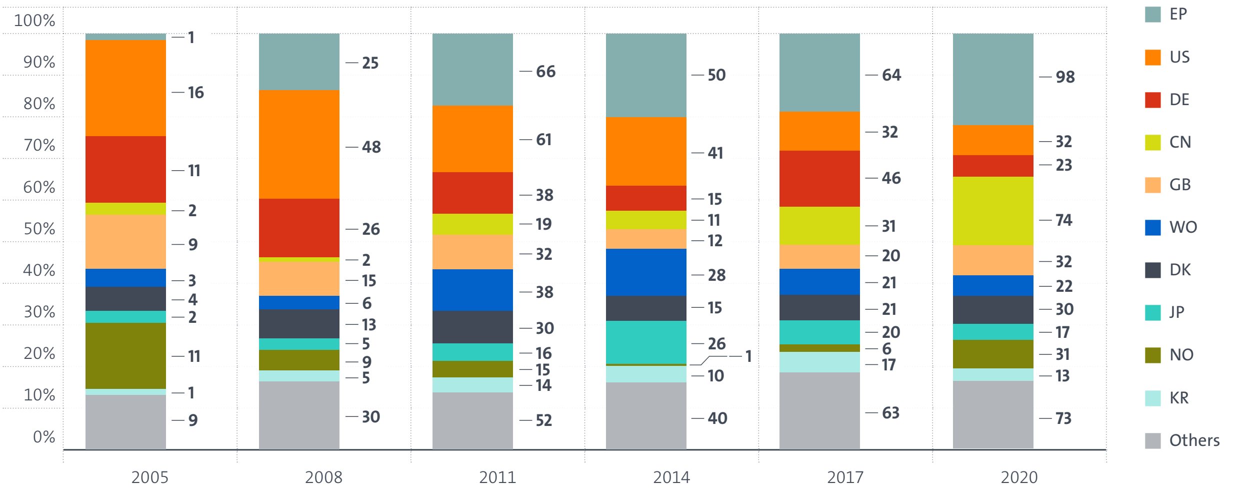


Figure 3.1.3b:

Patent offices of first filing (IPF)

Timeline representing the changing shares of countries where applicants file the earliest filing of a simple patent family, considering the queries for offshore wind energy (QA to QL)



We can observe major changes in the way applicants file their first patents. China, nearly absent until 2008, has subsequently received increasingly more first filings every year. For filings in 2020, CN together with EP, US, NO and GB represent 50% of all first filings (though NO and DK are nearly on par with GB and US). The fact that EP obtains a successively increasing share of the applications can be attributed to some of the top European applicants who systematically file their first applications at the EPO. These are: Siemens [DE, DK], Alstom Renewable Technologies [FR, ES], GE Renewable Energies [ES, NL], Nexans [FR], Orsted Wind Power [DK], Vestas [DK], Philips Electronics [NL] and others.

3.1.4 Top applicants

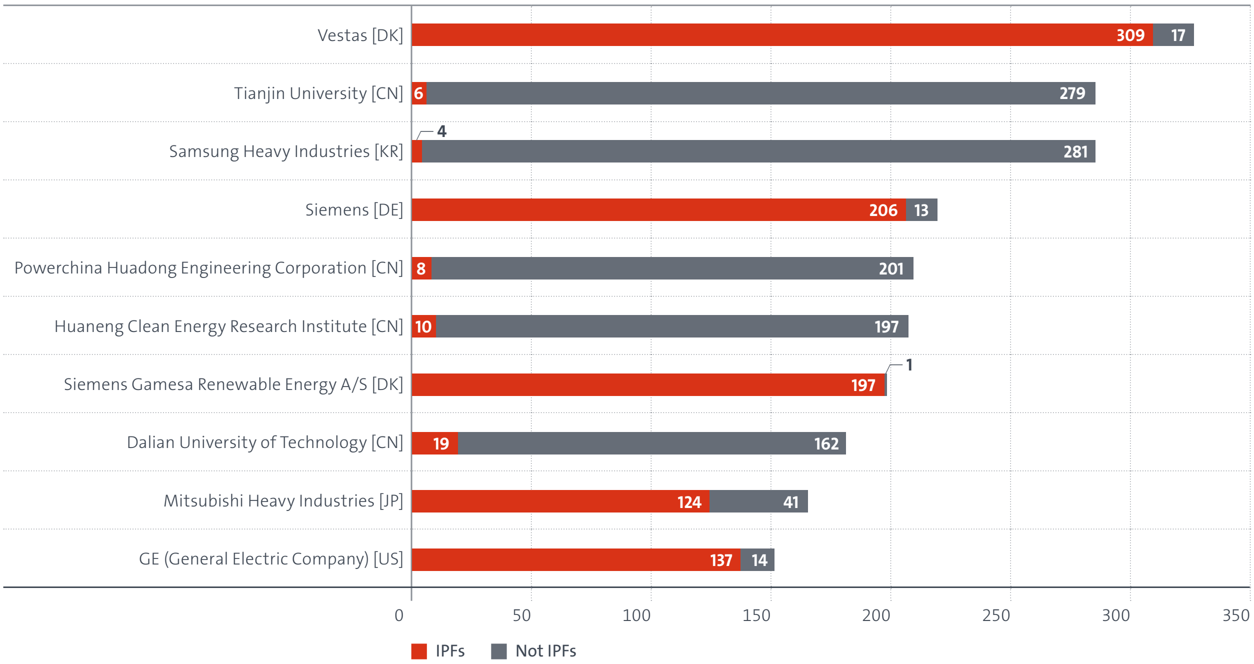
The Danish firm Vestas stands out as the main player in the realm of offshore wind energy technologies, showing remarkable activity. Its patent portfolio consists of IPFs, reflecting its global reach and influence. Very few of its patents (17 out of 326) are not international. It is important to highlight this distinction between IPF and non-IPF, especially when we consider the list of top 10 patent applicants. Here, we find Chinese and Korean companies that primarily direct their inventive efforts toward their respective domestic markets. This strategic approach is reflected in their patent portfolios, which mostly fall outside the category of IPFs. Instead, European companies are the most active actors in terms of net number of IPFs.

As previously mentioned, Vestas [DK] is the leading player when the focus is on IPFs alone: in the period from 2002 to 2022, Vestas [DK] developed 309 distinct IPFs included in one or more concept groupings (meaning in one of the 12 concepts from QA to QL). Interestingly, 78% of those IPFs were filed in the period from 2013 to 2022, while only 69 IPFs were developed in the initial period from 2002 to 2012. The German company Siemens is the second leading patenting entity in offshore wind, with 206 IPFs in the period 2002-2022. However, the patenting activity of Siemens [DE] is concentrated almost entirely within the 10 years from 2008 to 2017 (87% of the total IPFs were filed in that period). The third leading patenting company is Siemens Gamesa Renewable Energy [DK], established in 2016 after the merger of the wind business area of Siemens and the wind company Gamesa. This explains the low patenting activity for Siemens in the later period, as its own wind business moved to the newly established company. Figure 3.1.4a also shows that the American company General Electric is also active in offshore wind energy technologies, followed by Japan's Mitsubishi Heavy Industry. All the other companies listed in Figure 3.1.4a have 54 or less IPFs, well below the total number of IPFs of the leading companies.

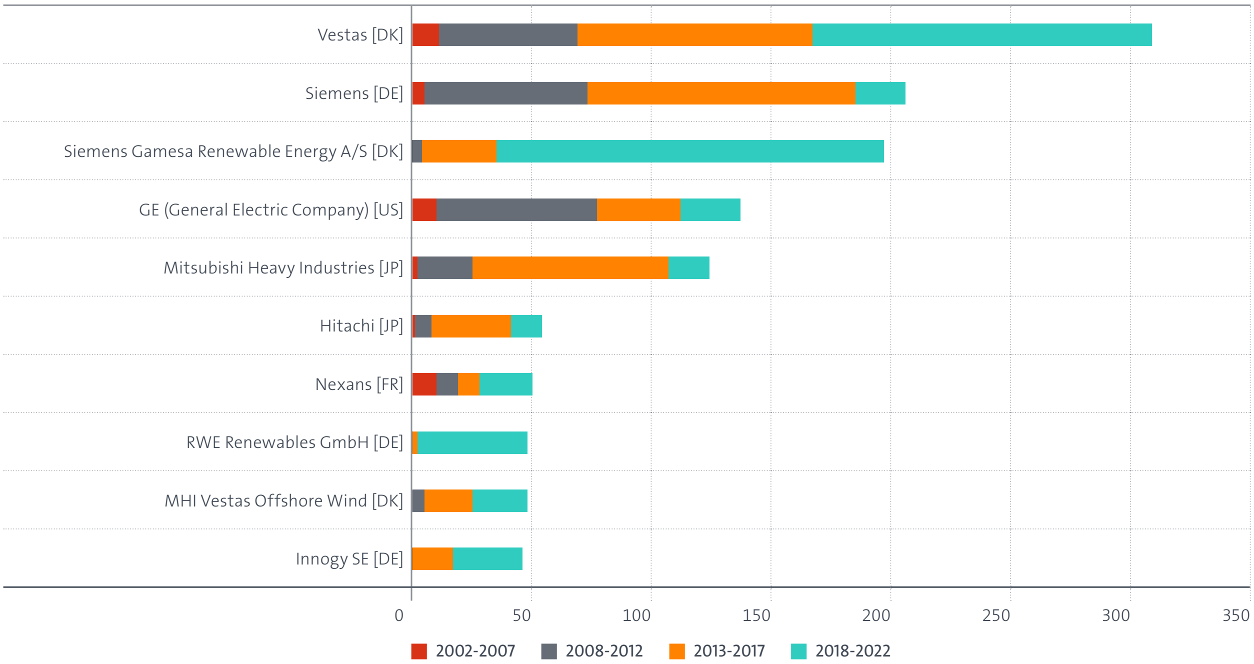
Figure 3.1.4a:

Top patent applicants (2002-2022)

All patent families



IPF only

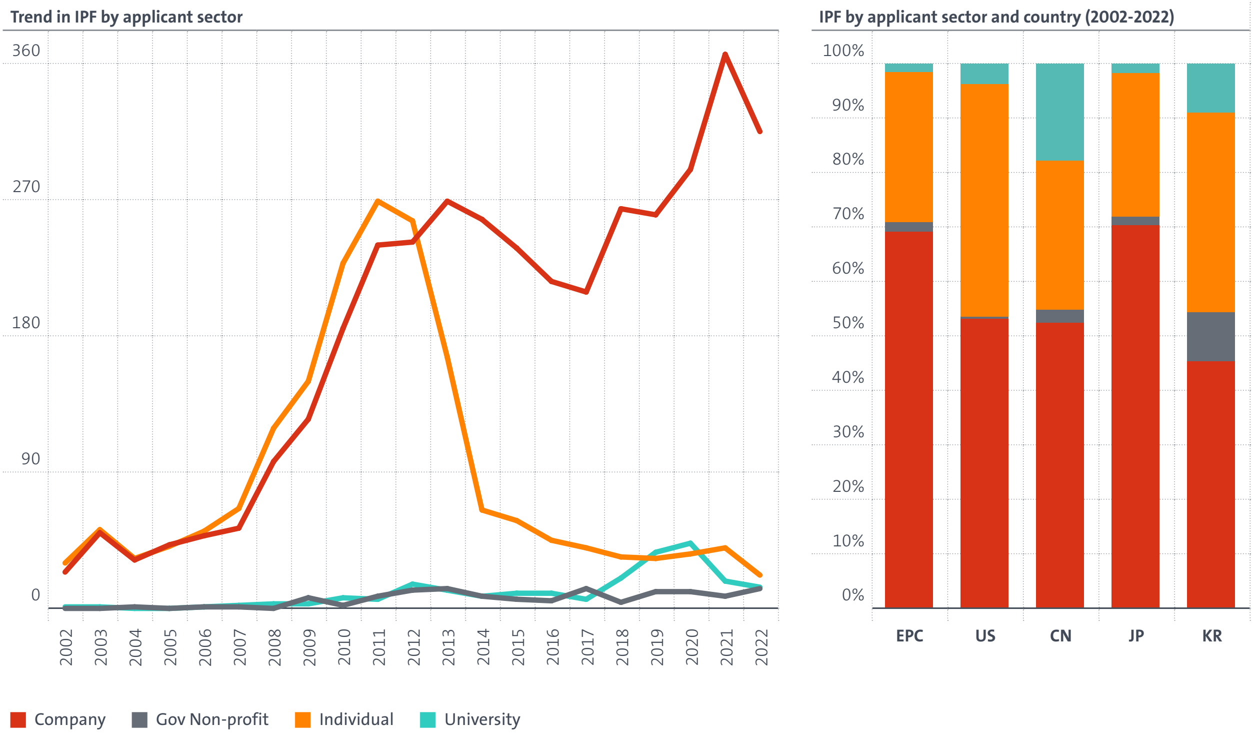


Top 10 patent assignees based on the total number of patent families (top chart) and IPFs only (bottom chart) in offshore wind energy (QA to QL) between 2002 and 2022.

As illustrated in Figure 3.1.4b, the development of IPFs over time shows a great contribution from companies rather than from other sectors (namely universities, governmental non-profit organisations or individual inventors). In the period from 2002 to 2022, IPFs developed by companies account for 64% of the total, with a strong increase between 2017 and 2021 from 209 to almost 366. Interestingly, patent publication originating from individuals peaked in 2011 with 269 international patents. After that, a significant decline is observed. This is also reflected in the maturity analysis that shows a decrease in the number of applicants, while the number of patents filed still increases. Among the IP5 members (chart at right in Figure 3.1.4b), EPC countries show the largest contribution of companies in developing IPFs related to offshore wind energy technologies, as they account for 69% of the total IPFs. Individual inventors in the USA have the largest share among the major players with 43% of IPFs (partly because inventors are registered as applicants when the patent is filed), while China is the country where universities develop a large share of IPFs, with 18% of the total.

Figure 3.1.4b:

Trend (left) and share among major world players (right) of patent applicant sectors based on the total number of IPFs in offshore wind energy (QA to QL) between 2002 and 2022.



Box 5: Newcomers in the offshore wind domain

While certain applicants display a long-term continuing interest in the technologies in question, a temporal perspective looking at new applicants that only recently started filing patents allows us to identify geographical specialisations as well as levels of intensity.

Some of the data also confirm strategic policy decisions. We know that China has been increasing investments in all green energy areas in its drive towards decarbonisation, but as most of the filings are non-IPF, only a few companies appear in the list of newcomers, such as China Three Gorges Corporation [CN].

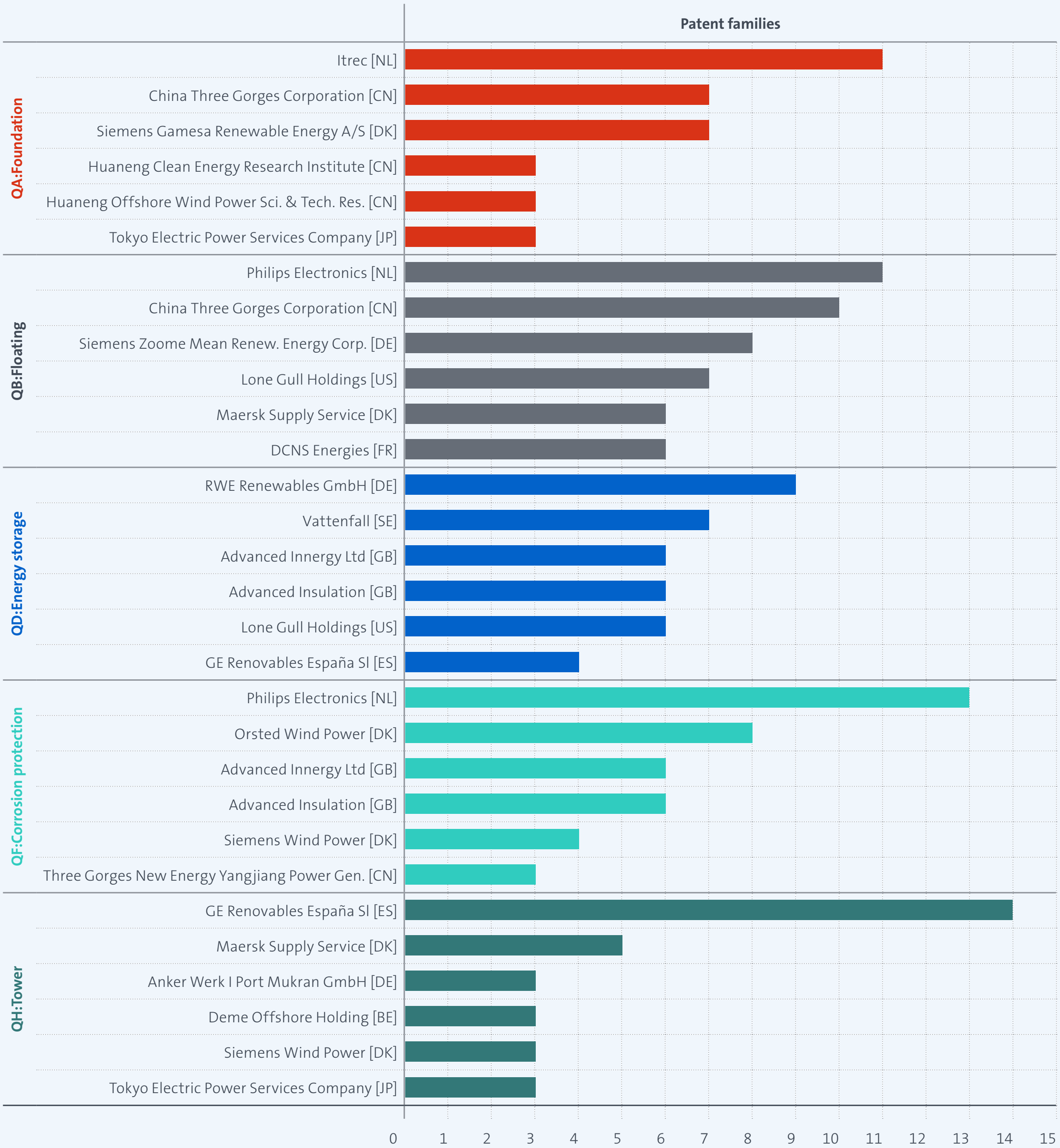
Technolgy concept	New applicants	Patent families
QB: floating foundation	278	428
QF: corrosion protection	112	119
QH: towers	109	132
QD: energy storage	94	82
QA: fixed foundation	94	144
QJ: grid	84	99
QK: transportation, installation, erection	65	73
QC: mechanical power transmission	60	51
QE: hybrid system	58	54
QL: submarine cables	28	42
QG: monitoring waves	25	21
QI: blades, rotors	12	8

Note: Total number of new applicants (first filing >= 2018) and their patent filings in the respective technological concepts

A growing challenge in offshore wind are the rising production costs for floating offshore wind turbines, insights into how harsh ocean environments around wind farms affect lifespan and maintenance costs, and elevated concern about securing the power grid. Therefore, the need for better exploitation through economies of scale is indispensable for the cost-efficient production of offshore wind energy.

While it can be said that several established international companies such as Philips Electronics, Siemens Wind Power (and Siemens Gamesa), Maersk Supply Service and GE Renovables España are not exactly newcomers as companies as such, they are nevertheless newcomers within the respective technological areas. Philips Electronics, the largest newcomer in "Corrosion protection", has 13 patent families (148 applications --> large patent families), covering technologies such as: cathodic protection and electrical anti-biofouling methods to prevent corrosion.

