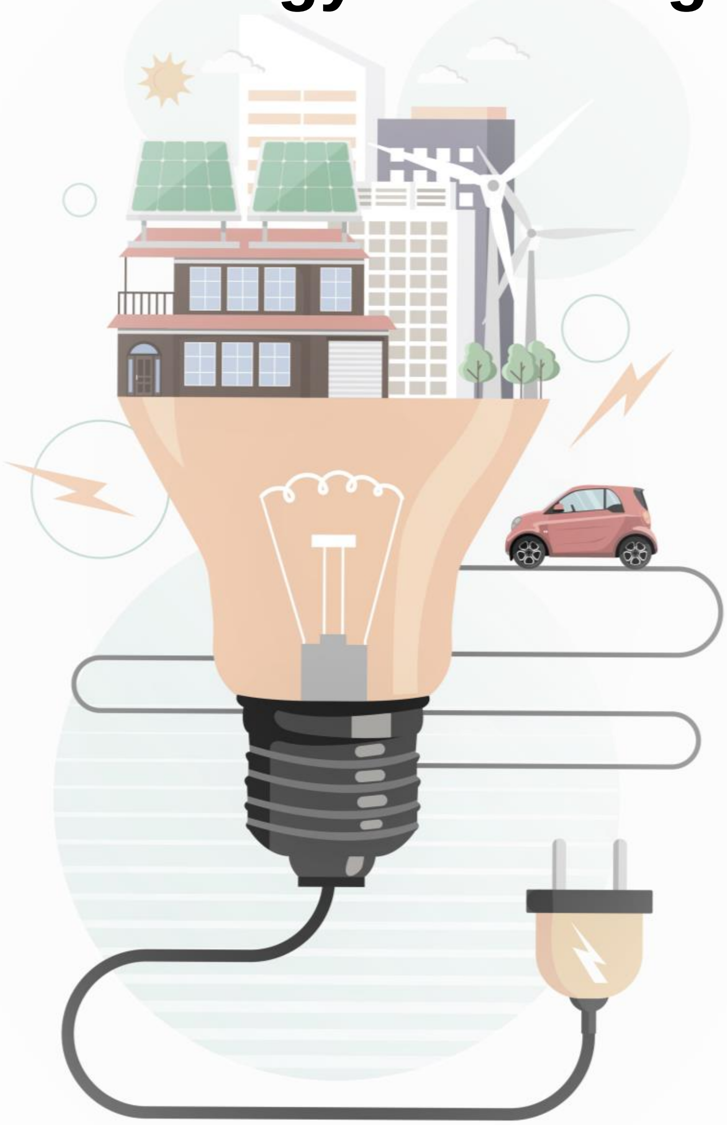
European Commission

ASSET Study on

Gathering data on EU Competitiveness on selected Clean Energy technologies



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About ASSET

The ASSET Project (Advanced System Studies for Energy Transition) aims at providing studies in support to EU policy making, research and innovation in the field of energy. Studies are in general focussed on the large-scale integration of renewable energy sources in the EU electricity system and consider, in particular, aspects related to consumer choices, demand-response, energy efficiency, smart meters and grids, storage, RES technologies, etc. Furthermore, connections between the electricity grid and other networks (gas, heating and cooling) as well as synergies between these networks are assessed.

The ASSET studies not only summarize the state-of-the-art in these domains, but also comprise detailed qualitative and quantitative analyses on the basis of recognized techniques in view of offering insights from a technology, policy (regulation, market design) and business point of view.

Disclaimer

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Authors

This study has been developed as part of the ASSET project by Guidehouse.

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Executive summary

This report **considers seven clean technologies** that rank differently on forecasted market size and expected market growth and can be grouped in the following way:

- Traditional and (largely) mature renewable energy (RE) technologies like Solar PV, Onshore Wind and Offshore Wind have a stronger hardware proposition and show substantially larger market sizes, but limited growth rates below 10%.
- Emerging digital technologies including energy management and grid management show both small current market sizes but stronger growth outlooks
- High-voltage direct current (HVDC) technology is assessed as small and low-growth market due to the scope of this study focusing on hardware components
- Ocean technologies including wave and tidal technologies are least mature for which no proper commercial market has developed so far

The EU-27 has a strong relative share of the offshore wind energy (at ~33% of global) and grid management (~35% of global) market across the reviewed clean technologies today.

In terms of **competitiveness** there is no market where the EU-27 is represented as specifically weak or dominating. The competitiveness and position of EU-27 companies depends across the specific value chain segments considered and the specific market characteristics. However, there is no specific value chain segment in which the EU-27 companies are consistently strong or weak across technologies.

- In **Offshore Wind** the EU-27 companies hold an overall strong market share with ~54% with relatively strong positions in Turbine manufacturing, Logistics & Installation and EPC. This is driven by the large domestic market and build-up of technical expertise via track records across these projects.
- **Onshore Wind** markets are in comparison rather cost-driven and more geographically dispersed. Here EU-27 companies have a relatively lower market share compared to offshore wind with ~43% and are specifically strong in the Balance of System (BOS) and in the deployment.
- In **Solar PV** EU-27 holds a 34% overall market share and is specifically strong in Solar PV equipment manufacturing, polysilicon production and monitoring & controls. The latter highlighting the European control software competence that is also visible in the BOS in wind.
- In the **Energy Management** we see a leadership position of EU-27 companies in the Building energy management systems including their deployment driven by their legacy role as building controls and heating, ventilation, air conditioning and cooling equipment providers. In contrast, the Home energy management system markets are rather led by North American players.
- In **Grid Management**, EU-27 holds a strong competitive position in the virtual power plant (VPP) segment as well as on the distributed energy resource analytics, as this is often coupled with VPPs. EU-27 also has some globally leading players in distributed energy resource management systems, but they face strong competitions from major operational technology vendors headquartered outside of EU-27.
- In **HVDC** the EU-27 companies have a strong position in most value chain segments. Specifically, large market shares estimated for the segments HVDC cables and for ultra-high voltage direct current applications, for the latter the EU-27 companies are even the sole suppliers globally.
- For **Ocean** technologies European actors are globally leading with the most advanced testing centres.

Wind Offshore, Onshore and Solar PV represent direct and indirect **employment** of ~110-150k each in the EU-27. The other technologies relate to lower employment numbers, largest being energy management with 12k and Ocean with 8k.

Similarly, the private **Research & Innovation investments** by far outpace the public R&I investments into the traditional and most established RE markets, especially large investments for Solar PV represent the cost competitiveness versus other generation technologies and its maturity. The remaining technologies receive rather similar amounts of private and public investments.

Start-up funding and activity for the seven technologies reflects the barriers to new entrants present in each market. Digital technologies represent a large share of start-up activity relative to their market size. The ease at which software-based digital solutions can be developed and launched will likely translate into future market growth. Capital-intensive technologies like HVDC, wind offshore, onshore, and Ocean involve larger barriers to entry to start-ups, hence we also see less start-up activity in these sectors. The larger activity in the Solar PV market reflects the relative maturity of the market and the ability for new companies to innovate in monitoring, deployment, and financing.

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1 Introduction

As indicated in the recovery plan proposal[1], the European Green Deal is Europe’s growth strategy and recovery actions are to drive Europe’s competitive sustainability. The Green Deal aims at transforming the EU economy in a “modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use”[2]. Enhancing economic competitiveness through the competitiveness of clean energy technologies and solutions will be essential to successfully achieve climate neutrality[3].

Assessing the progress of the EU's clean and low carbon energy technologies[4] and solutions competitiveness requires to look at the (declining) costs of these technologies (including through research and innovation), the markets (corporate turnover, exports, strategic value chain components which are critical for the successful scaling up of clean technologies) and the employment figures. Given the recovery context, specific focus will be set on the technologies and solutions for which the deployment is expected to be accelerated based on the current policy priorities.

This study focuses on seven technologies: High voltage direct current grid technology, Solar Photovoltaics, Offshore Wind, Onshore Wind, Ocean, Energy Management, and Grid Management.

Chapter 2 lays out the methodology employed for the data gathering. Chapter 3 provides an overview of the clean energy technologies analysed. Chapter 4 to 10 introduce the individual technologies as listed above, describing the market context & outlook, value chain segmentation, positioning of EU-27 companies, competitiveness indicators as well as profiles for key players.

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0456&from=EN

[2] COM(2019) 640 final https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF

[3] Competitiveness is to be understood as the ability to compete in national and international markets. This can be achieved with cheaper products (lower costs which allow for lower prices), and/or higher quality. In addition, other product endowments positively perceived by consumers can enhance competitiveness (e.g. fair trade, environmentally or climate neutral products). (DG ECFIN summer school 2018).

[4] Clean and low carbon technologies refer to specific sectors or segments within the economy that are directly responsible for supplying technologies, products, and services that have measurable environmental benefits in terms of their abilities to reduce GHG emissions and to improve both energy and resource efficiency (retrieved from https://op.europa.eu/en/publication-detail/-/publication/64e07ba8-4cf5-4ed1-990e-8fc83b356214/language-en).

2 Methodology

This chapter describes the methodology applied for all major quantifications in this report. In the table below, we provide an overview of key items, the approach we took (and we highlight if it differed by technology), and the major sources.

Item	Approach	Major sources
Market size	• Guidehouse Insight's market size forecast is based on the subject matter expert's estimation of each technology with respect to the stage of development of the industry in EU-27 and the rest of the world (RoW), and the economics of technology installations. The supply-side accounting method used to monitor past, present, and future installations on a regional or technology level • Estimates of the outcome beyond 2025 are based on an interpretation of the geopolitical picture in relation to climate change and energy security issues, as well as commitments to renewables.	• GH Insights expertise
Market outlook	• Projections are general guidelines given the many uncertainties associated policy frameworks and other factors likely to change significantly over the next decade as existing markets mature, and new markets emerge. • The outlook is indicative of the current regulatory environment, taking into consideration future projects and the progression the market has had	• GH Insights expertise
Market share	• Market share calculations are based on revenue estimates of selected key players in the market. Each company was examined for their presence across the value chain and market share was estimated for EU-27 companies vis a vis their global competitors.	
New entrants	• Companies were identified through a keyword search of privately held companies that have received equity or debt financing from outside private sources in 2019. • Each company was examined to determine which technology markets and which value chain segments the company operated in, based on the framework used throughout the project. • For companies where funding amount was withheld, estimates were made based on information from similar companies within the technology market or value chain segment.	• CBInsights • Crunchbase

Employment	• For Wind and Solar, the values were obtained directly from IRENA. • For Ocean, Europe's blue economy was used. • For digital technologies, a multiplying factor was obtained from academic literature, and was multiplied by the estimated market sizes to obtain an employment estimate • For HVDC the number of employees was based on the number of HVDC projects in Europe and the rest of the World.	• IRENA • Annual report on Europe's blue economy • T&D World • National Renewable Energy Laboratory
Trade	• Aggregated EU-27 import and export data were gathered based on HS codes identified within each technology section	• UN COMTRADE
R&D investment	• For Solar, Wind and Ocean, the values were obtained from the Euroobserver/JRC report and from IRENA for the rest of the world. For Ocean the European investments were obtained from the blue economy report. • For digital technologies and HVDC, the values were obtained from the ETIP SNET annual report, and segmentation of the value chain was based on the roadmap. • In case the values available in sources were not segmented into value chain steps, the segmentation of investment was based on the segmentation of the patenting data across the value chain.	• IRENA • Annual report on Europe's blue economy • IEA • ETIP SNET • Euro-observer/ JRC
Patents	• Google patents has a database of patents published in each patent office around the world. Key words from each technology were used and divided into the value chain segments.	• Google patents (2020) • IRENA (2013) •
Publications and research institutions	• Figures provided are based on an analysis of publications listed in a bibliographic database (Microsoft Academic). Publications have been matched to their respective research fields based on keywords. The number of research institutions active in a certain research field is calculated based on this list of relevant publications based on the publications' authors' affiliations.	• Navigant (2020) based on data from MS Academic
Gross Value Added	• GVA figures are estimated based on the market sizes for the individual technologies and their value chain segments. In addition, trade balances for the respective technology are considered as well as estimates for the (raw) material input of the value chain. • EU trade balances on sector level (e.g. an import surplus for the whole PV sector) are disaggregated to value chain segment level, proportionally to the market size of each value chain segment. Then, market sizes of each segment are corrected according to the segment's import or export surplus.	• GH Insights data • Fraunhofer ISI (2009)

	• The value added of the material input for a certain value chain is based on literature values. The market sizes for each segment are decreased according to the estimated share of material input for the segment.	
Company revenue & profitability	• Revenue was determined based on relevant company business units or estimated based on market share. • Profitability is defined as earnings before interest, taxes, depreciation, and amortization (EBITDA). Where identified, overall company EBITDA margin or overall segment EBITDA margin was applied to revenue. • Due to limited commercial activity for Ocean technology, revenue and profitability are not available for most companies profiled.	• CapitalIQ • D&B Hoover's • Company Investor reports

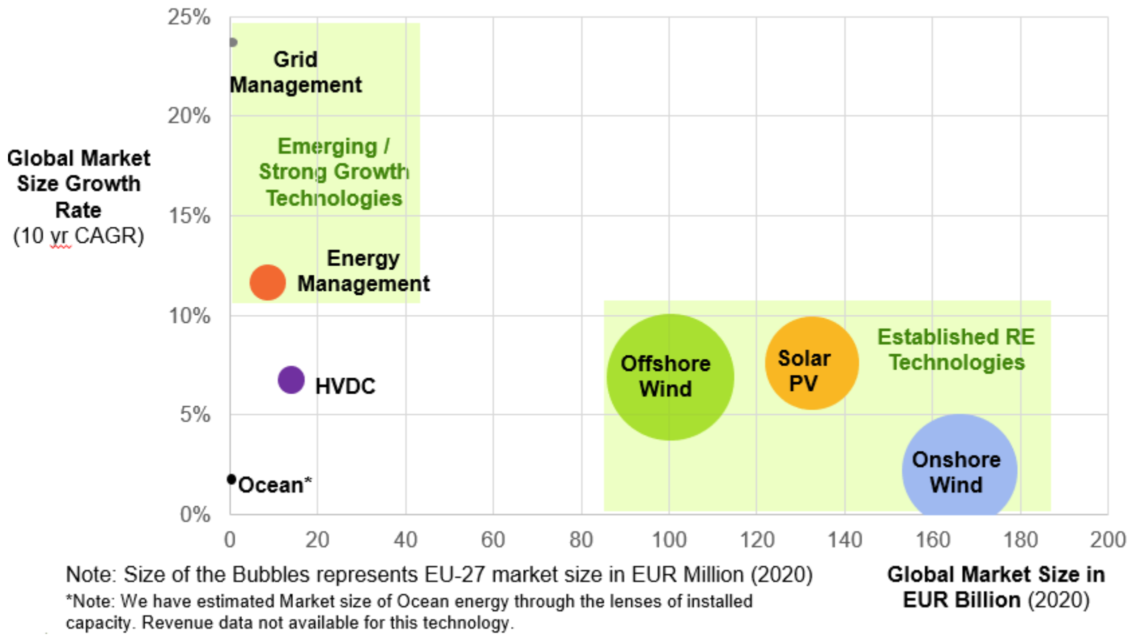
3 Overview of selected clean energy technologies and EU competitiveness

We consider four groups of technologies in this report that rank differently on market size and market growth estimates:

- Traditional and (largely) mature renewable energy technologies like Solar PV, Onshore Wind and Offshore Wind are more hardware driven and show substantially larger market sizes, but limited growth rates below 10%.
- Emerging digital technologies show larger growth rates (esp. grid management) but small market sizes
- High-voltage direct current (HVDC) technology is assessed as small and low-growth market due to the scope focusing on hardware components
- Ocean technologies are least mature for which no proper market has developed so far

The EU-27 has a strong relative share of the offshore wind energy (at ~33% of global) and grid management (~35% of global) market today.

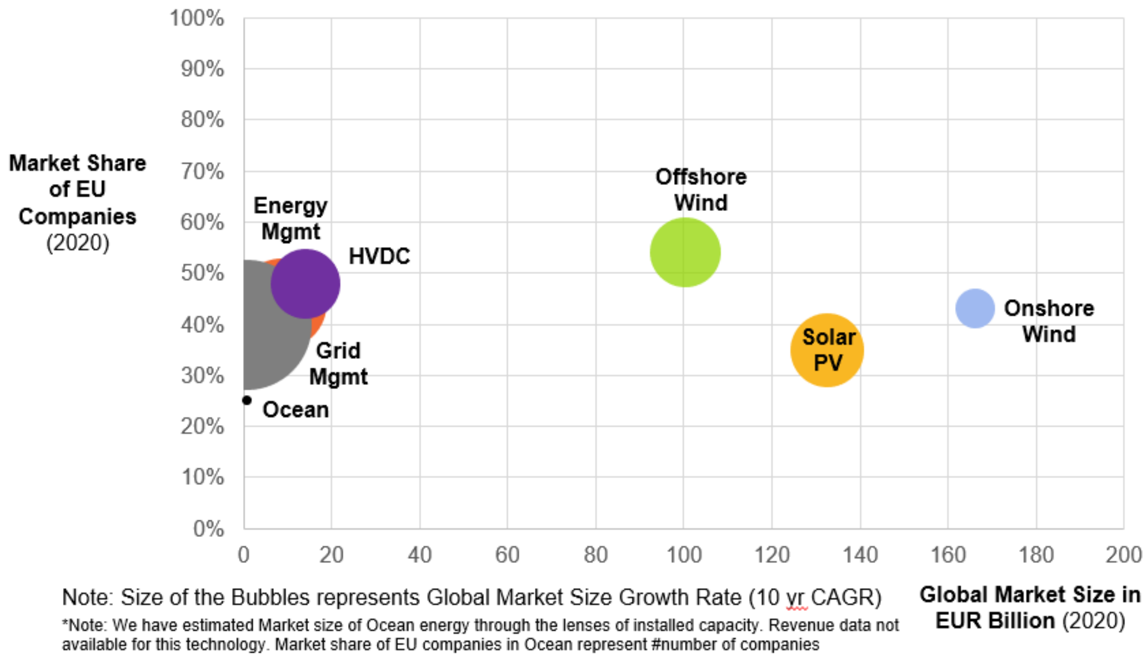
Figure 1: Market size and growth rates for selected clean energy technologies



Source: Guidehouse Insights (2020)

EU-27 companies have the strongest market share with ~54% in Offshore Wind which offers substantial market size, globally and in the EU-27. In the other rather mature RE technologies, EU-27 companies have lower shares, ~43% in Onshore Wind and in Solar PV with 34%. For the digital technologies and for HVDC the EU-27 companies footprint lies between ~40-48%. In Ocean the market share, represented here by number of companies is lowest in the set considered. More detailed analyses of competitiveness in specific steps of the value chain are included in the chapters by technology.

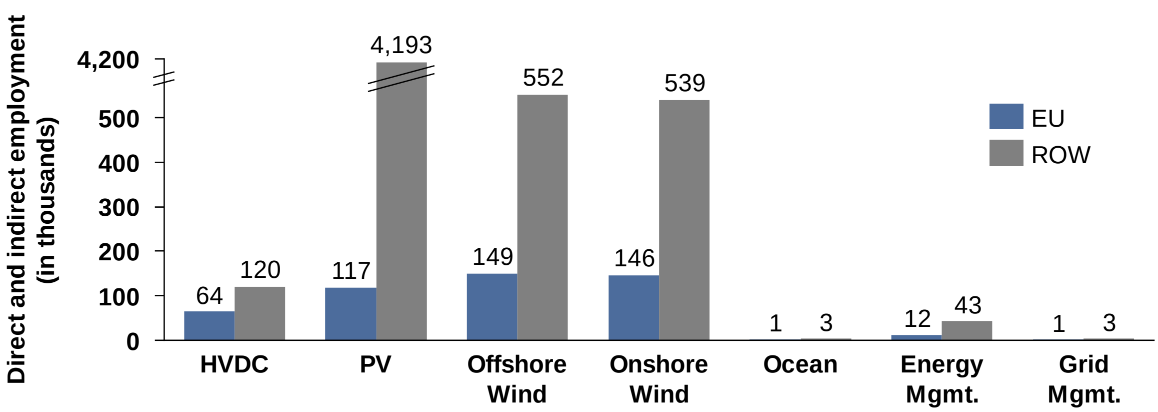
Figure 2: Market share of EU-27 companies in clean energy technology markets today



Source: Guidehouse Insights (2020)

Direct and indirect employment in these clean energy technology sectors, in general, resembles the market sizes for the different sectors. Solar PV by far accounts for the largest share (~73%) in the total number of 6 million jobs throughout all seven sectors, followed by Offshore (~12%) and Onshore Wind (~11%) with each about 700.000 employees. A smaller share in global employment (3%) is observed in the HVDC sector. Considering the EU's share in each sectors' employment figures, however, we find the highest share in the HVDC sector with about 35%. The not-yet-mature markets also show a strong employment footprint in the EU with 30% for Ocean, 26% for Grid Management and 22% for Energy Management. Within the Offshore and Onshore Wind sector about 21% of the jobs are located in the EU. A strong difference between European market share and share in employment exists in Solar PV, where only 3% of Solar PV sector's jobs are located within Europe.

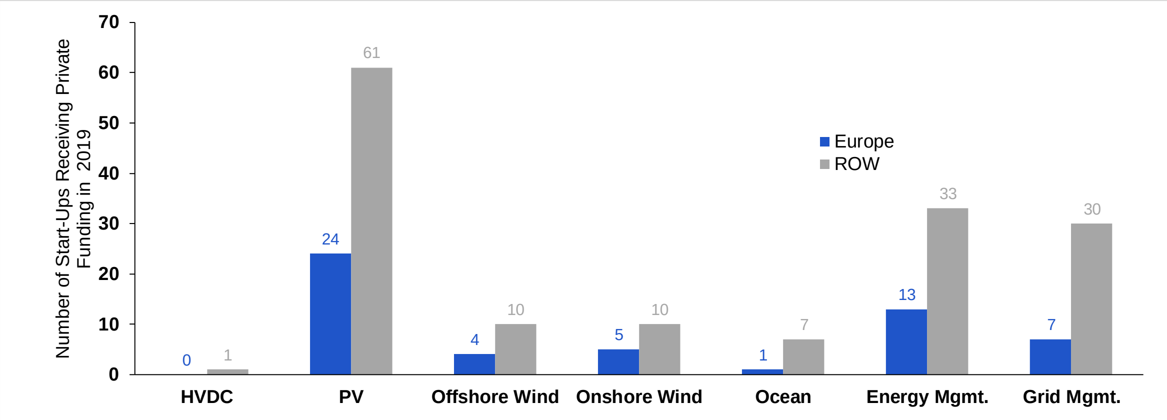
Figure 3: Direct and indirect employment in clean energy technology sectors



Source: Guidehouse (2020)

Start-up funding in these sectors reflects the barriers to new entrants present in each market. As can be seen in Figure 4, digital technologies (energy management and grid management) represent a large share of start-up activity relative to their market size. The ease at which software-based digital solutions can be developed and launched will likely translate into future market growth. Capital-intensive technology segments (HVDC, offshore wind, onshore wind, and ocean) represent markets where it is difficult for new companies to establish themselves. The activity in the photovoltaic market reflects the relative maturity of the market and the ability for new companies to innovate in monitoring, deployment, and financing.

Figure 4: Start-ups receiving funding in 2019 in clean energy technology sectors



Source: CBInsights, Crunchbase

The following chapters offer more detailed analyses on the markets and competitiveness in the selected clean energy technologies.

4 HVDC Grid

4.1 Summary

Scope	• High voltage direct current (HVDC) transmission technology provides low loss solutions for the integration of renewables and global grid expansion, especially for long distances or subsea cables. As HVDC technology advances, HVDC overhead lines and cables are well-positioned to become one of the most significant components of the future of Europe's and the global electric grid. • The primary components of HVDC systems are converter stations and conductors. Converter stations are specialized substations located primarily at the terminal ends of HVDC transmission lines. There are also several multi-terminal HVDC networks that have been deployed with more than two converters, enabling flexibility in network design and geographic footprint. Ultra-high voltage DC (UHVDC) is an additional market segment that is growing rapidly in Asia, but there are no active or planned deployments in Europe yet.

Market	• Guidehouse Insights expects the European market for HVDC systems to grow from €1.54 billion in 2020 to €2.74 billion in 2030, at a CAGR of 6.1% over the forecast period5.
Competitiveness of EU-27 companies	• The global market is led primarily by three companies, Hitachi ABB Power Grids, Siemens, and GE[6]. In China, an additional vendor, China XD Group, dominates the market. • The size of the European market relative to the global market represents the market activity within EU-27 and does not reflect the dominance of the EU-27-based companies Siemens and Hitachi ABB Power Grids. • Two EU-27 companies, Siemens and Hitachi ABB Power Grids (co-HQ'd in Sweden) lead this space by a wide margin over all competitors outside of China. Each commands a dominant market share of HVDC technologies, and they have collaborated to offer the only UHVDC offering in the world. • Prysmian and Nexans are two of the world's largest cable providers, with headquarters in Italy and France, respectively.

4.2 Introduction

Like much of the global electricity grid, many of the high voltage transmission systems in service today rely on the same technologies that existed at their conception over 100 years ago. However, in the last 20 years transmission technologies have benefited from significant innovation, leading to enhancements in transmission efficiency over long distances, reduction in system costs, and increased grid stability and reliability. Advances were first spurred by the deregulation and privatization of wholesale power markets and then further accelerated by the following factors:

- Growth in electricity demand and its concomitant effect on transmission system stability
- Continued electrification in developing countries
- System integration of renewable generation distant from population centres
- Strengthened continental-scale interconnected networks to help even out fluctuations of renewable energy generation and distribute temporary regional surpluses and deficits over a wider area at higher value, and for market benefits
- Need to increase capacity and reduce line losses to offset the diminishing capacity in existing systems
- Increased desire for international supergrid interconnections
- Expanded need for underground and underwater transmission cable networks

Significant capital investments are being made to build new and often large capacity transmission networks. Funds are also being directed toward R&D in transmission components and control technologies. Many of the new large-scale transmission projects planned or under construction are high voltage direct current (HVDC) systems. The remainder consists of high voltage alternating current (HVAC) systems.

[5] Guidehouse Insights (2020) Advanced Transmission & Distribution Technologies Overview. Retrieved at https://guidehouseinsights.com/reports/advanced-transmission-and-distribution-technologies-overview

[6] Guidehouse Insights (2020) *Advanced Transmission & Distribution Technologies Oviervew.* Retrieved at https://guidehouseinsights.com/reports/advanced-transmission-and-distribution-technologies-overview

In the past, the choice between HVDC and HVAC mainly came down to the required distance for the transmission system. HVAC was more suitable for a shorter length transmission and highly meshed grids, because at higher distances voltage and stability problems become harder to manage. HVDC was more suitable for long-distance point-to-point bulk power transmission, because of its low losses and of the relatively high costs of the converter stations at both ends. New developments in HVDC conversion and conductor technologies have shifted this dynamic, and HVDC systems are now being considered for shorter, multi-terminal applications. Additionally, HVDC, and specifically Ultra-High Voltage DC (UHVDC) is often the only practical option for high voltage power transmission over very long distances (although voltages in UHVAC have also increased recently). UHVDC projects underway such as the Changji-Guquan link in China, commissioned by the State Grid Corporation of China (SGGG) are up to 3,000 km long, with voltages up to 1,100 kV and capacities up to 12 GW[7].