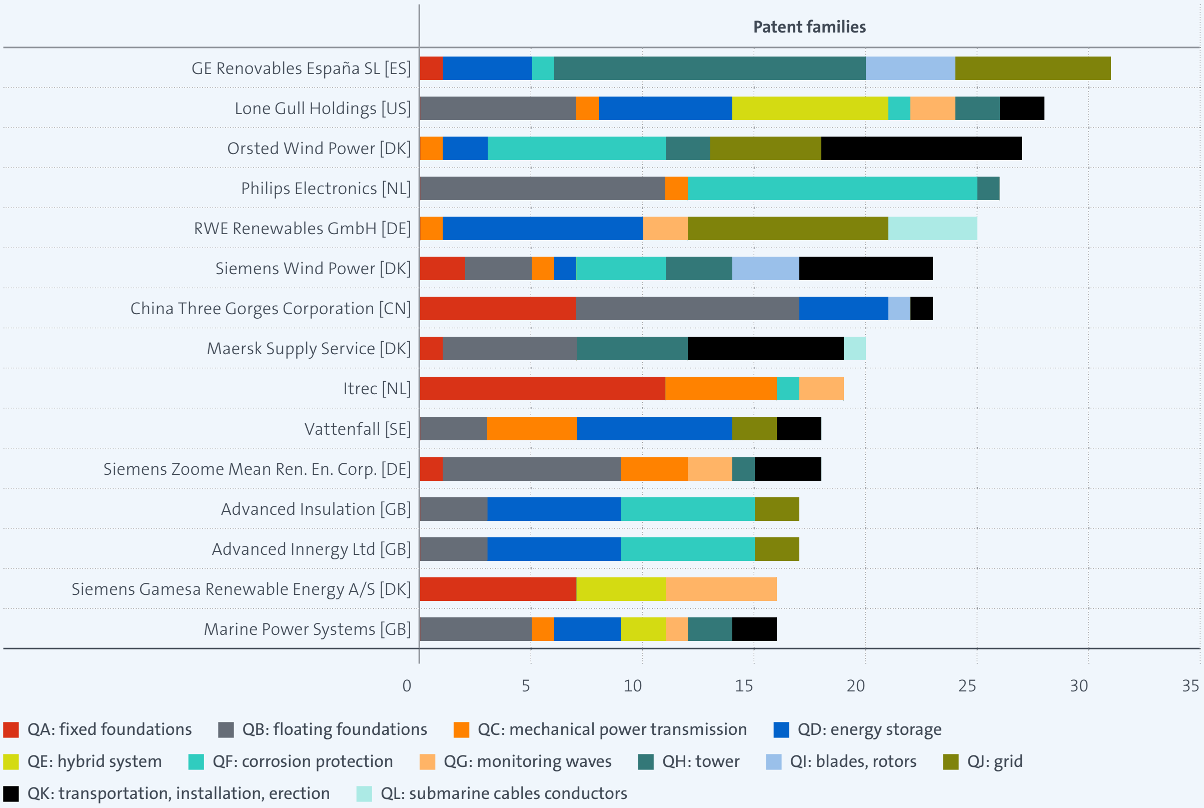
Top 6 new applicants per concept



Large patent families are a clear signal of willingness to protect the inventions in many countries. Philips' filings in "Floating" show a similar pattern, with 11 families and 96 patents mainly in the field of UV-C light-based anti-fouling applications.

We can also observe the entry of Maersk Supply Service and Deme Offshore Holding, active in the field of marine engineering with specific expertise in operating vessels and for offshore installations. Itrec, the main newcomer for "Foundation", provides highly specialised engineering services. Its patents cover technology for pile driving, holding and lifting during offshore installation.

Newcomers across concepts



Note: Graphs in this box show patent applicants not active (no patent filed) before 2018 specific for those concepts.

3.1.5 Maturity map

The technology maturity map[29] of IPFs shown in Figure 3.1.5 uses the number of published patent families (vertical axis), the number of patent applicants (horizontal axis) and the number of granted patents (size of bubbles) to illustrate the overall patent evolution in offshore wind energy technologies. The maturity map clearly shows four main phases of this development categorised as follows: i) Inception phase (2002-2007), ii) Growth phase (2008-2012), iii) Consolidation phase (2013-2017), and iv) Re-growth phase (2018-2022)

The inception phase considers the initial years (2002-2007) analysed in this report[30], and shows a limited number of granted patents and few distinct applicants active in this area. The growth phase (2008-2012) shows a rapid increase in all the three dimensions of the maturity map: IPFs, applicants and granted patents. Interestingly, the consolidation phase (2013-2017) starts with a significant decrease in the number of applicants, and a decrease in IPFs follows with a certain time delay. Likewise interestingly, the consolidation of applicants did not have a significant impact on the grant rate when comparing e.g. the numbers for 2011 and 2015. This may be an indication that the quality of the inventions was maintained. The time from 2018 to 2022 saw an average renewed growth in terms of IPFs and applicants, while less for granted patents. However, the grant rate in this period may still improve since the percentage of pending procedures is

29 Suzuki, Shin-Ichiro (2011) Introduction to Patent Map Analysis. https://www.jpo.go.jp/e/news/kokusai/developing/training/textbook/document/index/Introduction_to_Patent_Map_Analysis2011.pdf

30 Please note that the inception of offshore wind technology may have occurred already prior to 2002. Nevertheless, data for the analysis of this report are extracted considering 2002 to be the initial year.

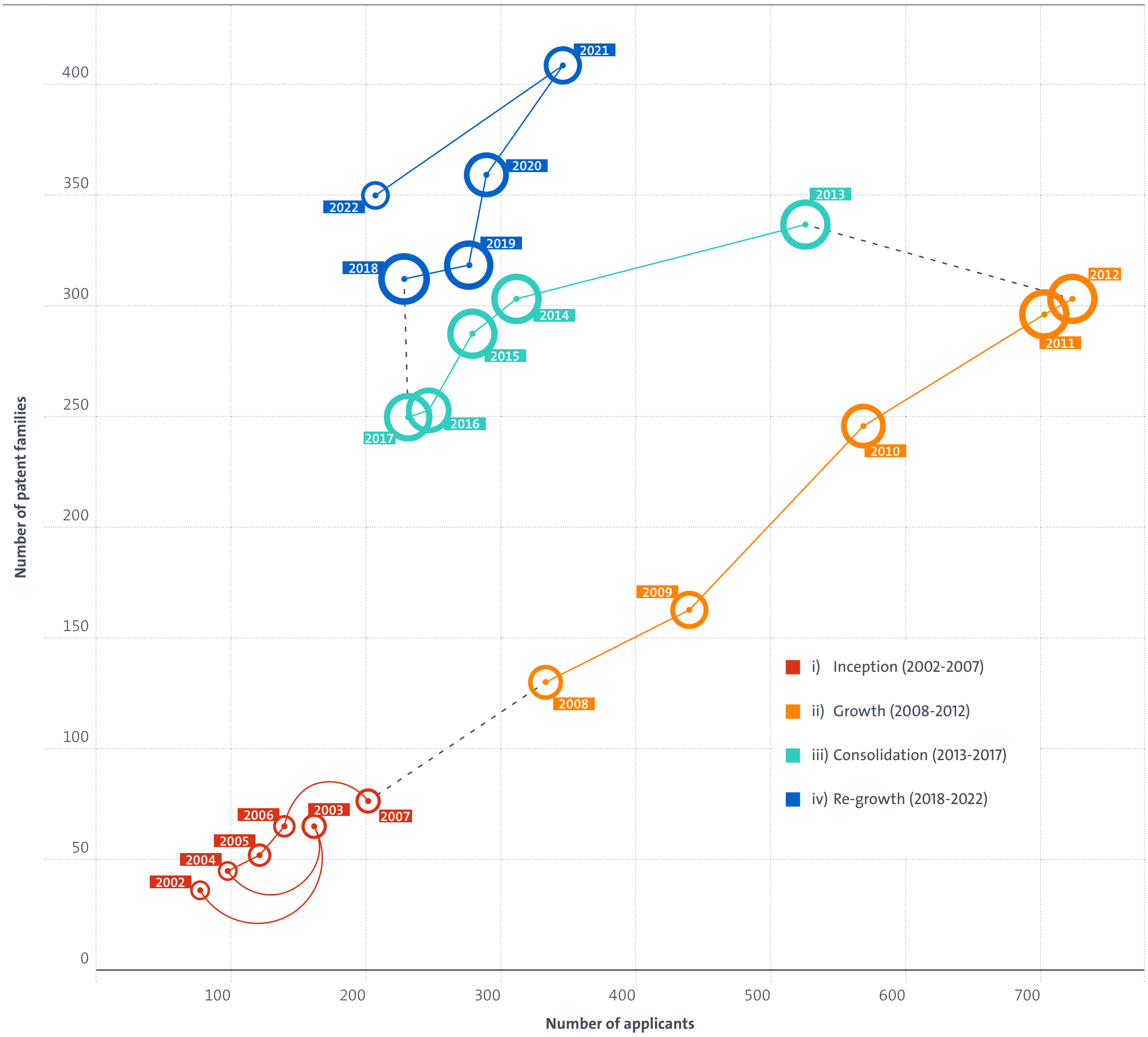
still high, and more patents can expect to be granted in the coming years. In 2022, the number of applicants is only about 30% of the top values in 2012, which is mainly due to the shift away from individual inventors.

Very often other indicators such as co-application and reciprocal citations are indicators for the consolidation phase. By analysing the data in depth, we see for example co-applications involving LM Wind Power and Blade Dynamics[31]. We can also see strong reciprocal citation figures, and we now know that both companies were acquired by GE. A similar process took place by NKT Cables' acquisition of the ABB high-voltage cables business.[32]

Figure 3.1.5:

Maturity map of offshore wind energy technologies patent applications between 2002 and 2022.

NB: The maturity map combines the number of IPFs (vertical axis), the number of patent applicants (horizontal axis) and the number of granted patents (size of bubbles).



31 Espacenet link

32 Espacenet link.

3.1.6 Citations

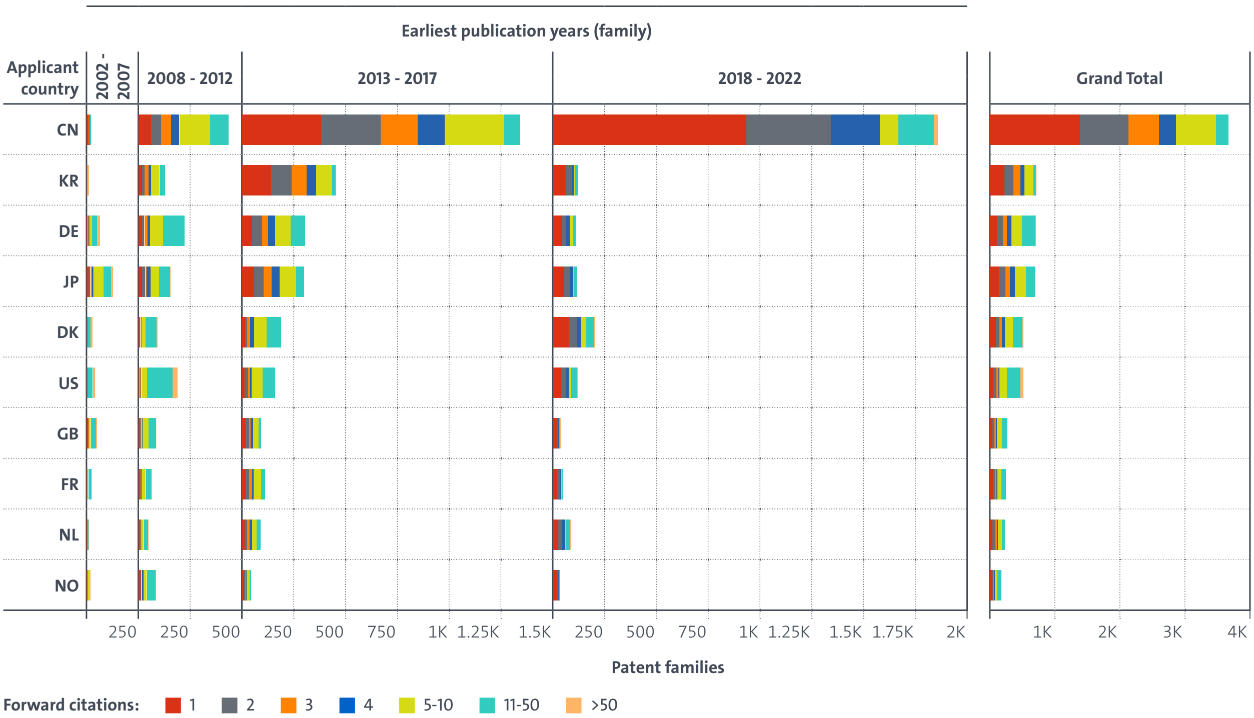
Forward citation counts are typically used to understand the impact of inventions, the idea being that important patents are often cited by subsequent filings that build on a specific technology. They are often used as a patent value indicator when looking at individual patents or a patent family. Forward citations can also be an indicator for technology flows where technology is considered as a resource that can be used by companies in other countries or even different technical domains. With newly emerging technologies we can observe, for example, that initial patents are filed by universities and research institutes and then gradually find their way to companies and the industries that file patents which build on the technology published in the patents filed earlier. This also allows for competitor monitoring, where the applicant from the earlier filed patent can monitor what technology other companies are "building on".

We can observe that up to 2007 hardly any patent applications were being cited (Figure 3.1.6a). From 2017 onwards, we can see a rapid increase in patents filed by CN applicants being cited. The second graph (Figure 3.1.6b) also shows that while the largest share of those citations can be attributed to other CN applicants, DE, DK and US applicants are also citing patents filed by CN applicants.[33] Similar for the US and KR, most of the citations originate from US and KR applicants. In general, US, DE and DK applicants intensively not only cite each other's patent applications, but also all other countries in the top 10 ranking. For many countries, more than 50% of all citations can be attributed to US, DE and DK. JP is strongly citing KR applications, but not the other way around.

Figure 3.1.6a:

Top applicant countries by forward citations (>1)

Number of forward citations based on the country of the applicant. The colour indicates citation intensity.



33 Self-citations were excluded from the data as much as possible

Figure 3.1.6b:

Applicant country cited/citing overview

Top applicant countries whose patents have been forward cited. It includes also domestic-only filings that also seem to have a significant impact.

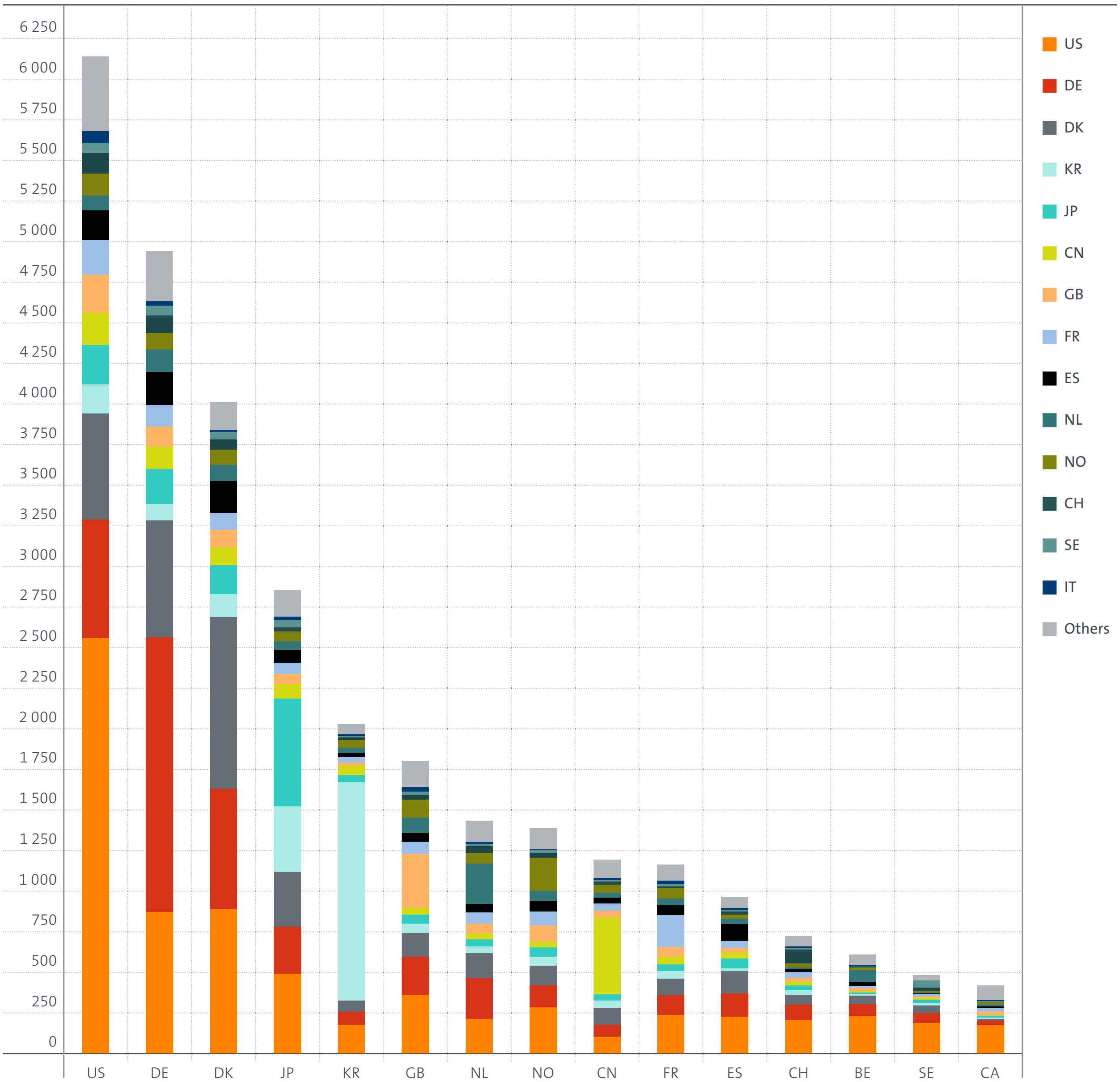


Table 3.1.6 lists the top 12 inventions in offshore wind energy technologies with the highest number of forward citations. It is not surprising that older inventions have higher numbers of forward citations, as time is an important factor in the citation process. For this reason, it is interesting to note that the fourth most cited invention was published in 2018, and it concerns non-magnetic stainless-steel wire with an adherent corrosion resistant coating. Most of the citations for this application originate from applications filed by AT&T, but those citing patents are not specifically related to electrical cables for wind energy.

Table 3.1.6:

Table listing 12 inventions with the most forward citations among those included in datasets generated for this report, using the 12 queries in offshore wind energy (QA to QL) and containing patent information between 2002 and 2022

Patent	Top – inventions - forward citations	Applicant	Pub. year	Citations
EP1483502	Offshore wind turbine	Ocean Wind Energy Systems [US]	2003	269
EP2271547	Column-stabilized offshore platform with water-entrapment plates and asymmetric mooring system for support of offshore wind turbines	Principle Power Inc [US]	2009	252
EP1415379	Coordinating renewable power production with a standard power grid	ABB AB [SE]	2003	193
EP2812457	Non-magnetic stainless steel wire as an armouring wire for power cables	Bekaert [BE]	2018	168
EP1996814	High voltage direct current link transmission system for variable speed wind turbines	Ingeteam [ES]	2007	160
EP1359321	Sensing of loads on wind turbine blades	GE (General Electric Company) [US]	2003	154
EP1474579	Wind turbine	Mecal Applied Mechanics B V [NL]	2002	140
EP1429025	Up-wind type windmill and operating method therefor	Mitsubishi Heavy Ind Ltd [JP]	2003	133
EP1507975	Methods of handling wind turbine blades and mounting said blades on a wind turbine, system and gripping unit for handling a wind turbine blade	Vestas Wind Sys AS [DK]	2003	129
EP1623111	Wind turbine blade with lift-regulating means	LM Glasfiber AS [DK]	2004	125
EP1460266	Wind turbine with laser apparatus for measuring the wind velocity	Mitsubishi Electric Corp [JP]	2004	122
EP1548419	Method and device for monitoring status of mechanical equipment and abnormality diagnosing device	NSK Ltd [JP]	2004	122

3.2 Technology concept grouping

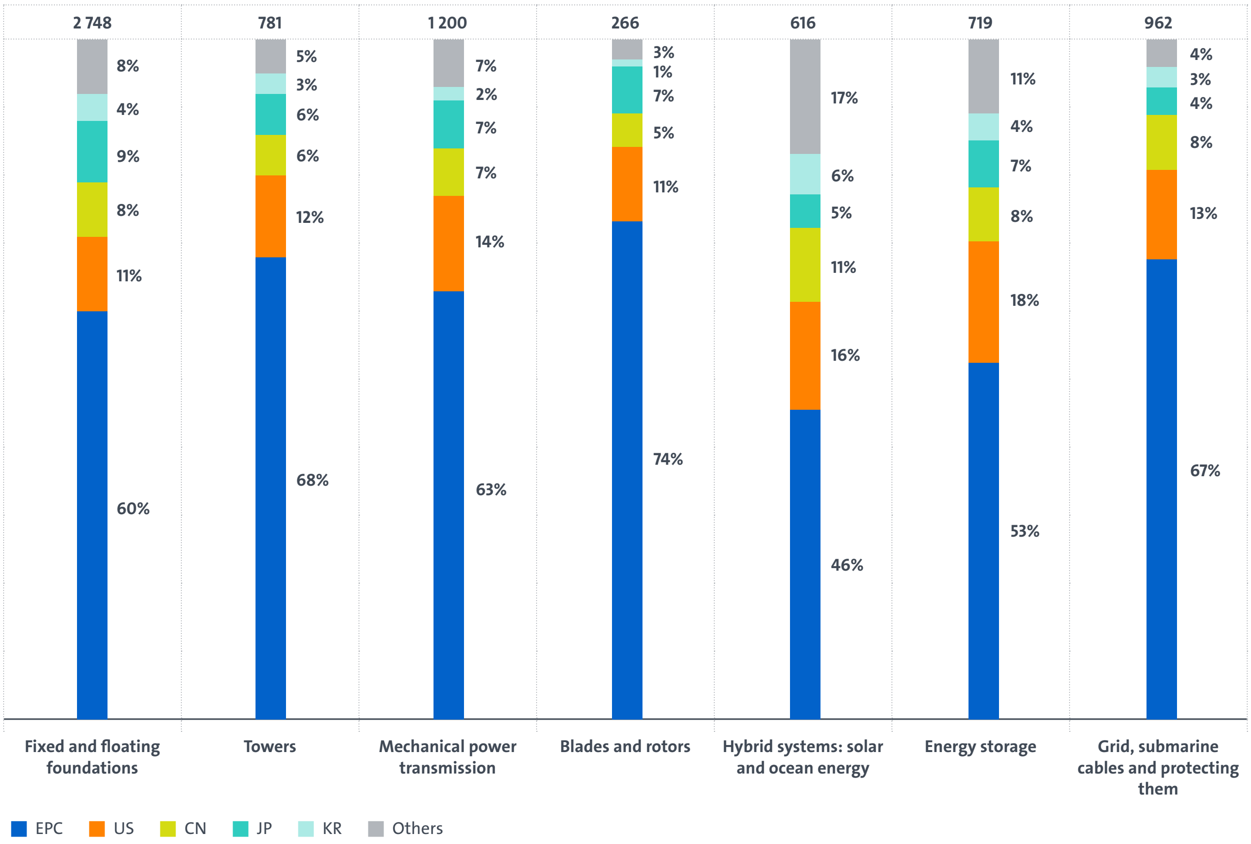
This section provides a summary of the significant findings obtained from the patent analysis concerning the seven technology concept groupings associated with offshore wind energy technologies. These groupings include: 1) Fixed and floating foundations, 2) Towers, 3) Mechanical power transmission, 4) Blades and rotors, 5) Hybrid systems, 6) Energy storage, and 7) Grid, submarine cables and protecting them. A comprehensive country-level overview of international patent families (IPFs) developed within the period from 2002 to 2022 is presented in Figure 3.2.

Among the seven concept groupings, EPC countries contribute to over 60% of the overall count of IPFs in five categories, except for Energy storage and Hybrid systems, where their combined share is 53% and 46%, respectively. The United States of America consistently maintains an average of 14% across all seven concept groupings, positioning it as the second leading country in IPFs within each of the identified offshore wind technology domains. China, Japan and the Republic of Korea follow, with cross-concept grouping averages of 7%, 6% and 3%, respectively, in terms of the total number of IPFs.

Figure 3.2:

Country patent share on offshore wind concept groupings, IPF (2002-2022)

Share of international patents between 2002 and 2022 and in relation to the seven concept groupings identified.
(NB: The country refers to the country of the patent applicants. The group EPC represents applicants from the 39 Member States of the European Patent Organisation.[34])



34 Member states of the European Patent Organisation: epo.org/about-us/foundation/member-states.html.

3.2.1 Fixed and floating foundations (QA & QB)

Observations

Floating foundations can be a game changer for the offshore wind market, bringing the turbines to deeper waters with abundant wind potential.

— Driven by its potential in deeper waters, patents filed for floating foundations have grown almost tenfold since 2002 and represent 80% of the foundation patents in 2022.

— Fixed foundations are still an established technology and play a role in the deployment of offshore wind technology. As a result, the number of filed patents shows a moderate increase in the past years —50% increase for the period 2018-2022. Gravity and monopile solutions account for 90% of patents filed for fixed foundations.

— The choice of a floating or fixed foundation depends mainly on the combination of technical and site conditions, and operational factors.

— European countries such as the Germany, Netherlands, and Denmark lead in fixed foundation tech patents, while the USA dominates in floating technologies.

In offshore wind systems, the foundation is a critical component that falls under two categories: fixed[35] and floating[36]. At present, fixed foundations are commonly used but have limitations and can only function in shallow water[37]. However, floating foundations can be used in water depths exceeding 60 meters and are gaining popularity. They allow for the opening of new markets in regions with deep water where fixed foundations become expensive and can provide additional benefits, such as having a lower impact on the seabed. The successful operation of first commercial projects has led to a gradual increase in the number of global floating offshore wind projects in recent years. The cumulative global capacity for floating wind is expected to reach 0.285 GW in 2023 from 0.205 GW in 2022, (a 40% increase)[38] and it is expected that the global pipeline of floating offshore wind projects will continue to grow in the coming years, with most of them located in Europe, USA, and South Korea[39]. As offshore wind energy technology advances, there is an increasing need to accommodate larger turbines for higher efficiency for which the choice of foundation will be highly crucial. The choice of a floating foundation depends mainly on the combination of technical factors, site conditions, and operational factors.

Looking at the patent data between 2002 and 2022, the trend of IPFs in both foundation and floating technologies shows an initial increase until the period of 2011-2013, followed by a subsequent decline. However, another surge in the total count of IPFs in both categories started around 2017, showing a near-constant trend of growth since then. On annual average, 78% of IPFs are dedicated to the development of floating solutions, while the remaining 22% are directed towards fixed foundation inventions. This shows the higher focus on advancing floating technologies, as these can be considered crucial to the advancement of offshore wind energy.

Leading the effort (in terms of patent fillings) in foundation technologies are European countries, as indicated in the chart at left in Figure 3.2.1b. Specifically, Germany takes the lead with 152 IPFs, followed by the Netherlands with 77 IPFs, and Denmark with 75 IPFs. In contrast, the United States, in fourth place in foundation patenting, emerges in the 2002-2022 period as first in IPF counts in offshore wind floating solutions with 308 IPFs (chart at right in Figure 3.2.1b). Germany and Denmark follow as the second and third contributors, while Japan takes fourth place, with a total of 244 IPFs. Examining the top patenting countries in Figure 3.2.1b, an intriguing trend emerges: across foundation solutions, an average of almost 90% of IPFs concern gravity or monopile foundations. However, within the area of floating solutions and on average across the leading patenting countries, only 9% of IPFs are directed towards floating stabilisation.

In the foundation category, the leading five companies are all from Europe. Germany takes the lead with Siemens [DE], Innogy Se [DE], and RWE Renewables GmbH [DE], followed by the Danish Vestas and the Dutch company Itrec. Specifically within the monopile foundation area, Innogy Se [DE] and Rwe Renewables GmbH [DE] are the leaders with 18 IPFs each. In the gravity foundation category, Siemens [DE] is first with 14 IPFs, followed by Vestas [DK] with 10 IPFs.

35 This includes gravity-based foundations, monopile foundations, tripod foundations and jacket foundations

36 Main structure types include spar buoy, tension leg platform, semi-submersible platform, and barge.

37 This includes gravity-based foundations, monopile foundations, tripod foundations and jacket foundations

38 Source: Wood Mackenzie Offshore wind long-term outlook database

39 Source: https://www.enerdata.net/publications/executive-briefing/floating-offshore-wind-evolution.html

Leading companies on floating technologies are Mitsubishi Heavy Industries [JP], Vestas [DK], Siemens Gamesa Renewable Energy A/S [DK], and Hitachi [JP]. Mitsubishi Heavy Industries [JP] and Hitachi [JP] have directed 67% and 63% of their respective IPFs to floating solutions during the period spanning from 2013 to 2017, showing substantial attention to floating technology during those years. Conversely, Siemens Gamesa Renewable Energy A/S [DK] has its inventive focus on floating solutions, with 94% of its IPFs to this category developed in more recent years from 2018 to 2022.

Box 6: Aquaculture

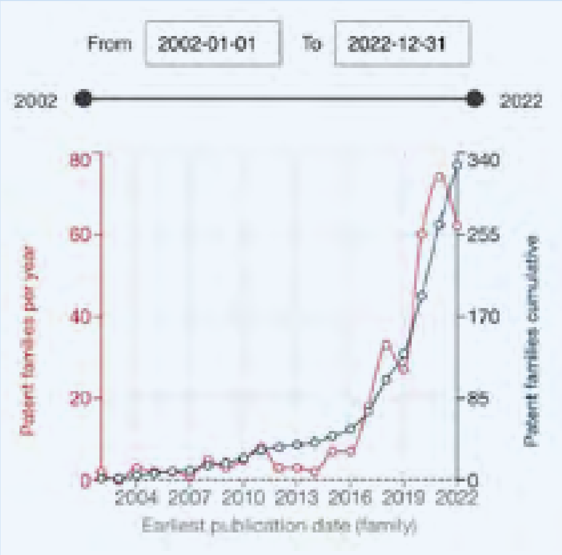
Because of the reduction in the number of fish available for commercial fishing, offshore aquaculture allows for greater economies of scales. Whereas aquaculture is traditionally conducted near shore, it is increasingly being moved farther offshore. Because aquaculture is moving increasingly farther from the shoreline, the installations require on-site power and communication means to control and monitor the plant. Power is also needed for the fish feeders, waste disposal, sensors, cameras and aeration to maintain the optimum dissolved oxygen concentration in the water. Concepts that integrate the development of offshore foundations and artificial islands aim to exploit the synergies of having power and anchoring available.

Floating structures that are tethered to the seafloor as well as fixed foundations can be directly integrated into the aquaculture system. This leads to increasing a project's profitability through sector coupling while supporting food security.

The line chart shows the evolution of patents being filed that combine offshore wind turbines (or energy) with aquaculture. The black line represents the cumulative evolution which shows a sharp increase.

The table in this box shows the top applicants. The majority are Chinese universities and research institutes. This is also confirmed by the fact that all current projects are proof of concepts, not at industrial scale by any standards.[40]

Applicants	Patent families
Univ Dalian tech	26
Univ Shanghai jiaotong	20
East China sea fisheries res inst cafs	16
Jiangsu Daoda wind power equipment tech co Ltd	16
Powerchina Huadong engineering corp Ltd	16
Univ Zhejiang	10
Ming yang smart energy group co Ltd	9
Univ Jiangsu science & tech	8
Univ Tianjin	6
Graduate school Shenzhen Tsinghua univ	5
Ocean univ China	5
Univ Shanghai ocean	5
CGN power co Ltd	4
Enertec AG	4
Guangzhou inst energy conversion cas	4



Source: ESPACENET using Q0 and IPC, CPC = "A01K61"/LOW

40 Yu (2021) "China plans 'world first' floating fish and wind farm linkup" Online at: https://www.intrafish.com/aquaculture/china-plans-world-first-floating-fish-and-wind-farm-linkup/2-1-985255

Figure 3.2.1.

Fixed and floating foundations

QA1: fixed → suction caisson | QA2: fixed → gravity | QA3: fixed → monopile | QB1: floating → stabilisation | QBL: floating → other

Figure 3.2.1a: **Trend of IPF**

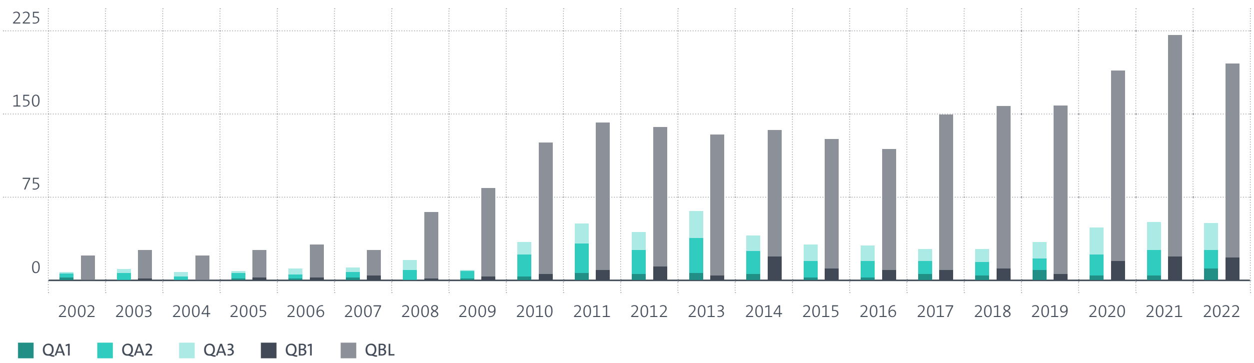


Figure 3.2.1b: **Top patenting countries (2002-2022)**

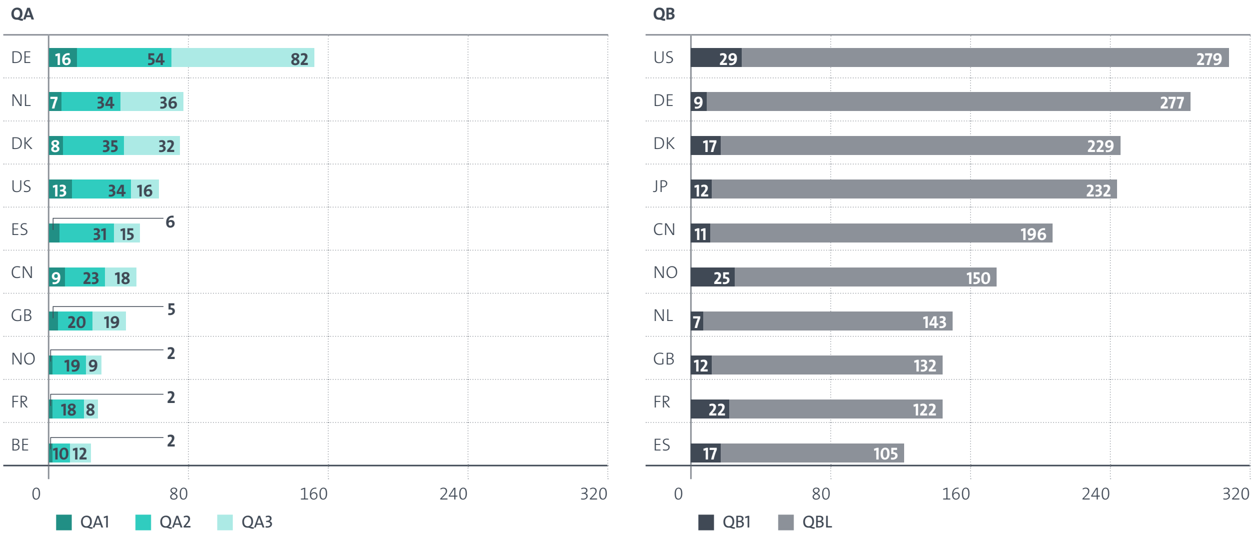
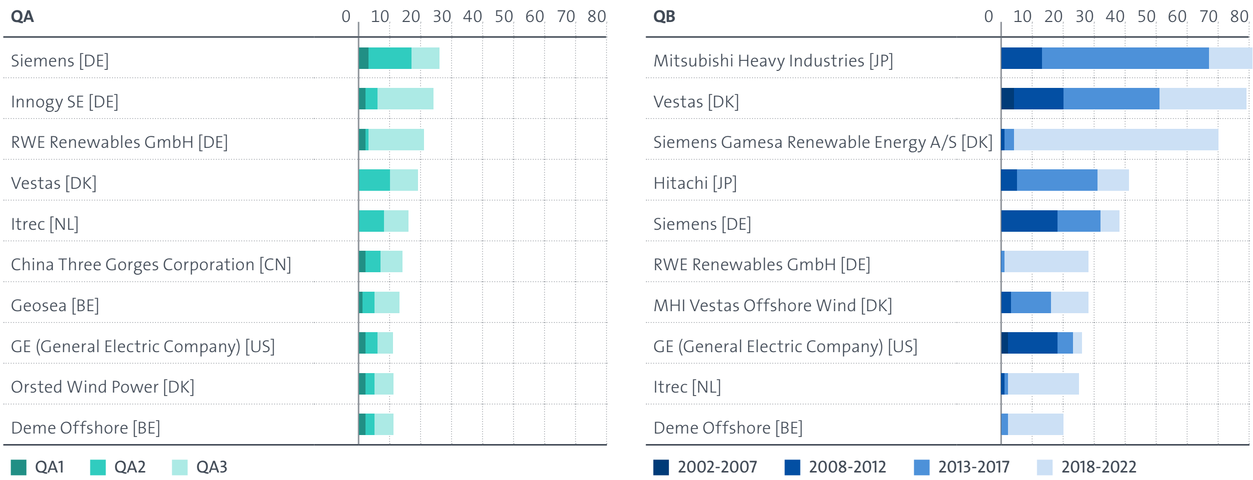


Figure 3.2.1c: **Top applicants (2002-2022)**



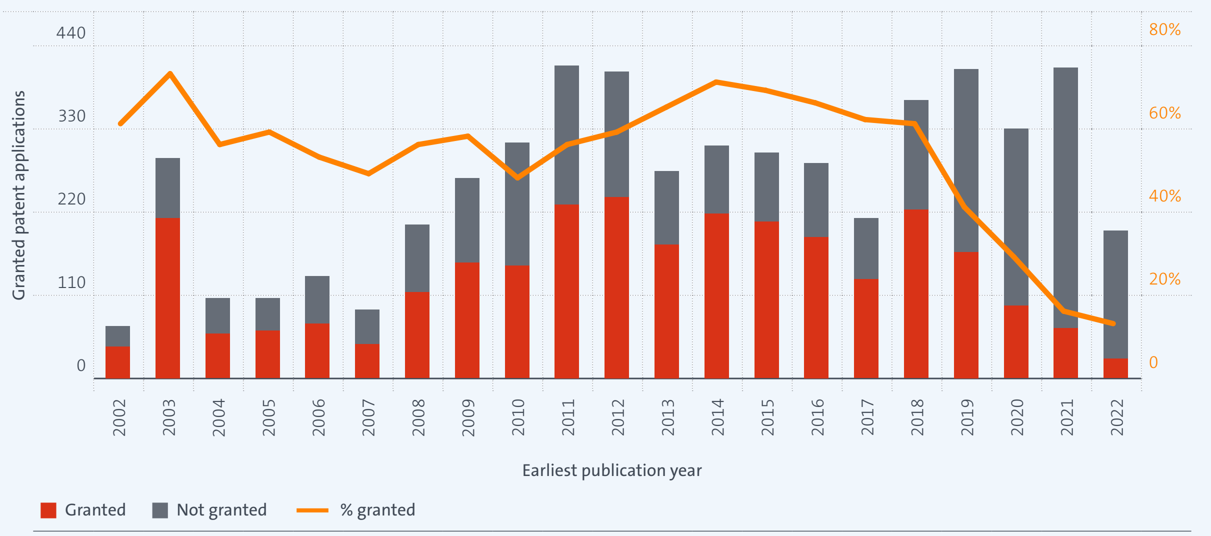
Box 7: Transportation, installation and erection (QK)

There are several challenges associated with the transportation, installation and erection of offshore wind turbines. Key challenges include logistics, transportation and harsh weather conditions. Port structures have to be adapted, specialised and often tailor-made service vessels need to be built and crews need to be trained and acquainted with offshore environmental conditions and dangers. Transporting and installing 100-metre-long (or longer) wind turbine blades on towers measuring over 150 metres high has become routine using specialised vessels. Looking back in the past, major scaling-up activity took place between 2000 and 2011. This was mainly due to the UK's first seabed leasing rounds which motivated several turbine manufacturers to enter the market for dedicated offshore wind turbines. The Kyoto Protocol entered into force in 2005, and in 2008 the European Parliament adopted the 2020 targets.