Although the first few true commercial electricity delivery systems used DC, AC quickly overtook DC as the technology for all transmission and distribution (T&D) of electricity. DC use only re-emerged in the early 1950s with the construction of Gotland 1[8], the world’s first commercial HVDC link, built in 1954. Gotland 1 was an undersea cable connection between the island of Gotland and the Swedish mainland. It was rated at 100 kV and 20 MW and used technology developed at ASEA, which eventually became ABB. Gotland 1 was followed by a number of other HVDC links, primarily for specialized applications such as underwater cables. In the last decade, technological enhancements have led to increases in capacity and voltage of HVDC converters - the facilities that convert AC to DC or DC to AC - and have fuelled significant growth in HVDC projects of many voltages and capacities across the globe, especially for the more versatile and flexible VSC systems.

Thus, while HVAC systems are still the leading transmission technology, the market for HVDC and especially VSC is accelerating in Europe, with benefits that include the ability to transmit bulk power underground and underwater with lower line losses than AC systems. The primary drawback to HVDC systems is the high capital cost of converting AC power to DC power for transmission, and then converting back to AC power for distribution to consumer loads.

The two key market segments for HVDC networks are renewables integration and grid interconnections, and supergrids. Each segment is driven by the advantages HVDC holds over HVAC for long-distance, low loss transmission underwater, underground, and overhead. There are several types of HVDC systems, including back-to-back converter stations (which enable interconnection of asynchronous AC grids) and point-to-point systems (which transmit power between two-terminal DC converter stations over distances that may range from less than 600 km (372 miles) to well over 2,000 km (1,242 miles)[9]. Point-to-point systems are often used for bulk power transmission, including transmission of wind power from remote generation sites to distant load centers. Point-to-point HVDC transmission is also used in underground and submarine applications. The newest type of HVDC systems are actual HVDC networks or meshed grids, going beyond multi-terminal point-to-point systems. Because an HVDC grid

[7] See e.g. CIGRE Technical Brochure 775, Global electricity network feasibility study, Sep. 2019

[8] ABB (2020) *ABB High Voltage Direct Current, Applications of a Well-Proven System.* Retrieved at https://new.abb.com/docs/librariesprovider78/eventos/jornadas-tecnicas-chile-2019/pgtr-y-pggi/maxwell-pinto-abb-hvdc-chile.pdf?sfvrsn=fdbc9715_2

[9] ABB (2020) *HVDC Classic Thyristor Valve Projects*. Retrieved at https://search.abb.com/library/Download.aspx?DocumentID=POW0013&LanguageCode=en&DocumentPartId=&Action=Launch

requires HVDC breakers to isolate just an individual link rather than the entire HVDC grid in case of an outage, and because HVDC breakers are a relatively newly commercialized technology, there are so far few examples of meshed HVDC grids[10].

Figure 5: Introduction on HVDC Value Chain

	Transformers	Converters	HVDC Breakers	DC Cables	UHVDC	Power Electronics/ Valves
Key activities	Power Transformer	Power Conversion	Power flow Interruption	Long-distance, low-loess power delivery	High-voltage, high-capacity power delivery over long distances	AC/DC Conversion
Market Size (M€)	Global 1.671; EU 152	Global 4.510; EU 306	Global 1.177; EU 137	Global 4.690; EU 662	Global 6.521; EU 0	Global 1.982; EU 179
Market Growth Outlook	Global: EU: • Increasing in voltage and capacity	Global: EU: • Increasing in voltage and capacity • Decreasing in geographic footprint	Global: EU: • Increasing in interruption response speed	Global: EU: • Increasing in capacity and voltage • Decreasing in cost	Global: EU: N/A • Increasing voltage, capacity, and distance • No application for UHVDC in the EU	Global: EU: • Increasing in conversion speed, reliability • Decreasing in cost
Key players EU	• Hitachi-ABB • Siemens	• Hitachi-ABB • Siemens	• Hitachi-ABB • Siemens	• Nexans • NKT Cables • Prysmian	• Hitachi-ABB • Siemens	• Hitachi-ABB • Siemens
Key players Rest of the World	• GE • Mitsubishi • Toshiba • NR Electric • China XD Group	• GE • Mitsubishi • Toshiba • NR Electric • China XD Group	• GE • Mitsubishi • Toshiba • NR Electric • China XD Group	• AMSC • Furukawa Electric • Fujikura • STI	• China XD	• GE • Mitsubishi • Toshiba • NR Electric • China XD Group
Critical materials	• Steel • Aluminum • Metal Alloys	• Steel • Aluminum • Metal Alloys	• Steel • Aluminum • Metal Alloys	• Copper • Bismuth • Titanium • Strontium	• Steel • Aluminum • Metal Alloys	• Silicon and/or conductive material for valves

Legend: (10 year CAGR) >15% >10% >5% >0%

Source: Guidehouse Insights (2020)

4.3 Industry Value Chain Analysis

The primary components of HVDC systems are converter stations and conductors. Converter stations are specialized substations located primarily at the terminal ends of HVDC transmission lines. There are also several multi-terminal HVDC networks that have been deployed with more than two converters, enabling flexibility in network design and geographic footprint. Ultra-high voltage DC (UHVDC) is an additional market segment that is growing rapidly in Asia, but there are no active or planned deployments in Europe yet. Because of the widespread scepticism of European populations towards any new overhead lines, and because UHVDC towers could be even higher than 400 kV AC towers, UHVDC is currently not considered to be a relevant technology segment in Europe. This may be considered a missed opportunity, as much of the commercialization of the European UHVDC technology developed by ABB and Siemens is being done first and best by China and expanding to other non-European regions.

4.3.1 Value Chain Segmentation

The value chain for HVDC grids can be segmented along the different hardware components needed to realize an HVDC line or an HVDC meshed grid. Major converter station components include the transformers, converters, breakers, and power electronics used to convert power from AC to DC and back again. Line-commutated

[10] See e.g. the various deliverables of the PROMOTioN R&D project funded by the EU under Horizon2020: https://www.promotion-offshore.net/results/deliverables/

converters (LCCs), also known as current source converters (CSCs), and voltage-source converters (VSCs) are the primary commercial HVDC converter technologies. Both LCC and VSC stations are more complex than HVAC substations, which drives up their cost[11]. Despite the integration of common technologies, HVDC transformers and converter stations are not standardized and designs and costs are highly dependent on local project specifications. Due to the technological complexity, installation of HVDC systems is generally managed by manufacturers, whereas turnkey HVAC systems are often delivered by engineering, procurement, and construction firms.

Additionally, developments in DC breakers, namely the design and implementation of hybrid breakers has provided a boost to the advantages that HVDC brings over HVAC transmission systems. In 2012, ABB announced the successful development of a hybrid DC breaker capable of interrupting power flows equivalent to a large power station within 5 milliseconds with negligible conduction losses[12]. The key design characteristic of a hybrid breaker is the combination of mechanical actuators with semiconductor IGBT valves. The hybrid breaker allows an HVDC system to maintain power flow throughout a fault scenario, strengthening HVDC's case for increased international deployment.

UHVDC, or Ultra-High Voltage DC power, is classified as an HVDC system at ratings of 800kV or higher. There are no known or planned HVDC projects in Europe. The majority of these projects are in China and other regions across Asia, and leading vendors in the UHVDC space are Siemens, ABB, and China XD Group. This represents a potentially missed opportunity in the space, as the majority of the research and development funding for UVHVDC is being co-developed by Hitachi ABB Power Grids and Siemens, both European companies. UHVDC systems are nearly always going to be overhead lines, which are increasingly difficult to approve and construct throughout Europe. Notably, the UHVDC market segment is not listed in the value chain segmentation in the remainder of this chapter, since major UHVDC components include transformers, breakers, and others, and these segments are included within their respective component specific value chain segments.

The primary value proposition of HVDC transmission systems is the ability to transmit bulk power over long distances with lower losses, reduced equipment costs, and narrower right-of-way requirements. The transmission line cost per unit of transmission capacity is generally lower for HVDC systems than for HVAC systems, especially at higher voltage, capacity, and distance. Additionally, overhead HVDC transmission systems of all voltages typically use smaller towers than HVAC systems,, reducing land requirements, easing permitting and construction challenges, reducing installation costs, and limiting environmental impacts. This is especially critical for the potential development of any overhead transmission lines in Europe.

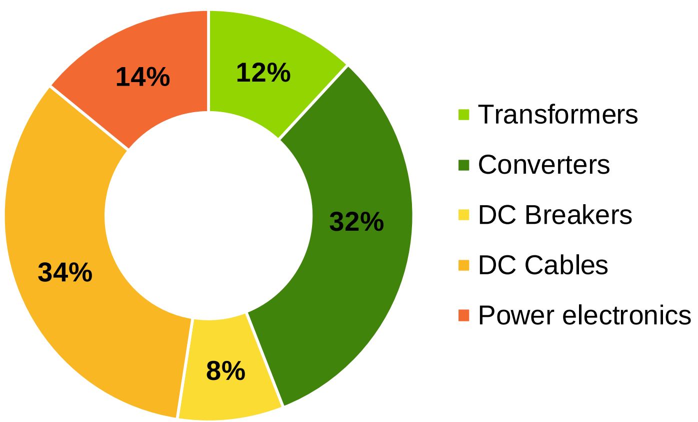
The cost-effectiveness of overhead HVDC transmission lines, however, can be partially or completely offset by the high costs of DC converter stations and cable undergrounding across Europe. As a result, overhead HVDC systems are generally considered cost-effective only for transmission distances of approximately 600 km or more. This threshold falls significantly for underground and submarine applications, where DC transmission is often the technology of choice due to reactive power losses associated with AC transmission and the cost-efficiency of DC systems. In submarine and

[11] Guidehouse Insights
[12] ABB (2012) *They Hybrid HVDC Breaker.* Retrieved at https://new.abb.com/docs/default-source/default-document-library/hybrid-hvdc-breaker---an-innovation-breakthrough-for-reliable-hvdc-gridsnov2012finmc20121210_clean.pdf

underground applications, DC systems become more cost-effective for transmission distances of approximately 50 km or more.

Across the value chain, decisions on the integration of specific components from major manufacturers are made largely by the project characteristics and the capabilities of vendors to supply the required parts at the lowest cost. HVDC projects are not cheap, and project costs can exceed EUR 1 billion[13]. The most common model for HVDC converter stations is a consolidated solution supplied by one of three major vendors: ABB, Siemens and GE.

Figure 6: Value Chain Segmentation, Global, 2020



Source: Guidehouse Insights (2020)

Across all value chains, HVDC equipment is very expensive. Critical components such as transformers, converters, breakers, power electronics, and cables are required for each project, and the relative costs of each will be highly variable based on project parameters, characteristics, size, voltage, capacity, location and others. However, across historical projects and looking forward to future ones, the market share shown in Figure 6represents each segment's proportion of the overall value chain. In Europe, the market share for cables is higher than in many other areas of the world, where overhead lines are the primary transmission architecture deployed for HVDC systems.

4.3.2 Deep-dive on Converter Technologies

Two primary HVDC converter technologies are commercially applied today, line-commutated converters (LCCs), also known as current source converters (CSCs), and voltage-source converters (VSCs).

VSC technology significant expands the capabilities of line-commutated converters (LCC) HVDC and magnifies many of the advantages already held by HVDC over HVAC. These advantages include reactive power, black-start capability, and a smaller converter and conductor footprint. These characteristics have driven the market since its introduction, and voltages and capacities have risen over time. For the first decade, VSC systems were capable of handling capacities up to about 350 MW at voltages up to 200

[13] EIA.gov (2018) *Assessing HVDC Transmission for Impacts of Non-Dispatchable Generation.* Retrieved from https://www.eia.gov/analysis/studies/electricity/hvdctransmission/pdf/transmission.pdf

kV. Additional advances in IGBTs, VSC conductors, and other station components have driven up the maximum VSC system specs, and ABB announced in mid-2019 that its new VSC systems could handle loads up to 3,000 MW over distances up to 2,000 km at voltages up to 640kV.[14]

VSC technology utilizes power transistors and is a less mature technology than LCC. Advantages of VSC include its relatively small footprint compared to LCC and its ability to provide reactive power control functions. This makes it particularly well-suited to integrating renewables. LCC technology, by contrast, requires a separate reactive power system. VSC converter systems are commonly used for offshore wind transmission and are also advantageous for lower voltage and capacity systems. VSCs will also more commonly apply as large-scale solar and energy storage systems proliferate.

VSC technology is in a state of continuing development with the objective of increasing capacity. It offers a number of advantages over LCC technology, which are outlined below:

- Independent power transfer and power quality control
- Low power operation
- Power reversal
- Low environmental impact due to small converter, tower footprint, and indoor converter design
- Predictable power transfer and voltage control
- Reduced losses in connected AC systems
- Increased transfer capacity and voltage utilization
- Blackstart capabilities and fast power restoration
- Magnetic fields allow for small conductor installation footprint

The advantages above position VSC technology well for the following applications:

- Wind, solar, and remote hydro renewables integration
- Transmission grid stabilization, necessary due to intermittent generation
- Energy sharing and trading by interconnecting energy markets
- Overcoming right-of-way limitations for land and sea cable networks
- Converting existing AC networks to DC
- Connecting offshore platforms to onshore generation, eliminating the need for onsite combustion generation, enhancing safety

The reduced complexity and smaller installation footprint make VSC stations the technology of choice for offshore wind farm connections, such as many of those in Europe, as the smaller-scale and lower weight converters are better suited for offshore platforms. Since an IGBT-based VSC is self-commutated, the converters can feed into an un-energized AC network. Therefore, VSC is now an established solution for shore-to-platform (oil & gas) applications. Further benefits of VSC system topology and in particular, the newer modular multilevel converter technologies are highlighted below:

- A highly modular construction both in the power section and in control and protection gives the system excellent scalability and the overall design can be engineered in a flexible way. Thus, the converter station can be adapted to the

[14] ABB. *HVDC Light (VSC)* Retrieved at https://www.hitachiabb-powergrids.com/offering/product-and-system/hvdc/hvdc-light

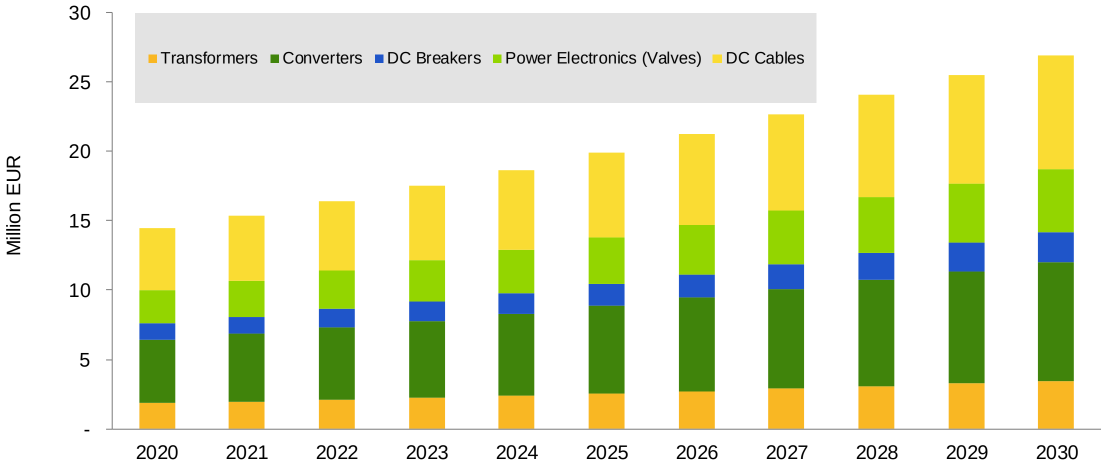
local requirements, and depending on those requirements, the design can favour either a converter hall with a small footprint or a building with a low profile.

- In normal operation, no more than one level per converter arm switches at any given time. As a result, the AC voltages can be adjusted in fine increments and a DC voltage with very little ripple can be achieved, which minimizes the level of generated harmonics and, in most cases, eliminates the need for AC filters. The small voltage steps that do occur cause very little radiant or conducted high frequency interference.
- The low switching frequency of the individual semiconductors results in low switching losses. Total system losses are therefore relatively low for MMC technology, and the efficiency is consequently higher in comparison with existing two- and three-level solutions.
- Solutions use industrially proven standard components, such as IGBT modules, which are robust and highly reliable. These components have proven their reliability and performance under severe environmental and operating conditions in other applications, such as EVs, appliance motor drives, solar inverters, and high frequency welders. This wide range of applications results in long-term availability and continuing development of these standard components.
- The achievable power range and the achievable DC voltage of the converter is determined essentially only by the performance of the controls, i.e., the number of power modules that can be operated. With the current design, transmission capacities of 2,000 MW and voltages up to approximately 640 kV and above can be achieved.
- Due to the elimination of additional components such as AC filters and their switchgear, high reliability and availability can be achieved. The elimination of components and the modular design can also shorten project execution times, all the way from project development to commissioning.
- With respect to later provision of spare parts, it is easy to replace existing components with state-of-the-art ones, since the switching characteristics of each power module are determined independently of the behaviour of the other power modules. This is an important difference to the direct series-connection of semiconductors as in the two-level technology where nearly identical switching characteristics of the individual semiconductors are mandatory.
- Internal and external faults, such as short circuits between the two DC poles of the transmission line, are reliably managed by the system, due to the robust design and the fast response of the protection functions.

The latest HVDC systems also boast a variety of technological advantages that provide greater flexibility for the installer and operator of the system. MMCs can be connected to smaller and weaker AC grids, the systems can operate on little or no transmission power, and the voltage and phase can be adjusted minutely and nearly instantaneously.

4.3.3 Market Size Analysis

Figure 7: Total Annual Market Size, EU-27: 2020-2030

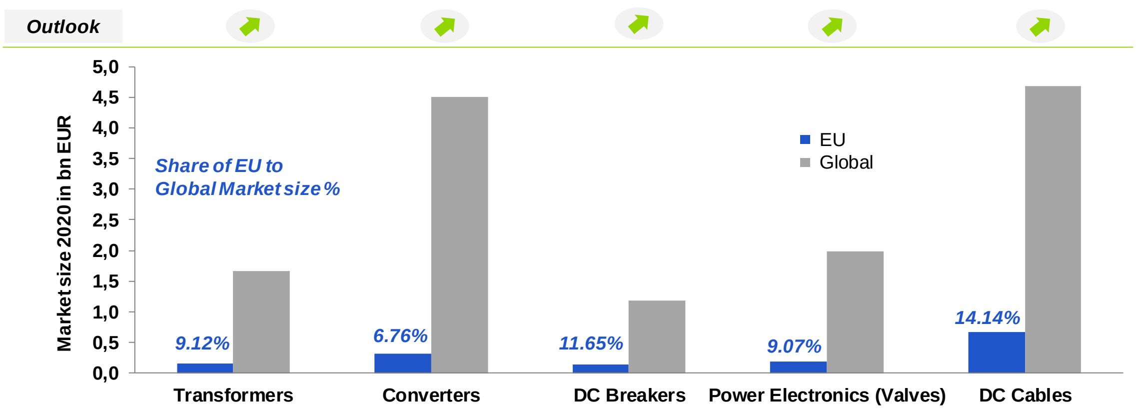


Source: Guidehouse Insights (2020)

Throughout the forecast period, Guidehouse Insights expects a compound annual growth rate of 6.08% annually in Europe, growing from €1.43bn in 2020 to €2.6bn in 2030. Although the market demonstrates moderate growth over the forecast period, the overall market share of European HVDC projects to global spend is heavily skewed by the immense spending in the Asia Pacific region. For context, Guidehouse Insights expects the APAC region to spend more than €11bn on HVDC in 2020, which is nearly 8 times the anticipated EU spent on the same market segment in the same year.

4.3.4 Share of the EU Market

Figure 8: Share of EU-27 Market Size to Global Market, Value Chain Segment: 2020



Source: Guidehouse Insights (2020)

The figure above represents Europe's overall market share of the deployment for HVDC technologies. Despite Europe having a higher overall market activity than many other regions, the pure scope and scale of the Asia Pacific region, and China in particular, dwarfs the European market, leaving it with small market shares of each technology type in general. Europe's overall market share of VSC technologies would be is much higher comparatively.

Europe is seeing more movement toward HVDC than North America, driven partly by the need to integrate renewables but also by the need to increase transmission capacity in the face of land constraints and regulatory barriers. The permitting process for new transmission projects in Europe can take well over a decade. Combined with the reality of limited land for new transmission corridors, the EU is pursuing underground DC transmission and is also exploring opportunities to convert existing HVAC infrastructure to HVDC to transmit more power over the same right-of-way while bypassing the lengthy and complex permitting process. Other factors driving growth in the European HVDC market include the need to integrate new offshore wind power and plans to link the grids of North Sea countries, such as Norway and Germany, using subsea HVDC interconnectors. Currently, the global market for offshore wind transmission using HVDC technology is concentrated heavily in Europe, where Germany has pioneered offshore HVDC and is pursuing an ambitious program to increase offshore wind capacity located far from the coast. To transport remote offshore wind efficiently, multiple farms located in relatively close proximity will be connected at a central point using AC cables. The power is then converted to DC for transmission to shore via subsea HVDC cables.

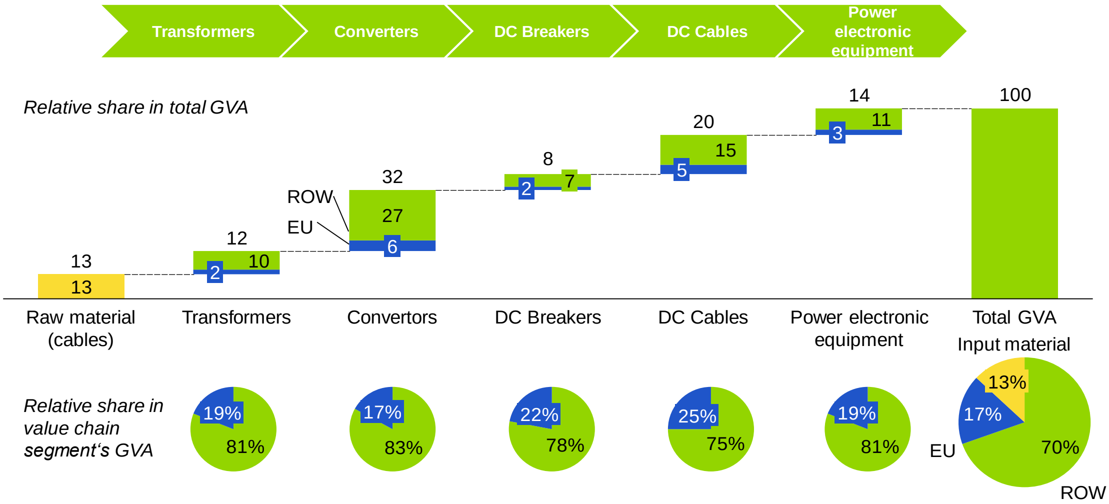
Increasing integration among Western and Eastern European power markets is also expected over the coming decades, driven by EU interconnection policies, the economic advantages of larger energy markets, and the ability to balance variable renewable resources more efficiently across wider territories. Both solar and wind potential are significant in Eastern Europe, and new generation is expected to come online, driving transmission system extensions. The largest utility-scale renewable energy markets in the Eastern European region include Turkey, Romania, and Slovakia.

Whilst the market for UHVDC is growing, there is no market for long-distance, high-voltage overhead transmission networks in the EU-27. The nature of the difficulty of installing overhead lines and the shorter distances required for transmitting power compared to parts of Asia and China makes for no applications for UHVDC inside Europe. However, companies such as ABB and Siemens are spending significant research and development time and money, as well as manufacturing dollars, to produce UHVDC equipment and send it abroad, mostly to Asia and increasingly to areas of South America.

Instead, Europe has a higher potential market for another subset of HVDC technology, voltage source converters. A newer alternative to line commutated converters, voltage-sourced converter (VSC) systems bring various advantages to Europe, are more suitable to underwater and underground lines, and are better equipped to support the integration of distributed energy resources and renewables.

4.3.5 Gross Value Added

Figure 9: Breakdown of GVA throughout HVDC value chain



Source: Guidehouse Insights (2020)

The gross value added in general resembles the market sizes for the respective value chain segment and region, adjusted for a trade surplus/deficit and the value of input material. For the HVDC sector, the considered input material is used for cable manufacturing. The largest share of the GVA is found in the converters segment, where the EU captures a share in the GVA of about 17%. Notably, the UHVDC market – which is not listed here since it is an intersection of all value chain segments – is only served by European companies. Therefore, within the UHVDC market almost all GVA can assigned to the EU, even though the European market for UHVDC is zero.

4.4 Market Outlook

With high potential and planned offshore wind generation and a yearning for stability-enhancing grid interconnections, Europe will see a HVDC revenue CAGR of 6.1% between 2020 and 2030[15]. Western Europe will drive most of this growth, as Germany and Denmark have significant offshore wind developments, and there are several major grid interconnection projects in the Nordic countries. Point-to-point HVDC transmission is also used in underground and submarine applications and is increasingly the technology of choice for the transmission of offshore wind power throughout much of Europe.

4.4.1 Drivers and Barriers

As the global transmission grid grows and evolves, the need for long distance, low loss transmission is becoming increasingly important in size and scope. HVDC holds many advantages over HVAC and lower voltage transmission technologies, and despite the cost, is often the right choice for the growing number of new transmission networks to incorporate renewables, expand and interconnect the grid, and enhance grid stability and reliability.
The global market for HVDC is largely driven by the following key market drivers:

[15] Guidehouse Insights

- **Renewables Integration:** With many of the strongest potential wind and solar generation sites located offshore or in areas far from load centres, respectively, there is a need to efficiently carry power over long distances, under water, underground, and over land to areas where it can serve large populations. HVDC allows a cost-effective solution for transmitting the power with low losses and a small right-of-way requirement. In particular, areas such as Germany and the UK have ramped up their far-offshore wind projects and will contribute significantly to the growing HVDC market over the next decade. The integration of renewables also poses significant potential for changes in voltage stability and power quality, and the load flow controllability, flexibility and reactive power functions of HVDC VSC technology will prove to be a difference-maker in handling these changes[16]. In addition to this power flexibility, an HVDC system allows a remote wind or solar generation plant to decouple from an AC grid in the case of a network fault. In this scenario, the HVDC can evacuate the excess power generated at the wind farm, causing minimal disturbances to wind turbines.

- **Transmission Network Expansion & Interconnection:** Any regional, domestic, or global grid with coordinated operations and HVDC flexibility will allow high volumes of electricity to flow across large regions, enabling more efficient use of installed capacity than exists under a fragmented grid system. This is particularly the case with the geography, topography, and geopolitical conditions that exist across Europe. More so than any other region in the word, a potential European supergrid would bring tremendous benefits to parties involved. Wider area operational coordination would create efficiency gains via the sharing of dispatchable plants and storage across wider geographies and among larger populations and by taking advantage of different peaking times in different regions due to variation in time zones and seasonal load profiles. Variation in peaking times combined with the smoothing effect of integrating renewables across a wider territory would reduce the overall capacity requirements, including reserve requirements, needed to ensure system reliability under all daily and seasonal load profiles. In addition, the ability to export excess supply in one region to areas with unmet demand would reduce the curtailment of renewable power when renewable generators shut down or are otherwise underutilized during times of electricity oversupply. With an integrated grid with long distance HVDC connections, excess supply in one region could be used to meet generation shortfalls elsewhere. HVDC networks can also act as a fuse to connect and disconnect asynchronous AC networks. HVDC is the only transmission solution for connecting AC grids and energy markets that operate at different frequencies. These networks are often called back-to-back DC ties, and usually entail two HVDC converters installed in the same location. Excess generation from one network can be traded to meet demand on another, which can postpone or even eliminate the need for additional generation to be installed on the high demand networks.

[16] Guidehouse Insights

- **Reducing Costs and Losses:** an HVDC network that enables consumers across a wide region to share resources and take advantage of optimally sited renewables would expand the size of the market, increase competition, and reduce the total installed capacity required to ensure reliable system balancing, while increasing the potential integration of renewable generation. It would also allow optimized investment in transmission and generation infrastructure and make greater use of low-cost renewable power by enabling greater penetration of renewables in the generation mix and reducing curtailment rates due to well-planned transmission and wider area integration. Today, curtailment wastes low cost power and often means carbon-emitting resources are used where zero-emitting resources could have been. If carbon taxes or emissions trading schemes are introduced in the future, the substitution of viable renewable power with fossil fuel-based power could further increase the costs of curtailment. HVDC transmission networks can be used to bring power to islands or remote load centres that might otherwise be faced with building their own generation. This saves financial and environmental resources, as an HVDC link can eliminate the need to install local generation, especially for islands and heavily populated areas surrounded by water, such as San Francisco.

Market barriers limiting the growth of HVDC networks include:

- **Regulatory Limitations:** Existing regulatory structures stand as one of the greatest obstacles to transmission network development at both the domestic and international level. On the domestic front, patchwork regulations at the subnational level can inhibit the development of long-distance transmission lines intended to transport power across multiple states or provinces. Similarly, burdensome permitting and right-of-way processes can raise the risk profile of projects, potentially deterring developers or investors that might otherwise see a strong business case for building supergrid corridors. For this reason, many proposed HVDC projects never get off the ground. However, Europe has made significant progress towards easing these regulatory limitations through the development of harmonized standards that apply not only to EU countries but also to National Grid and Swissgrid outside the EU. Additionally, ENTSO-E developed a Network Code in 2016 on HVDC connections that specifies requirements for interconnections and HVDC systems. Outside of EU connections, and specifically for potential global supergrid interconnections with North Africa, Russia and potentially even Asia the absence of harmonized codes and standards across regions and nations represents a critical impediment to the development interconnected HVDC projects. For these regions, and to realize a global supergrid, the need for clear rules governing cross-border electricity trade will also need to be addressed as a prerequisite to HVDC development as potential participants grapple with concerns surrounding the reliability of supply, obligations of exporters to importers, and the availability of mechanisms to enforce penalties for failure to comply with established rules. For regions without current HVDC codes and standards, designing the technical standards and operational rules governing a supergrid will demand significant time, effort, and political commitment.

- **Political & Geopolitical Obstacles:** Political barriers include inertia and lack of domestic policy support on the one hand and geopolitical concerns on the other. On the domestic front, competing policy priorities may constrain action or entirely forestall discussion of renewable generation installations, grid interconnection, and HVDC development. This may occur in developing countries with limited financial resources, weak existing power infrastructure, and large populations still living without access to electricity. It may apply equally in fully electrified regions like the US and Europe, where a national supergrid would require action and resource commitments on a scale unlikely to find support in the current political and economic climate. On the geopolitical side, concerns about security of supply remain a key obstacle to integration with neighbouring countries. Historically, energy security has been a matter of national concern, and many countries hesitate to rely on imported power or entrust electricity supply to their neighbours. Within the EU, there is progress in countries' governments accepting that they may need to rely on imports for their security of supply, but even there this is not fully accepted in all member states yet. Furthermore, initiatives requiring international cooperation, negotiation, and coordinated action are often hampered by delays and diplomatic gamesmanship as each party seeks to protect and promote its sovereign interests.
- **Financial Constraints:** Lack of financing commonly constrains major infrastructure projects, and HVDC projects are no exception. Attracting the investment required to implement large grid projects is influenced by underlying macroeconomic conditions at both the national and global level and by the prevailing regulatory framework and political regime. Financing transmission projects is further complicated by uncertain cost allocation and recovery mechanisms for projects that cross state or national borders. Additionally, right of ways for large transmission lines require rather significant amounts of land. Much of that land must be cleared of vegetation, cutting large swaths through forests (especially in the case of cables). The process can be extremely expensive and often amounts to a significant proportion of the entire project cost. In some protected areas routing is impossible, necessitating the rerouting or cancellation of a proposed project.
- **Public Opposition to Infrastructure Development.** Transmission towers or pylons can dominate a view, especially if it was pristine before construction, which negative impacts on ratepayers', regulators', and politicians' opinions of a proposed project. Acquiring access to that land through lease or purchase, as well as possible compensation payments, can be a major economic factor in the overall line cost, and have major impacts to citizens and land owners. There are methods for potential HVDC deployment that allow transmission operators to bypass many of the right-of-way issues, such as installing a line where an old AC line used to be in an existing but undeveloped on right of way or burying the cable under a railroad track or roadway surface. These options can be expensive but there is often less public, political or regulatory opposition.

4.4.2 Raw Material Usage

The most significant use of raw materials in the HVDC value chain segment is the metal used to make steel, aluminium, and other metal alloys for major system components. Generally, these are not considered at-risk supply chains to Europe. However, superconducting materials used to construct the high temperature superconductor (HTS) cables may differ. These materials often require chemical compounds including the following[17]:

- Copper
- Barium
- Titanium
- Sapphire
- Bismuth
- Strontium
- Magnesium
- Silver
- Calcium

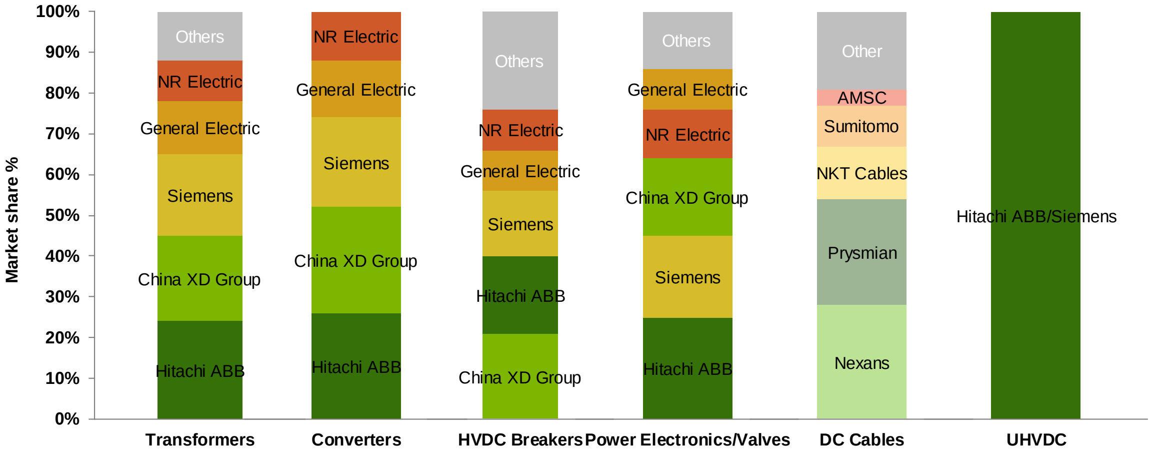
Among these, Magnesium and Bismuth are considered high-risk for supply in Europe.

4.5 Competitive Landscape

The global market for HVDC converter stations and components is dominated by Hitachi-ABB, Siemens, and GE. There are several other players that operate regionally, specifically in Asia and China, but the majority of worldwide projects are completed by one of those three major vendors. Other market players include Mitsubishi, Toshiba, China XD Group, LS Industrial Systems and NR Electric company. These companies though, do not play in the HTS cable space. Major global HTS cable providers are Nexans, STI, American Superconductor, and Furakawa Electric.

[17] European Commission: JRC Report https://rmis.jrc.ec.europa.eu/?page=crm-list-2017-09abb4

Figure 10: Top Key Market Players and Market Share, Global, 2020



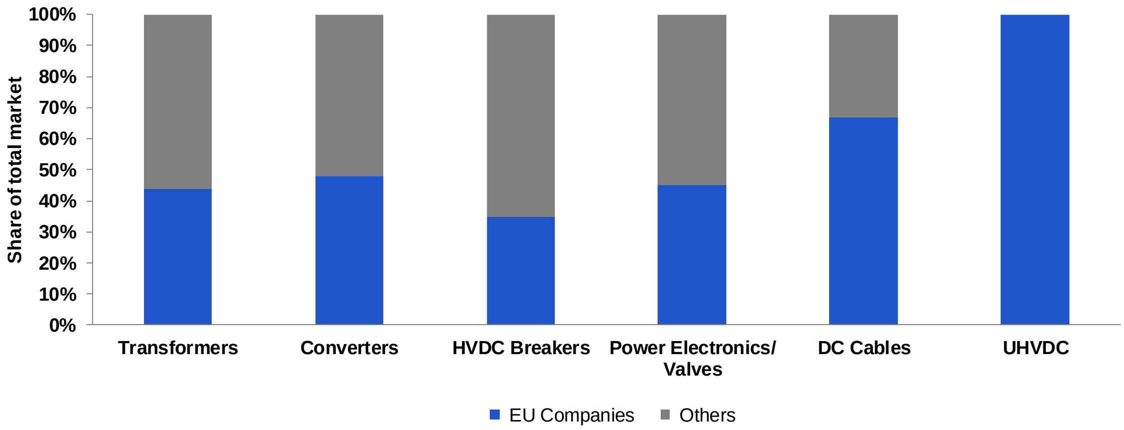
Source: Guidehouse Insights (2020)

Across the entire HVDC value chain, there are only a few major suppliers of HVDC equipment and solutions. ABB, Siemens and GE dominate the market for most HVDC projects out of China, with ABB and then Siemens commanding the highest market shares for transformers, converters, breakers, and power electronics/valves. For Chinese projects, which make up a large portion of the global HVDC market, projects are sourced mainly from China XD Group and/or NR Electric, although both companies do have their own suppliers, also from inside the country. The market for UHVDC systems is not pictured in the chart above, as there is only one market entrant, and it's a collaborative development group anchored by both ABB and Siemens. Together, the two companies developed and have since deployed the only UHVDC systems in the world. Although some UHVDC components are supplied by partner vendors and SGCC suppliers, all UHVDC systems have been designed and built by ABB and Siemens together.

4.6 Value Chain Segment Competitiveness

4.6.1 Competitive Intensity

Figure 11: Competitive Intensity across each Value Chain Segment, Global, 2020



Source: Guidehouse Insights (2020)

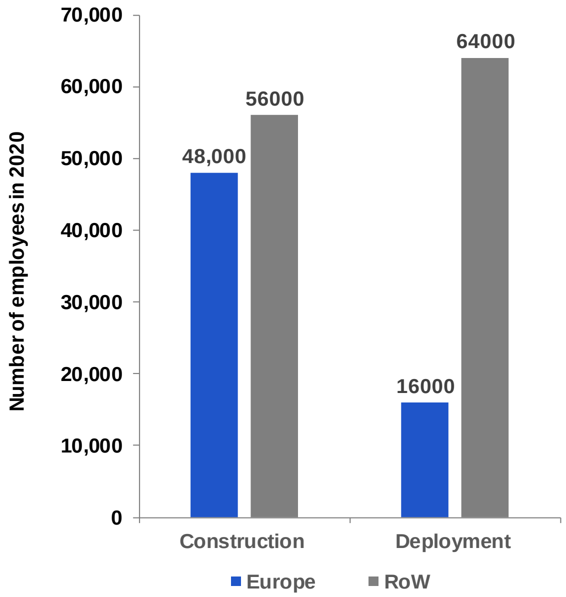
European companies have a major market presence for HVDC across all value chain segments, as two of the major market players - ABB and Siemens are located in Europe. The majority of the non-European market for transformers, converters, breakers, and vales is made up of GE and several Chinese companies, while there are several major cable companies from Japan. Additionally, Prysmian, Nexans, and NKT Cables, three major cable providers are located in Europe as well, giving the EU a strong market presence across that value chain.

4.6.2 New Entrants

HVDC systems and components require large capital investments, posing a barrier to new entrants. Additionally, the need to navigate government policy and sustain long sales cycles favours incumbent competitors with business in more established transmission technology. In combination, this creates an adverse environment which inhibits new companies from entering the market. Only one company operating throughout the HVDC value chain was identified to have received external private funding in 2019.[18]

4.6.3 Employment Indicators

Figure 12: HVDC employment indicators[19]



On the deployment and construction side, there are 200 HVDC projects around the world and of those, 40 are in the EU-27[20]. Of those, 14 are under construction around the world and 12 are under construction in the EU-27. A project under construction typically generates 4,000 jobs and a project in operation creates 400 jobs[21]. Therefore, an estimate of the employment numbers was generated as shown in Figure 12. Due to the nature of the HVDC market and how small it currently is, it is very difficult to segment these jobs into the value chain. It is also difficult to estimate the split between direct

[18] CBInsights and Crunchbase
[19] The Brattle Group (2011). Transmission jobs study.
[20] T&D world (2018).
[21] National Renewable Energy Laboratory (2013). Economic Development from New Generation. https://www.nrel.gov/docs/fy13osti/57411.pdf

and indirect jobs. On the research side, the number of employees for Europe is likely to be much larger which will be explored in the next section.

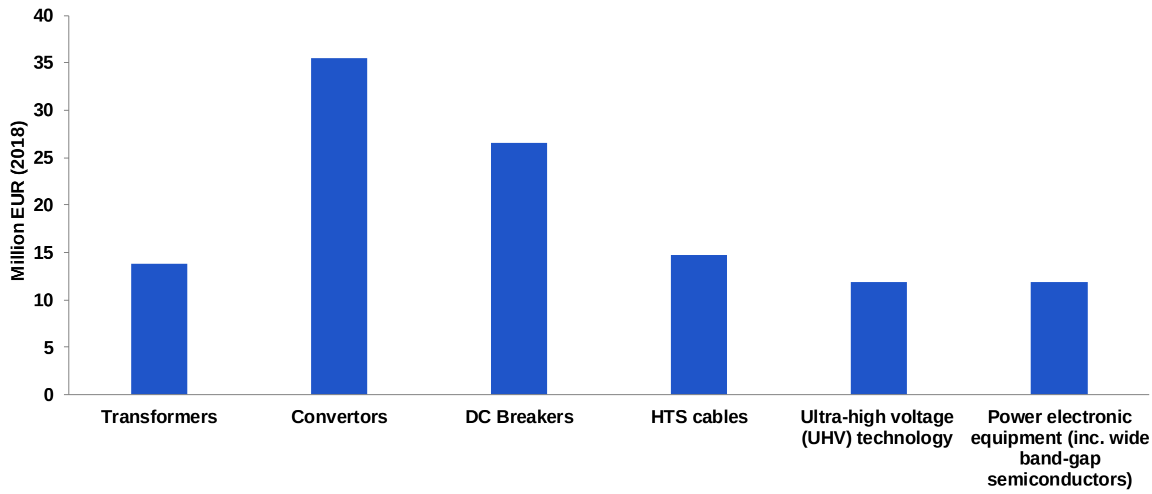
Although there have been conversations with industry experts and market leaders in HVDC manufacturing such as ABB, the employment figures for manufacturing are still very unclear for both the EU-27 and the rest of the world.

4.6.4 Trade (EX, IM)

The EU-27 is a net exporter of transformers, converters, and breakers (HS Codes 850421, 850422, 850440, and 853529).[22] Though this is not specific to the HVDC equipment encompassed for HVDC applications is captured in these statistics. Most major companies in the HVDC market are located in Europe.

4.6.5 R&I activities

Figure 13: HVDC R&I investments by value chain[23] [24] [25]

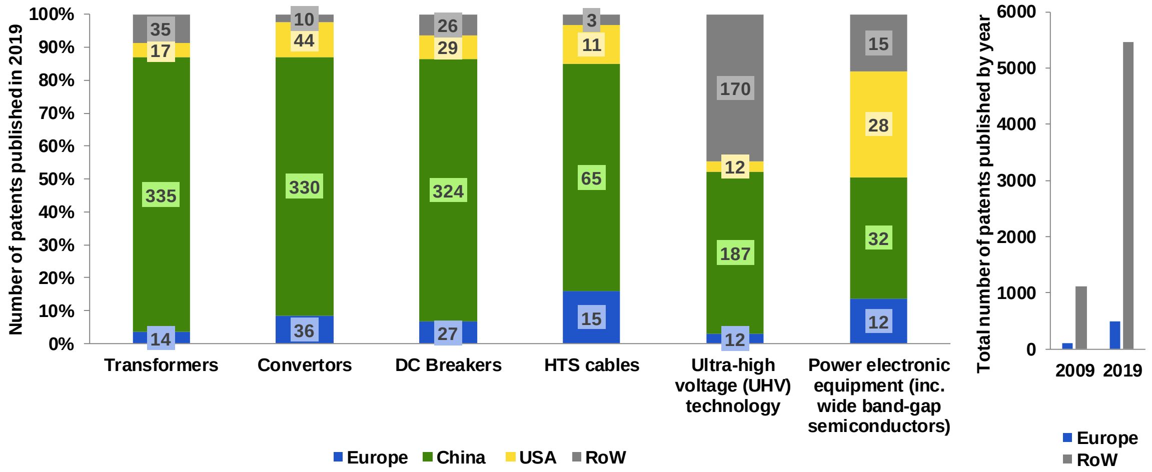


According to the ICF[26], a lot of the current available research on the HVDC topic originates from Europe, where many HVDC projects are being proposed for renewables integration. The sources used in their study are mostly peer-review journals, research reports, industry newsletters, or case studies published by industry vendors, research labs, and other reputed transmission industry stakeholders. Therefore, the research investments were only available from Europe. The Investments for Europe were

[22] Guidehouse analysis of UN COMTRADE
[23] ETIP SNET (2020). R&I Roadmap 2020-2030
[24] IEA (2019). World energy investment https://www.iea.org/reports/world-energy-investment-2019
[25] ETIP SNET (2018), Presentation of recent and ongoing R&I projects in the scope of the ETIP SNET. https://www.etip-snet.eu/wp-content/uploads/2018/11/Project_monitoring_Part1-Final-1-1.pdf
[26] ICF (2018). Assessment of the Potential for High-Voltage Direct Current Transmission to Mitigate the Impacts of Non-Dispatchable Generation technologies. https://www.eia.gov/analysis/studies/electricity/hvdctransmission/pdf/transmission.pdf

obtained from ETIP SNET for 2018. We are going to engage with industry associations to get a more accurate estimate for the rest of the world.

Figure 14: HVDC Patents by Value Chain/HVDC patents by Region[27]



In the value chain segmentation, the USA and Europe have similar patent publications in 2019. However, China seems to be dominating the value chain in terms of the amounts of patents they have been publishing. Note that patents being published in China could belong to European companies. Overall, the trend has increased between 2009 and 2019 for both Europe and the rest of the world.

Considering research publications and institutions, the US is the dominant player with about 110 research institutions active in this field, being responsible for 200 publications. Overall, there are about 140 research institutions from Horizon2020 member states active in research on transmission infrastructure, compared to 330 in the rest of the world. These institutions' efforts resulted in about 240 (Horizon2020), respectively 670 (ROW) publications in a 5-year timeframe.[28]

4.7 Company profiles

Company & key financials	Short description	Operational footprint & geographic focus	
HITACHI ABB		*HQ*	▪ Zurich, Switzerland and
Hitachi ABB **Turnover: EUR8.1 billion** **EBITDA: EUR0.9 billion**	▪ Hitachi ABB, a new joint venture as of July 1, 2020, reports an HVDC portfolio of projects of over 120 GW, estimated to be half of the global installed base of HVDC capacity ▪ The company has a strong position in UHVDC projects, as the only provider to offer 1,100kV system	*R&I or Production*	▪ 100+ office locations across Europe ▪ Due to Merger completed in July 2020, details on exactly which R&I and production locations remain with ABB are unclear
		Sales	▪ Global presence, involvement in a large

[27] Google patents (2020).
[28] Navigant (2020) - International Strategic Partnerships in Energy

	▪ The company can also supply most of the parts and equipment required for a full turnkey HVDC installation ▪ Prior to the merger, Hitachi had produced HVDC products in Japan, although the technology was developed as part of a 2014 joint venture with then-ABB ▪ The current joint venture's HVDC portfolio is almost entire the legacy European ABB technology, and most of the R&D done in the segment will remain in Europe as part of the legacy ABB business ▪ Despite Hitachi's current HQ in Japan, the joint venture company that produces HVDC systems will remain headquartered and based in Europe.		percentage of the world's HVDC projects

Company & key financials	Short description	Operational footprint & geographic focus	
SIEMENS		*HQ*	▪ Munich, Germany
Siemens	▪ Siemens is one of the largest players in the HVDC market. ▪ Reports the participation in more than 55 HVDC projects, dating back to 1975, both VSC and LCC ▪ 20% of transmission business orders are HVDC ▪ Siemens' Vision 2050 incorporates extended transmission distances to bring renewable generation from all over Europe to areas of high load, while maximizing the cost and generation efficiency through low line losses. This entire vision is VSC-MMC projects.	R&I or Production	▪ 7 R&I centres, 16 production facilities – across Morocco, China, India, Denmark, Germany, Spain, UK, USA, Brazil
Turnover: EUR86.8 billion			
EBITDA: EUR10.5 billion		Sales	▪ Global presence across 37 countries ▪ Spain, United States, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Denmark, Egypt, France, Germany, Greece, Hungary Italy, United Kingdom

Company & key financials	Short description	Operational footprint & geographic focus	
		HQ	▪ Boston, MA
General Electric			GE opened a state-of-the-art testing facility in the UK to run

Turnover: EUR10.2 billion	▪ Reports an estimated global installed HVDC capacity of more than 35 GW on five continents, offering both LCC and VSC technology up to 800 kV ▪ Pioneered HVDC hybrid network, incorporating FACTS devices for de-icing and multi-terminal HVDC networks ▪ GE trails ABB and Siemens in technology investment and in overall project numbers for HVDC	R&I or Production	some of the most advanced and extreme tests on HVDC systems, specifically the valves for both LCC and VSC.
Profit: EUR140 million		Sales	▪ Global presence across 170+ countries ▪ Spain, United States, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Denmark, Egypt, France, Germany, Greece, Hungary Italy, United Kingdom

Company & key financials	Short description	Operational footprint & geographic focus	
		HQ	▪ Xi'an China
General Electric	▪ Leading research and supplier and electrical equipment in China ▪ Largest manufacturers of special transformers in the world and has contributed to all modern HVDC projects in China ▪ Most projects are expected to be LCC projects due to long distances, and Guidehouse Insights cannot confirm any VSC HVDC projects	R&I or Production	The company operates as many as 50 or more subsidiaries for supply of equipment, research, testing, manufacturing, and other project requirements ▪ China
Turnover: EUR2.0 billion			
Profit: EUR0.1billion		Sales	

4.8 List of Abbreviations

AC	Alternating Current
CSC	Current Source Converter
DC	Direct Current
DER	Distributed Energy Resources
GW	Gigawatts
HVAC	High Voltage Alternating Current
HTS	High Temperature Superconductor
HVDC	High Voltage Direct Current
kV	Kilovolts
LCC	Line Commutated Converters
MW	Megawatts
T&D	Transmission & Distribution
TSO	Transmission System Operator
UHVDC	Ultra-High Voltage Direct Current
VSC	Voltage Source Converter

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5 Solar Photovoltaics

5.1 Summary

Scope	• A solar PV system consists of solar modules and balance-of-system (BOS) components, such as inverters that convert the DC power generated by the solar module into AC, and other system components such as racks and wiring. • Beyond the hardware, the solar PV value chain also includes the development, deployment and daily operation and maintenance of solar systems, including solar digitalisation technologies like monitoring and control.
Market	• According to Guidehouse Insights, the EU-27 market for solar PV is expected to grow from EUR17.1 billion in 2020 to EUR27.2 billion in 2030 at a CAGR of 4.7% during this period[29].
Competitive-ness of EU-27 companies	• European companies like Wacker Chemie, Centrotherm, Meyer Burger or Schmid are still leaders in some of the segments, like polysilicon production and Solar PV equipment manufacturing and with them, the development of new technologies in the PV space. • However, this leading position is threatened by a move by Asian (Chinese, Korean and Taiwanese) companies into these segments, offering good-enough products and benefitted by the regions' dominance of cell and module manufacturing, some of which are moving upstream in the PV value chain, displacing EU-27 products in the Asian markets. • European companies have also maintained a leading position in deployment, where established players like Enerparc, Engie, Enel Green Power or BayWa.re have been able to move into new solar markets and win market share.

5.2 Introduction

Solar PV technology has been experiencing a surge that only started about 15 years ago, in which the industry has seen significant transformation. The industry developed in Europe, California and Japan, but Asian countries like South Korea and Taiwan and later China took advantage on the economies of scale they had in the silicon industry (due to their computer chip manufacturing base) and an active industrial policy in the sector to capture a significant share of the revenues in the value chain.

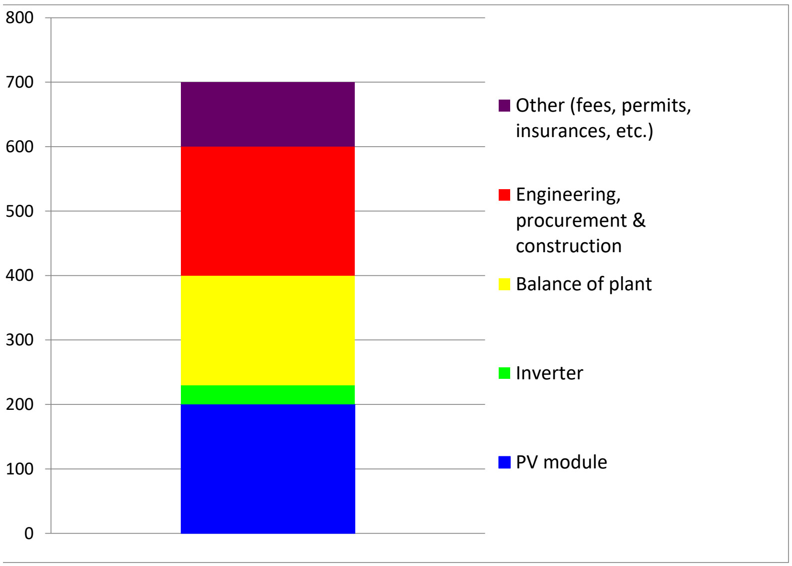
Overall, the industry has achieved significant milestones. In manage to reduce the cost of solar by 90% in a decade, making solar PV generation the cheapest source of electricity in many markets and costs continue to fall at a rate of 23%[30] every time the install capacity doubles – or roughly 8% per year over the last decade.

The dramatic reduction in solar module prices during the past few years has exposed the importance of balance of system (BOS) costs and non-hardware cost like

[29] Guidehouse Insights Estimates
[30] Guidehouse Insights Analysis

development, sales and marketing, permitting and financing costs. Module and inverter manufacturers are increasingly finding themselves squeezed by the trifecta of the growing number of grid requirements, customer demands for increased functionality and the need for solar to keep reducing costs to achieve grid parity in most of the world. Price reductions for modules, inverters, and BOS components are expected to continue. They are projected to be the main cost reduction drivers for deployed PV installations, as soft costs related to solar PV systems are more difficult to tackle; non-hardware costs are increasing their share of the overall system cost. Inverters, racking and other BOS components have historically fallen around 8% per year; these trends are expected to continue for the next decade[31].

Figure 15: System Price of PV EUR/kW peak



Source: JRC PV Status Report 2019

While cell and module manufacturing has left the EU-27, a significant portion of R&D in the PV industry still remains in the region. Research centres usually work along PV equipment manufacturers to bring new technologies to the market[32]. Equipment manufacturers then sell their equipment to cell and module producers licensing their technology.
Another area in which EU companies lead is in the development and financing of solar farms. The early boom and bust cycle of the industry in Europe forced developing companies to globalise early in their history, and now are overrepresented at a global scale.