With this newfound visibility, turbine manufacturers announced larger turbine platforms and, throughout the industry, production facilities were put in place for a new generation of blades, towers, nacelles, substations, and the foundations needed to support them. Offshore projects became more complex, and this equally spurred ongoing activity for more efficient offshore installation to drive down costs. The renewed spurring of patent filings starting in 2017 is probably due to governments implementing a zero-subsidy offshore wind policy, leading to new innovative solutions to streamline the value chain.

The graph below shows the patent trends applicable to the vessels, installation cranes and lifting devices, etc., needed to install or move offshore wind turbines. The graph illustrates the number of yearly patent filings, with the green bars representing the patents that have been granted. The grey trend line shows the grant rate percentage, which decreases in more recent years because most of those patents are still in the examination and granting process.

Granted patent applications (2002-2022)



3.2.2 Towers (QH)

Observations

Modular tower design concepts are crucial for enhancing wind turbine performance, reducing the use of energy intensive raw materials, easing transportation and maintaining economics, especially with the increasing size of modern wind turbines.

- After a 40%-growing rate decade since 2010, the average number of IPF filings has remained relatively steady at around 50 per year. However, when considering non-IPFs, concrete towers filed in China instigate an upgoing trend due solely to a massive quantity of 754 domestic filings.
- Regarding designs and materials, tubular steel remains the preferred option due to the optimum balance between cost of energy and materials with potentially higher capacity factors achieved at higher heights. Both concrete due to lower costs and lattice tower designs due to taller hub heights and steel saving potentials have been gaining attention over the past decade.
- USA shows the largest share of IPF in welded or tubular steel (29% of total IPF), followed by Germany (10%) and Denmark (10%) which, in turn, are the two leading countries for lattice and concrete towers. Meanwhile China, though active in terms of IPFs, appears to be focusing its efforts on the internal market.

Tower structures are essential in the development of offshore wind energy technology, as they contribute to cost-effectiveness, durability, weight optimisation, robustness, and streamlined installation. To achieve these goals, various tower design concepts have been explored. The three main designs are welded or tubular steel towers (QH1), lattice towers (QH2), and concrete towers (QH3). While all three designs have their advantages and disadvantages, the tubular steel design has become the industry standard. However, the extensive use of energy-intensive steel in this design is a major drawback. In contrast, concrete and lattice towers use less steel, but their higher number of components result in higher labour costs[41]. By adopting recycling practices, such as increased use of scrap metal[42], and incorporating modularity with alternative tower types like concrete and lattice, the wind industry has the potential to reduce the intensity of raw material utilisation and associated emissions during tower construction. These aspects should set the innovation agenda for this specific domain.

Between 2002 and 2022, lattice towers took the lead in terms of IPFs, accounting for approximately 55% of the total inventions within this specific technological sub-concept. Inventions concerning concrete towers contributed to 37% of the overall IPFs. While welded or tubular steel towers held a modest share at about 8%, it is important to note that this sector has been experiencing reinvigorated attention marked by a discrete number of IPFs developed in the years 2021 and 2022. This interest in welded or tubular steel towers may potentially give early forecasting of upcoming innovations and advancements in this domain.

In terms of top applicant countries related to the three tower sub-concepts (Figure 3.2.2b), USA shows the largest share of IPFs in welded or tubular steel (29% of total IPFs), followed by Germany and Denmark which, in turn, are the two leading countries for lattice and concrete towers. In all three sub-concepts, Germany and Denmark together account for more than 30% of the share of IPFs. While Japan and China appear among the top countries in both welded or tubular steel and concrete (in total about 20% of IPFs in both sub-concepts), they are not present in the top list for lattice towers – a sub-concept in which European countries takes the largest share of IPFs (Great Britain, Spain and The Netherlands have 28% of IPFs).

In the years from 2002 to 2022 and summing up all IPFs addressing welded or tubular steel towers (QH1), lattice towers (QH2) and concrete towers (QH3), the Danish company Vestas was the biggest inventor with a total of 59 inventions. Vestas [DK] significantly outpaced the second-ranking patent applicant, American GE (General Electric Company) [US], which had 29 IPFs in total. However, an interesting distinction should be made concerning the focus of inventive efforts between these two entities: Vestas [DK] directed 77% of its IPFs to lattice towers, peaking at 17 IPFs in 2017. In contrast, GE (General Electric Company) [US] developed 66% of its IPFs related to welded or tubular steel towers, with a peak of 8 IPFs in 2011.

41 Lantz, Eric, Owen Roberts, Jake Nunemaker, Edgar DeMeo, Katherine Dykes, and George Scott (2019). Increasing Wind Turbine Tower Heights: Opportunities and Challenges. National Renewable Energy Laboratory; Golden, Colorado.

42 IRENA (2023), Towards a circular steel industry, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/Publications/2023/Jul/Towards-a-Circular-Steel-Industry

Box 8: Corrosion protection

Corrosion is a critical aspect for offshore wind foundations since it may negatively impact the viability and safety of these structures. Corrosion is mostly caused by the harsh marine environment, characterised by constant wave action and high exposure to saltwater and fluctuating temperatures. Solutions for preventing corrosion and protecting offshore wind structures are needed to ensure the integrity of wind turbine foundations, thereby increasing lifespan and reducing maintenance costs and potential environmental hazards. As installations of new offshore wind farms grow, organisations are working hard to find new technical solutions for corrosion protection (i.e. innovations in coatings, materials and cathodic protection).

In terms of total number of IPFs, in the period 2002-2022, EPC countries showed an elevated level of activities in the field of corrosion protection: 328 IPCs were developed in EPC countries, accounting for 69% of the total IPFs. China and USA followed with 53 and 46 IPFs, respectively. Among the EPC countries, Denmark and Germany together accounted for about half of the total IPFs.

IPF (2002-2022)

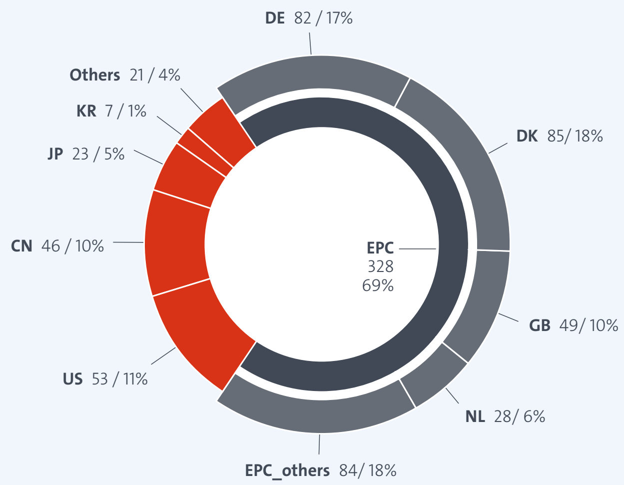


Figure 3.2.2.

Towers (QH)

QH1: tower → welded or tubular steel   QH2: tower → lattice   QH3: tower → concrete

Figure 3.2.2a: **Trend of IPF**

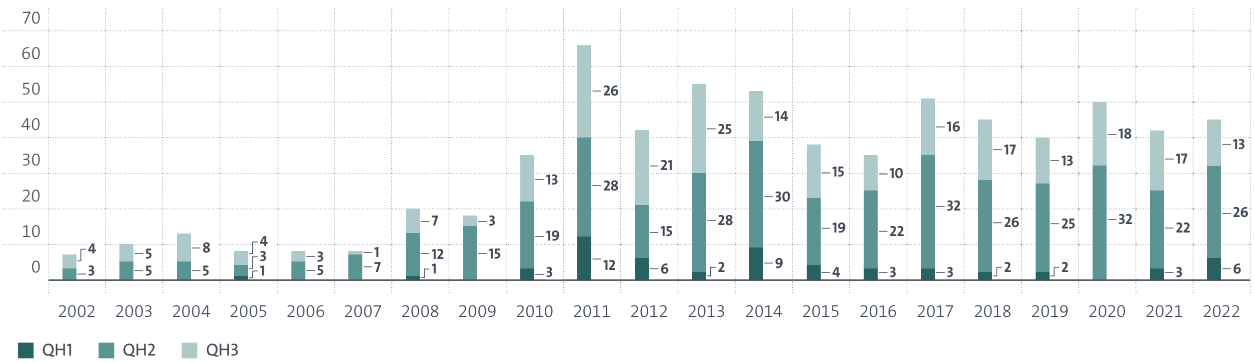


Figure 3.2.2b: **Top patenting countries (2002-2022)**

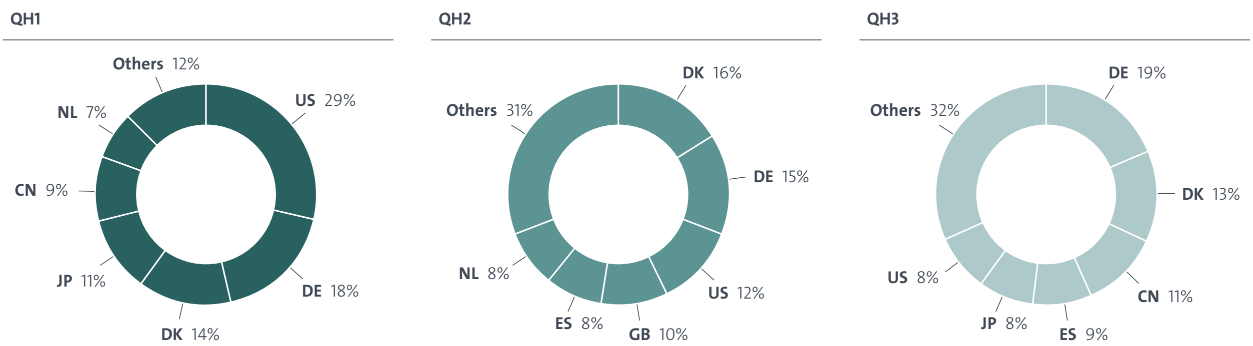
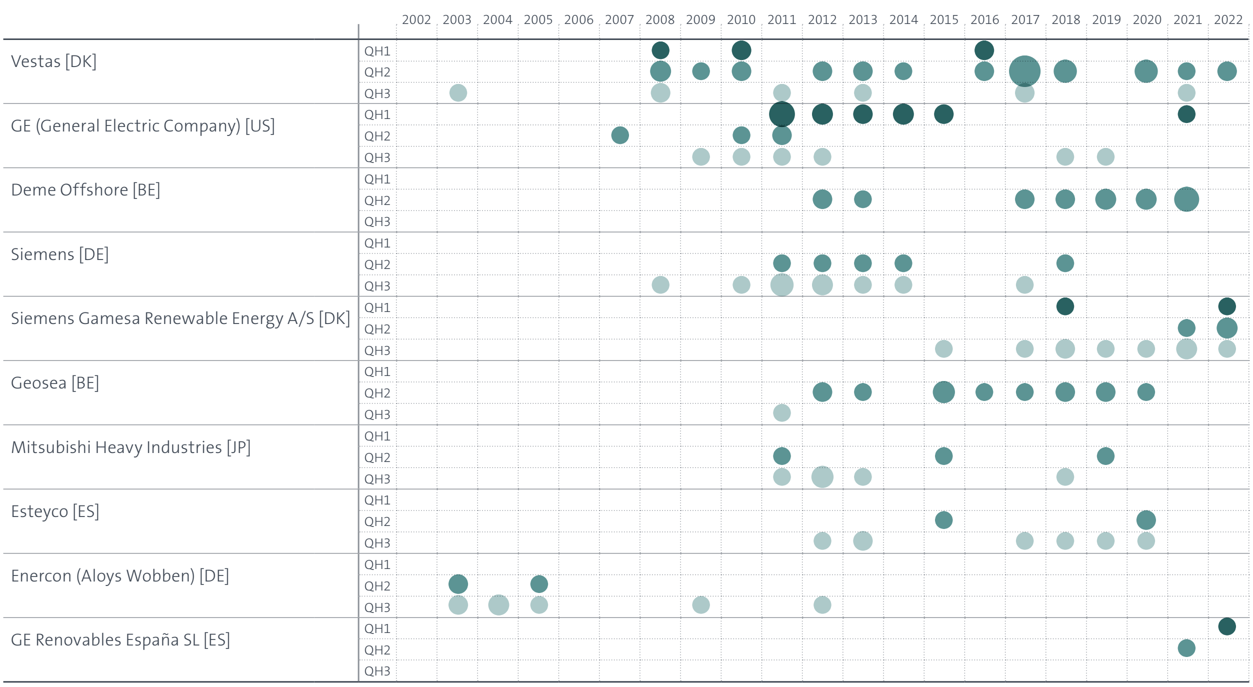


Figure 3.2.2c: **Top applicants**



3.2.3 Mechanical power transmission (QC)

Observations

Wind turbine drivetrain systems are dominated by two types: gearbox and direct-drive systems. Cost, power density, size, weight and – especially for offshore wind applications – reliability seem to be the most important factors in choosing one of these two types. The need for rare earth materials for permanent magnet generators could also determine future market trends, even though they are growing at a fast pace in the market for replacing rotor windings.

- Over the period from 2002 to 2022, two out of every three IPFs have been directed toward direct-drive systems, although this proportion has changed over time. In more recent years, from 2018 to 2022, this share has increased up to 80%.
- Permanent magnet synchronous generators (PMSG) have become the preferred generator technology for offshore applications and are found in over three-fourths of all offshore wind turbines worldwide.
- Overall, three major phases are observed: a first growing phase up to 2013 (+22% average YoY), a declining phase between 2013 and 2018 (-20% average YoY), and a new growing phase up to 2021 (+42% average YoY).
- The top 3 applicant countries for patents related to mechanical power transmission are Denmark, USA and Germany, each having 15%. The top applicants are Vestas [DK], Siemens [DE] and GE [US].

Innovation developments in offshore wind energy technology involve two major mechanical power transmission systems: the gearbox, which includes doubly fed induction generators (DFIG), and direct-drive systems, which include permanent magnet synchronous generators (PMSG) and electrically excited synchronous generators (EESG). The direct-drive systems offer higher efficiencies, but entail larger and heavier generators for large capacities. Between the two direct-drive options, PMSGs allow higher power density and reduced size and weight. PMSGs have been dominating since the beginning of the offshore wind market. As of 2018, generators containing permanent magnets were used in nearly all offshore wind turbines in Europe and in approximately 76% of offshore wind turbines worldwide.[43]

However, the risks related to rare earth elements (neodymium and smaller quantities of dysprosium) for PM generators in wind turbines is a major concern for the industry due to increasing global demand[44], despite prices falling to pre-2011 levels. While some alternatives to permanent magnet generators exist, they typically lack the efficiency and performance needed for offshore applications. As such, it’s crucial to expand innovation in this area and explore global partnerships to diversify rare earth supply and meet rising demand in future.

The development of IPFs in the period from 2002 to 2022 (Figure 3.2.2a) shows the trajectories of these two technical options — gearbox and direct-drive — indicating the sector’s efforts to optimise power transmission in offshore wind systems. The trajectory of IPFs shows a consistent growth between 2004 and 2013, peaking at 113 filings in that year. Despite a subsequent downturn in the following years, IPFs within both gearbox and direct-drive transmission systems exhibited a resurgence from 2018 onwards. Over the entire span from 2002 to 2022, 68% of IPFs have been directed toward direct-drive systems, although this proportion has changed over time. The period between 2002 and 2016 maintained an annual average share of 63%, whereas in the subsequent six years spanning 2017 to 2022 this figure increased to 75%. This observed trend may potentially imply a shift reflecting changing technology priorities between gearbox and direct-drive systems in the context of offshore wind energy technology.

In the years from 2002 to 2022, three are the top patenting countries in terms of IPFs related to mechanical power transmission: Denmark leads with 214 IPFs, followed by the USA with 195 IPFs and Germany with 185. In these three countries, the focus seems to be on IPFs related to direct-drive systems, as these outweigh those related to gearbox technology, with shares ranging between 70% and 76%. In contrast, Japan – the fourth-largest country for total number of IPFs in mechanical power transmission – shows nearly equal effort (in terms of the number of IPFs) in direct-drive and gearbox systems. This trend shows the Japanese pursuing balanced expertise across both technological sub-concepts, differently from other leading countries with a clear dominant trend in one area only.

43 Source: Alves Dias, P., Bobba, S., Carrara, S. and Plazzotta, B., The role of rare earth elements in wind energy and electric mobility, EUR 30488 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-27016-4, doi:10.2760/303258, JRC122671 https://publications.jrc.ec.europa.eu/repository/handle/JRC122671

44 IRENA (2023). Geopolitics of the Energy Transition: Critical Materials. International Renewable Energy Agency, Abu Dhabi https://www.irena.org/Publications/2023/Jul/Geopolitics-of-the-Energy-Transition-Critical-Materials

The presence of a Danish and a German company as the leading patent applicants of mechanical power transmission IPFs from 2002 to 2022 aligns with previous insights. Vestas [DK] is first with 97 IPFs, closely followed by Siemens [DE] with 83 IPFs. The next three ranking companies, namely Siemens Gamesa Renewable Energy A/S [DK], GE (General Electric Company) [US], and Mitsubishi Heavy Industries [JP], have an almost similar number of IPFs. The top four companies display a tendency toward direct-drive systems, with 65%, 88%, 98%, and 85% of their respective IPFs directed towards this technology domain. However, the Japanese company Mitsubishi Heavy Industries has only 54% of their IPFs concentrating on this specific technological sub-concept.