Figure 16: Introduction on Solar PV Value Chain

[31] IRENA: Renewable Power Generation Costs in 2019 https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019
[32] Fraunhofer ISE: Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems 2015. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/AgoraEnergiewende_Current_and_Future_Cost_of_PV_Feb2015_web.pdf

	Equipment for PV manufacturing	Solar PV panels (Silicon, Cells, Modules)	Monitoring & Controls	Balance of system	EPC	Deployment
Key activities	• PV manufacturing equipment • New PV technology development	• Manufacturing of silicon ingots, cells and PV modules	• Developing hardware and software to improve the performance of solar farm	• All non-module hardware (Inverters, Trackers, Steel structures, cabling, etc.)	• Engineering design • Construction • Lease & Insurance • Commissioning	• Development • Finance • O&M
Market Size (M€)	Global 1.329 EU 66	Global 57.842 EU 7.368	Global 2.694 EU 678	Global 25.707 EU 3.275	Global 17.995 EU 2.292	Global EU
Market Growth Outlook	**Global:** ↗ **EU:** ↗ R&D directed to HJT	**Global:** ↗ **EU:** → Focus on increasing cell efficiency	**Global:** ↑ **EU:** ↗ Focus diagnostics and optimisation	**Global:** ↗ **EU:** → Increasing warranties and cost reduction	**Global:** ↗ **EU:** → Focus on factory vs field work	**Global:** ↗ **EU:** → Access to low cost capital and leading technology is key
Key players EU	• Valoe • Centrotherm • SCHMID	• Hanwha Q-cells (Partially EU) • Wacker Chemie • 3Sun	• GreenPower Monitoring • AlsoEnergy (partially EU) • Solar-log • Meteo&Control	**Inverters** • SMA **Trackers** • Soltec	Highly fragmented market dominated by local players	• Enel Green Power • Engie • BayWa.re
Key players Rest of the World	• Meyer Burger	• Trina Solar • Jinko Solar • GCL-Si • Hanwha Q-cells (Partially KR) • JA Solar • Longi • Tongwei	• AlsoEnergy (partially US) • Inaccess	**Inverters** • Huawei • SunGrow **Trackers** • Nextracker • Array Tech	Highly fragmented market dominated by local players	• Nexterra • BP Lightsource
Critical materials	None	Silver, Copper	None	None	None	None

Legend: (10 year CAGR) ↑ >15% ↗ >10% ↗ >5% → >0%

Source: Guidehouse Insights (2020)

5.3 Industry Value Chain Analysis

5.3.1 Value Chain Segmentation

A solar PV system consists of solar modules and balance-of-system (BOS) components, such as inverters that convert the DC power generated by the solar module into AC, and other system components such as racks and wiring. Rather than converting heat and mechanical energy into electricity as traditional power plants do, the operation of a photovoltaic (PV) cell requires three basic attributes: The absorption of light, generating either electron-hole pairs or excitons; the separation of charge carriers of opposite types and the separate extraction of those carriers to an external circuit[33].

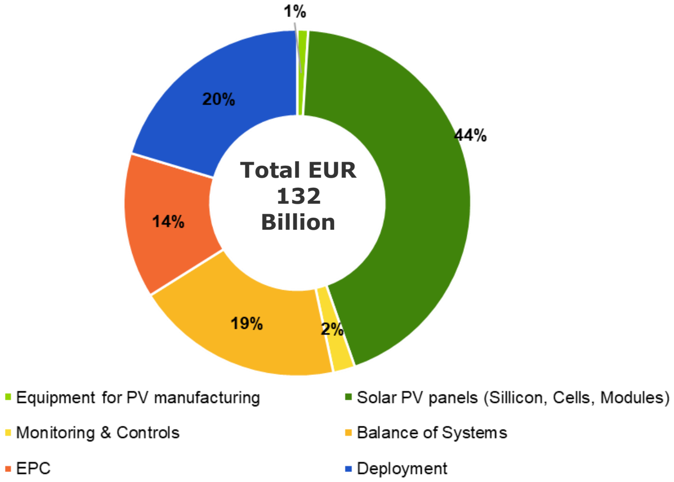
Useful terms for understanding the Solar PV market include:

- Cell: A device made from crystalline silicon designed to absorb sunlight and convert it into electricity
- Module: A group of multiple Solare PV cells with wiring, glass, junction box, and a frame (sometimes confused with a Solar PV array)
- Array: A group of Solar PV panels wired together to create an integrated Solar PV energy system
- Inverter: The inverter transforms the direct current (DC) electricity produced by the solar array (or module in the case of microinverters) into 50Hz-60Hz Alternating Current (AC)

[33] European Commission review notes

Beyond the hardware, the solar PV value chain also includes the development, deployment and daily operation and maintenance of solar systems, including solar digitalisation technologies like monitoring and control.

Figure 17: Value Chain Segmentation, Global, 2020



Source: Guidehouse Insights (2020)

According to Guidehouse Insights, the EU-27 market for solar PV is expected to grow from EUR17.1 billion in 2020 to EUR27.2 billion in 2030 at a CAGR of 4.7% during this period. Of this the largest share of revenues (44%) of the value chain EUR57.8 billion of this market is dominated by Solar PV panels.

5.3.2 Market Size Analysis

In 2019, the solar industry continued to break records despite a significant slowdown in China and India[34]. In any case, solar maintained its title as the most attractive power generation source installed in 2019. As in the years before, not only was more solar PV added than all fossil fuel and nuclear power generation capacities combined, it also saw nearly twice as much power installed as wind and more than all other renewables together. However, these positive developments showing solar dominating annual global power generation capacity additions needs to be put into perspective. When looking at Solar's cumulative installed capacity share, it is still very small, adding up to only 8.5% by the end of 2019[35]. Regarding actual output, all solar PV systems united generated a mere 2.6% of the global power output[36].

The global solar industry historically has gone through boom-bust cycles in specific markets caused by local regulatory changes, but despite this, it has managed to grow in every year of the last decade except one as new markets open while others close. Globally, there are 20 markets installing at least 1 GW of new solar PV capacity[37].

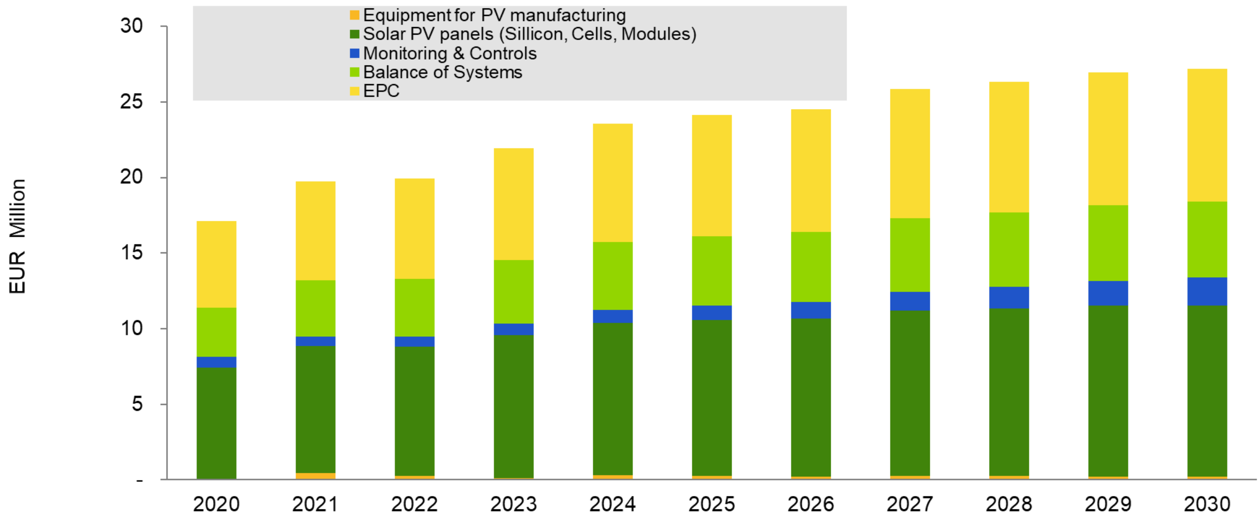
[34] Solar Power Europe: Global Marker Outlook https://www.solarpowereurope.org/wp-content/uploads/2018/09/Global-Market-Outlook-2018-2022.pdf
[35] IEA: World Energy Outlook 2019 https://www.iea.org/reports/world-energy-outlook-2019
[36] JRC: PV Status Report 2019 https://ec.europa.eu/jrc/sites/jrcsh/files/kjna29938enn_1.pdf
[37] Guidehouse Insights Solar PV market Forecasts

The EU-27 solar market remains strong for Solar PV and renewable electricity more generally, with some countries reaching deployment levels for storage and renewable generations, sufficient to meet demand with 100% renewable supply for days or weeks during some stretches of the year.

Europe is expected to add 292GW of Solar PV between 2020-2030, generating EUR 204.1bn in revenue[38]. Germany, France, and Spain are expected to retain relatively strong markets overall, while new markets in Turkey and Eastern Europe are expected to accelerate as they take advantage of low solar prices and high solar potential. Approximately 143.9 GW of European capacity added over the forecast is projected to be distributed[39].

Unlike at global level, the industry in Europe saw a significant collapse of the capacity additions during the middle part of last decade as once large markets like Spain, Germany and Italy went to significant regulatory changes and reductions in their incentive programmes. A new growth phase that started 2017 in Europe has gained huge momentum in 2019 – both for the entire continent and the European Union. After increasing demand in the low two-digit range, at 21% to 11.2 GW in 2018, solar additions in Europe more than doubled to 22.9 GW in 2019, which has made the region to become the second largest solar market in the world last year.[40] The EU-27 alone added 16.5 GW, translating into an even larger growth of 106%. In the EU-27, there were 3 markets (Spain, Germany, Netherlands) with over 1GW of new capacity in 2019 and two more (Poland, France), very close to this mark.[41]

Figure 18: Total Annual Market Size, EU-27: 2020-2030

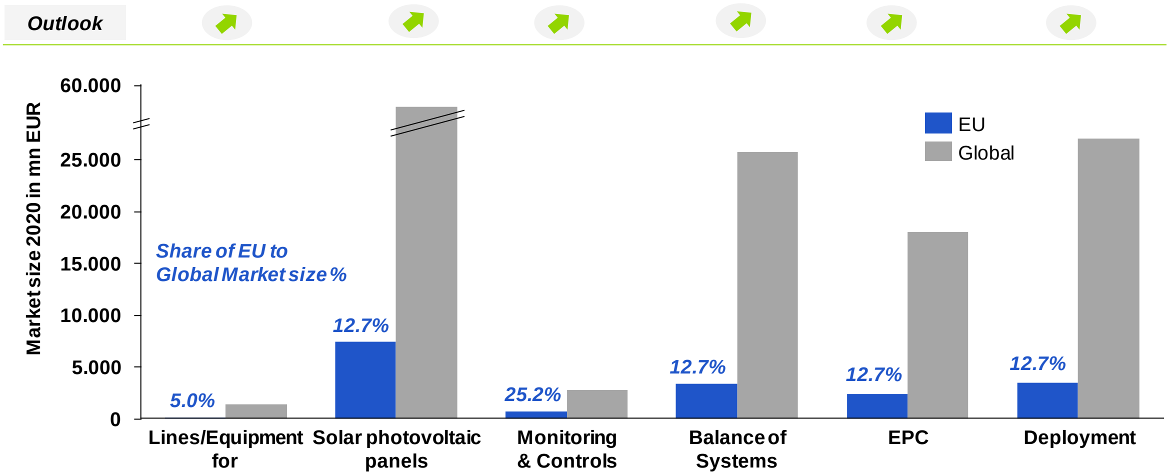


Source: Guidehouse Insights (2020)

5.3.3 Share of the EU Market

38 Guidehouse Insights Estimates
39 Guidehouse Insights Solar PV market Forecasts
40 Guidehouse Insights Solar PV market Forecasts
41 Guidehouse Insights Solar PV market Forecasts

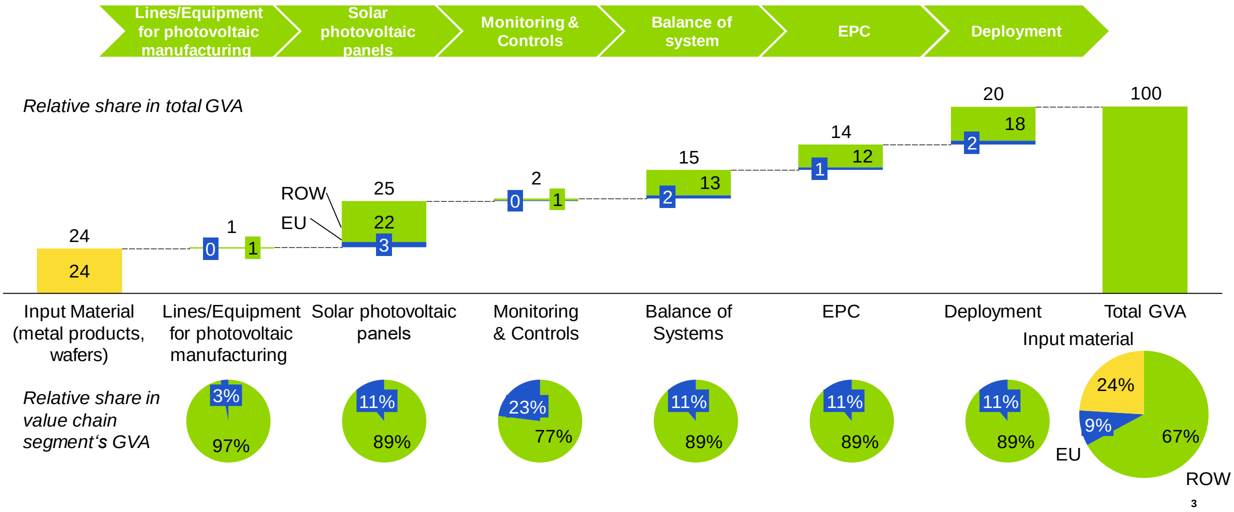
Figure 19: Share of EU-27 Market Size to Global Market, Value Chain Segment: 2020



Source: Guidehouse Insights (2019) Note: The 12.7% is the EU's share of PV installations in 2019.

5.3.4 Gross Value Added

Figure 20: Breakdown of GVA throughout solar PV value chain



Source: Guidehouse Insights (2020)

The gross value added in general resembles the market sizes for the respective value chain segment and region, adjusted for a trade surplus/deficit and the value of input material. The available trade data on sector level had been disaggregated proportionally according to market size of the different segments. Therein a potential source for inaccuracies in the GVA calculation may be found since it is likely that an export surplus exists in some segments (equipment for PV manufacturing) whilst a negative trade balance is likely for PV panels. For the solar PV sector, metal products and wafers are considered as input material, which are used mainly for panel manufacturing. The largest share of the GVA is captured by the panel manufacturing.

5.4 Market Outlook

5.4.1 Drivers and Barriers

The global electric power industry is evolving from a model that relies on large centralized power plants owned by utilities to one that is more diverse in sources of generation and ownership of generation assets. Regulatory and legislative structures are evolving away from structures that incentivized widespread solar deployment to more nuanced mechanisms that enable solar growth to be controlled and directed.
These mechanisms aim to avoid negative outcomes at the system level as renewable penetration increases. They also aim to ensure that resources are allocated to new generation projects as efficiently as possible in a competitive, technology-agnostic manner. The following drivers are shaping current solar markets and the forecast outlook:

- **New technologies are raising solar module efficiency and overall system yield:** The constant pressure to reduce cost in the solar industry is continuously driving innovation. New technologies have appeared in the last 5 years that have raised the average efficiency of solar modules from around 16% in 2015 to close to 20% in 2020[42]. In addition, the digitalisation and automation of solar, including system monitoring and control, diagnostics and analytics, tracking systems and trading solutions has helped plants to optimise their output and revenues by between 5% and 10%[43].
- **Price drops continue:** Crystalline module costs global average dropped from roughly EUR3.17/W (USD4.00/W) in 2006 to a global average of EUR0.27/W (USD0.30/W) in 2019[44]. In 2019, auctions in Portugal saw bids for utility-scale solar capacity at bid prices of €0.01476/kWh[45]. Prices below €0.05/kWh are commonplace in the EU[46]. Lower prices open new markets for Solar PV and accelerate solar toward grid parity in high cost retail electricity markets.
- **Solar auctions begin to replace FITs:** The success of Solar PV in recent years has forced governments at the state and national levels to revaluate their

[42] Fraunhofer ISI: Photovoltaics Report 2020 https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

[43] Huawei: PV Magazine Special, 2019. https://16iwyl195vvfgoqu3136p2ly-wpengine.netdna-ssl.com/wp-content/uploads/2019/05/Huawei2019-SpecialEdition.pdf

[44] IRENA: Renewable Power Generation Cost in 2018 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf

[45] PV Magazine: Winners, projects, prices of Portugal's record PV auction, 2019. https://www.pv-magazine.com/2019/08/09/winners-projects-prices-of-portugals-record-pv-auction/

[46] Guidehouse Insights Analysis

support for solar. Feed-in tariffs (FITs) have been largely curtailed or replaced by reverse auction systems. Emerging and leading markets are financing gigawatts of Solar PV projects, and numbers are expected to grow over the next decade. However, completion rates for auctioned projects are not yet known.

- **Grid parity and self-consumption:** Solar PV at the energy consumer premises (residential or commercial roof-tops) is now competitive with grid-source electricity in many markets. This is driving the installation of solar system for self-consumption purposes at the consumer level (residential and C&I) and creating an industry around it.
- **Corporate PPAs and merchant solar**: As solar PV becomes the cheapest source of electricity in many markets, developers have looked at developing solar plants without government subsidies. Developers usually sign long-term power purchase agreements (PPA) with corporations looking to procure green electricity, but in some instances, solar deployments are being developed to sell their electricity directly in the wholesale market.
- **Capital availability and investor confidence:** As the PV technology matured, investors became more confident in the technology's revenue predictability and the associated risk. This is allowing companies deploying solar project access to capital in a very competitive environment, helping developers reduce their levelized cost of electricity produced.

5.4.2 Raw Material Usage

Today's solar industry is dominated by polysilicon solar cells. The polysilicon PV industry relies on raw materials widely available globally. Its main raw material is silica (sand), but it utilises small amounts of boron, phosphorus, silver and copper[47].
Other technologies require different materials, but currently they have a small market share of the solar PV market or are at technology demonstration stages. The specific materials and the solar cells they are used to manufacture, are as follows.

- Amorphous Silicon: Germanium
- CdTe technologies: Cadmium, Tellurium
- CIGS technologies: Cooper, Indium, Gallium, Selenium
- Perovskite: Calcium, Titanium Oxide

5.5 Competitive Landscape

Europe, along the US state of California and Japan, jump started the large-scale solar PV market in the mid-2000s. This early start positioned EU companies – mostly German, Spanish and Italian as the leaders in the industry. Since then, the market has moved to other regions and with that, some of the leaders in the industry.

Different parts of the value chain performed differently. European companies like Wacker Chemie, Centrotherm, Meyer Burger or Schmid are still leaders in some of the segments, like polysilicon production and Solar PV equipment manufacturing and with them, the development of new technologies in the PV space. This leading position is threatened by a move by Asian (Chinese, Korean and Taiwanese) companies into these

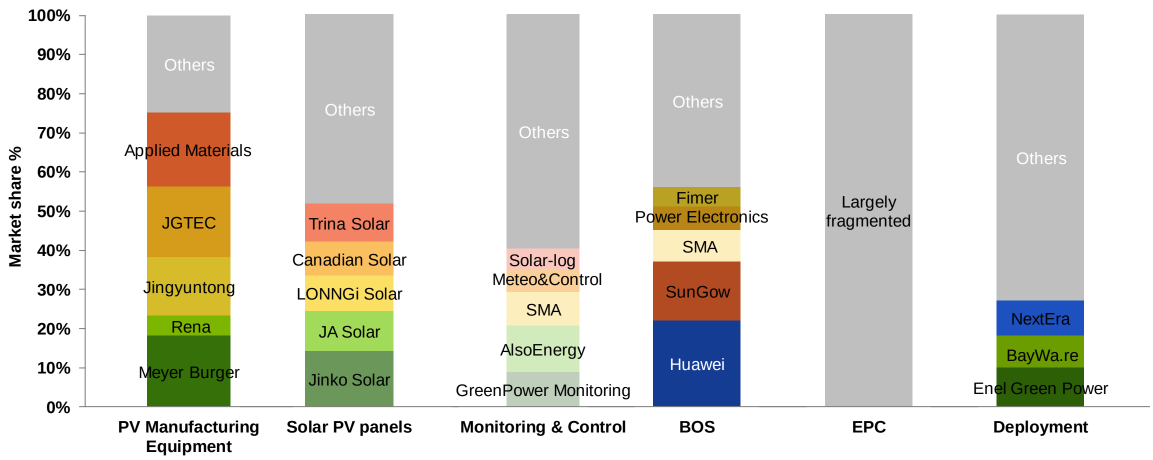
[47] EC: Report on Critical Raw Materials for the EU http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

segments, offering good-enough products and benefitted by the regions' dominance of cell and module manufacturing, some of which are moving upstream in the PV value chain, displacing EU-27 products in the Asian markets.

Another area in which European companies have maintained a leading position is in deployment, where established players like Enerparc, Engie, Enel Green Power or BayWa.re have been able to move into new solar markets and win market share.
Another area in which EU-27 companies have managed to remain competitive is in BOS and Monitoring and Control. The EU-27 host some of the leaders in inverter manufacturing, like SMA, FIMER, Siemens, Gamesa Electric, Ingeteam and Power Electronics. In solar trackers, Soltec is considered a leader and in Monitoring and Control, the EU-27 host leaders like GreenPower Monitoring, Meteo&Control and Solar-log.

One area in which the EU has fallen behind is cell and module manufacturing. Early European leaders like Solar World have mostly fallen victim to the intense competition in this market and only small players with unique technologies like 3Sun remain active. Cell and Module manufacturing has moved to East and South East Asia, where they can benefit from economies of scale. Today, all top 10 manufacturers of cells and modules are headquartered in this region. These include Jinko Solar, JA Solar, Trina Solar, LONGi, Risen Energy, Astronergy and GCL SI, which are headquartered in PR China, Canadian Solar (formally headquartered in Canada but with most activities in PR China) and Hanwha Q Cells from the Korean Republic (with some activities in Germany).

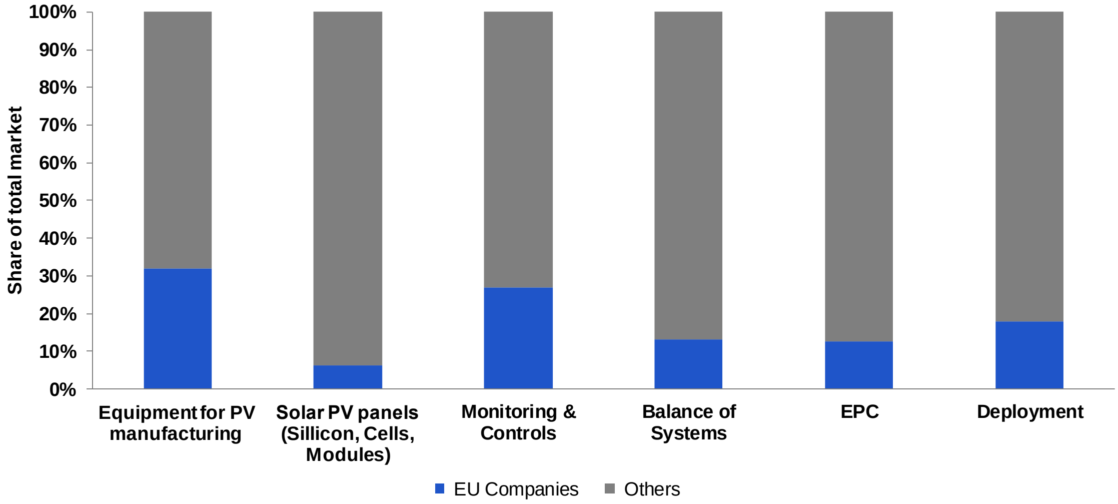
Figure 21: Competitive Intensity across Each Value Chain Segment, Global, 2020



Source: Guidehouse Insights (2019)

5.6 Value Chain Segment Competitiveness

Figure 22: Competitive Intensity across each Value Chain Segment, Global, 2020



Source: Guidehouse Insights (2019)

5.6.1 New Entrants

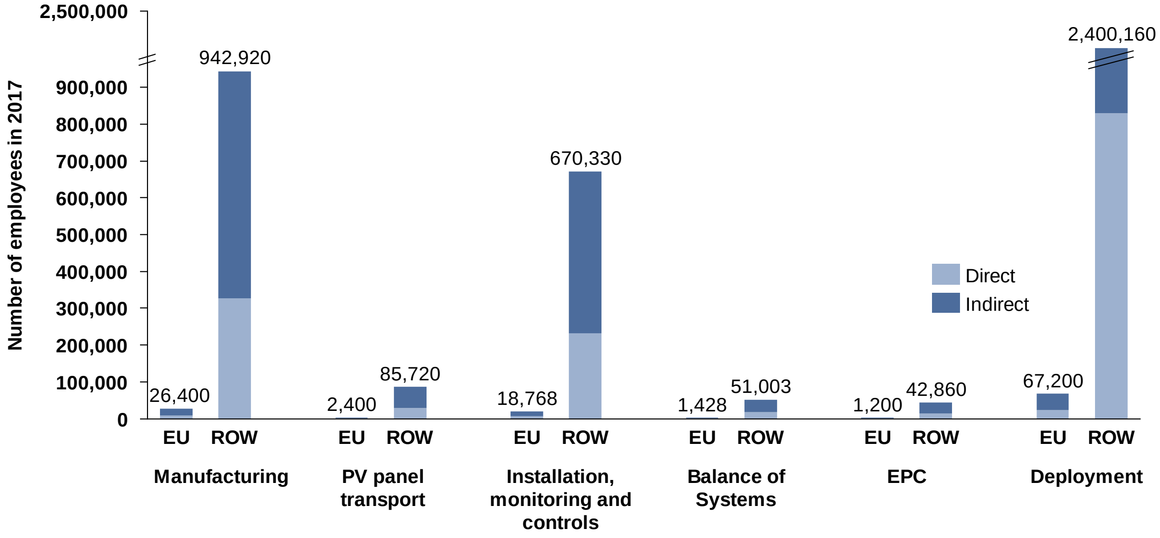
Guidehouse has identified 85 start-ups active in solar photovoltaics who have received private funding in 2019, more than any other technology evaluated.[48] This reflects the relative maturity of the market. However, these companies are primarily focussed in the EPC and Deployment value chain segments. Substantial investment in R&D is required for companies to compete in many of the value chain segments. Additionally, the capital equipment required for the manufacture of photovoltaic panels and the production of equipment for photovoltaic manufacturing pose additional barriers to entry into the market.

Overall, the EU-27 is over-represented in the start-up environment of the solar photovoltaic market. Start-ups headquartered in the EU-27 represented 32% of the total and accounted for 34% of the total private funding received in 2019.[49] However, the EU-27 represents only 13% of the global market in 2020. Much of the start-up activity is centred around EPC and deployment, which requires an established market for opportunities to emerge. This maturity in the EU-27 market coupled with the technological gains that increase predictability and reduce risk, create an environment where EU-27 start-ups can compete.

5.6.2 Employment Indicators

[48] CBInsights and Crunchbase
[49] CBInsights and Crunchbase

Figure 23: Solar Employment by value chain [50] [51]



The Employment values are obtained from IRENA. The deployment value chain step had the largest number of employees in both Europe and the rest of the world. Indirect jobs also formed the majority of jobs in all segments in both Europe and the rest of the world. The contribution that Europe has is much smaller when compared to the rest of technologies. This is likely due to the large market for Solar energy worldwide.

5.6.3 Trade (EX, IM)

EU-27 has experienced a negative trade balance in the solar PV sector[52]. The EU trade balance in the solar PV sector is negative, with a rapid decrease, starting from 2007. The European trade balance of solar PV is totally influenced and skewed by imports rather than exports, which are almost constant over the years. In particular, the total EU solar PV imports are clearly dependent on imports from China.[53]

5.6.4 R&I activities

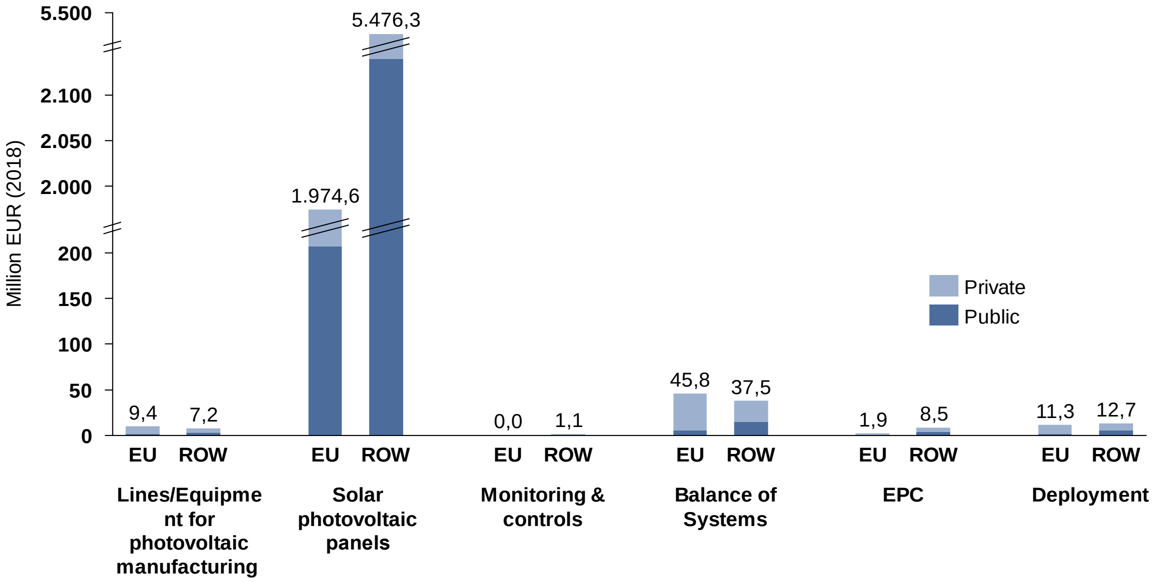
[50] IRENA (2017). Renwable Jobs annual review. https://www.irena.org/documentdownloads/publications/irena_re_jobs_annual_review_2017.pdf

[51] IRENA (2017), Leveraging for Solar Energy. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Jun/IRENA_Leveraging_for_Solar_PV_2017.pdf

[52] Guidehouse Insights Estimates of UN COMTRADE data

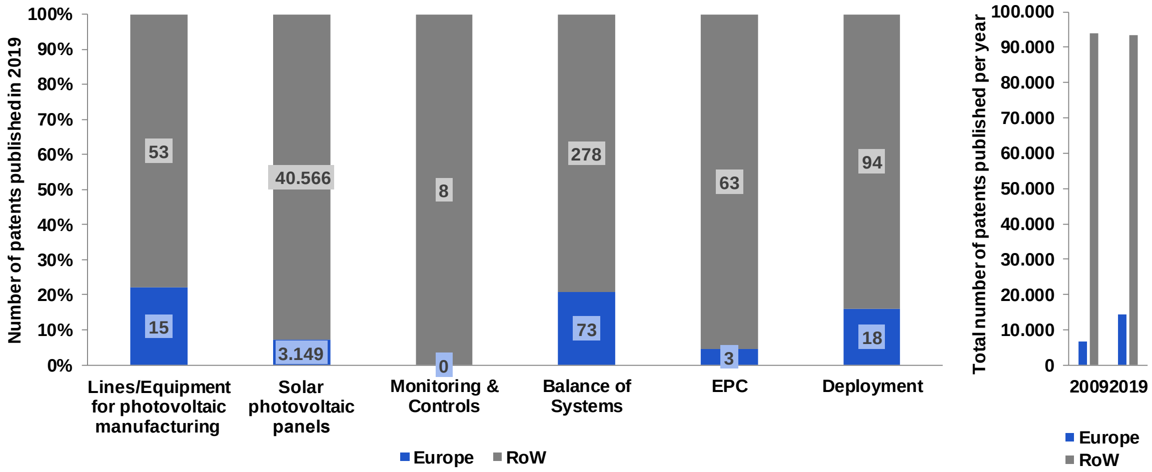
[53] JRC Report: EU energy technology trade - https://publications.jrc.ec.europa.eu/repository/handle/JRC107048

Figure 24: R&D investments in solar energy [54] [55]



The R&D investments for Europe were obtained from Euroobserver and from IRENA for the rest of the world. The largest investment area was in the PV panels segment, while the rest of the segments had very small investment numbers. Europe shares in that lie at around 30%. There is a smaller split in private vs. public investment in Europe when compared to the rest of the world. Europe has a much larger private investment share when compared to the rest of the world, where the split lies at around 40-60 between public and private. However, private investment was the majority in both regions.

Figure 25: Solar Patents by Value Chain / Solar PV Patent Trends by Region [56]



[54] Euroobserver (2018). The state of Renwable Energies in Europe.

[55] IRENA (2020). Investment trends in Renwable energy. https://www.irena.org/Statistics/View-Data-by-Topic/Finance-and-Investment/Investment-Trends

[56] Google Patents database (2020).

The patenting data shows that the largest amount of research is being done in the Solar PV panels segment, and Europe's share in that lies at under 10%. Overall, the share that Europe has globally increased between 2009 and 2019, but still remains at a modest 10-15%.

Considering research publications and institutions, the US is the dominant player with about 70 research institutions active in this field, being responsible for 210 publications. Overall, there are about 80 research institutions from Horizon2020 member states active in research on solar PV, compared to 230 in the rest of the world. These institutions' efforts resulted in about 260 (Horizon2020), respectively 680 (ROW) publications in a 5-year timeframe.[57]

5.7 Company profiles

Company & key financials	Short description	Operational footprint & geographic focus	
MEYER BURGER	E → S → M → B → E → D	*HQ*	▪ Thun, Switzerland
Meyer Burger	▪ Meyer Burger is a specialist in innovative systems and production equipment for the photovoltaic (solar), semiconductor and optoelectronic industries. ▪ Meyer Burger's product portfolio is complemented by a worldwide service network with spare parts, consumables, process know-how, customer support, after-sales services, training and other services. ▪ Meyer Burger is known for bringing new technologies into the PV market ▪ In 2020, Meyer Burger announced that they will spot sales of their leading technology and enter the panel manufacturing segment	*R&I or Production*	▪ Switzerland (4 R&D centres) ▪ Germany (3 R&D centres) ▪ France (R&D partnership with CEA)
Turnover: CHF 262 million			
Profit: CHF -17 million		*Sales*	• Mostly in Asia Pacifc

Company & key financials	Short description	Operational footprint & geographic focus

[57] Navigant (2020) - International Strategic Partnerships in Energy

WACKER	E S M B E D	*HQ*	▪ Munich Germany
Wacker Chemie	▪ In the PV industry, Wacker Chemie is a leader in polysilicon production. ▪ In addition, Wacker provides the industry with silicon rubbers to bond solar-cell laminates into their frames and for the encapsulation of the cells and connectors into rigid and flexible modules.	*R&I or Production*	▪ 29 locations in the EU ▪ Germany (R&D centre and polysilicon production facilities in Burghausen and Nunchritz) ▪ US (Production facility in Charleston)
Turnover: EUR4.9 Billion			
Profit: EUR0.8 Billion		*Sales*	• Mostly in Asia Pacifc

Company & key financials	**Short description**		**Operational footprint & geographic focus**
Soltec	E S M B E D	*HQ*	▪ Murcia, Spain
Soltec	▪ Soltec is a leading manufacturer of solar trackers and steel structures. ▪ Soltec is active globally and has a production capacity of 5 GW of tracker capacity, and annual sales of 2+ GW.	*R&I or Production*	▪ 29 locations in the EU ▪ Germany (R&D centre and polysilicon production facilities in Burghausen and Nunchritz) ▪ US (Production facility in Charleston)
Turnover: Est EUR 230 million			
Profit: EUR 10 million		*Sales*	▪ Spain, Italy, Denmark, Latin America, US, Australia,

			India and China

Company & key financials	Short description	Operational footprint & geographic focus	
	E S M B E D	*HQ*	▪ Rome, Italy
Enel Green Power	▪ A majority-owned subsidiary of Enel Spa. ▪ Enel Green Power develops, own and operate renewable energy projects. ▪ Enel Green Power manages a combined capacity of 46 GW of renewables capacity (4.7 GW of Solar in 119 projects, 14 countries around the world). ▪ Enel Green Power owns 3Sun, a manufacturer of HeteroJuction solar Modules at it is planning to expand its manufacturing capacity to 1 GW+.	*R&I or Production*	▪ 3Sun R&D and production facility in Catania, Italy
Turnover: Est EUR 7.7 Billion			
Profit: EUR 4.6 million		*Sales*	▪ 14 countries around the world (Italy, Spain, Greece, Romania, US, Mexico, Panama, Brazi, Chile, Peru, Colombia, South Africa, Zambia, Australia)

Company & key financials	Short description	Operational footprint & geographic focus	
	E S M B E D	*HQ*	▪ Changzhou, China
Trina Solar	▪ Trina Solar is a Chinese solar company, usually one of the top 3 supplier of solar	*R&I or Production*	▪ Manufacturing centres in China,

	modules in the world and has sold over 50GW of solar PV module capacity. ▪ Trina Solar has developed a vertically integrated supply chain, from the production of ingots, wafers and cells to the assembly of modules, solar tracker, power electronics, communications, monitoring and control and solar farm design development.		Vietnam and Thailand.
Turnover: EUR 2.9 billion			
Profit: EUR 0.1 billion		*Sales*	▪ Globally

Company & key financials	Short description		Operational footprint & geographic focus
SMA SOLAR TECHNOLOGY	E S M B E D	*HQ*	▪ Niestetal, Germany
SMA Solar Technology AG	▪ SMA is a producer and manufacturer of solar inverters for photovoltaics systems with grid connection, off-grid power supply and backup operations. ▪ SMA is the third largest Solar inverter manufacturer in the world, just behind Huawei and Sungrow. SMA is the largest supplier of inverters if you exclude the Chinese market. ▪ More recently, SMA has entered the Solar Monitoring and Control market.	*R&I or Production*	▪ Kassel, Germany ▪ Frankfurt, Germany.
Turnover: EUR 1.1 billion			
Profit: EUR 42 million		*Sales*	▪ Globally, sales and service subsidiaries.

5.8 List of Abbreviations

DER Distributed Energy Resources

5.9 References

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6 Offshore Wind

6.1 Summary

Scope	• The offshore wind value chain segments include turbines, support structure or foundations, logistics/ installations, balance of systems, EPC and deployment. Increasing investments and focus on research and innovation across turbine and components across the region have resulted in a competitive supply chain. • The supply chain is further evolving in a number of areas, such as next-generation drivetrains with increasing turbine efficiency and reliability and foundation structures suitable for deeper-water sites located farther offshore and increased siting complexity.
Market	• According to Guidehouse Insights, the EU-27 market for offshore wind is expected to grow from EUR 31.3 billion in 2020 to EUR59.2 billion in 2030 at a CAGR of 6.6%[58] during this period.
Competitive-ness of EU-27 companies	• EU companies are strongest in the Turbine and EPC value chain segments. Multiple market leaders are headquartered and do a large part of their business in Europe. These include Siemens Gamesa, MHI Vestas, GE and Jan de Nul. The turbine OEMs have leveraged their strength as equipment suppliers to vertically integrate across the value chain and offer a more consolidated solution of project owners. The largest research and innovation investment area was in the Turbine segment, followed by the support structure. Europe shares in the turbine segment lie at around 20-25%[59]. • Europe has a much larger private investment share (40-60%) when compared to the rest of the world. In case of public sector investments in R&I the share of Europe is much lower, between 5-10%[60].

6.2 Introduction

Offshore wind is growing rapidly, as it offers a unique value proposition: It is an abundant clean energy solution for many coastal load centres where a greater proportion of population and energy demand is located - often areas where the onshore wind resource is more difficult to develop. However, the key challenge is to export the energy produced to inland load centres.

Additional key factors driving offshore wind project development include higher plant capacity or load factors, more stable power output resulting in lesser intermittency, innovative solutions and rapidly declining costs. The cost proposition is proving compelling. A decade ago, in the infancy of offshore wind, there were concerns that offshore would be too expensive to grow at large scale and be competitive with traditional market prices. However, projects in multiple markets are moving toward

58 Guidehouse Insights (Global Wind Energy Database 2020)
59 Guidehouse Insights Estimates (2019)
60 Guidehouse Insights Estimates (2019)

construction without subsidies and are willing to take fluctuating market prices. Offshore wind is also expanding to new markets as cost reductions in the technology and demand for renewable energy become attractive to governments, power utilities, and other stakeholders.

New markets include investments in technology, geography and applications. For example, Port of Rotterdam made history by installing the first GE Haliade-X 12 MW prototype. The average distance to shore (59 km) and water depth (33 m) also continue to increase even though most wind farms are bottom-fixed. Additionally, offshore wind farms continue to get bigger. Sizes have almost doubled over a decade from 313 MW in 2010 to 621 MW in 2019[61]. This is a result of both better stable wind resources and the depletion of near-shore locations. Innovation in larger turbine sizes such as the 12 MW Haliade-X reiterates that turbine sizes continue to grow larger and newly commissioned projects explores the usage of multi-GW scale machines.

The European market is well into a phase of transition to more market-oriented policies that track and fluctuate alongside broader market rates as opposed to more rigid fixed price systems, such as a FIT. The UK's shift from Renewables Obligation Certificates (ROCs) to Contracts for Difference (CFD) is a prominent example. Other countries with promising offshore wind pipelines and policies like the Netherlands, Belgium, Germany and Denmark are employing market-oriented support mechanisms for offshore wind and auction systems to push wind prices downward through competition. These as a whole represent the most significant market dynamic occurring in the European offshore wind market and inform how the rest of the world will likely eventually move from an incentives-perspective. Europe's offshore wind sector was under the spotlight in 2019. The International Energy Agency (IEA) published their Offshore Wind Outlook 2019[62] and stated that, by 2040, offshore wind could become Europe's main electricity source, playing a crucial role in Europe's journey to become carbon neutral.

[61] WindEurope: Offshore Wind in Europe, Key trends and statistics 2019, https://windeurope.org/about-wind/statistics/offshore/european-offshore-wind-industry-key-trends-statistics-2019/

[62] International Energy Agency: Offshore Wind Outlook 2019 https://www.iea.org/reports/offshore-wind-outlook-2019

Figure 26: Introduction on Offshore Wind Value Chain

	Turbine	Support Structure/ Foundation	Logistics and Installation	Balance of system	EPC	Deployment
Key activities	• Turbine	• Foundation	• Assembly and installation • Site Access and Staging	• Electrical Infrastructure • Development • Project Management	• Contingency • Construction Finance • Lease & Insurance • Commissioning	• O&M
Market Size (B€)	Global 19 EU 6	Global 9 EU 3	Global 8 EU 2	Global 19 EU 6	Global 13 EU 3	Global 32 EU 11
Market Growth Outlook	**Global:** **EU:** Growth in average rated capacity	**Global:** **EU:** Increasing investment in floating wind	**Global:** **EU:** Moving farther offshore, into deeper waters	**Global:** **EU:** Innovative heavy-lift jack-up vessels	**Global:** **EU:** Decrease in CAPEX per MW	**Global:** **EU:** Depletion of near-shore resources
Key Players EU	• Siemens Gamesa • MHI Vestas • GE Renewable Energy	• Sif • Navantia-Windar • Bladt • ASM Industries	• Van Oord • Jan de Nul • A2Sea • Geosea	• Boskalis Subsea • DeepOcean • Tideway • Schneider Electric • CG Power Systems	• Van Oord • Jan de Nul • A2Sea • Geosea • Seaway 7	• Deutsche Windtechnik AG • GE Renewable Energy • Nordex SE • Juwi AG
Key Players Rest of the World	• SEwind • Bard Engineering	• EEW • Lamprell	• Fred Olsen • Seajacks	• ABB • Tideway • JDR Cable Systems	• Fred Olsen	• -N/A
Critical materials	• Copper • Steel • Fiberglass	• Steel and Iron • Concrete • Lattice	• Polymer materials • Copper and alloys • Aluminum	• Electronics • Polymer material • Copper and alloys	• N/A	• Electronics • Polymer material

Legend: (10 year CAGR) >15% >10% >5% >0%

Source: Guidehouse Insights (2020)

Recent project tenders, construction activity, turbine orders, and financing arrangements are showing that these market-oriented policy mechanisms can lower the cost of wind power to the consumer and taxpayer. This will also enable the European offshore wind market to build at substantial capacity. This is not only a top-down regulatory approach but also the result of the broader offshore wind market attacking costs. Industry stakeholders including OEMs are increasing the efficiency of their projects to lower the power offtake cost needed to support financially feasible projects. As the offshore wind energy sector in Europe develops, it is expected to create major growth opportunities across each of the value chain segments.

The cost of offshore technologies can help make the technology more competitive. However, this will require incremental investments in research and development into innovative turbines, supply chain optimization, transmission, and monitoring and control technologies. Europe will continue to be a forerunner in the offshore wind industry, as it leads in the design and manufacture of offshore wind components and has the installation know-how to work far-shore and in deeper waters[63]. Introduction of higher capacity turbines which can offer increased reliability, lower operating costs and advanced logistical integration across the value chain components can position the EU countries to achieve a competitive edge in this accelerating market.

[63] EY: Offshore wind in Europe, Walking the tightrope to success, 2015. https://www.ewea.org/fileadmin/files/library/publications/reports/EY-Offshore-Wind-in-Europe.pdf

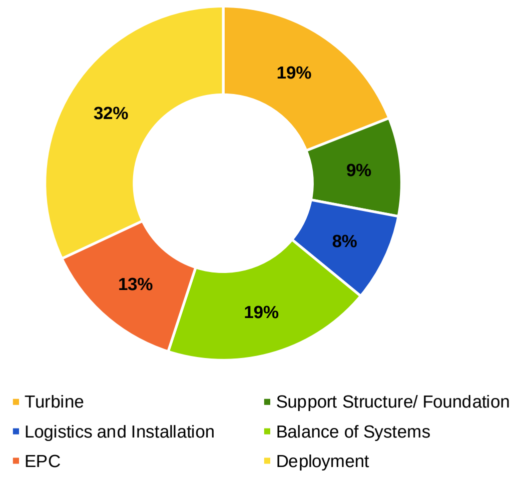
6.3 Industry Value Chain Analysis

6.3.1 Value Chain Segmentation

The Offshore Wind value chain segments include turbines, support structure or foundations, logistics/installations, balance of systems, EPC and deployment. The supply chain is evolving in a number of areas. The offshore wind supply chain has a strong cohort of major component suppliers which contract directly with project developers. This top level of the value chain is commonly referred to as Tier 1, typically supplying Turbine, Foundations and Balance of Systems (Substations, Export and Array Cables). The Turbine market, in particular, has been dominated by key players such as Siemens Gamesa and MHI Vestas. Next generation turbines of greater size and capacity are increasingly being brought to the market but the number of suppliers competing for wind turbine supply is still limited. Larger turbines and rotors allow for increased energy capture and production.

Next-generation drivetrains will result in increasing turbine efficiency and reliability[64]. There is a recent trend of increasing offshore wind power prices, which are driven largely by a movement toward deeper-water sites located farther offshore, increased siting complexity and higher contingency reserves that result from greater uncertainty when working in the offshore environment[65]. R&D advancements can help to reverse this increase in offshore wind power prices.

Figure 27: Value Chain Segmentation by Total Market Size, Global, 2020



Source: Guidehouse Insights (2020)

6.3.2 Market Size Analysis

According to Guidehouse Insights estimates, the offshore wind development is increasing worldwide at a 16% compound annual growth rate (CAGR) over a 10-year forecast[66]. China, Taiwan, and Europe are the leading markets, with the US soon to join

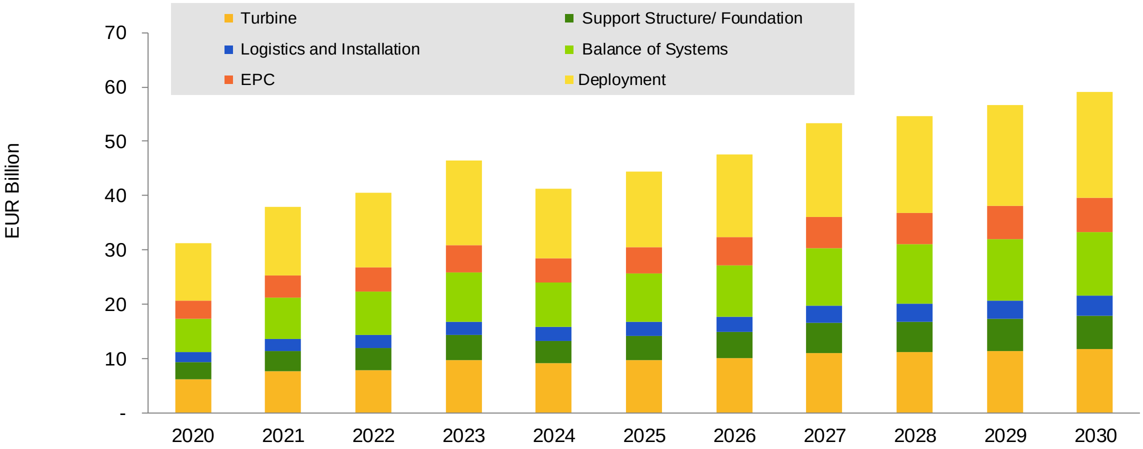
[64] Next-Generation Wind Technology, https://www.energy.gov/eere/next-generation-wind-technology

[65] IRENA - Future of Wind: Deployment, investment, technology, grid integration and socio-economic aspects, 2019, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf

[66] Guidehouse Insights, 2020

when the first large-scale offshore wind plants are commissioned in coming years along the northeast coast of the country.
Among the markets challenged by changes in policy, many are recovering and adjusting to a new normal of intense price competition. Some, such as the US and China in the short term, are experiencing rapid near-term increases of capacity additions.

Figure 28: Total Annual Market Size, EU-27: 2020-2030



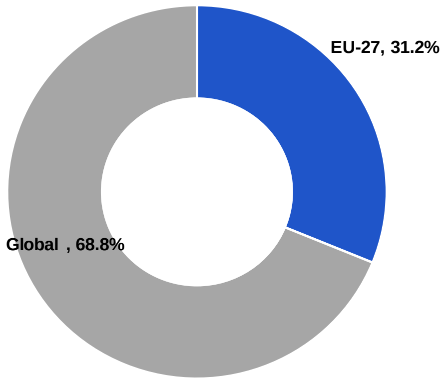
Source: Guidehouse Insights (2020)

According to Guidehouse Insights, the UK and Germany continue to be the strongest markets but are expected to be joined by new capacity coming from the Netherlands and France, and with less annual consistency from Belgium and Denmark. The largest markets see new capacity installed every year while smaller markets such as Belgium and Denmark have more sporadic annual installations as some years see projects commissioned and other don't. France, despite awarding offshore wind contracts a few years ago, has been slow to see these wind plants materialize. However, the plants should begin construction soon and see the first capacity, 498 MW, added in 2022[67].

[67] Petroleum Economist: France bets big on offshore wind 2020. https://www.petroleum-economist.com/articles/low-carbon-energy/renewables/2020/france-bets-big-on-offshore-wind

6.3.3 Share of the EU Market

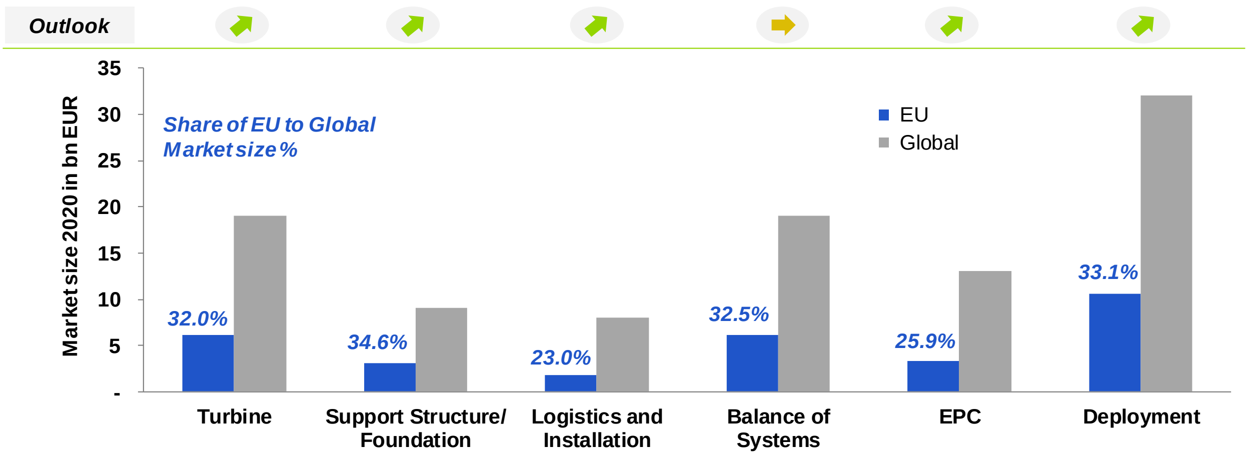
Figure 29: Share of EU-27 Market Size to Global Market, Total: 2020



Source: Guidehouse Insights (2020)

The EU-27 contributes to about 30% of the total market size in revenues. Technical know-how and project experiences give the EU-27 market players an edge as compared to the overall global market. This also reflects in the share of revenues and competitive intensity across the offshore wind supply chain. Balance of Systems including electrical infrastructure and project are offered as an integrated solution. This is expected to grow at a medium rate based on contractual agreements.

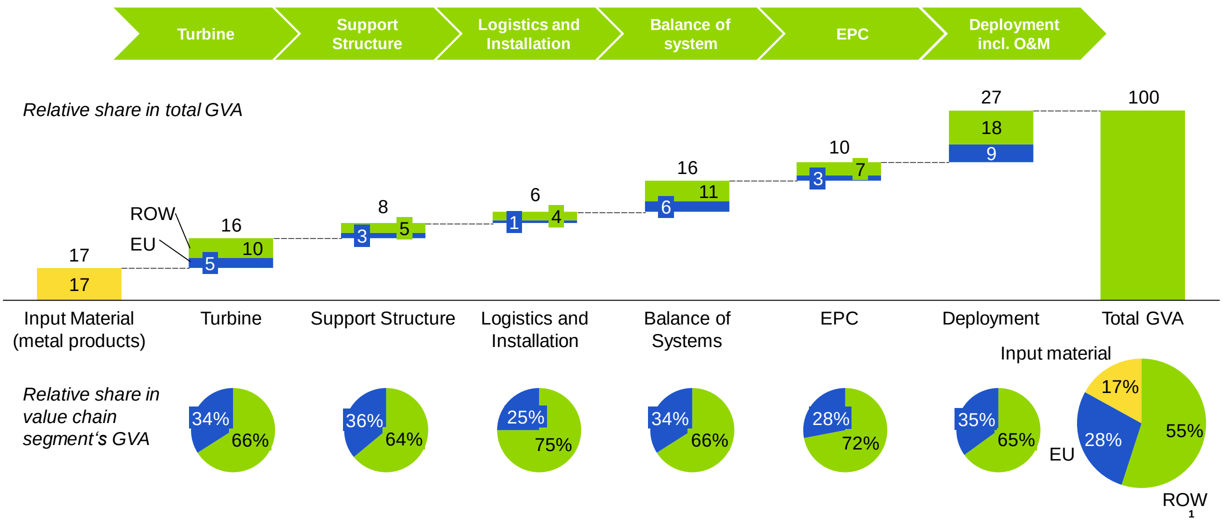
Figure 30: Share of EU-27 Market Size to Global Market, Value Chain Segment: 2020



Source: Guidehouse Insights (2020)

6.3.4 Gross Value Added

Figure 31: Breakdown of GVA throughout offshore wind value chain



Source: Guidehouse Insights (2020)

The gross value added in general resembles the market sizes for the respective value chain segment and region, adjusted for a trade surplus/deficit and the value of input material. For the offshore wind sector, the considered input material is used mainly for turbine and support structure manufacturing. The largest share of the GVA is captured by the deployment segment, where the EU manages to capture a relative share slightly higher than in the other segments.