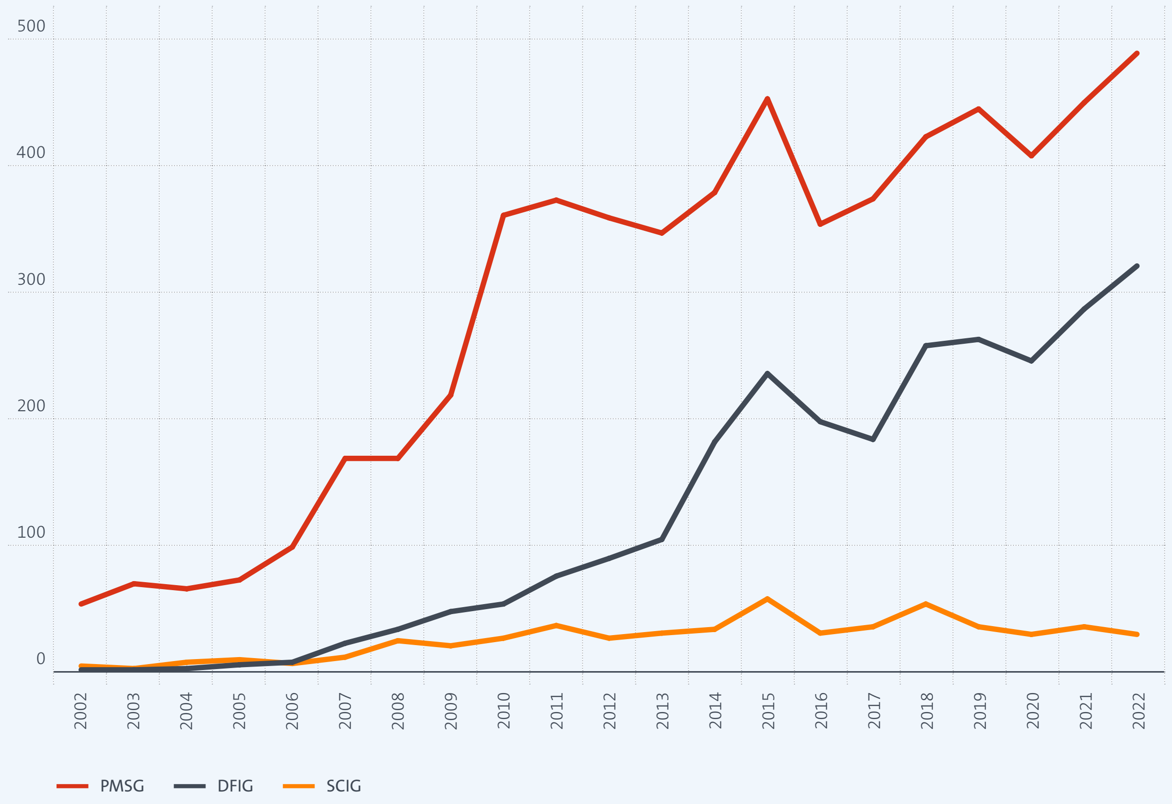
Box 9: Generators: Permanent magnet synchronous generators (PMSG) and doubly fed induction generators (DFIG)

The selection of the generator technology that better suits modern wind turbine drivetrains depends on whether the generator is applied in onshore or offshore turbines. Currently, both PMSGs and DFIGs are used extensively in the latter.

When looking into patent data, one can see that there is an upgoing trend of patents being filed for both PMSG and DFIG technologies. However, it is worth noting that patent filings specifically classified as "offshore" are too few to conduct meaningful analysis, so we expanded the search to include all wind energy patents.

Between 2002 and 2022, the number of patent filings covering these two technologies increased by a factor of fourteen. The driving force behind this trend is the need for a cost-effective option over the turbine's total lifecycle. This is especially true for offshore wind turbines, where the logistics for carrying out regular maintenance require more resources. Because PMSGs do not require gearbox technology, it has become the preferred generator technology for offshore wind turbine applications.

Generator technology used in wind power (tot patent families)



Source: ESPACENET.

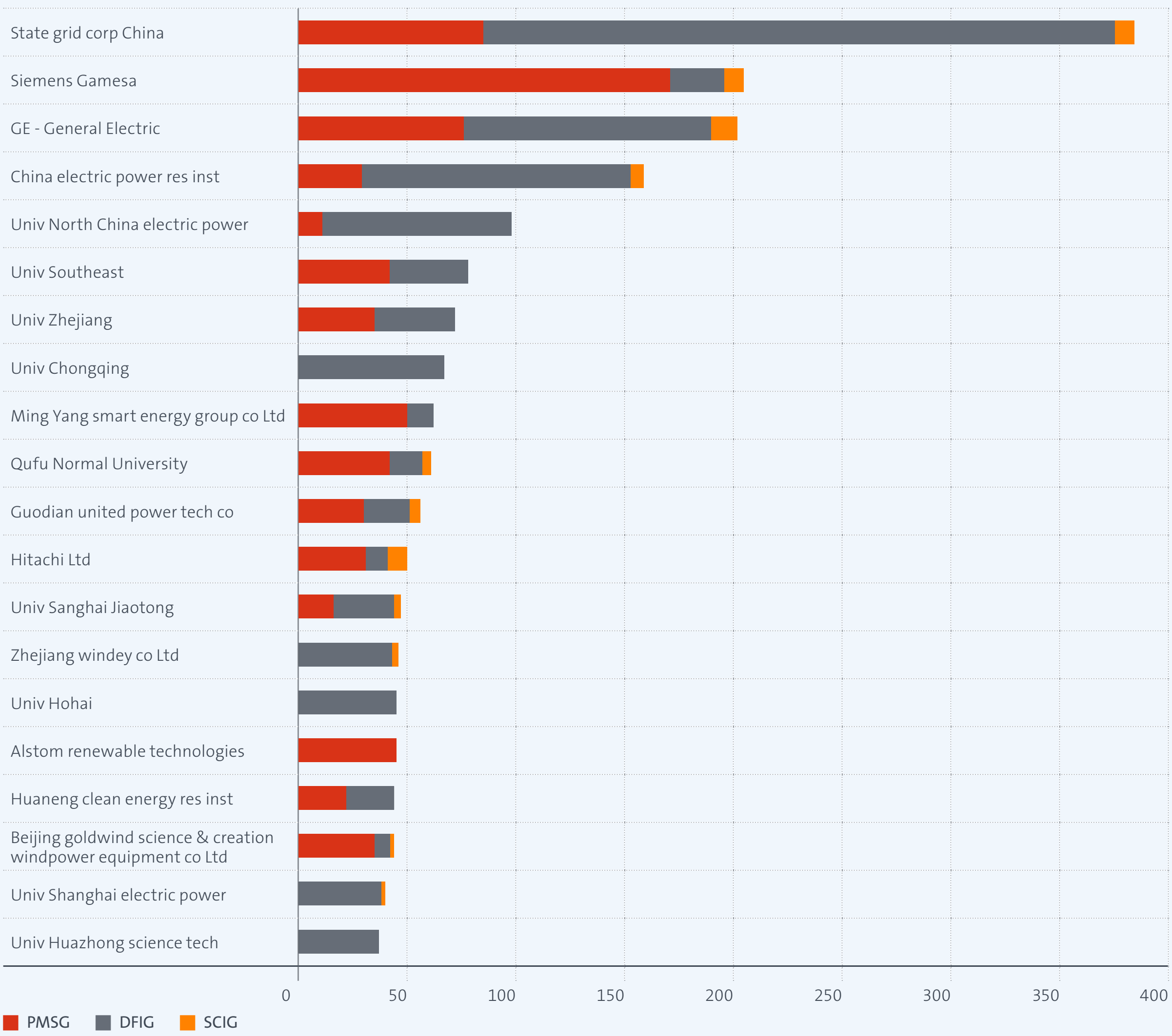
PMSGs have been the dominant choice since the beginning of the offshore wind market. As of 2018, generators containing permanent magnets were used in nearly all offshore wind turbines in Europe and in three-quarters of offshore wind turbines worldwide.

DFIGs are gaining popularity in wind farms due to their ability to control active and reactive power separately. The number of patents filed has increased sixfold since 2010. However, the risk of insufficient supply of rare earth elements (neodymium and smaller quantities of dysprosium) for permanent magnet generators in wind turbines is a major concern for the industry due to increasing global demand, despite prices falling to pre-2011 levels.[45]

From a geographical approach, it is important to observe that the upward trend is solely due to non-international patent applications filed at the CN patent office by Chinese applicants starting from 2007 onwards. This is also clearly observed when comparing the applicant rankings. CN applications serve to protect the domestic market and are seldom filed in other patent jurisdictions.

Note: For this analysis, the scope of the data was not limited to international patent filings and includes all wind energy classified patents

Top applicants generator for wind energy (tot patent families)



Source: ESPACENET.

45 Source: Alves Dias, P., Bobba, S., Carrara, S. and Plazzotta, B., (2020), The role of rare earth elements in wind energy and electric mobility, Luxembourg, doi:10.2760/303258

Figure 3.2.3.

Mechanical power transmission (QC)

QC1: mechanical power transmission → direct drive   QC2: mechanical power transmission → gearbox

Figure 3.2.2a: **Trend of IPF**

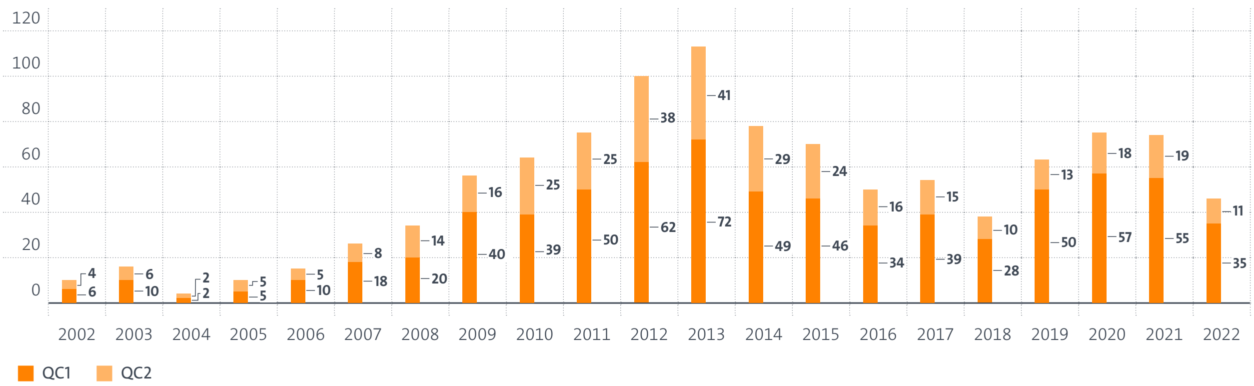


Figure 3.2.3b: **Top patenting countries (2002-2022)**

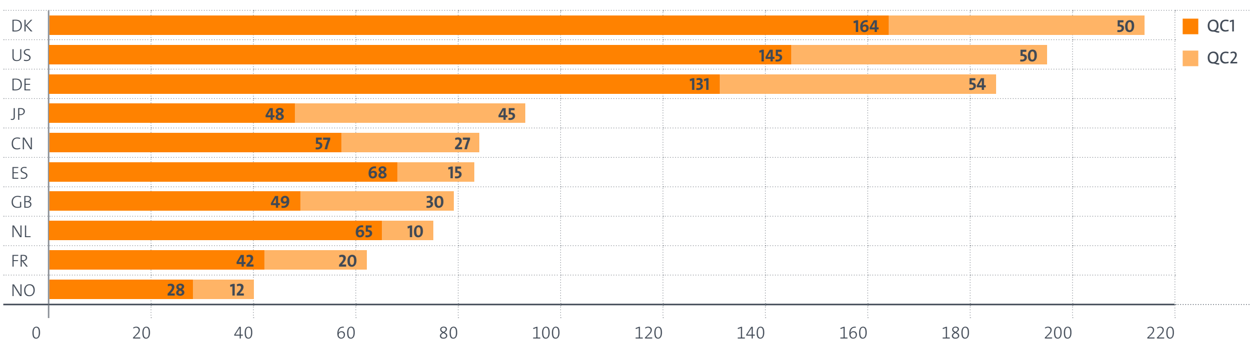
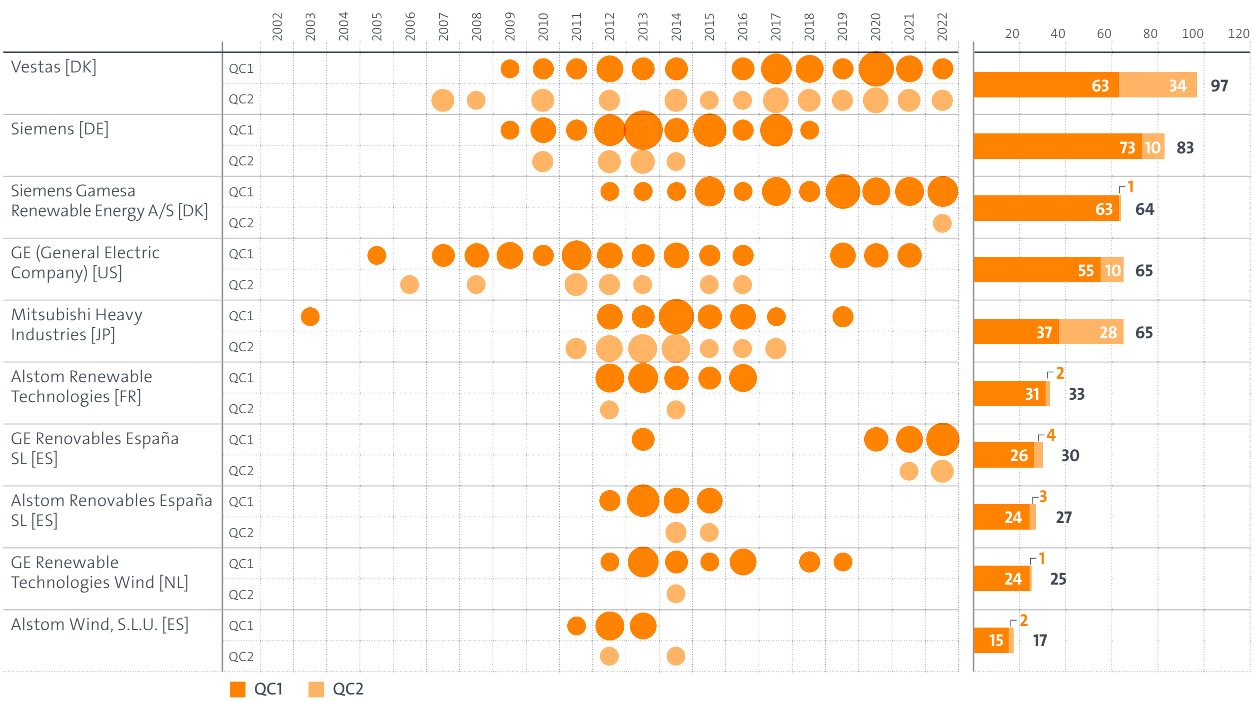


Figure 3.2.3c: **Top applicants**



3.2.4 Blades and rotors (QI)

Observations

The development of blades and rotors is evolving into larger designs that increase the power capacity of wind turbines. Better aerodynamic profiles and materials, including recycling, and new logistic approaches are at the core of innovation activities in the wind market.

- IPF trends for blades and rotors followed the same pattern as those for mechanical power transmission up to 2016: a first growing phase until 2013 was followed by a phase of decline until 2016, which suggests that they evolved under a certain coordination, as from a technological standpoint they are correlated. After 2016, blades and rotors recovered, reaching the peak patent filing by 2018, after which a declining trend has remained prevalent.
- The cumulative IPF count for blade technologies between 2017 and 2022 stands at 122, surpassing the collective IPFs generated over the preceding 15-year span from 2002 to 2016.
- Denmark, Germany and USA are the leaders in blade technology development – with these three countries jointly accounting for approximately 76% of the overall IPF count associated with modular blades and rotors.

In offshore wind energy technology, the development of blades and rotors is at a critical stage as a pivotal response to challenges like harsh operating conditions and the need for larger blades to capture more energy. With the increase in blade length, critical aspects such as manufacturing under rigorous design standards and certifications[46], easing transportation and logistics, incorporating circular economy practices that reduce usage of raw materials and recycle them at the end of turbine service life[47] need to be paid special attention.

As offshore wind farms expand further into deeper waters and more remote locations, the continuous refinement of blade and rotor designs becomes crucial. This need is further mirrored in the IPF trend shown in Figure 3.2.4a. As offshore wind energy technology moved toward maturation, there was a corresponding increase in the count of IPFs. The trajectory reveals an initial period of gradual innovation within this technological domain, succeeded by a swift surge. Notably, the cumulative IPF count between 2017 and 2022 stands at 122, surpassing the collective IPFs generated over the preceding 15-year span from 2002 to 2016, which amounted to 105 IPFs.

From 2002 to 2022, Denmark has taken the lead among countries in the developing rotor and blade inventions, with 108 IPFs, followed by Germany (45) and the USA (30). Remarkably, these three countries jointly contribute around 76% of the overall IPF count associated with modular blades and rotors, in contrast to the 63% represented in the other category. In this second category, Denmark ranks first with 26 IPFs, a figure exceeding double the quantity of German IPFs, which stands at 12.

Consistent with the earlier ranking, four Danish companies are among the top patent applicants during the period from 2002 to 2022. Vestas [DK] leads with 52 IPFs followed by Siemens Gamesa Renewable Energy A/S [DK] with 20. The top list also includes the Japanese Mitsubishi Heavy Industries [JP] in third place, followed by American GE (General Electric Company) [US]. Nevertheless, an important distinction emerges: Vestas [DK] and Siemens Gamesa Renewable Energy A/S [DK] have primarily developed their inventions within the most recent six years, specifically between 2017 and 2022, accounting for 87% and 85% of their respective total IPFs. In contrast, Mitsubishi Heavy Industries [JP] and GE (General Electric Company) [US] directed many of their inventive efforts in the initial phase spanning from 2002 to 2016, contributing 60% and 79% of their respective total IPFs during this period. This trend highlights the innovative dynamism exhibited by the Danish companies, supporting their widely recognised status as key innovators in the offshore wind energy arena.

46 M. Hagenbeek, S.J. van den Boom, N.P.M. Werter, F. Talagani, M. van Roermund, B.H. Bulder, and H.J. van der Mijle Meijer (2022); The blade of the future: wind turbine blades in 2040; Delft

47 Mishnaevsky Jr. Leon (2022); Recycling of wind turbine blades: Recent developments; Current Opinion in Green and Sustainable Chemistry; Vol 39; https://doi.org/10.1016/j.cogsc.2022.100746

Box 10: Recycling of rotor blades

With the growth of wind energy being deployed to increase the share of emission-free, renewable and affordable clean energy (UN, SDG 7)[48], the area swept by the rotor obtained through increased lengths of wind turbine blades has been and will continue to be one of the main keys to bringing down the per-kwh costs and increase efficiency. With a designed lifetime of 20-25 years, the question arises as to how to dismantle and recycle those rotor blades. After reaching end-of-life and in the context of circular economy, materials must be separated and recycled in new applications. Wind turbine blades consist of further material such as balsa wood, foams, coatings and metal parts. As the blade industry is technologically advancing at quick pace, it is not expected that materials used for blades and resulting waste material recycling are going to become standardised nor homogeneous anytime soon. This makes it very hard to develop an efficient pre-processing and recycling industry. However, producers of wind turbine blades announced a joint commitment to provide so called "blade material passports"[49] to support recycling activities. The patent data were extracted from ESPACENET and can be separated in 4 different areas:

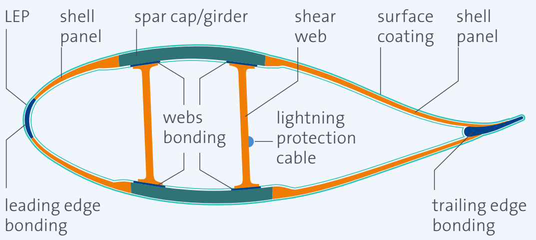
A. (94 families) The major group of patents is related to recovery of the plastics via destructive distillation, melting, hydropyrolysis and evaporation, combined with technologies preventing release of fumes and other hazardous materials. (IPC/CPC codes C10B, B29B17, C10J, B08B15, B09B3/29 and B09B3/40; link)

B. (87 families) The second group involves mechanical processes that include crushing, cutting, granulation and the sifting and screening of the debris. Related processes are washing and magnetic separation. (IPC/CPC codes B02C, B07B, B09B3/30 and B29B9; link)

C. (25 families) A third group involves recovery of waste materials via chemical breaking down processes using for example selective solvents and acids (solvolysis). (IPC/CPC codes C08J11, C08H and C08G; link)

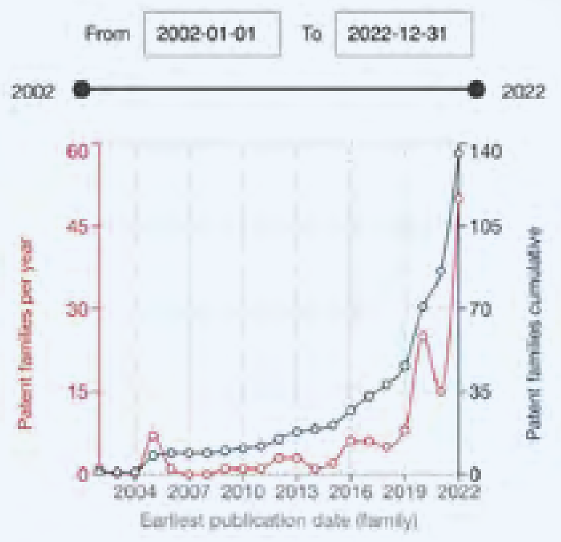
D. (23 families) A fourth group specifies the application and use of the waste materials, mainly as fillers for mortar, concrete, artificial stone or even in new composites. (IPC/CPC code C04B; link)

Generic cross-section of rotor blade



- **Spar cap/girder:** unidirectional glass or carbon fibre, supported by epoxy, polyester, polyurethane or vinyl ester matrix resins
- **Shear web and shell panel:** multiaxial glass giber reinforced polymer in sandwich laminate using for example balsa or interpenetrated polymer network foam (IPN)
- **Leading and trailing edge:** epoxy or polyurethane based structural adhesive
- **Lighting protecting cable:** aluminium or copper
- **Surface coating:** gelcoat or a paint made of unsaturated polyester, epoxy, polyurethane or acrylic
- **LEP (Leading Edge Protection):** Ultra-high molecular weight polyethylene film, polyurethane coating or gel

The use of different materials, especially the combination of glass fibre and epoxies, make it difficult to develop efficient and sustainable recycling processes.