6.4 Market Outlook

6.4.1 Drivers and Barriers

The value of the offshore wind industry to the supply chain is also impacted by changes in capital and operational costs. These costs are influenced by improvements in industry efficiency, fabrication technology, and wind turbine and foundation technology, as well as changes in material costs, market demand, commodity prices, and other factors.

As the industry gradually matures and uncertainties are reduced, both capital costs and the levelized cost of electricity (LCOE) from offshore wind facilities are expected to plateau and trend downward[68]. In addition to larger turbines and floating foundations, innovations and trends are expected to have the greatest increase in probability over the next ten years include superconducting generators and advanced tower materials. High-voltage circuitry and power converters, the development of active load-shedding rotor controls movement to serial production volumes and pre-emptive turbine response to changing wind conditions are also perceived to increase.

Innovations including floating substructures, hurricane tolerance, sea- and surface-ice tolerance, and transitional water-depth foundations are anticipated to have the greatest ability to open up new markets to offshore wind technology by mitigating the existing

[68] IRENA: Future of Wind, 2019 https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf

barriers at different scales (technology, economic, socio-political and environmental) that could hinder the deployment of wind capacities in the next three decades[69]. Grid access, public acceptance, planning procedures and planning uncertainties, economies of scale, access to finance, subsidies for traditional energy are among the key barriers. Mitigating the existing barriers immediately, through a range of supportive policies and implementation measures including innovative business models, financial instruments is vital to boost future deployment of wind capacities to enable the transition to a low-carbon, sustainable energy future.

Offshore wind project developers are willing to take market prices for electricity without a subsidy, although they are expected to protect their revenue streams with financial hedges and other mechanisms to cope with fluctuating electricity market prices[70]. Although the news of zero subsidy for offshore wind projects (Germany and the Netherlands) has been known for some time, it is no less of an achievement.

6.4.2 Raw Material Usage

According to a recent European Commission Report, EU companies are ahead of their competitors in providing offshore generators of all power ranges, due to a well-established European offshore market and the increasing size of newly installed turbines[71]. However, for the four main materials used for the production of wind rotors for example (i.e. boron, molybdenum, niobium and REEs), there is no EU production. For the other materials (i.e. cobalt, natural graphite and manganese), the EU's share of global production is below 1% (Source: EC/JRC China Flagship Report). China is the largest global supplier for about half of these materials. This does create import dependencies on rare earth materials, specifically for permanent magnets. Another risk of future material shortage arises due to the limited amount of substitutes available for many raw materials. Offshore wind towers in the future may employ concrete, composites, or other alternative materials to help combat corrosion and reduce steel content while simultaneously enabling taller hub heights. The construction of wind turbines is resource-intensive (esp. steel and concrete for foundations and towers, but also copper). Rare earth metals are used in the production of mechanical and electrical parts, but no shortages are expected.

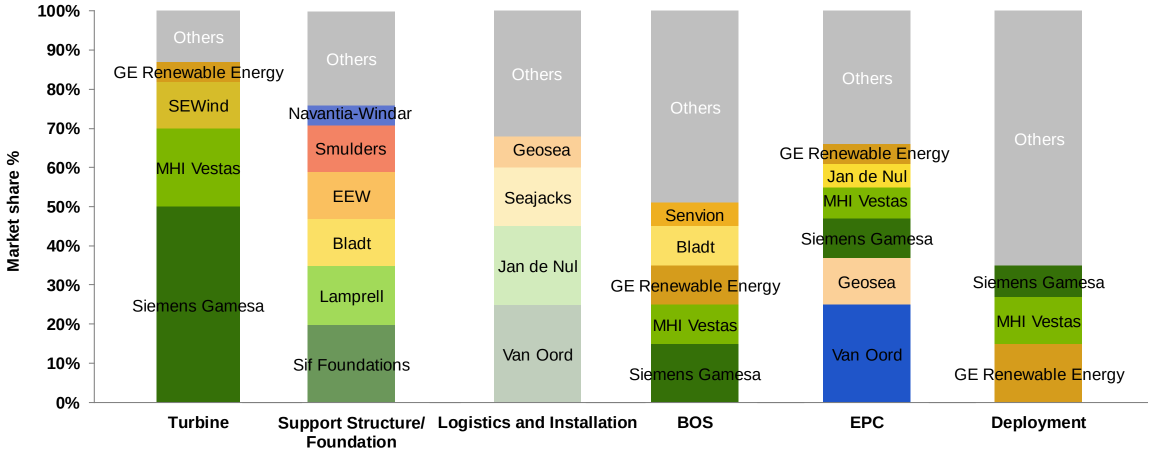
[69] IRENA: Floating foundations, A Gamechanger for Offshore Wind, 2016 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Offshore_Wind_Floating_Foundations_2016.pdf

[70] EWEA (European Wind Energy Association) The Economics of Wind Energy, 2009 https://www.ewea.org/fileadmin/files/library/publications/reports/Economics_of_Wind_Energy.pdf

[71] EC/JRC China Flagship Report (2019): https://ec.europa.eu/jrc/en/publication/china-challenges-and-prospects-industrial-and-innovation-powerhouse

6.5 Competitive Landscape

Figure 32: Top Key Market Players and Market Share, Global, 2020



Source: Guidehouse Insights (2019)

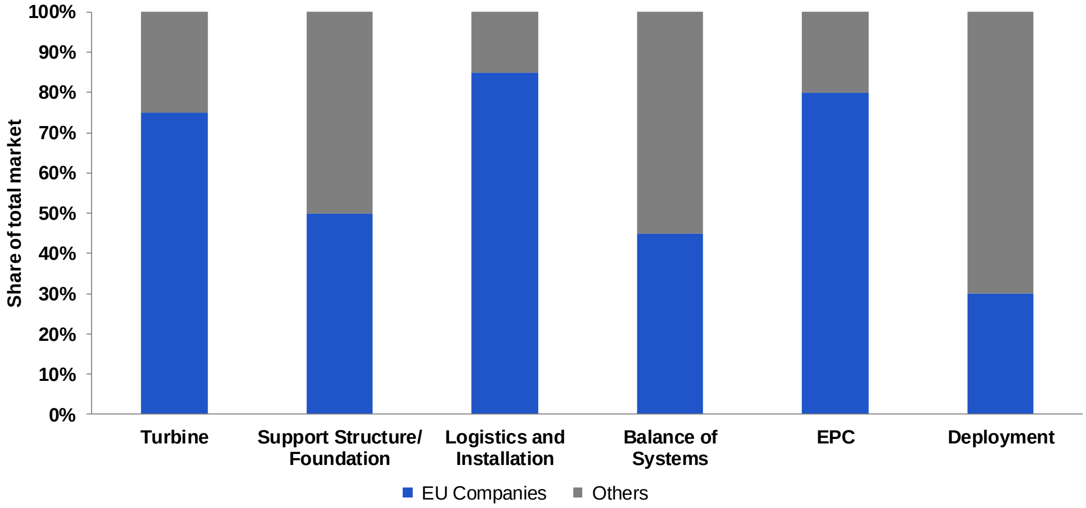
EU companies are strongest in the Turbine and EPC value chain segments. Multiple market leaders are headquartered and do a large part of their business in Europe. These include Siemens Gamesa, MHI Vestas and Jan de Nul. The turbine OEMs have leveraged their strength as equipment suppliers to vertically integrate across the value chain and offer a more consolidated solution of project owners. Digital technologies such as monitoring and control including advanced asset performance solutions are part of the deployment value chain segments and offer these companies the option of recurring revenue generation[72]. By having established relationships and brand recognition in the offshore as well as the onshore wind market they have been successful in expanding to overall project delivery solutions in Europe and rest of the world.

[72] Guidehouse Insights interviews with industry stakeholders, 2019.

6.6 Value Chain Segment Competitiveness

6.6.1 Competitive Intensity

Figure 33: Competitive Intensity across each Value Chain Segment, Global, 2020



Source: Guidehouse Insights (2020)

Figure 23 shows that the EU companies have high market share across the offshore wind space. The market is characterized by a few integrated providers, typically larger OEM vendors. The larger market players are vertically integrated across the value chain with several subcontractors working towards the constructions and installation of offshore wind turbine plants. The balance of system and deployment segments have several stand-alone providers within the respective niche technology solution offerings such as monitoring and controls and asset management. Deployment services and ongoing maintenance are also typically offered by niche software providers, leading to a competitive market dynamic across that segment.

6.6.2 New Entrants

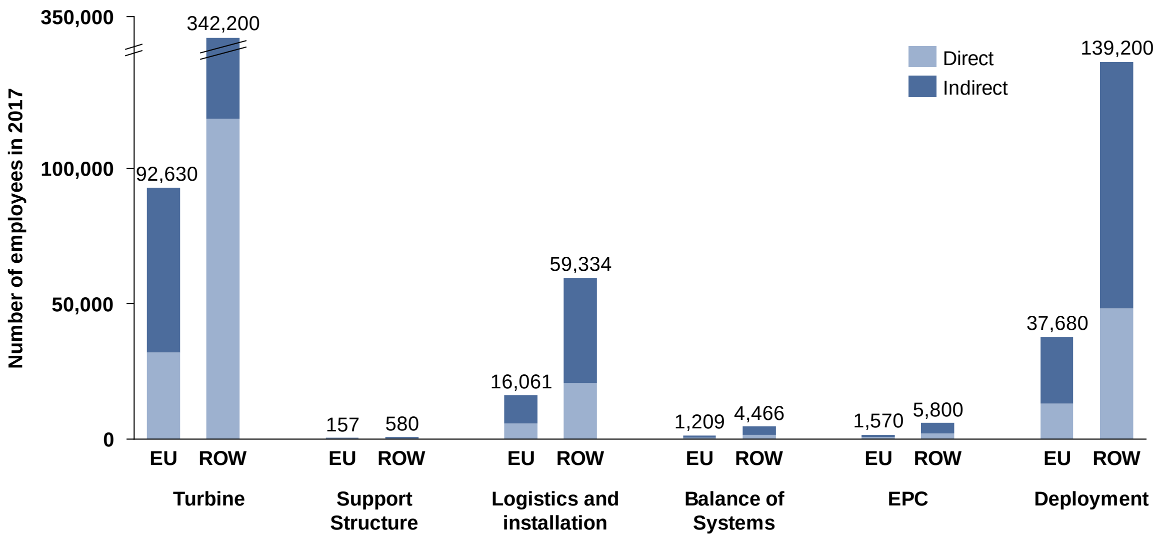
Significant barriers to entry in the offshore wind market make it difficult for new entrants to emerge. These barriers include the scale of investment needed to establish operations, the need for a track record in the industry, and a requirement for investment in port infrastructure.[73] Credibility and an established history of successful deployments are a key factor in selection throughout the value chain, preventing new companies from competing against incumbents.[74]

These barriers are reflected in the start-up funding data collected by Guidehouse. Only 14 companies were identified to have received private funding in 2019 in the offshore wind industry.[75] The EU-27 represented 29% of these start-ups.

[73] HM Government (2013)
[74] Murphy (2018)
[75] CBInsights and Crunchbase

6.6.3 Employment Indicators

Figure 34: Offshore Wind Employment by Value Chain [76] [77]



Employment values were obtained from IRENA. For offshore wind, the manufacturing of turbine value chain had the largest number of employees in both Europe and the rest of the world. Indirect jobs also formed the majority of jobs in all segments in both Europe and the rest of the world. The contribution of jobs that Europe has in offshore wind energy stands at around 25%, which is much larger than the solar employment figure. European offshore wind market creates jobs also creates employment across the region. Poland has established supply chains for the North Sea projects; economies in early offshore wind development stage benefit from the industry.

6.6.4 Trade (EX, IM)

EU27 exports to the RoW have increased steadily and the region is a net exporter in the wind energy market[78]. Top EU exporters are Denmark, Germany, and Spain. Between 2016 and 2018, 8 out of the top 10 global exporters were EU countries. Key RoW competitors are China and India. Between 2016 and 2018, the largest RoW importers were Mexico, Turkey, Chile and Pakistan[79].

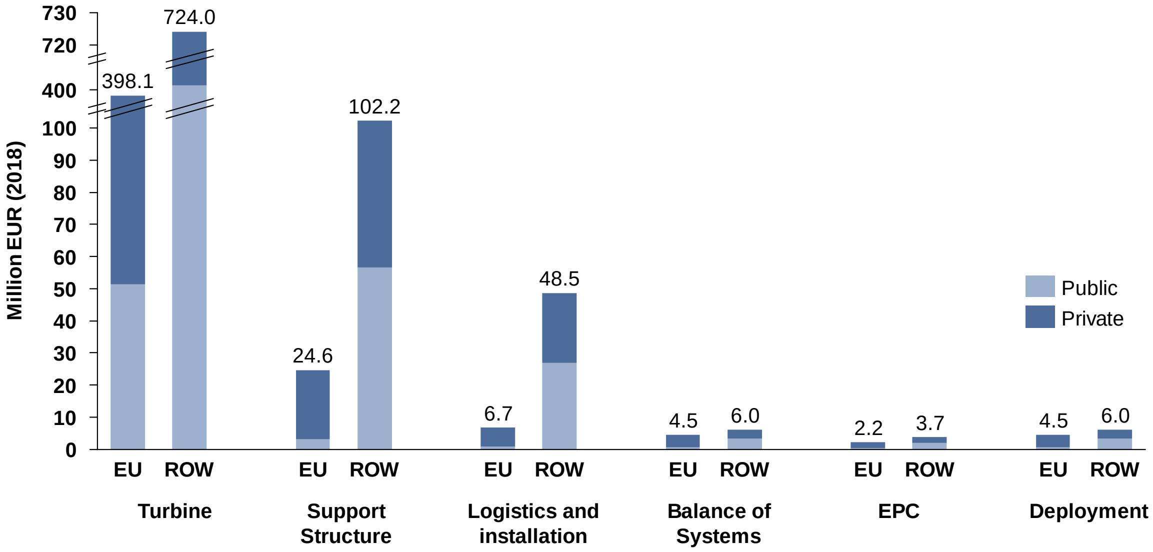
[76] IRENA (2017). Renwable Jobs annual review. https://www.irena.org/documentdownloads/publications/irena_re_jobs_annual_review_2017.pdf

[77] IRENA (2017), Leveraging for Offshore wind. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/May/IRENA_Leveraging_for_Offshore_Wind_2018.pdf

[78] Guidehouse Insights Estimates of UN COMTRADE data
[79] European Commission: DG GROW Study, 2020

6.6.5 R&I activities

Figure 35: R&D investments in Offshore Wind [80] [81]

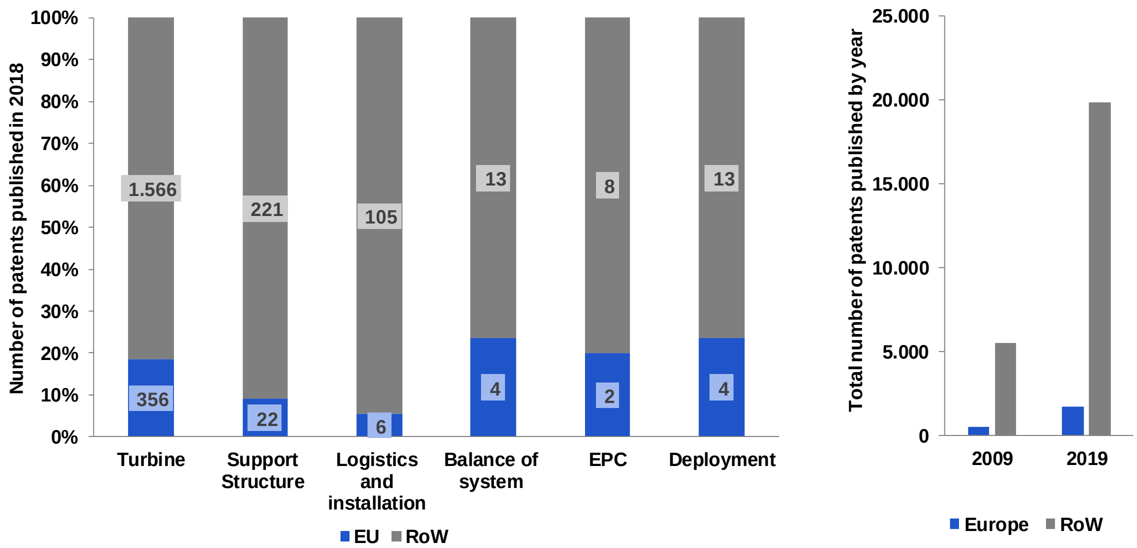


Investments were obtained from the Euroobserver for Europe and IRENA for the rest of the world. The segmentation was based on patents segmentation. The largest investment area was in the Turbine segment, followed by the support structure. Europe shares in that lie at around 20-25%. There is a smaller split in private vs. public investment in Europe when compared to the rest of the world. Europe as much larger private investment share when compared to the rest of the world, where the split lies at around 40-60 between public and private.

[80] Euroobserver (2018). The state of Renwable Energies in Europe.

[81] IRENA (2020). Investment trends in Renwable energy. https://www.irena.org/Statistics/View-Data-by-Topic/Finance-and-Investment/Investment-Trends

Figure 36: Offshore Wind Patents by Value Chain / Offshore Wind Patent Trends by Region [82]



The patenting data shows that the largest amount of research is being done in the Offshore wind turbine segment, and Europe's share in that lies at just under 20%. Overall, the share that Europe has globally increased between 2009 and 2019, but still remains at around 10%. This is likely due to the large research growth in China for wind turbine equipment.

Considering research publications and institutions, the US is the dominant player with about 80 research institutions active in wind power research (onshore and offshore), being responsible for 150 publications. Overall, there are about 140 research institutions from Horizon2020 member states active in this research field, compared to 290 in the rest of the world. These institutions' efforts resulted in about 270 (Horizon2020), respectively 560 (ROW) publications in a 5-year timeframe.[83]

6.7 Company profiles

Company & key fina ncials	Short description	Operational footprint & geographic focus	
SIEMENS Gamesa RENEWABLE ENERGY	Turbine · Support Structure/ Foundation · Logistics and installation · Balance of system · EPC · Deployment	*HQ*	▪ Zamudio, Pais Vasco, Spain
Siemens Gamesa **Turnover: EUR10.2 billion**	▪ Siemens Gamesa is the largest player in the offshore wind market, with the largest installed base and the largest order book in the industry. ▪ It has a strong position in Europe and China with a unique brand and mature value chain and strong presence in emerging markets, such as the US or Taiwan.	*R&I or Production*	▪ 7 R&I centres, 16 production facilities – across Morocco, China, India, Denmark, Germany, Spain, UK, USA, Brazil
Profit: EUR1.1 billion		*Sales*	▪ Global presence across 37 countries ▪ Spain, United States, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Denmark, Egypt, France,

[82] Google Patents database (2020)
[83] Navigant (2020) - International Strategic Partnerships in Energy

	▪ They offer state-of-the-art technologies and solutions to secure continued LCoE reductions, essential in a subsidy-free offshore market.		Germany, Greece, Hungary Italy, United Kingdom

Company & key financials	**Short description**	**Operational footprint & geographic focus**	
MHI VESTAS OFFSHORE WIND	Turbine › Support Structure/ Foundation › Logistics and Installation › Balance of system › EPC › Deployment	*HQ*	▪ Aarhus, Midtjylland, Denmark
MHI Vestas **Turnover: EUR 1,435 million**	▪ MHI Vestas Offshore Wind is a joint venture between Vestas Wind Systems A/S and Mitsubishi Heavy Industries. ▪ MHI Vestas is a provider of sustainable energy solutions that designs, manufactures, installs, and services wind turbines.	*R&I or Production*	▪ R&I centres in Europe and Asia – including Denmark, Germany, Portugal, United Kingdom, India ▪ Production centres in Europe, Asia, North America and Latin America
Profit: EUR 151 million	▪ The company has a high order backlog which provides a good foundation for future activity.	*Sales*	▪ Sales locations across Europe, Asia, North America and Latin America

Company & key financials	**Short description**	**Operational footprint & geographic focus**	
SENVION wind energy solutions	Turbine › Support Structure/ Foundation › Logistics and Installation › Balance of system › EPC › Deployment	*HQ*	▪ Germany
Senvion **Turnover: EUR 1.89 billion**	▪ Senvion ranks third in the global market of offshore wind capacity installed. The German company was previously named Repower, and previously owned by the Suzlon Group of India.	*R&I or Production*	▪ Germany
Profit: EUR78 million	▪ Its sale to US-based private equity fund Centerbridge Partners LP for EUR1 billion was completed in 2015 and it has been a publicly traded wind turbine company since ▪ In 2019, Senvion filed for self-administered restructuring proceedings after refinancing discussions with lenders did not come to a positive conclusion. ▪ Later in 2019, Senvion and Siemens Gamesa reached an agreement through which Siemens Gamesa will acquire a large part of Senvion's European Onshore Services business and an onshore blade manufacturing facility in Portugal for EUR 200 million	*Sales*	▪ Germany, the UK, and Belgium

Company & key financials	Short description	Operational footprint & geographic focus	
		*HQ*	▪ Netherlands
Sif	▪ Sif Group is leading in offshore foundations for wind turbines and oil & gas platforms. ▪ Continuous investments in production equipment and in enlarging their production capacity to produce XL monopiles up to 11 meters in diameter as well as investments in floating wind foundations ▪ In anticipation of Market developments indicate more powerful wind turbines (10-12 MW) located in deeper water Sif Group has expanded its production capacity ▪ With the addition of this extra capacity, Sif can produce and coat monopiles with a diameter of 11 meters and a maximum weight of 2000 tonnes, using lean manufacturing serial production technology	*R&I or Production*	▪ Netherlands
Turnover: EUR315 million			
Profit: EUR21.2 million		*Sales*	▪ North America – USA, Europe, Asia- Japan, Taiwan

Company & key financials	Short description	Operational footprint & geographic focus	
		*HQ*	▪ Dubai, UAE
Lamprell	▪ Lamprell provides engineering, procurement and construction services to the renewables and oil & gas energy industries successfully building multiple high-quality platforms, foundations and process modules for installation offshore to clients operating in them. ▪ While they focus on the EPC elements of the project, they also partner with leading transportation and installation companies to provide a full, seamless suite of services. ▪ Lamprell's strategic goal is to become the fabricator of choice in the offshore wind installation market. It has gained new build construction of wind turbine installation vessels for Seajacks and Fred Olsen Windcarrier	*R&I or Production*	▪ UAE – Sharjah, Jebel Ali, Hamriyah ▪ Iraq
Turnover: EUR224 million			
Loss: (EUR57.2 million)		*Sales*	▪ Globally – including North Sea and Europe

	major companies in this expanding marketplace. ▪ The offshore wind sector provides Lamprell with the opportunity to utilise its engineering skills in a fast-growing sector where there is a recognised lack of installation capacity. Having fully constructed two such vessels which are now operationing in the European market the company is currently constructing a further three of these vessel types.		

Company & key financials	Short description	Operational footprint & geographic focus	
Van Oord Marine ingenuity		*HQ*	▪ Rotterdam, Netherlands
Van Oord **Turnover: EUR2.4 billion** **Profit: EUR364 million**	▪ The company provides all-round solutions, often as turnkey projects including EPC and assumes full responsibility for entire projects. ▪ They focus on Balance of Plant contracts (BoP, all supporting components and auxiliary systems other than the wind turbines) and on transport and installation (T&I) projects. ▪ Van Oord aims to expand its current strong position in northwestern Europe with their innovative solutions, specialised equipment, and the cooperation with partners, to continue their edge in the offshore wind market. ▪ Van Oord's offshore installation vessel Aeolus, which we designed in-house, is purpose-built to transport and install foundations and offshore wind turbines. Heavy lift installation vessel Svanen is the largest crane vessel in the world, with a lifting capacity of 8,000 tonnes. The Nexus, Van Oord's first cable-laying vessel, is equipped with a deck layout that was designed and developed in-house.	*R&I or Production*	▪ Netherlands
		Sales	▪ Operates in more than 50 countries – including Netherlands, Belgium, Germany, United Kingdom,

6.8 List of Abbreviations

DER	Distributed Energy Resources
EPC	Engineering, Procurement and Construction
FIT	Feed-in-tariffs
REE	Rare Earth Elements
LCOE	Levelized Cost of Electricity
ROC	Renewables Obligation Certificates
CfD	Contracts for Difference
OEM	Original Equipment Manufacturer
C&I	Commercial & Industrial

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7 Onshore Wind

7.1 Summary

Scope	• The Onshore Wind value chain segments include turbines, support structure or foundations, logistics/ installations, balance of systems, EPC and deployment. As the wind energy market grows in emerging markets such as Asia, the outsourcing of blades to independent suppliers is gaining popularity among the OEMs as it offers a higher flexibility of supply.
Market	• According to Guidehouse Insights, the EU-27 market for onshore wind is expected to grow from EUR 25.3 billion in 2020 to EUR35.4 billion in 2030 at a CAGR of 3.4% during this period[84].
Competitive-ness of EU-27 companies	• Despite increasing globalization of the onshore wind power business, Chinese turbine manufacturers are still mainly active in their home markets and a few neighbouring countries. The European wind energy players are more broadly represented across many global markets due to increased competitiveness as an integrated value provider. • The installation and cost challenges in the wind market are driving constant improvement and innovation among top European wind OEMs to build more efficient and cost-effective wind plants. This challenge will help sustain growth in many global markets over the coming years.

7.2 Introduction

The global wind power industry is expected to install more than 600 GW of new capacity over the next decade. This new capacity translates to a market worth more than EUR 77 billion in 2019 and almost EUR 1 trillion over the forecast decade[85]. Among the markets challenged by changes in policy, many are recovering and adjusting to a new

[84] Guidehouse Insights Estimates
[85] Guidehouse Insights Estimates

normal of intense price competition. Some, such as the USA and China in the short term, are experiencing rapid near-term increases of capacity additions as one policy door closes while another opens. Despite the similarities in total shipments, turbine technology improvements have a direct impact on nacelle, blade and tower dimensions, therefore placing additional stress on turbine transport requirements.

Along the same line, turbine repowering activity further increases the number of large-scale components being transported during this peak demand period. Luckily, a majority of these shipments are comprised of shorter blades and smaller nacelles, while the number of repowering projects is limited compared with the total new unit build capacity to be commissioned[86]. Nevertheless, the repowering activity does place additional stress on the transportation industry. In the European market, strong demand and a market wide initiative to lower levelized cost of electricity has promoted different sourcing methods, with supply chain participants developing their own strategy to meet the market's needs per their corporate guidelines.

For instance, in the USA, Vestas still executes an in-house based tower production strategy for most of its installs, while GE employs multiple third-party tower suppliers exclusively[87]. A more "distributed" supply chain allows for some level of logistics optimization, as more suppliers usually means more sourcing locations. In an ideal world, depending on the project location, the closest manufacturing site would supply the necessary components to the site – although that's not always the case.