We can observe a near exponential growth in patent applications. 2023 data are not complete, but even here we can see a continuous, strong increase especially in destructive distillation.

48 United Nations, Sustainable Development Goal 7: "Ensure access to affordable, reliable, sustainable and modern energy for all".

49 https://decomblades.dk/index.php/2023/04/25/638/ (formerly known as product disposal specification)

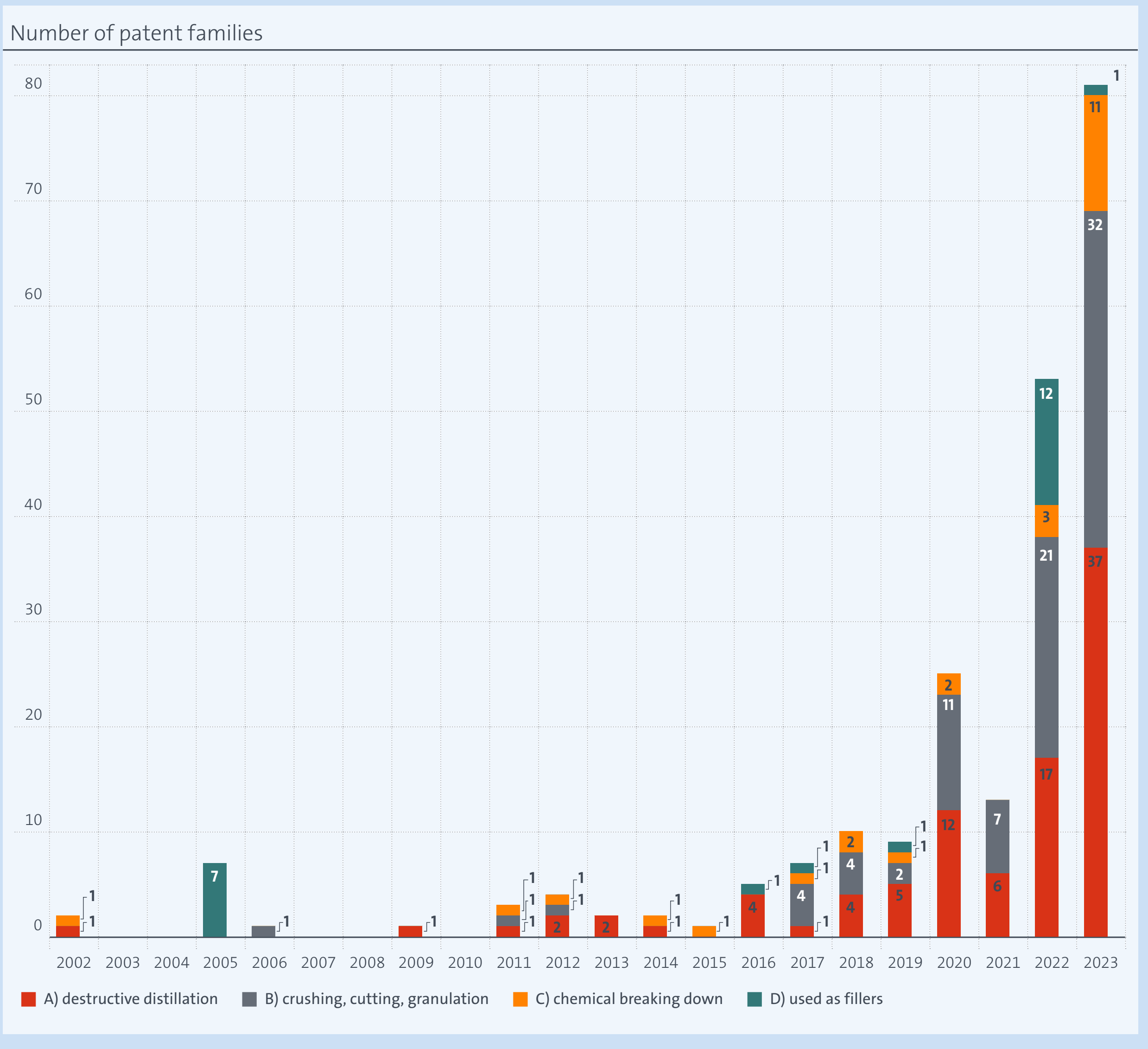

Number of patent families
80
70
60
50
40
30
20
10
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
A) destructive distillation
B) crushing, cutting, granulation
C) chemical breaking down
D) used as fillers

Figure 3.2.4.

Blades and rotors (QI)

QI1: blades, rotors → modular   QIL: blades, rotors → others

Figure 3.2.4a: **Trend of IPF**

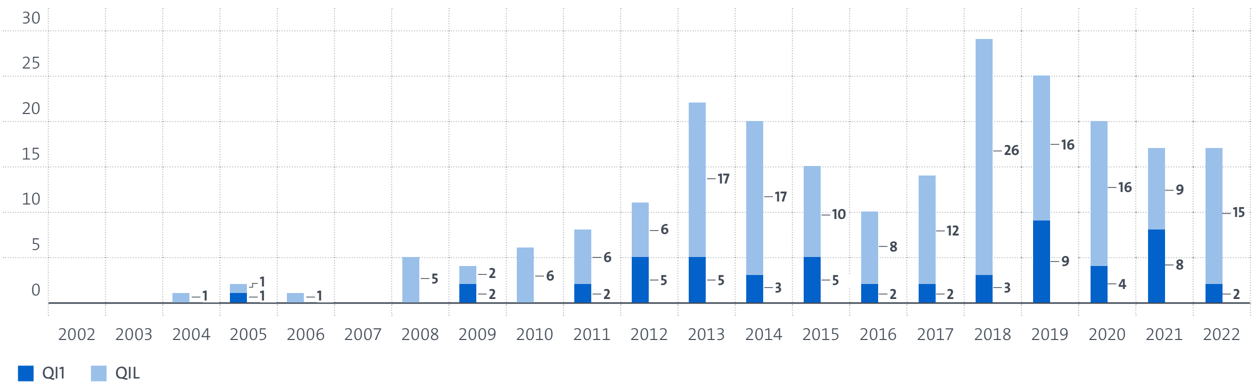


Figure 3.2.4b: **Top patenting countries (2002-2022)**

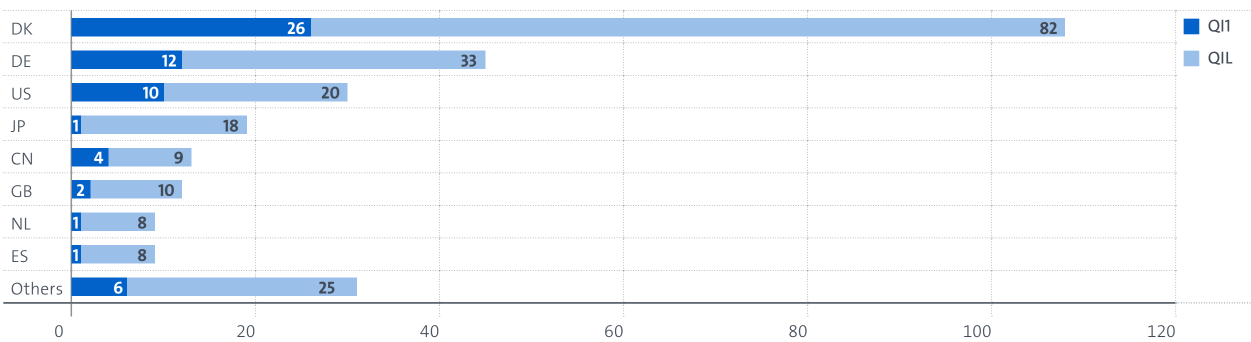
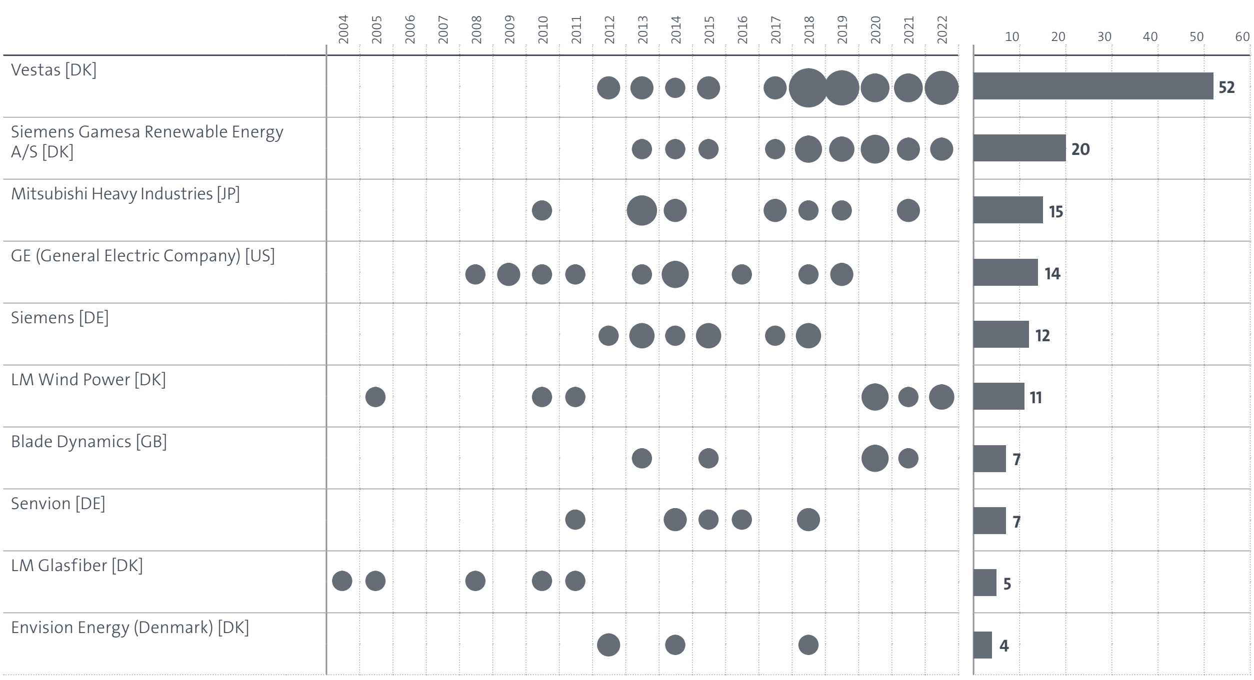


Figure 3.2.3c: **Top applicants**



3.2.5 Hybrid systems: solar and ocean energy (QE)

Observations

Clustering offshore renewables such as offshore wind energy with solar and ocean-based technologies is an alternative for increasing on-site power production that makes the most of the offshore infrastructure and can also contribute to creating a blue economy.

Among the hybrid systems, combining offshore wind and ocean energy — tidal and wave — leads in terms of IPFs.

The period 2008-2013 was the most active, followed by a declining period up to today. This correlates with the maximum LCOE values of offshore wind[50], which sets the needs for more efficient solutions. After 2013, LCOE declines steadily, disincentivising the deployment of hybrid systems, which add more complexity.

USA and China are the most active players in this group. European companies show little activity after 2013 likely due to the less attractive economics of these systems.

Hybrid systems, which are a combination of offshore wind with other renewable sources such as solar photovoltaics or ocean energy, including wave and tidal energy, present options for maximising the use of offshore infrastructure. One obvious choice is to combine offshore wind energy and wave energy. However, wave energy is currently at a much earlier development stage than offshore wind energy. Combining offshore wind energy with solar energy is also in an early stage of development and current installations mostly serve the purpose of proof-of-concepts and testing stations. Co-locating floating solar panels in offshore hybrid parks can share network infrastructure and grid connections, but it may increase costs and risks for wind farms. PV technology can be used solely for turbine operation or as a production source. Both fall under the same patent category. By deploying hybrid systems, the overall efficiency of the plant can be enhanced and the sources can provide improved flexibility services to the power grid. For instance, offshore wind power can provide a consistent base load, while the complementary wave and solar energy sources contribute during peak demand periods.

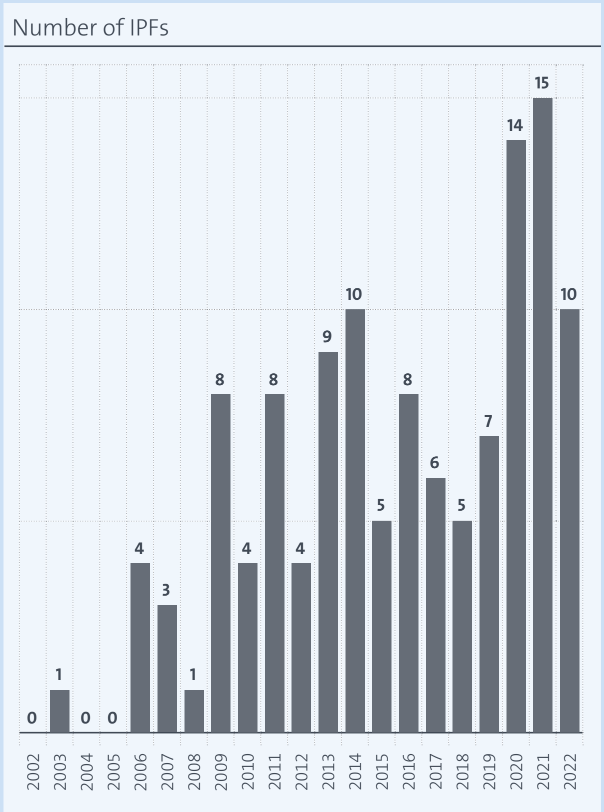
When considering IPFs, the focus has been on hybrid systems that integrate offshore wind energy with ocean energy sources (QE2). This category constitutes approximately 83% of all inventions between 2002 and 2022. Interestingly, the majority of these IPFs were developed from 2008 to 2013, with subsequent years showing a gradual yet consistent decrease in IPF numbers. The reason behind this decline might be the offshore LCOE historical trend. The period from 2013 to 2018 shows the highest LCOE values, which drove the need for more efficient solutions to bring these LCOE values down. Once the costs of offshore wind alone started a steadily decline trend in 2013, the commercial benefit of hybrid systems was reduced because, ultimately, they bring more complexity from an operational and maintenance perspective.

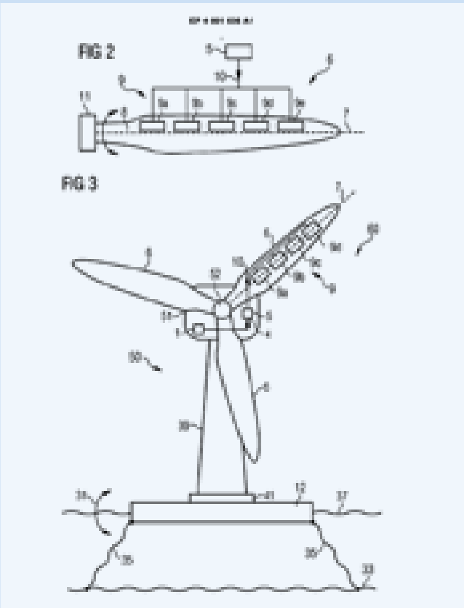
China and the United States of America are the leading patent applicant countries in hybrid systems combining offshore wind and solar technologies, with 18 and 17 IPFs, respectively, from 2002 to 2022. Furthermore, the United States of America holds the top position in hybrid systems involving offshore wind coupled with ocean energy sources, summing a total of 89 IPFs. Great Britain follows with 69 IPFs, and China is third with 59 IPFs in this category. Among leading patent applicants (in terms of total IPFs in the period 2002-2022) we find four companies (Voith Patent [DE], Tidal Generation [GB], Marine Current Turbines [GB] and Lone Gull Holdings [US]), one university (Dalian University of technology [CN]) and five independent applicants. This unusual top list indicates the distinctive nature of this technology domain within offshore wind energy, which can be seen as a niche. Here, the interplay between foundational research from academic institutions and the inventive attitude of individuals remains crucial, as it continues to guide the evolution of this technology toward its ultimate commercialisation phase.

50 IRENA (2021), Renewable Power Generation Costs in 2021, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021

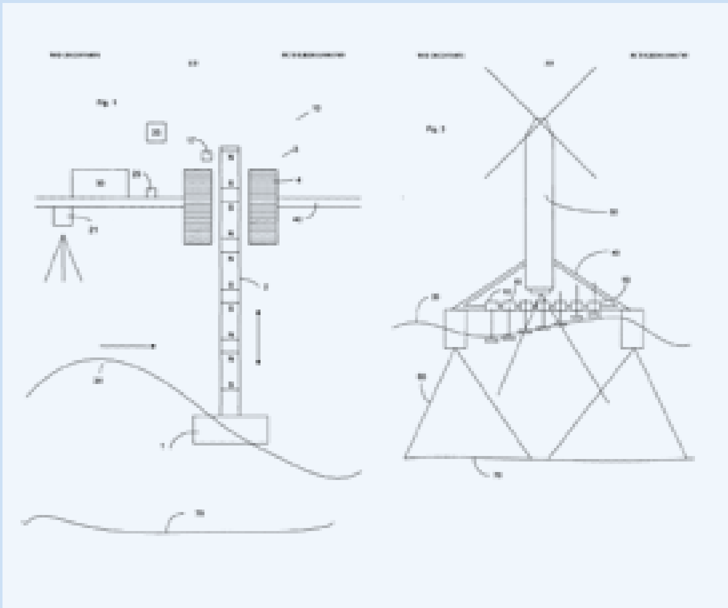
Box 11: Monitoring waves

Monitoring waves and wave loads is crucial for fatigue assessment. It allows us to better understand a substantial part of the dynamics of the forces inherently acting on offshore wind turbines. It helps to minimise operation and maintenance costs and to assess the lifetime of offshore wind turbines structures during their operation. State-of-the-art monitoring techniques are completely automated so that no human-interaction is required, and today's systems can track even the smallest of changes in the dynamic behaviour of offshore wind turbines. The data generated by the monitoring systems can also be used to steer damping controllers to respond to sea wave motion and reduce vibration. Technology for monitoring the waves is also needed and often combined with wave energy converters.





Espacenet: Flow regulating device (9) to counteract acceleration or oscillation due to the rolling motion of platforms



Espacenet: Combined technology: generating electricity or damping platform movements.

Figure 3.2.5.

Hybrid systems(QE)

QE1: hybrid system → solar   QE2: hybrid system → ocean energy

Figure 3.2.5a: **Trend of IPF**

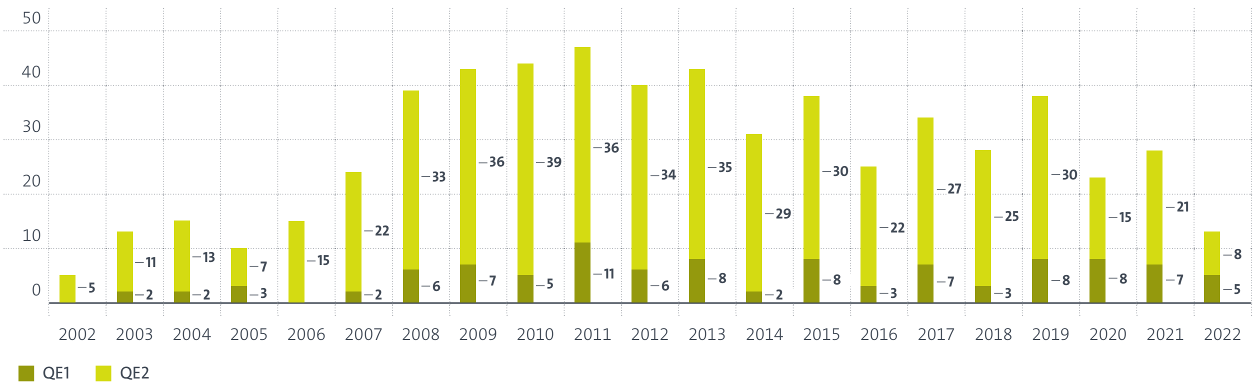


Figure 3.2.5b: **Top patenting countries (2002-2022)**

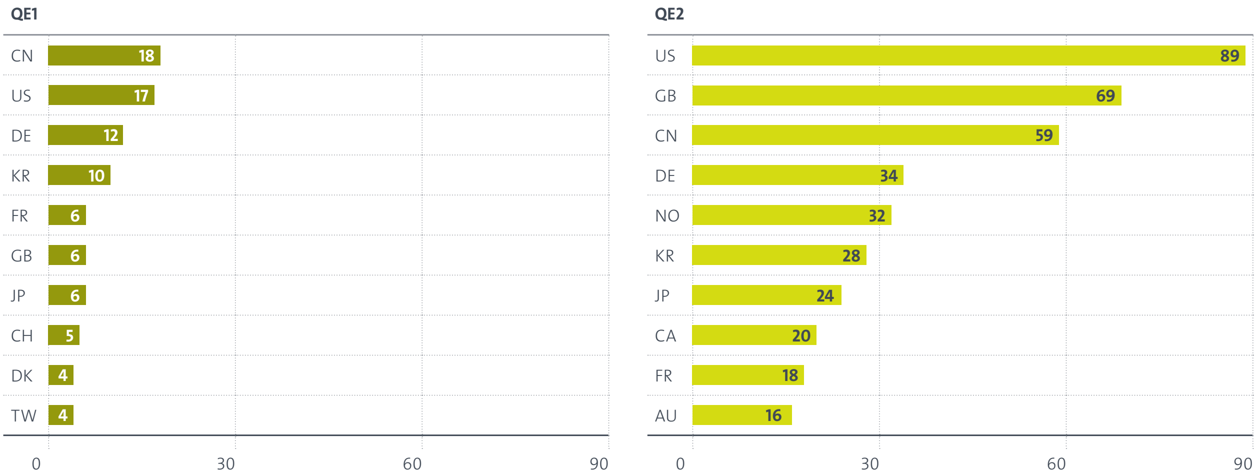
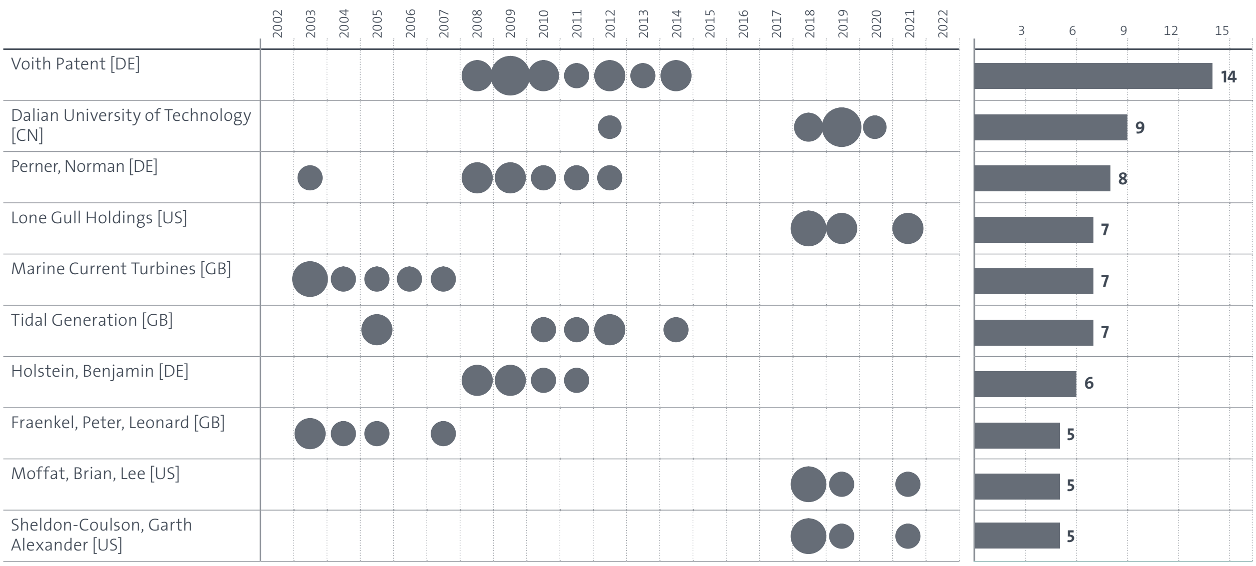


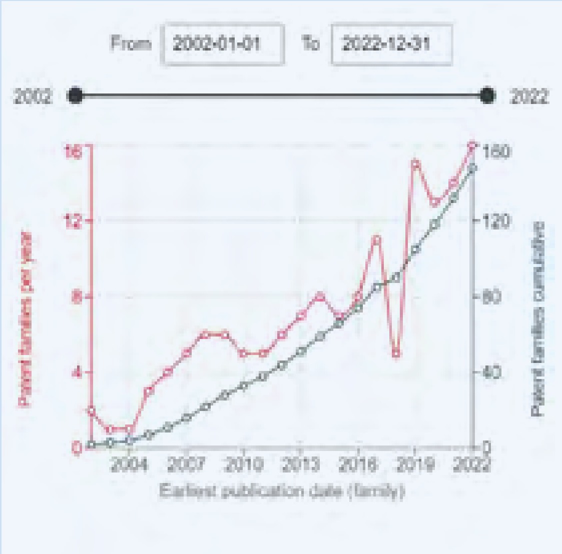
Figure 3.2.5c: **Top applicants**



Box 12: Desalination and offshore wind energy

Reverse osmosis is the most dominant process for water desalination. It is a very energy-intensive process. Around 36% of the operating expenses of seawater desalination plants are related to energy consumption.[51] While initial hybrid test projects put the desalination plant on shore and only made use of the electricity produced offshore, new systems are being developed to integrate the desalination plant onto floating semisubmersible structures, ensuring minimised impact of seawater desalination on the maritime and terrestrial environment. The fact that the complete structure is floating also allows for some form of relocation by sea if necessary. While desalinated seawater can then be used for municipal/ potable or agricultural irrigation, it is also a logical first step in the process of producing green hydrogen, using surplus electricity to power electrolysers. Hydrogen can then be pumped to shore or used as alternative fuels for decarbonising the shipping industry.

A patent search using the CPC code Y02A20/141, which is used to classify desalination in combination with wind energy, retrieves 1 060 patent families. Restricting this to offshore wind energy (Q0) results in 148 patent families. About 30% of those patent families have a classification code or relevant keywords related to hydrogen production or electrolysers.



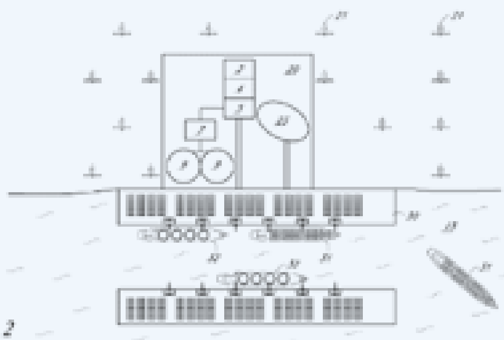


FIG. 2

US2011169269A1
Systems and methods for producing, shipping, distributing and storing hydrogen

51 https://www.energy.gov/sites/default/files/2019/09/f66/73355-7.pdf (page 86)

3.2.6 Energy Storage (QD)

Observations

The rising installed generating capacity of renewables and the need for flexible energy systems has led to greater innovation in energy storage solutions. One emerging business model is the combination of offshore wind farms with green hydrogen production units that can help decarbonise hard-to-abate end-use applications.

- In the last four years the number of IPFs dedicated to energy storage solutions with offshore wind plants has roughly grown fourfold, driven mainly by the uptake of the pipeline of green hydrogen projects.
- The IPF activity trends show a plateau for the period 2010-2018 common to all technology groups, which could be explained by the macro-economic environment (post-financial crisis), as the relatively high technology costs that remained high until 2015.
- Big European and US companies are front runners, while the Chinese sector seems to be more fragmented. Yet, China is the largest hydrogen consumer and an early adopter from a market perspective. The fact that this report focuses on IPFs may miss the internal market, focus of Chinese players.

Offshore wind power is characterised as a “variable renewable source” due to its high variable electricity output and poses challenges in terms of maintaining system adequacy and flexibility. To address this concern, there is increasing demand for new energy storage solutions that can effectively capture and store surplus energy during periods of overproduction. The stored energy can then be strategically released during peak demand periods, ensuring a consistent and reliable energy supply that aligns with consumption patterns and grid requirements. In recent years, energy storage solutions in combination with offshore wind installations have experienced significant growth, mostly driven by innovation in electrolysers for green hydrogen production and the foreseeable economic attractiveness of producing hydrogen offshore[52].

The development of national hydrogen strategies by over 30 countries has created a supportive environment for innovation in this area[53].

In recent years, several inventions have been developed in the context of energy storage solutions in combination with offshore wind installations. As depicted in Figure 3.2.6a, the peak of IPFs is observed in 2022, characterised by the emergence of approximately 90 new inventions. Among these, a significant 63% pertain to storage using hydrogen produced by on-site offshore electrolysers (QD4), while an additional 16% are linked to compressed air technologies (QD1). These two sub-concepts are predominant, accounting together for 77% of the total IPFs developed within the period spanning 2002 to 2022.

First place in rankings of the total number of IPFs between 2002 and 2022 is held by the US, with 66 IPFs identified as belonging in the hydrogen domain (QD4) and 67 IPFs in compressed air technologies (QD1). Germany and Great Britain follow, ranking second and third place, respectively. China is the fourth-place patenting country, with a substantial number of IPFs in batteries (QD3) as well.

Among the top applicants during the period of 2002 to 2022 (as illustrated in Figure 3.2.6c), only four of these were actively engaged in the development IPFs associated with energy storage during the initial years spanning 2002 to 2016. These four entities are Siemens [DE], GE (General Electric Company) [US], Vestas [DK], and Mitsubishi Heavy Industries [JP]. Except for Vestas [DK], the remaining three entities directed approximately 90% of their cumulative IPFs towards energy storage solutions within this initial period. All major patent applicants exclusively generated their IPFs within the most recent five years under study (2017 to 2022), showing an intensified focus on new energy storage solutions during this recent period. The leading applicant in this ranking is the Danish corporation Siemens Gamesa Renewable Energy A/S, with a total of 28 IPFs, mostly concentrated in the hydrogen domain (QD4), which is also the most targeted domain by other key players in terms of total IPF counts.

52 EPO and IRENA (2022), Patent insight report. Innovation trends in electrolysers for hydrogen production, EPO, Vienna https://www.epo.org/news-events/news/2022/20220512.html

53 IRENA (2022), Geopolitics of the Energy Transformation: The Hydrogen Factor, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen

Figure 3.2.6.

Energy storage (QD)

QD1: compressed air | QD2: kinetic | QD3: battery | QD4: hydrogen | QD5: thermal - Liquid air

Figure 3.2.6a: **Trend of IPF**

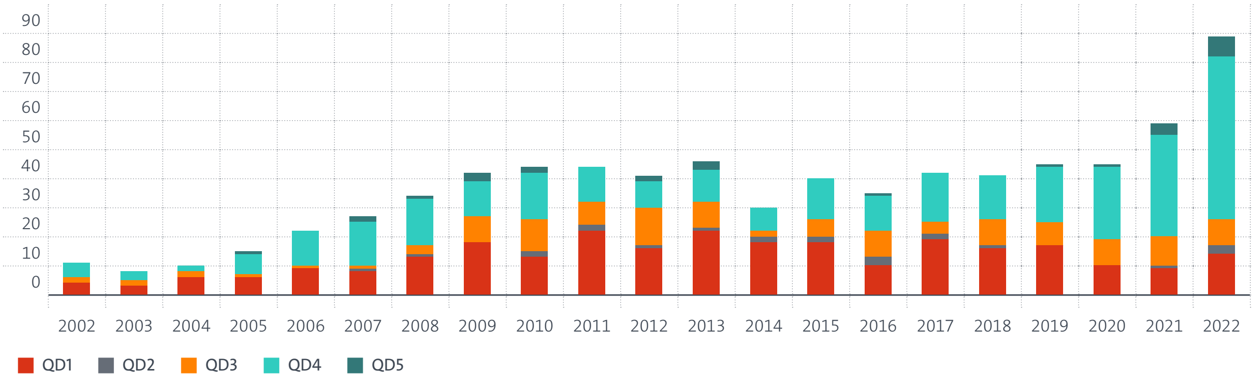


Figure 3.2.6b: **Top patenting countries (2002-2022)**

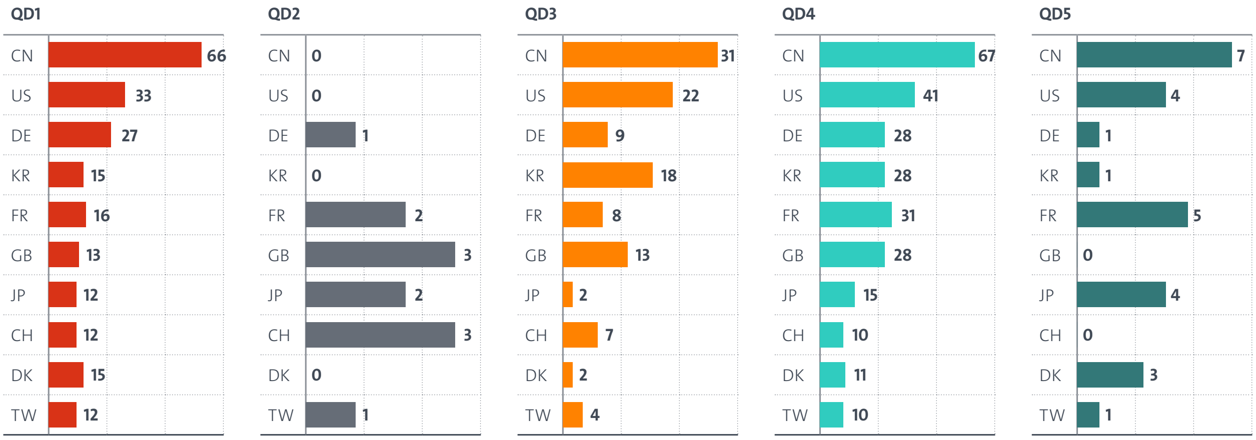
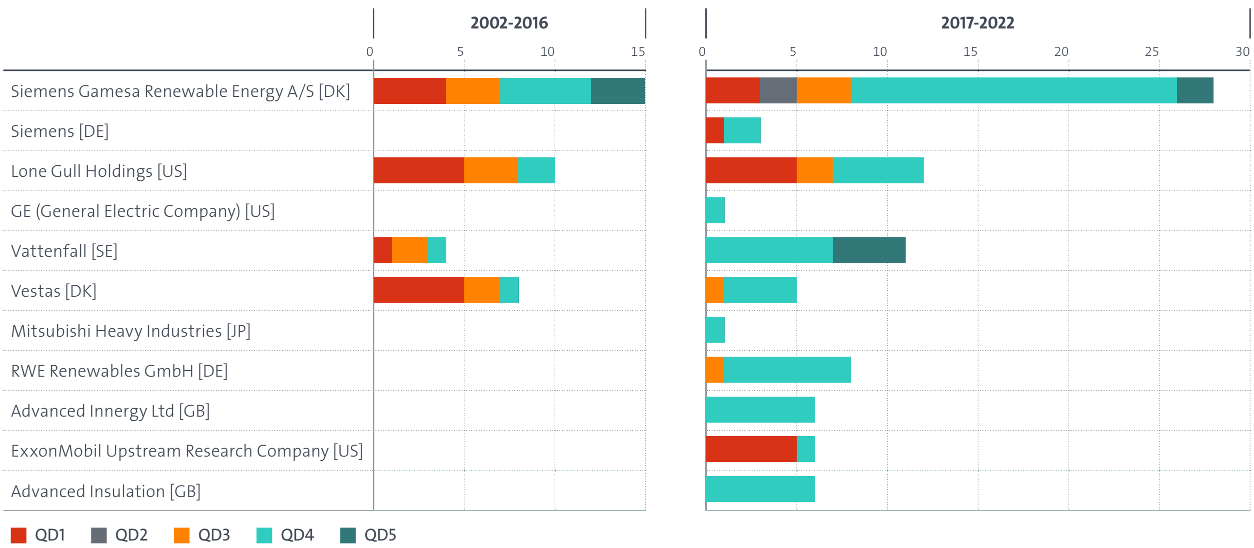


Figure 3.2.6c: **Top applicants**



3.2.7 Grid, submarine cables and protections (QJ & QL)

Observations

For successful expansion of offshore wind projects, it is essential to develop enabling grid infrastructure and associated protection equipment.

- Innovations related to submarine cables have shown increased patenting activity in recent years. This trend matches with the one shown for fixed and floating foundations, with a certain time lag.
- Focusing on submarine cable, leading countries differ from those identified for the fixed and floating foundations. This suggests the niche nature of this area of expertise. France is the major player thanks to a specific company with a long tradition in grid transmission solutions.
- Innovation in the grid-related domain, which is a broad area beyond offshore wind, is dominated by traditional big players in the global wind energy field, namely Germany, Denmark and USA.

The deployment of offshore renewable projects far from shore usually requires the installation of a new cable connection, as grid connections are not already readily available. Transmission lines for offshore wind projects are essential to realising developers' plans. The US market offers estimated total savings of USD 20 billion if robust and effective undersea cables are deployed[54]. When it comes to offshore projects, high-voltage direct current (HVDC) transmission is one option and can become cost-effective for grid connection lengths between 80 and 150 kilometres.[55] On the operational side, a range of digital solutions are being explored to effectively coordinate and optimise assets. Predictive modelling techniques can factor in wake effects and work collaboratively with optimisation techniques to regulate power electronic devices and storage, ensuring longevity and stable performance.[56]

This section analyses inventions related to grid, submarine cables and other solutions to protect them. As noted above, it is difficult from a patent search perspective to identify patents that only relate to offshore wind turbines, as such types of technical solutions may also be relevant for other technology areas. Nevertheless, the analysis in this section is a good approximation of what is happening in the offshore wind technology sector.