Figure 37: Introduction on Onshore Wind Value Chain

[86] Wood Mackenzie: Supply Chain bottlenecks 2019
[87] Guidehouse Insights interviews with industry stakeholders, 2019

	Turbine	Support Structure/ Foundation	Logistics and Installation	Balance of system	EPC	Deployment
Key activities	• Turbine	• Foundation	• Assembly and installation • Site Access and Staging	• Electrical Infrastructure • Development • Project Management	• Contingency • Construction Finance • Lease & Insurance • Commissioning	• O&M
Market Size (B€)	Global 66, EU 12	Global 4, EU 1	Global 12, EU 1	Global 15, EU 2	Global 12, EU 2	Global 58, EU 7
Market Growth Outlook	**Global: EU:** Increase in technological maturity	**Global: EU:** Increasing investment in tower height	**Global: EU:** Fluctuates with economic cycles	**Global: EU:** Development of local capabilities	**Global: EU:** Integration within a turnkey project	**Global: EU:** Opportunity for recurring revenues
Key Players EU	• Vestas • Siemens Gamesa • GE Renewable Energy • Enercon	• Peikko • Ramboll • Farinia Group • OWEC Tower	• Siemens Gamesa • Vestas • GE Renewable Energy • Enercon	• Siemens Gamesa • Vestas • GE Renewable Energy • Schneider Electric	• Siemens Gamesa • Vestas • Nordex	• GE Renewable Energy • Bachmann • Ingeteam
Key Players Rest of the World	• Goldwind • Envision	• Titan Wind Energy • Mabey Bridge • Suzlon Energy	• ABB	• ABB	• Wood Group • Black and Veatch	• ABB • Envision
Critical materials	• Copper • Steel • Fiberglass	• Steel and Iron • Concrete • Lattice	• Polymer materials • Copper and alloys • Aluminum	• Electronics • Polymer material • Copper and alloys	• N/A	• Electronics • Polymer material

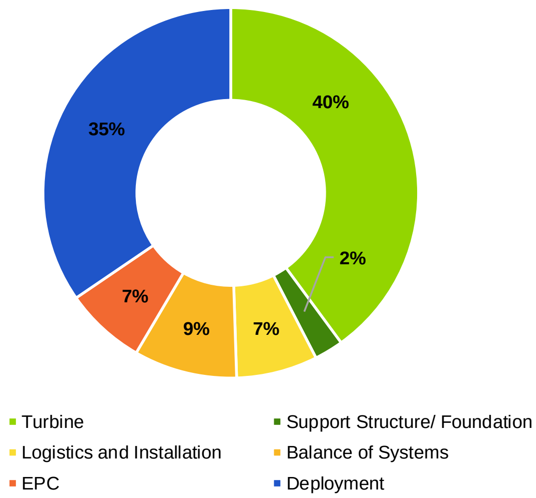
Legend: (10 year CAGR) >15% >10% >5% >0%

Source: Guidehouse Insights (2020)

7.3 Industry Value Chain Analysis

7.3.1 Value Chain Segmentation

Figure 38: Value Chain Segmentation to Total Market, Global, 2020



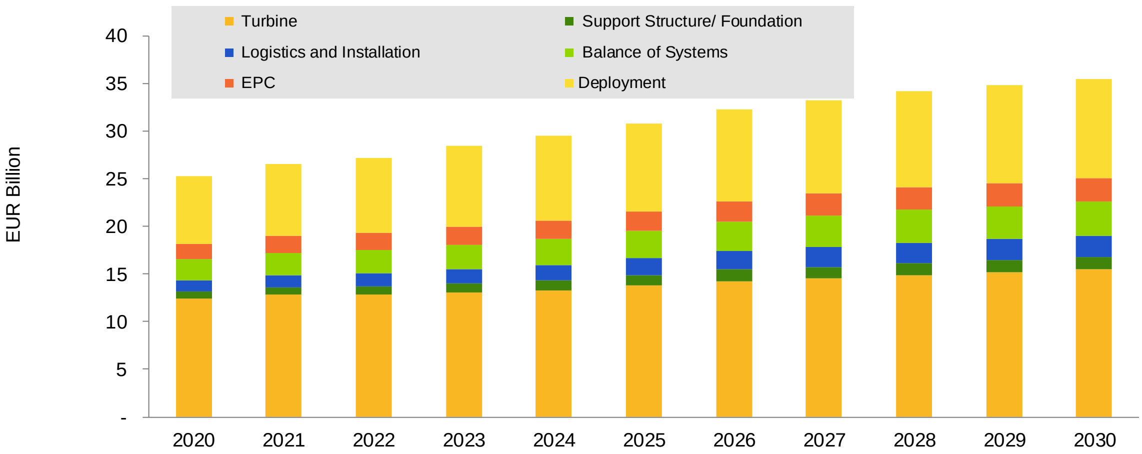
Source: Guidehouse Insights (2019)

The Onshore Wind value chain segments include turbines, support structure or foundations, logistics/ installations, balance of systems, EPC and deployment. As the

wind energy market grows in emerging markets such as Asia, the outsourcing of blades to independent suppliers is gaining popularity among the OEMs as it offers a higher flexibility of supply. The Asian independent suppliers lead the global outsourcing market of blades, power converters and towers while the European independent suppliers lead in control systems. As transformers are a standardized power transmission product, transformer suppliers are located across all major markets.
Most European manufacturing facilities are located in the country of the company's headquarter or countries with increased wind energy deployment[88]. Manufacturing related with blades, nacelles and the general turbine assembly show the highest number of facilities in Europe. 48% of active companies in the wind sector are headquartered in the EU. 7 out of the top 10 countries where these companies are located are within the EU, with the UK and Germany standing out. Specifically, for wind rotors the share of EU companies is 58%, with most headquartered in Germany, Denmark, the UK and France. Europe is for example leading in all parts of the value chain of sensing and monitoring systems for onshore wind turbines, including research and production. Historically, more patent applications in the wind energy sector have been filed in the EU than in the RoW and, in 2016, Europe was still leading in the field of patent applications[89].

7.3.2 Market Size Analysis

Figure 39: Total Annual Market Size, EU-27: 2020-2030



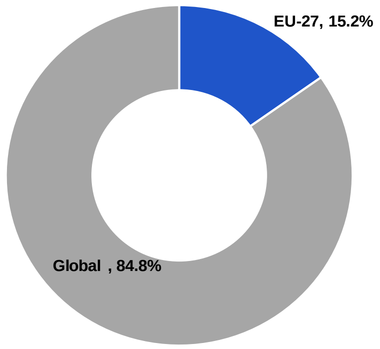
Source: Guidehouse Insights (2019)

Some countries with mature wind markets are facing flat or declining growth due to adjustments to more competitive policy environments and reductions or elimination of subsidies. Slow market growth is being offset by increasing wind power development in a variety of countries that were not historically good wind power markets. This movement is led by countries in Asia Pacific, non-traditional markets in Europe, Latin America, and the Middle East & Africa.

7.3.3 Share of the EU Market

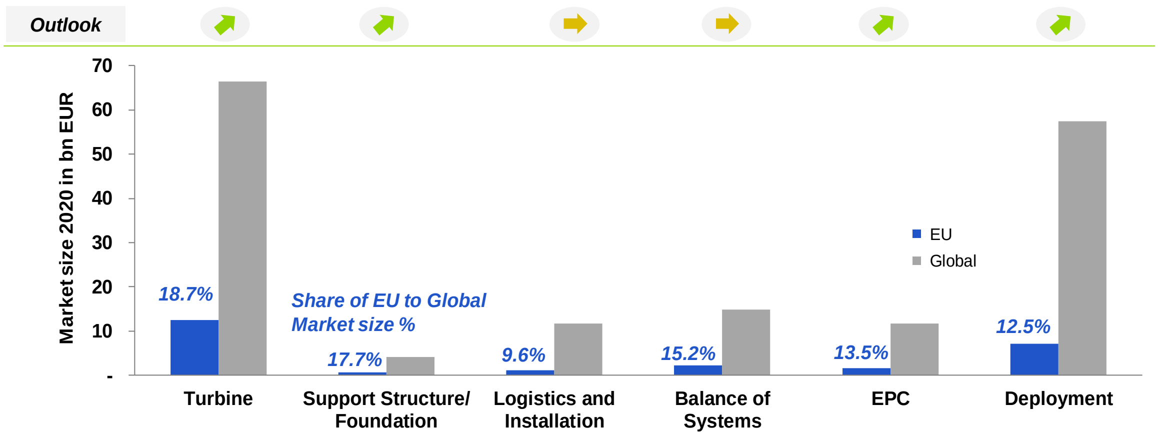
[88] Company Websites
[89] Guidehouse Insights Estimates

Figure 40: Share of EU-27 Market Size to Global Market, Total: 2020



Source: Guidehouse Insights (2019)

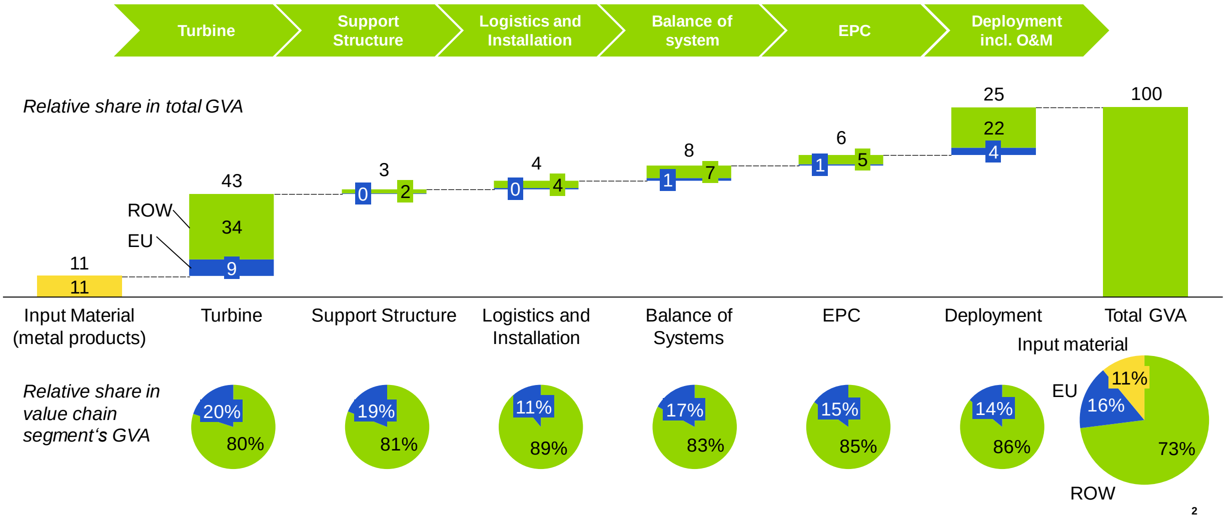
Figure 41: Share of EU-27 Market Size to Global Market, Value Chain Segment: 2020



Source: Guidehouse Insights (2019)

7.3.4 Gross Value Added

Figure 42: Breakdown of GVA throughout onshore wind value chain



Source: Guidehouse Insights (2020)

The gross value added in general resembles the market sizes for the respective value chain segment and region, adjusted for a trade surplus/deficit and the value of input material. For the onshore wind sector, the considered input material is used mainly for turbine and support structure manufacturing. The largest share of the GVA is captured by the trubine manufacturing segment, where the EU captures a relative share higher than in the other segments.

7.4 Market Outlook

7.4.1 Drivers and Barriers

Onshore wind has proven to be the most cost-effective renewable technology in contributing to an affordable and secure low-carbon energy mix. It has been, and remains, a crucial part of the energy mix, and its importance is set to grow in the future as more sites are developed.

More competitive policy environments and reductions or eliminations of subsidies also highlight an upside. The top wind turbine OEMs have responded to more challenging market conditions with constantly improving wind turbines that offer higher annual energy output, lower levelized cost of energy (LCOE) and better resiliency and reliability. These upgrades are enabling wind power to compete at the cost level against traditional fossil generation with minimal or no subsidies in the right markets and wind resource regimes.

Even with modest new electricity demand in many parts of the US, utilities and large commercial and industrial (C&I) players are motivated to purchase wind power while it is still at a reduced price, as supported by the phasing out tax credits. The boom is expected to be followed by a rapid deceleration after 2020, when wind competes purely at market cost and demand has been largely met by the previous build cycle.
Development in Europe has been challenged in recent years by the broad switch in European markets to competitive power contract auctions, which force the entire wind plant value chain to reduce costs as much as possible in order to secure contracts.

Auction and tender price caps and capacity limits further constraint development. Cost challenges are driving development from turbine OEMs of more efficient and cost-effective wind turbines, but inevitably the market condition has reduced total overall installations in some markets in the near term. The wind industry is adapting to the more challenging conditions and growth is expected to recover modestly throughout Europe to meet energy demand and as auction systems harmonize with the latest generation of more cost-effective wind turbines.

China's wind power sector is likely not to experience major downturns because of strong underlying energy demand and a wind power sector and supply chain sector that is cost efficient since so much of the supply chain is based in China, and often with state-owned or subsidized companies[90].

Some players are anticipated to weather the downturn better than others. Second-tier wind turbine OEMs stand little chance of maintaining sales and first-tier OEMs are expected to reduce capacity and staff. Some developers may shift to offshore, but that area is so specialized that European-based global developers already involved in the US offshore sector are likely to be the same majority of players 5-10 years from now. Developers in the US with no experience in offshore could find it challenging to make the shift; many developers are anticipated to shift to solar as a means to diversify.

7.4.2 Raw Material Usage

There is no EU production of the four main materials used for the production of wind rotors i.e. boron, molybdenum, niobium and REEs. For the other materials (i.e. cobalt, natural graphite and manganese), the EU's share of global production is below 1 %[91] (Source: EC/JRC China Flagship Report). China is the largest global supplier for about half of these materials. This does create import dependencies on rare earth materials, specifically for permanent magnets. Another risk, of future material shortage, arises due to the limited number of substitutes available for many raw materials. The construction of wind turbines is resource-intensive (esp. steel and concrete for foundations and towers, but also copper). Rare earth metals are used in the production of mechanical and electrical parts, but no shortages are expected.

7.5 Competitive Landscape

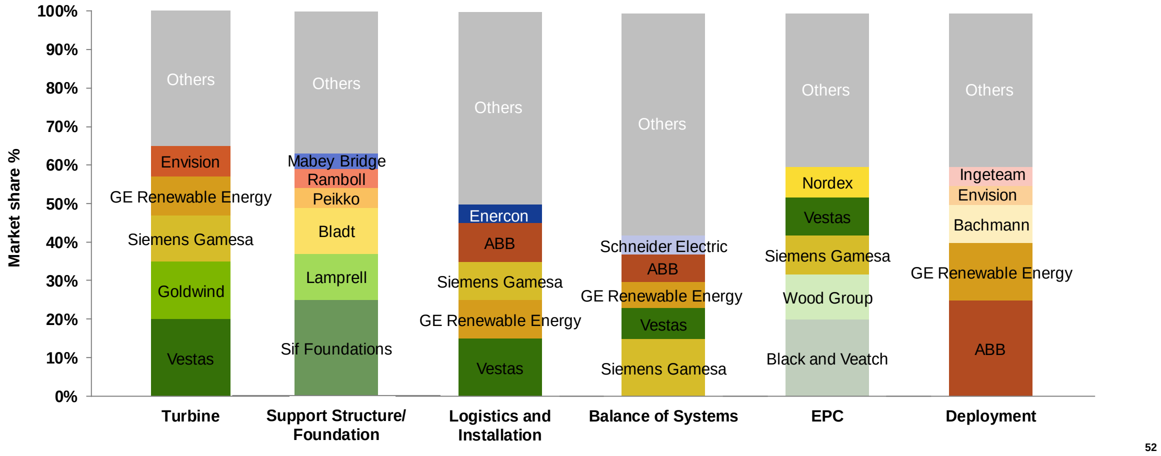
Wind turbine components are manufactured either in-house or by independent suppliers. Leading OEMs have in-house manufacturing capacity for the most critical wind turbine components. The exception is the gearbox component which is outsourced by almost all turbine vendors.

Towers for wind turbines are generally designed by each turbine manufacturer, since the entire wind turbine has to be type approved as a unit. So even if some towers are manufactured by independent producers, they are always specific for each manufacturer.

[90] IRENA: Future of Wind, Deployment, investment, technology, grid integration and socio-economic aspects, 2019. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf

[91] EC/JRC China Flagship Report (2019): https://ec.europa.eu/jrc/en/publication/china-challenges-and-prospects-industrial-and-innovation-powerhouse

Figure 43: Top Key Market Players and Market Share, Global, 2020



Source: Guidehouse Insights (2019)

Developers, turbine OEMs, supply chain sectors, and other players in the onshore market could see lower growth over the next 2 years. Turbine OEMs Enercon and Nordex, for example, have no offshore offerings and thus are confined to low growth and higher price pressure. Senvion technically has an offshore offering but the turbine OEM had entered insolvency proceedings. An overreliance on the flat European market and offshore platform lacking in size contributed to Senvion's downfall[92]. Meantime, SGRE, Vestas, MHI-Vestas, and GE are the top tier vendors with both on and offshore offerings likely to capture most of Europe's future growth.

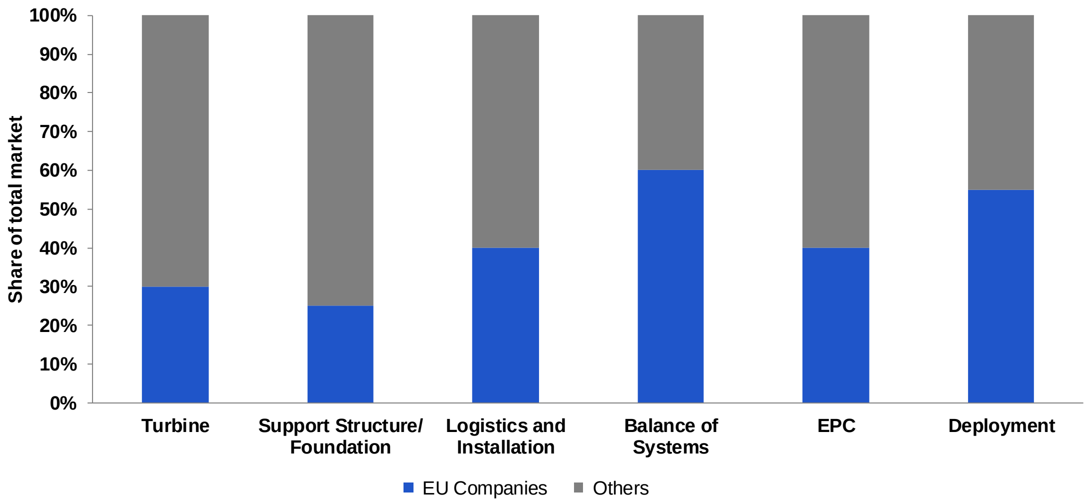
OEMs locate their manufacturing facilities not only where their headquarters are but also in countries where they supply wind turbine components and services. Gamesa (ES) and Senvion SE (DE) are exceptions; their manufacturing facilities are only placed in their country of origin. Similarly, smaller OEMs tend to have their facilities around their headquarters. Examples are: Acciona (ES), Alstom Wind (FR), Lagerwey (NL), Mervento (FI), Riablades (PO), Sway (NO) and Turbowinds (BE)[93].

7.6 Value Chain Segment Competitiveness

7.6.1 Competitive Intensity

[92] WindPower: What next for Senvion? A look at the possibilities, 2019 https://www.windpowermonthly.com/article/1590308/next-senvion-look-possibilities
[93] Company Websites

Figure 44: Competitive Intensity across each Value Chain Segment, Global, 2020



Source: Guidehouse Insights (2019)

Germany's OEMs are all facing significant challenges as their domestic German market experiences major reductions in onshore wind deployment. They are also affected by capacity reductions or flat growth in many other European markets. Enercon and Senvion are the most affected. The onsore wind power market is essentially two global markets: China, and the rest of the World. Although the Chinese turbine OEMs install an impressive number of wind turbines each year, the capacity is almost exclusively in China. Conversely, only a few Chinese OEMs install outside of China, and the capacity is minimal despite years of internationalization efforts.

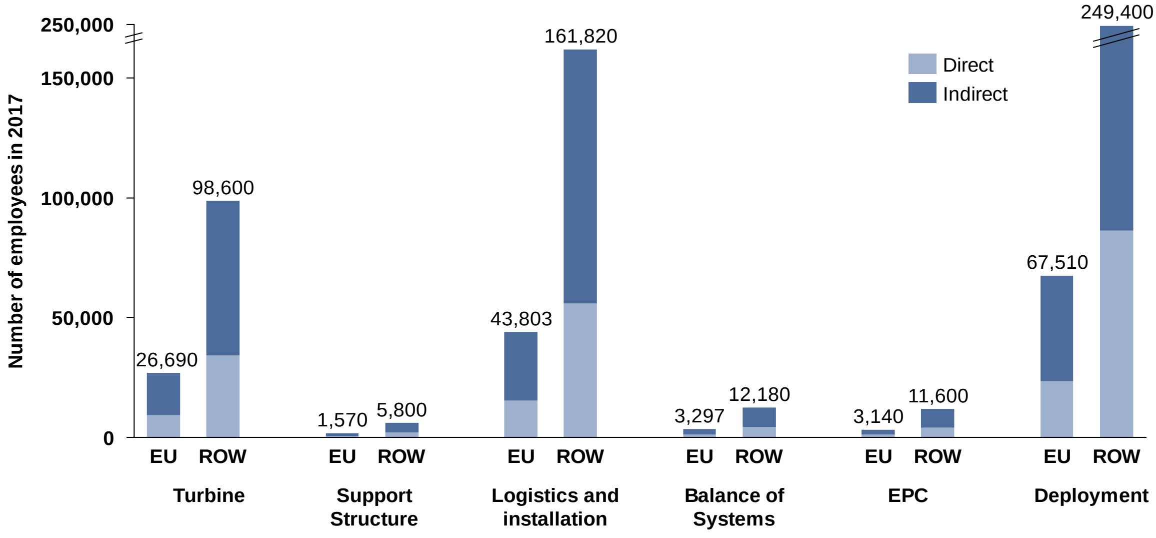
7.6.2 New Entrants

Onshore wind projects represent large investments with fierce pricing competition, driving down margins. As a result, economies of scale provide a competitive advantage which means the established industry incumbents provide strong competition. These forces create an adverse environment for start-ups throughout the value chain. Indeed, Guidehouse identified only 15 start-ups in the onshore wind value chain who received private funding in 2019.[94] Of these companies, 40% were headquartered in the EU-27.

7.6.3 Employment Indicators

[94] CBInsights and Crunchbase

Figure 45: Onshore wind employees by value chain [95] [96]



Employment figures were obtained from IRENA. The deployment value chain had the largest number of employees in both Europe and the rest of the world. Indirect jobs also formed the majority of jobs in all segments in both Europe and the rest of the world. The contribution of jobs that Europe has in onshore wind energy is quite significant here when compared to the rest of the world.

7.6.4 Trade (EX, IM)

EU27 exports to the RoW have increased steadily and the region is a net exporter in the wind energy market. Top EU exporters are Denmark, Germany, and Spain. Between 2016 and 2018, 8 out of the top 10 global exporters were EU countries. Key RoW competitors are China and India. Between 2016 and 2018, the largest RoW importers were Mexico, Turkey, Chile and Pakistan. [97]

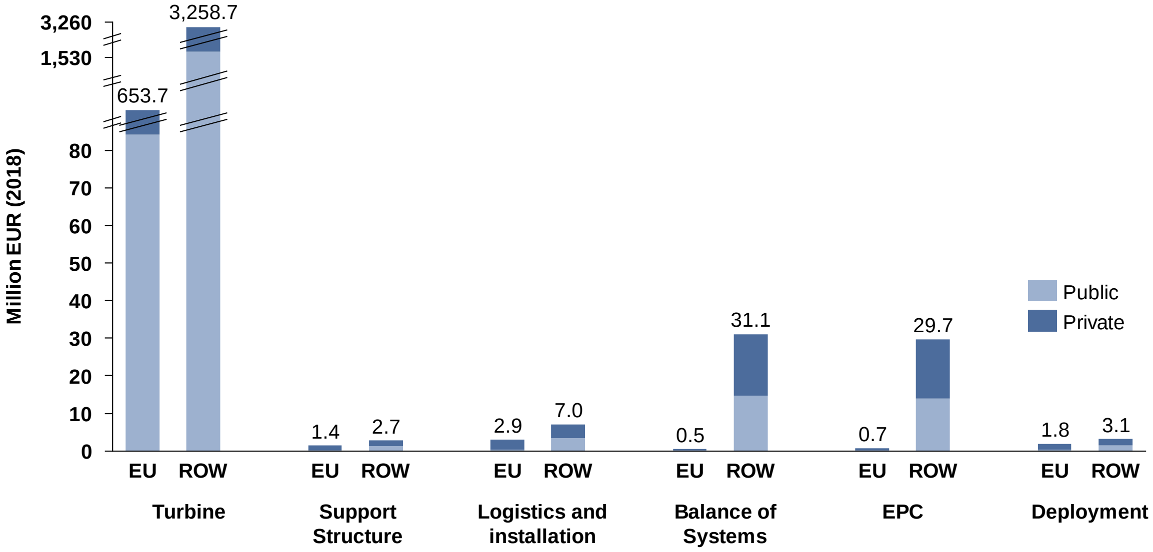
7.6.5 R&I activities

[95] IRENA (2017). Renwable Jobs annual review. https://www.irena.org/documentdownloads/publications/irena_re_jobs_annual_review_2017.pdf

[96] IRENA (2017), Leveraging onshore wind. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Jun/IRENA_Leveraging_for_Onshore_Wind_Executive_Summary_2017.pdf?la=en&hash=9E05D357E39A1E054583A3F3FB8820927C68233A

[97] European Commission: DG Grow Study

Figure 46: R&S Investments in Onshore Wind [98] [99]

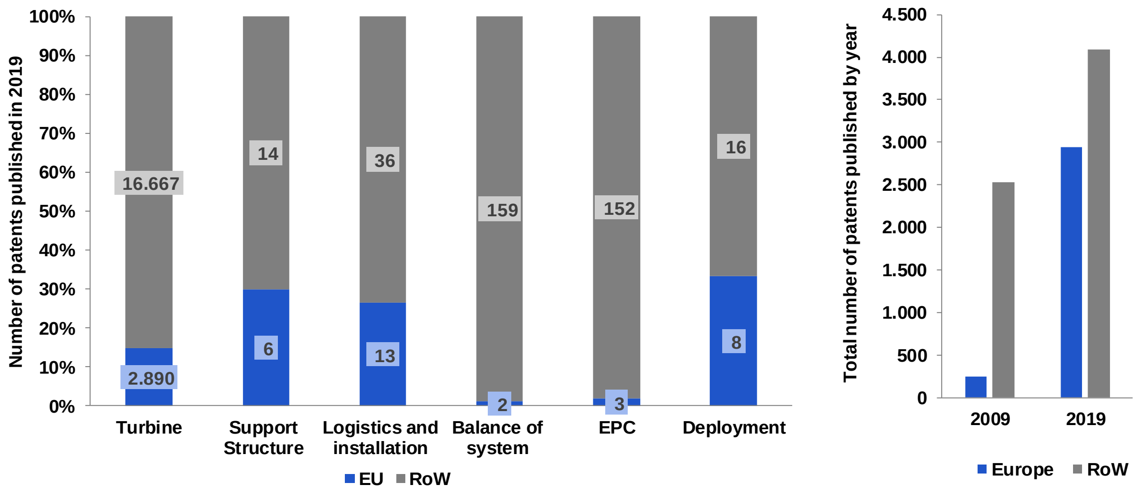


Investments were obtained from the Euroobserver for Europe and IRENA for the rest of the world. The segmentation was based on patents segmentation. The largest investment area was in the Turbine segment. Europe's share in that lies at around 25%. There is a smaller split in private vs. public investment in Europe when compared to the rest of the world. Europe as much larger private investment share when compared to the rest of the world, where the split lies at around 40-60 between public and private. Overall, there was around 3.5x more investment in onshore wind when compared to offshore wind.