From Figure 3.2.7a it can be observed that IPFs related to power grids grew earlier than those related to submarine cables, which only in the later years became as important as grid-related innovations in terms of net number per year. As for previous sub-concepts, Figure 3.2.7a shows upward and downward trends, indicating that those two offshore wind areas as well follow macro dynamics occurring in the overall offshore wind sector. However, this group of innovations, unlike others presented before, show a downward trend in recent years which may suggest certain maturity levels at least for today´s requirements.

European countries are the leading players in developing IPFs related to both grids and submarine cables (Figure 3.2.7b). German IPFs account for 21% of the total IPFs in the period 2002-2022, followed by Denmark with 18% of the total. In contrast, France is the leading country for submarine cables, with an important overall contribution also from non-European countries like the USA and China.

These insights at country level are also found in the analysis of the top patent applicants (Figure 3.2.7c). Accordingly, Vestas [DK] and Siemens [DE] are the two companies developing the highest number of IPFs in the period from 2002 to 2022 (60 and 54, respectively). Nexans [FR] is the company developing the largest number of IPFs related to submarine cables (51 in total). Overall, it is interesting to note that almost all companies listed in Figure 3.2.7.c. are specialised either in grid or in submarine cables, indicating high technological specialisation with high R&D intensity and limited technological transferability. This means that companies focus their R&D efforts on either grid-related technologies or submarine cable technologies, resulting in specialised expertise within each domain. Transfer of technological capabilities from one domain to the other becomes challenging, indicating difficulties in leveraging expertise across both sectors due to their unique technical demands.

54 BloomberNEF (2023), Wind Farms Urged to Lengthen Undersea Cables, Saving $20 Billion

55 IRENA (2016), Innovation Outlook: Offshore Wind, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2016/oct/innovation-outlook-offshore-wind

56 IRENA (2019), Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation paper), International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2019/Oct/Future-of-wind

Figure 3.2.7.

Grid, submarine cables and protecting them (QJ & QL)

QJ: grid | QL1: submarine cables conductors → protection | QLL: submarine cables conductors → others

Figure 3.2.7a: **Trend of IPF**

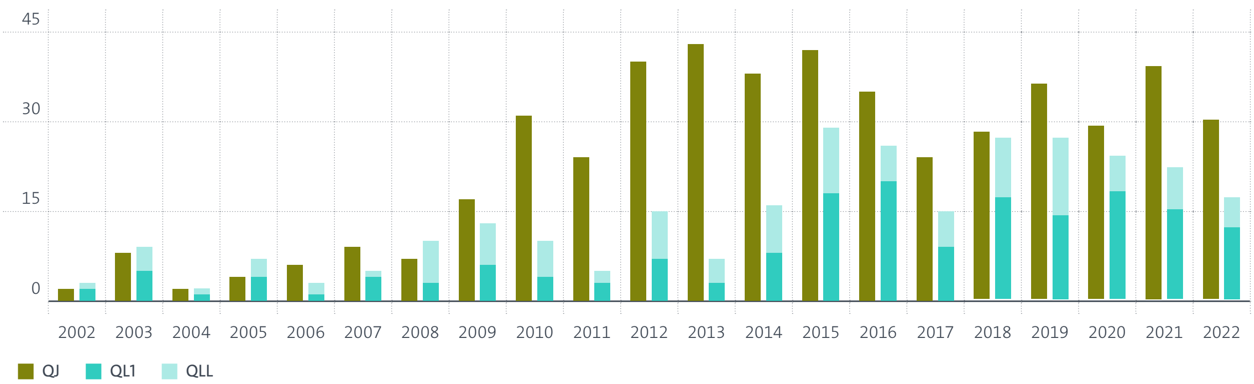


Figure 3.2.7b: **Top patenting countries (2002-2022)**

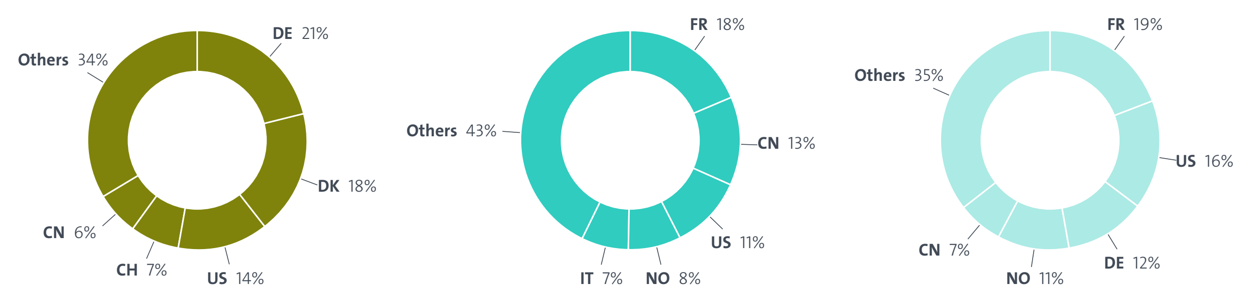
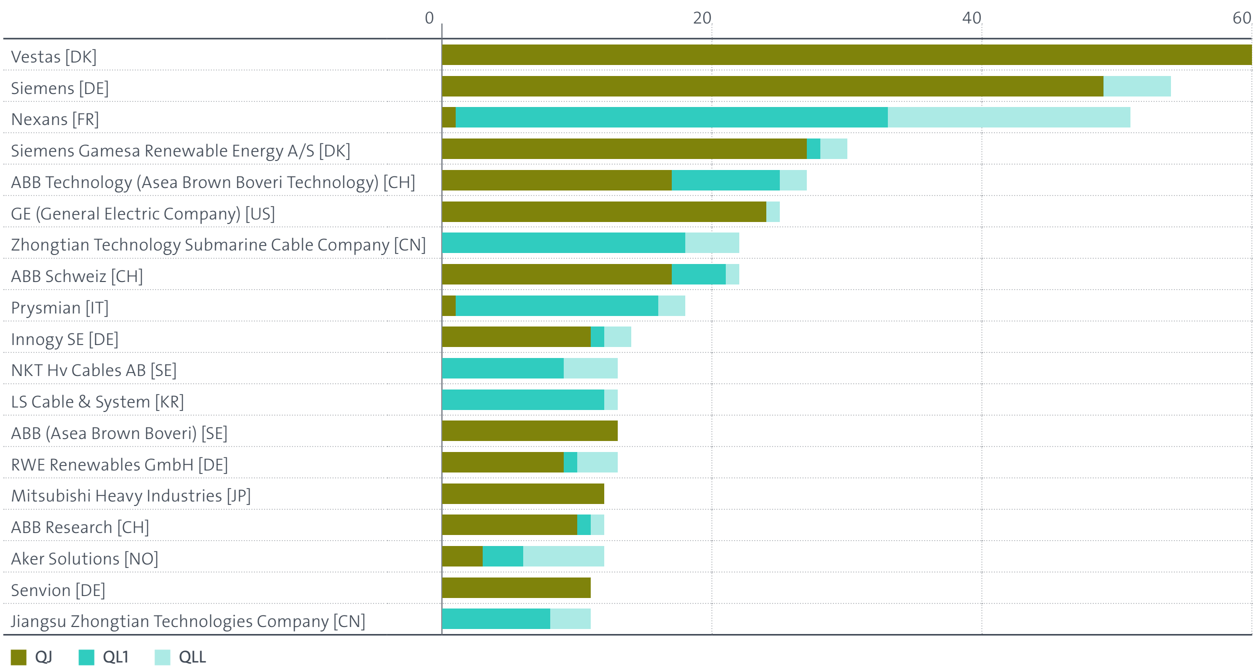


Figure 3.2.7c: **Top applicants (2002-2022)**



4. Conclusion

Offshore wind energy is emerging as a crucial renewable source for addressing climate change challenges (UN SDG 13) and mitigating global warming, and supporting UN SDG 7 by providing a clean and sustainable energy source by harvesting offshore energy resources. To enhance this potential, it is crucial to understand the current state of technological advancements, so attention can be focused on areas requiring additional research and development efforts.

Within this context, this report provides an overview of the landscape of offshore wind energy technologies by analysing patenting trends within various concept groupings in this technology field. The concept grouping offers a deeper level of granularity, as well as spotlighting areas where innovation is high and potential reasons for it, including market-driven factors.

This study identifies approximately 17 000 patent families related to offshore wind energy technologies published between 2002 and 2022, as well as revealing a significant surge from 2015 onwards. European countries, particularly Denmark and Germany, have taken the lead in generating inventions. While China has also made considerable contributions, its focus has predominantly been on its domestic market, with only 4% of its patent families also filed outside China. This low figure contrasts with the fact that China alone accounts for almost half of the world's total installed offshore wind-power generating capacity. This may be explained by a sectoral maturity level, which implies effective knowledge transfer across markets and competitive technology costs.

In terms of international patent families, Vestas [DK] is the leading company followed by Siemens [DE]. Over time, this industry has been shaped by a series of mergers and acquisitions, a factor that explains the third-place ranking for Siemens Gamesa Renewable Energy [DK]. General Electric [US], Mitsubishi Heavy Industries [JP], and Hitachi [JP] also emerge as key players in the list of top IPF applicants.

An analysis across the concept groupings reveals several insights.

For **foundations**, it is evident that floating foundations are gaining increasing traction in the industry due to access to deeper waters. Almost 80% of patents in this area in 2022 related to floating foundations, with the USA emerging as the leading innovator. Fixed foundations nevertheless remain the most dominant technology.

Tower designs for offshore wind turbines remain tubular steel according to the patent data. However, the need to reduce raw-material intensities and costs, has driven interest in alternative designs (concrete and lattice) and modular approaches. Between 2002 and 2022, 55% of IPFs were ascribed to lattice designs, with Denmark and Germany being the lead innovators.

Patent data for **drivetrains** reveal the popularity of direct-drive systems due to their effective cost-weight-power density ratio, as well as a preference for utilising permanent synchronous magnet generators. Between 2002 and 2022, two out of every three IPFs filed for drive trains were directed at direct-drive systems, with this share reaching 80% between 2018 and 2022). Denmark, Germany and USA are driving innovation in this space.

Blades continue to grow larger as wind turbine manufacturers aim to increase the wind capacity factor. Patent data reveal that Denmark is the leader in this area, accounting for approximately 85% of inventions between 2017 and 2022. The number of patents associated with blade recyclability has also seen significant growth in recent years.

Energy storage is one of the areas showing strong growth in patenting. The need for flexibility options that maximise the use of offshore wind energy is the driving force behind this development. The growth in hydrogen-related innovations as a source of flexibility is particularly relevant, with the USA taking the lead in this field. In 2022 IPF data peaked at 90 inventions related to energy storage, of which 63% pertained to storage using hydrogen produced by on-site offshore electrolysers.

In terms of the **hybridisation of offshore wind** with complementary technologies such as ocean or solar energy, trends in patenting activity are diametrically opposed to those seen in the energy storage group, with filings declining steadily since 2015. This may be due to the sharp cost reduction in offshore wind technologies, which makes combining it with other technologies due to the inherent complexity and high costs of this approach.

Grid, cables and associated protections are necessary to ensure that offshore wind projects have an effective channel to connect with onshore activities. High-voltage direct current (HVDC) transmission is an option and becomes cost-effective for grid connection lengths between 80 and 150 kilometres. There are also ongoing efforts to introduce digital technologies to monitor and optimise these assets. Patent data reveal a growing focus on submarine cables due to their tremendous cost-saving potential for the transmission infrastructure. France has been identified as the leading innovator in this space, having created a niche for itself.

Overall, growing patenting activity in the offshore wind domain points to continuous growth in technological deployment in the coming years. The need for a rapid roll-out of offshore wind power production calls for the ongoing development of innovative solutions that make the technology more cost-competitive.

Policy makers using patent data to inform areas of focus to promote offshore wind development and deployment. This analysis showcases how useful patent data can be in terms of identifying areas at the forefront of invention activity, as well as invention gaps. In the case of offshore wind, floating foundations, logistics for transporting and installing equipment as well as the production of green hydrogen are attracting invention activity. However, despite some activity at present, greater efforts are still needed in areas such as electrical infrastructure, reduced demand for materials, hybridization of energy generation systems and sustainability. Governments may consider strengthening their dialogue with industry, academia and scientific community to address those aspects, as well as continue using patent data, among other information sources, to inform their decision-making in the energy field.

Glossary and notes

Applicant	A person (natural person) or an organisation (i.e. legal entity, company) that has filed a patent application. A patent application may be filed by more than one applicant (joint applicants).
Assignee	An applicant who did not originally file the application but who acquired it from the previous applicant (assignor).
Blue economy	Economic system that seeks to conserve marine and freshwater environments while using them in a sustainable way to develop economic growth and produce resources such as energy and food.
Capacity factor	The capacity factor of a power plant is the ratio of its actual output over a period of time to its potential nominal output if operating constantly at full nameplate capacity over the same period of time. Link: https://www.sciencedirect.com/topics/engineering/capacity-factor
Citations (in a patent)	Backward citations (back in time): mainly used to describe a reference within a patent search report that documents the prior art relevant to the claims. Forward citations: forward in time seen from the perspective of the cited document; generally accepted as a proxy for patent value.
Co-applicant	One of the joint applicants (see "Applicant").
Decarbonisation	Increasing the share of low-carbon energy sources, particularly renewable energy sources such as wind and sun.
DFIG (doubly fed induction generator)	Generator that allows the amplitude and frequency of the output voltages to be maintained at a constant value, no matter the speed of the wind turbine rotors. Direct-drive wind turbine Where the generator speed is equivalent to the rotor speed because the rotor is connected directly to the generator without gearbox
Direct-drive wind turbine	Where the generator speed is equivalent to the rotor speed because the rotor is connected directly to the generator without gearbox
EESG (Electrically excited synchronous generator)	Generator using coils on the rotor.
Electrolyser - electrolysis	Apparatus and the process that uses electricity to separate the hydrogen and oxygen in water molecules.
EPC (European Patent Convention)	Multilateral international treaty instituting the European Patent Organisation and setting out the rules for granting European patents. EPC contracting states are those countries that are members of the European Patent Organisation. The mission of the European Patent Organisation is to grant European patents in accordance with the EPC.
EPO, European Patent Office	European Patent Office Organ of the European Patent Organisation that examines patent applications and grants European patents in accordance with the EPC. European patents may be granted for all EPC contracting states and may be effected in several non-contracting states (validation and extension states).
Espacenet	Free service from the EPO for searching patents and patent applications. Includes more than 130 million documents.
International patent family (IPF)	Patents that have more than one country in the list of publications, assignees, inventors or first priority countries. Using this concept allows identification (and exclusion) of single national filings that have no family members in other patent jurisdictions. Patents filed at the EPO, WIPO and other regional patent organisations are by default IPF.

Invention	Technical device, method or use which is new, non-obvious and may be applied in industry, including agriculture.
Inventor	A person designated as an inventor in a patent application. An inventor can also be an applicant. An inventor is always a natural person. There may be more than one inventor per application.
IRENA (International Renewable Energy Agency)	Intergovernmental organisation representing 168 Member States and the European Union, mandated to facilitate co-operation and promote the adoption and sustainable use of renewable energy
Jurisdiction	A country or countries (territory) for which a patent may be granted by the responsible intellectual property office.
Lattice tower	A type of support structure that is self-supporting with multiple legs and cross bracing of structural steel.
LCOE (Levelised cost of energy)	Average cost of the unit (kWh) generated by a system. It is calculated by the ratio of the total annualised cost of the system to the total electrical load served.
Ocean energy	All forms of renewable energy derived from the sea. There are three main types of ocean energy: wave, tidal, and ocean thermal.
Patent application	Document describing the invention for which patent protection is sought. It consists of claims which define the scope of the invention, description which explains the invention and (optionally) drawings which illustrate the invention.
Patent authority	The patent office where a patent was filed. Normally represented using a WIPO STANDARD ST.3 code: wipo.int/export/sites/www/standards/en/pdf/03-03-01.pdf.
Patent classification	CPC or IPC classifications: classification scheme or system of codes that groups inventions according to technical area. Often used in patent analytics to create uniform patent samples.
Patent family	A set of patent documents covering the same or similar technical content, depending on the patent family definition. The size of the patent family refers to the number of patent applications in the family.
PATSTAT	The EPO's PATSTAT database has become a point of reference in the field of patent intelligence and statistics. It helps users perform sophisticated statistical analyses of bibliographical and legal event patent data.
PMSG (Permanent magnet synchronous generator)	Generator where the excitation field is provided by permanent magnets instead of a coil.
Priority filing	The earliest patent application of a family from which subsequent applications of that family claim priority. The priority date is the date on which the earliest application (priority application) was filed.
SCIG (Squirrel cage induction generator)	Constant speed generator needing a gearbox.
Utility model	A registered right that gives its holder an exclusive right to an invention. It is granted for a limited period of time in return for disclosure of that invention. It usually requires a lower standard for inventive step than a patent. Utility models are often issued without examination, and the term of protection tends to be shorter than that of a patent.

DISCLAIMER

The data and information presented in this report have been produced, prepared, compiled and presented with the utmost care by the two collaborating organisations, namely the European Patent Organisation and the International Renewable Energy Agency. Nevertheless, no guarantee can be given to their accuracy or completeness.

The findings, conclusions and interpretations presented in the report cannot serve as a basis for any expectations regarding future actions or measures from the collaborating organisations, their governing bodies, or members. The information contained herein does not necessarily represent the views of all members of the collaborating organisations. The mention of specific companies or certain projects or products does not imply that they are endorsed or recommended by the collaborating organisations in preference to others of a similar nature that are not mentioned. The designations employed and the presentation of material herein do not imply the expression of any opinion on the part of the collaborating organisations concerning the legal status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

The European Patent Organisation and International Renewable Energy Agency shall not be liable for any damages, cost, losses or third-party claims resulting from the reliance on the data, information, findings, conclusions and interpretations presented in this report.

RIGHTS AND PERMISSION

Unless otherwise stated, material in this publication may be freely used, shared, copied, reproduced, printed and/or stored, provided that appropriate acknowledgement is given of the European Patent Office and the International Renewable Energy Agency. Material in this publication that is attributed to third parties may be subject to separate terms of use and restrictions, and appropriate permissions from these third parties may need to be secured before any use of such material.

You may not use this work for commercial purposes.

CITATION

EPO and IRENA (2023), Patent insight report: Offshore wind energy, EPO, Vienna

About the EPO

The European Patent Office (EPO) examines European patent applications, enabling inventors, researchers and companies from around the world to obtain protection for their inventions in up to 44 countries through a centralised and uniform procedure that requires just one application. The EPO is effective and transparent, responding to the needs of users and agile in managing the changing demands and conditions of a dynamic global patent system. The EPO's work contributes to a safer, smarter and more sustainable world.

About IRENA

The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge and a driver of action on the ground to advance the transformation of the global energy system. A global intergovernmental organisation established in 2011, IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

Follow us

- Visit **epo.org**
- Subscribe to our newsletter at **epo.org/newsletter**
- Listen to our podcast at **epo.org/podcast**

This report is published and edited by the European Patent Office (EPO) and International Renewable Energy Agency (IRENA)

© EPO, IRENA 2023
www.epo.org
www.irena.org

Authors
Geert Boedt (EPO)
Johannes Schaaf (EPO)
Francisco Boshell (IRENA)
Jaidev Dhavle (IRENA)
Gayathri Prakash (IRENA)
Juan Pablo Jimenez Navarro (IRENA)
Francesco Pasimeni (Technology University of Eindhoven – TU/e)

Acknowledgements
Christoph Sinn
Paul Komor (IRENA)
Michael Taylor (IRENA)
Diala Hawila (IRENA)
Gerardo Escamilla (IRENA)
Nazik Elhassan (IRENA)
Laurent Libeaut (EPO)

Design
European Patent Office