[98] Euroobserver (2018). The state of Renwable Energies in Europe.

[99] IRENA (2020). Investment trends in Renwable energy. https://www.irena.org/Statistics/View-Data-by-Topic/Finance-and-Investment/Investment-Trends

Figure 47: Onshore Wind Patents by Value Chain / Onshore Wind Patent Trend by Region [100]



The patenting data also shows that the largest amount of research is being done in the onshore wind turbine segment, and Europe's share in that lies at 15%. This is slightly smaller than offshore wind. Overall, the share that Europe has globally increased between 2009 and 2019, but still remains at around 15%. This is likely due to the large research growth in China for wind turbine equipment.

Considering research publications and institutions, the US is the dominant player with about 80 research institutions active in wind power research (onshore and offshore), being responsible for 150 publications. Overall, there are about 140 research institutions from Horizon2020 member states active in this research field, compared to 290 in the rest of the world. These institutions' efforts resulted in about 270 (Horizon2020), respectively 560 (ROW) publications in a 5-year timeframe.[101]

7.7 Company profiles

Company & key financials	Short description	Operational footprint & geographic focus	
Vestas	Turbine / Support Structure/ Foundation / Logistics and Installation / Balance of system / EPC	*HQ*	▪ Aarhus, Denmark
Vestas **Turnover: EUR11.9 billion** **Profit: EUR1.1 billion**	▪ Vestas is driving the energy transition forward by focusing on three core business areas: onshore wind, service solutions and offshore wind. ▪ The company aims to expand its solutions offering to address critical steps in the renewable energy value chain, such as turnkey (EPC) projects and co-	*R&I or Production* *Sales*	▪ Denmark, Germany, Taiwan, India, Italy, Romania, the United Kingdom, Spain, Sweden, Norway, Australia, China, Brazil and the United States ▪ Globally present. The company's sales, service and supply

[100] Google Patents database (2020)
[101] Navigant (2020) - International Strategic Partnerships in Energy

	development solutions, while capturing additional value. ▪ In 2019, Vestas introduced the EnVentus™ platform, leveraging its scale, research and development investments, and experience to deliver further improvements in the annual output, cost and value of wind energy. ▪ Designs, manufactures, installs, and services wind turbines across the globe, and with more than 113 GW of wind turbines in 81 countries		chain organisation, leverages both Vestas' and Mitsubishi Heavy Industry's global experience ▪ Core markets include UK, Germany, the Netherlands, and Scandinavia

Company & key financials	Short description	Operational footprint & geographic focus	
GOLDWIN		*HQ*	▪ Beijing, China
Goldwind	▪ Goldwind offers a comprehensive turnkey menu of services including R&D, project development, turbine manufacturing, project management and after-sale service. It has an installed capacity base of 38 GW across six continents. ▪ Goldwind is principally engaged in researching, developing, manufacturing and marketing large-sized wind turbine generator sets. ▪ The company's major products include 1.5MW, 2.0MW, 2.5MW, and 3MW(S)[5] Permanent Magnet Direct-Drive (PMDD) wind turbine generators. The company also provides wind power technology services, investment and sale of wind power projects and technology transfer service	*R&I or Production*	▪ China, USA, Denmark and Germany
Turnover: EUR4.65 billion			
Profit: EUR393 million		*Sales*	▪ Europe, Asia Pacific and Americas. ▪ Regional headquarters across key regions.

Company & key financials	Short description	Operational footprint & geographic focus	
GE Renewable En		*HQ*	▪ Paris, France

GE Renewables **Turnover: EUR13.2 billion**	▪ GE Renewables held its fourth place position in the global annual rankings with 5,042 MW, representing a 10% market share. ▪ The 5,042 MW total of new installations does not include a substantial amount of partial repowering activity in the US in 2018, totalling 965 MW. Partial repowering is work of a significant nature on older wind turbines to upgrade major components, such as gearboxes and generators, and to conduct blade repairs and replacements. ▪ GE Renewables' significant repowering capacity is somewhat unique to GE because the company has the highest market share of older wind turbines installed 10-15 years ago. ▪ These instillations are targets for repowering due to age and a new 10-year cycle of PTCs GE Renewables initiated for repowering older wind projects	*R&I or Production*	▪ Brazil, Canada, China, Denmark, India, Poland, Spain, France, Turkey and the United States
Loss: (EUR575 million)		*Sales*	▪ Present globally – including Canada. USA. Brazil. Spain France. India. China, Germany.

Company & key financials	**Short description**	**Operational footprint & geographic focus**	
		*HQ*	▪ Shanghai, China
Envision **Turnover: EUR900 million**	▪ Envision rose one position in the global top rankings to fifth place in 2018 with 4,181 MW and an 8% market share. ▪ Envision is solidifying itself as the firm number two OEM in China as it almost exclusively installs in China. the company is active in parts of Latin America, but no new commissioned capacity could be confirmed for this region in 2018 ▪ In early 2016, Envision launched a new operational head office in Hamburg, Germany, to provide service to	*R&I or Production*	▪ Shanghai, and an innovation centre in Silkeborg, Denmark ▪ Battery-storage R&D centre in Osaka, Japan, a cloud service centre in Houston, and a digital innovation centre in Silicon Valley, California.
Profit: EUR112 million		*Sales*	▪ North America, Europe, Latin America, Asia and China – including Chile, New Zealand, London, Sweden,

	its international clients in European countries and a Global Blade Innovation Center in Boulder, Colorado to lead the R&D of blade design in the US.		Mexico, Germany, USA,

Company & key financials	**Short description**	**Operational footprint & geographic focus**	
ENERCON ENERGY FOR THE W		*HQ*	▪ Aurich, Germany
Enercon **Turnover: EUR4.0 billion**	▪ Enercon offers a series of different turbine models, each with its own power production capabilities. ▪ Enercon slipped one ranking place to sixth place in 2018 with 2,765 MW installed, representing 5% of the market share. ▪ This drop is partly the result of Enercon's heavy reliance on the German market, which is experiencing lower volumes of wind being built under power contract auctions ▪ Enercon wind turbines have some special technical features compared to turbines of most other manufacturers. ▪ The Enercon generator has no permanent magnets, allowing the company to not rely on rare-earth metals. However, the direct connection also causes grid losses. Rotation speed and the mechanical load changes over the service life are lower than geared systems.	*R&I or Production*	▪ Production facilities in Germany (Aurich, Emden and Magdeburg), Sweden, Brazil, India, Canada, Turkey and Portugal.
Loss: (EUR198 million)		*Sales*	▪ 37 worldwide sales offices ▪ Enercon has installed about 13,000 of its turbines in more than 30 countries; the company's primary customers include energy companies in Canada, Australia, India, and several countries in Europe and South America.

Company & key financials	**Short description**	**Operational footprint & geographic focus**	
NORDEX acciona Windpower		*HQ*	▪ Hamburg, Germany

Nordex	▪ Nordex's home market of Germany is challenged by power contract auctions, Nordex's decision to acquire Acciona's wind division in 2015 offers geographic diversification, as the Acciona wind turbine platform continues to be installed in significant numbers in Latin America ▪ With the N149/4.0–4.5, the Nordex Group was the first company to launch a turbine platform with a flexible rating as part of its core design philosophy and operation strategy. ▪ This design approach, combined with a variety of operating modes, enables the Delta4000 turbine to adapt to the grid operator's individual requirements, local wind conditions and noise constraints.	*R&I or Production*	▪ The production network comprises plants for turbine assembly and rotor blade production in Germany, Spain, Brazil, India, Mexico, Argentina and the United States
Turnover: EUR 3.3 billion			
Profit: EUR124 million		*Sales*	▪ The Nordex Group has installed wind power capacity of more than 28 GW in over 40 markets ▪ In selected markets, the Nordex Group also operates as a project developer for wind farm

Company & key financials	Short description		Operational footprint & geographic focus
peikk		*HQ*	▪ Lahti, Finland
Peikko	▪ Peikko supplies a large selection of concrete connections and composite beams for both precast and cast-in-situ solutions in a wide variety of applications including onshore wind installations. ▪ Peikko solution consists of design, manufacturing and installation of both gravity and rock foundations ▪ The wind turbine foundation design is seamlessly integrated with production and includes the relevant components – anchor cage and reinforcement. The company offers a quick shipping turnaround starting from 3 weeks.	*R&I or Production*	▪ 11 countries – North America, Europe, Middle East, China and Australia
Turnover: EUR231million			
Profit: EUR9.8 million		*Sales*	▪ 33 countries globally

	▪ Global warehousing of standard components further adds to the flexibility of delivery.		

7.8 List of Abbreviations

DER	Distributed Energy Resources
EPC	Engineering, Procurement and Construction
FIT	Feed-in-tariffs
REE	Rare Earth Elements
LCOE	Levelized Cost of Electricity
ROC	Renewables Obligation Certificates
CfD	Contracts for Difference
OEM	Original Equipment Manufacturer
C&I	Commercial & Industrial

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European Wind Energy Association (2011). Wind in our Sails

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EurObserver (2018). The state of Renwable Energies in Europe.

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European patent office (2019).

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8 Ocean

8.1 Summary

Scope	• Ocean technologies focuses on tidal and wave energy conversion: Tidal energy is the more mature of the two leading ocean technology segments. Tidal devices typically have a higher technology readiness level (TRL) than wave devices and are considered to be at the demonstration stage[102]. Wave devices are largely at the prototype stage, while ocean thermal and salinity gradient technologies are in the earliest stages of research and development. • Ocean thermal energy conversion (OTEC) and salinity gradient technologies are not in scope as they are in the earliest stages of testing and virtually no grid-connected capacity has been installed
Market	• Ocean technologies show lower levels of maturity compared to other clean technologies reviewed in this report. As there are no proper markets established, we focus on the capacity for market sizing. • As of 2020, there were ~37 MW of cumulative marine energy generation installed globally[103] Guidehouse expects the global market for ocean energy to grow to 165MW by 2030, with the EU-27 accounting for 85 MW and the rest of the world contributing the remaining 95 MW.
Competitive-ness of EU-27 companies	• Europe is the global leader in ocean energy development. It is home to the most advanced testing centres in the world, and the EU-27 accounts for a third of companies active in the ocean generation space worldwide[104]. These companies have decades of experience in developing and testing tidal devices and set the bar for similar projects in the US, China, and elsewhere. • Ocean technology generated focused interest from developers and investors in the mid-2010s, and particularly in Europe. Early acquisitions of marine start-ups by established players like Siemens and DNV-GL lent momentum to project development. However, a failure to meet technology targets in subsequent years led many OEMs to exit the market, reduced funding opportunities for

[102] ETIP. (2020). Strategic Research and Innovation Agenda for Ocean Energy. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/05/ETIP-Ocean-SRIA.pdf

[103] IRENA. (2020). Renewable Energy Statistics 2020. https://www.irena.org/publications/2020/Jul/Renewable-energy-statistics-2020. Tidal barrage and tidal range projects manually excluded.

[104] EMEC. (2020). EMEC. (2020). Marine Energy. http://www.emec.org.uk/marine-energy/

	marine energy resources, and ushered in a lull in overall innovation and development[105]. • Companies that survived early market consolidation have continued to develop, test, and improve wave and tidal technology at testing centres and research facilities around the world. Minesto, SIMEC Energy Atlantis, CorPower Ocean, and others have now tested grid-connected devices at the commercial scale. The increasing number of commercial devices has led to renewed interest and support at the national level (e.g. Minesto's project at Holyhead Deep[106]).

8.2 Introduction

This report focuses on tidal and wave energy conversion, as ocean thermal energy conversion (OTEC) and salinity gradient technologies are in the earliest stages of testing and virtually no grid-connected capacity has been installed. It looks at the competitiveness of ocean energy sector through the lenses of installed capacity, active companies across wave and tidal and the associated devices under development, as well as the patent and employment landscape and trade data. In each case, it evaluates the competitive standing of the EU-27 against the global landscape. The section concludes with project highlights and profiles of key companies in the ocean sector.

[105] Renewable Energy World. (2014). Siemens Announces Plan to Exit Marine Power Sector. https://www.renewableenergyworld.com/2014/11/25/siemens-announces-plan-to-exit-marine-power-sector/#gref

[106] Minesto. (2019a). Welsh Government awards €14.9 million of EU funding to leading marine energy developer Minesto. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE_Trends-Stats_2019_Web.pdf

Figure 48: Introduction on Ocean Value Chain

	Tidal Energy Conversion	Wave Energy Conversion	Balance of Systems	EPC	Deployment
Key activities	• Tidal range and tidal current converter device design & development	• Wave energy converter device design & development	• Project design and consulting services, mooring and component design	• Project engineering and design services	• Testing centers • Monitoring and telemetry • Grid connection
Market Size (MW)	Global 25, EU 12	Global 3, EU 2	• N/A	• N/A	• N/A
Market Growth Outlook	Nearing design convergence, major grid-connected projects	Active testing landscape, early stages	Market will grow as devices enter series production	Largely in-house, very few commercial projects	Activity concentrated in testing centers, led by individual companies
Key Players EU	• Sabella • Minesto • Andritz Hydro • Magallanes Renovables • HydroQuest SAS	• CorPower Ocean • AW-Energy • Nemos • Seabased	• N/A	• N/A	• PLOCAN
Key Players Rest of the World	• SIMEC Energy Atlantis • Hangzhou United Energy Co. Ltd	• Orbital Marine Power • Guagzhou Institute of Energy Conversion	• N/A	• N/A	• European Marine Energy Center • US Navy Testing Center
Critical materials	• Steel • Concrete • Fiberglass	• Steel • Concrete • Lattice	• Electronics • Polymer materials • Copper and alloys	• None	• None

Source: Guidehouse Insights (2020)

8.3 Industry Value Chain Analysis

8.3.1 Value Chain Segmentation

Tidal energy is the more mature of the two leading ocean technology segments. Tidal devices typically have a higher technology readiness level (TRL) than wave devices and are considered to be at the demonstration stage[107]. Wave devices are largely at the prototype stage, while ocean thermal and salinity gradient technologies are in the earliest stages of research and development.

Tidal developers are behind the earliest large-scale commercial deployments of ocean generation. Most notably, the SIMEC Atlantis Energy MeyGen project has exported nearly 25 GWh of electricity to the grid since it came online in 2016[108]. More recently, Swedish developer Minesto secured an agreement to install 2.2 MW of capacity based on its tidal kite technology in the Faroe Islands, which is expected to scale to 30-70 MW

[107] ETIP. (2020). Strategic Research and Innovation Agenda for Ocean Energy. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/05/ETIP-Ocean-SRIA.pdf

[108] Institution of Mechanical Engineers. (2020). MeyGen tidal-energy array exports electricity for whole of 2019. https://www.imeche.org/news/news-article/world%27s-largest-tidal-stream-array-has-record-201

in the coming years[109]. Ocean Energy Europe expects 5.2 MW of tidal energy capacity to be added in 2020[110].

Wave energy technologies are promising and have a wider range of potential sites than tidal stream, but they are also more nascent. At least 4.2 MW of wave energy installations are expected in 2020[111]. More than 200 wave energy devices are under development worldwide, representing dozens of potential design pathways, and the industry has yet to coalesce around a single set of design principles. This creates competition and an opportunity for developers to innovate around designs that reduce CAPEX and OPEX in a bid to make wave energy competitive with other renewable resources.

EMEC (2020) maintains a list of start-ups and companies involved in ocean energy generation.[112] While the list of 400 companies far exceeds the number with commercial promise at this time, it nevertheless provides a high-level view into the technology landscape from which new market players may emerge.

Of 400 companies, 318 (80%) were involved in tidal or wave generation, with a majority focused on wave energy conversion Figure 49 Balance of systems (BoS), Engineering, procurement, & construction (EPC), and deployment are expected to grow as more devices pass the demonstration phase and enter series production. Currently, the latter largely consists of testing centres. The emphasis on wave generation as an active development area tracks well with patent patterns and other R&I indicators, as explored in section 8.5.6.

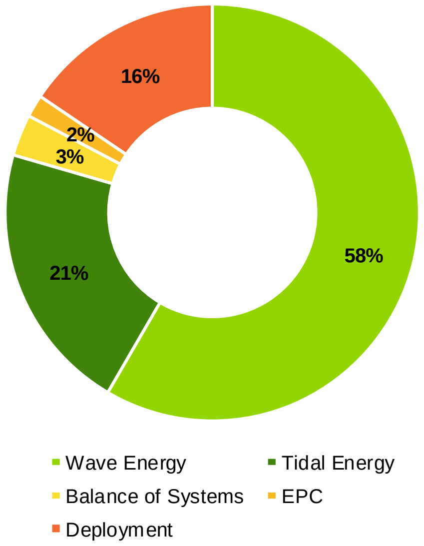
[109] Minesto. (2020). Minesto Signs PPA with Electric Utility SEV for Utility-Scale Tidal Energy Installations. https://minesto.com/news-media/minesto-signs-ppa-electric-utility-sev-utility-scale-tidal-energy-installations

[110] Ocean Energy Europe. (2020). Ocean Energy: Key Trends and Statistics 2019. Ocean Energy Europe. (2020). Ocean Energy: Key Trends and Statistics 2019. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE_Trends-Stats_2019_Web.pdf

[111] Ocean Energy Europe. (2020). Ocean Energy: Key Trends and Statistics 2019. Ocean Energy Europe. (2020). Ocean Energy: Key Trends and Statistics 2019. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE_Trends-Stats_2019_Web.pdf

[112] EMEC. (2020). Marine Energy. http://www.emec.org.uk/marine-energy/

Figure 49: Share of Ocean Companies by Value Chain Segment, Global, 2020



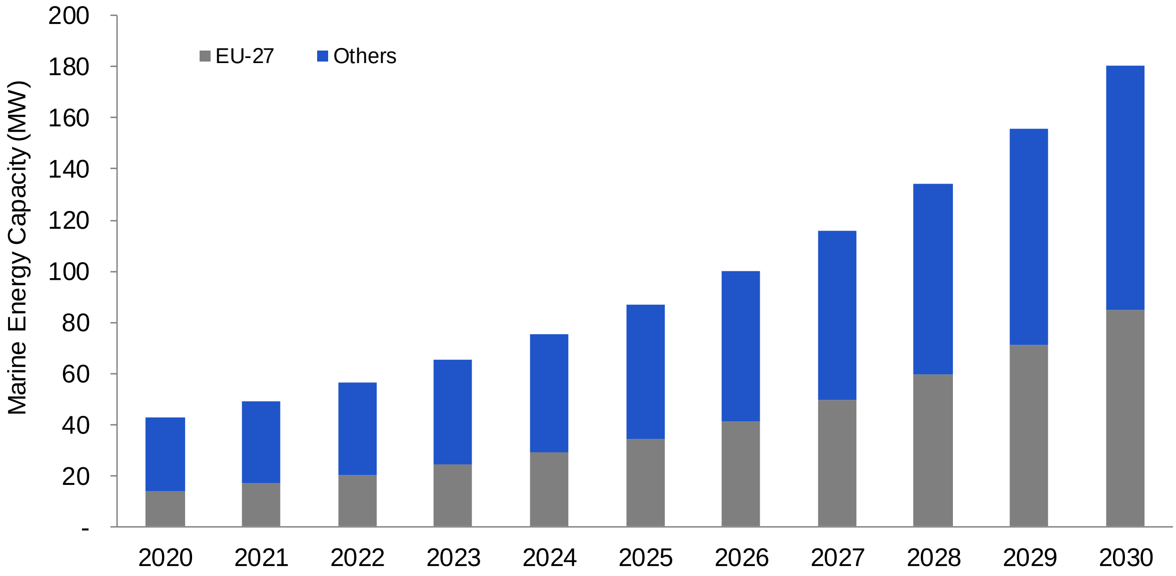
Source: Guidehouse Insights (2020)

8.3.2 Market Size Analysis

Guidehouse expects the global market for ocean energy to grow to 165MW by 2030, with the EU-27 accounting for 85 MW and the rest of the world contributing the remaining 95 MW (Figure 50). As of 2020, there were approximately 37 MW of cumulative marine energy generation installed globally[113] (Figure 51).

[113] IRENA. (2020). Renewable Energy Statistics 2020. https://www.irena.org/publications/2020/Jul/Renewable-energy-statistics-2020. Tidal barrage and tidal range projects manually excluded.

Figure 50: Total Annual Market Size, EU-27 vs Rest of World: 2020-2030



Source: Guidehouse Insights (2020)

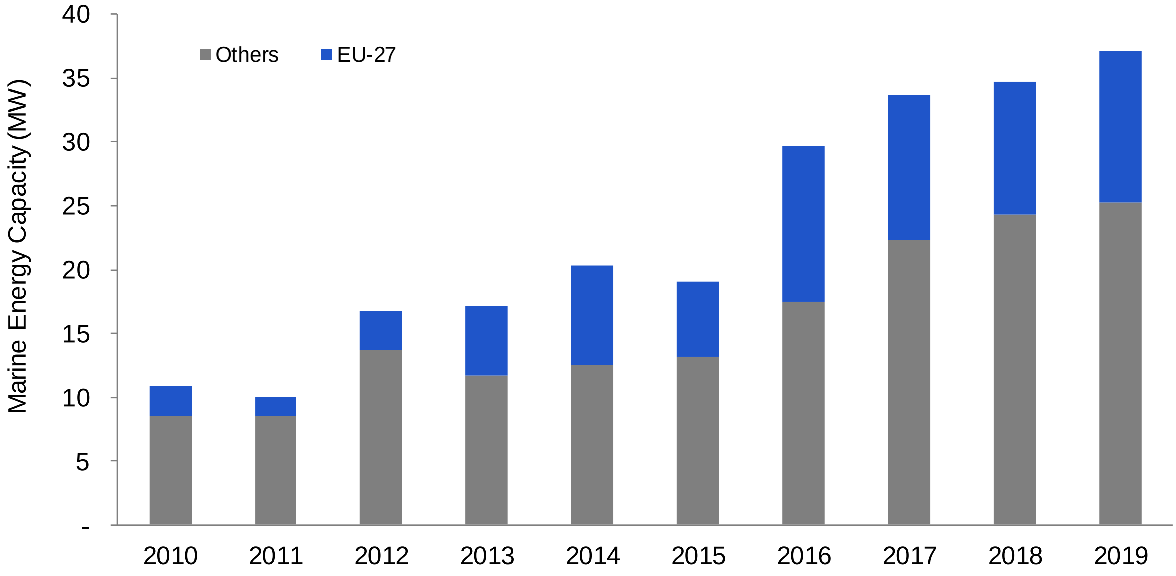
8.3.3 Share of the EU Market

Ocean Energy Europe has called for the EU-27 to install 100 MW of ocean energy capacity by 2025.[114] The EU-27 accounts for 11.9 MW, more than 30% of global capacity. Capacity numbers fluctuate year over year as some demonstration projects complete their trial periods and are decommissioned while new projects are brought online.

Though installations in the EU have increased by a factor of 10 over the last decade, present trends leave the EU-27 well short of 100 MW in 2025 (Figure 50). Strong national and private support targeted at scaling the most promising wave and tidal technologies in combination and driving down LCOE will be essential to accelerate development.

[114] Ocean Energy Europe. (2020b). Ocean energy industry calls for European target of 100MW by 2025. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/08/Press-Release-100MW-by-2025-Offshore-RES-strategy.pdf

Figure 51: Historical of EU-27 Market Size to Global Market, Installed Marine Capacity (Excludes Tidal Range)



Source: Guidehouse Insights (2020)

8.3.4 Demonstration Project Highlights

Only a handful of commercialized ocean energy projects exist around the world, with most at a small-scale testing proofs of concept. As of 2020, 34 projects were in the water around the world. Of these, more than 15 are grid-connected and 18 are located geographically in the EU-27.[115]

Key demonstration projects include:

- **Faroe Islands (Minesto).** The Faroese utility SEV and Minesto reached an agreement to integrate 2.2 MW of tidal energy conversion capacity to the Faroe Islands grid system, with plans to scale to between 30 and 70 MW of total capacity (Renewables Now, 2020). Its project portfolio also includes a 0.5 MW tidal energy conversion facility at Holyhead Deep in North Wales. Minesto is a Swedish company supported in part by funding from the EU.
- **MeyGen (SIMEC Energy Atlantis).** The MeyGen project in Scotland is one of the longest-running commercial projects, supplying power to the local electricity grid since 2016. Atlantis' tidal stream array was online for the entirety of 2019 and as of 2020 had supplied nearly 25 GWh of electricity (Institution of Mechanical

[115] Ocean Energy Europe. (2020). Ocean Energy: Key Trends and Statistics 2019. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE_Trends-Stats_2019_Web.pdf

Engineers, 2020). Three of the four turbines used in this array were produced by the Austrian manufacturer Andritz Hydro Hammerfest.

- **Morlais Tidal Stream (Sabella, HydroQuest, Magallanes Renovables)**. Morlais is in the permitting stage, but three tidal and wave developers from the EU-27 are planning to deploy testing devices in North Wales (Renewables Now, 2020).
- **Holyhead Deep (Minesto)**. Swedish tidal energy developer Minesto completed its first 0.5 MW trial of the Deep Green Tidal Kite at Holyhead Deep in 2018. A second phase of testing began in 2019 following adjustments to the launch and recovery and autonomous control mechanisms (Minesto, 2019b). Minesto has a leasing agreement for up to 10 MW of capacity at the site.
- **WaveBoost (CorPower Ocean)**. The Waveboost project, led by Swedish company CorPower Ocean, involved a pan-European consortium of industry partners. The project was a successful test of CorPower's advanced power take-off system, demonstrating a nearly 30% reduction in LCOE and providing a detailed analysis of component maintenance and survivability challenges.[116]

8.4 Market Outlook

Europe has an established history with tidal and wave generation and an edge in the global market. Though the UK's exit from the EU results in a loss of some installed capacity and expert knowledge, the EU-27 remain well positioned to lead the ocean industry. Strong national support, abundant ocean resources, and a landscape of advanced open water testing facilities foster a competitive and world-leading environment for developers.

At least 80 ocean generation developers are active in the EU-27, including 59 developers of wave energy technology and 23 developers of tidal energy conversion technology[117]. Outside of the EU-27, there is substantial development activity in the Asia Pacific, particularly in Australia (5 tidal developers and 8 wave developers), China (6 wave developers and at least 3 testing sites), and Japan (2 tidal developers and 4 wave developers).

The US has also invested significant funding in ocean research and development. The US Department of Energy Water Power Technologies Office (WPTO) announced a range of programs in 2019 to accelerate development of "next-generation" wave and tidal devices, backed by more than EUR 57 million in funding[118]. According to EMEC (2020), the US has nearly twice as many wave and tidal developers as the UK (105 against 49 in the UK). The US also has at least 13 active test sites, the most of any one country in

[116] CorPower Ocean. (2020). https://www.ri.se/sites/default/files/2020-06/WaveBoost-Results.pdf

[117] EMEC. (2020). Marine Energy. http://www.emec.org.uk/marine-energy/

[118] US Department of Energy. (2019). US Department of Energy Awards $25 Million for Next-Generation Marine Energy Research Projects. https://www.energy.gov/articles/us-department-energy-awards-25-million-next-generation-marine-energy-research-projects

the world; the US Navy Wave Energy Test Site in Hawaii has hosted recent tests from Ocean Energy, C-Power, and other developers[119].

National funding support for early-stage through commercial-scale projects is essential for the development of the ocean energy market, both in the EU and worldwide. Strong support will reduce uncertainty for private investors who are hesitant to invest in high-risk trials and demonstration projects. Industry organizations such as Ocean Energy Europe are advocating for the EU-27 to take the additional step of establishing an insurance and guarantee fund to protect investors if and when some projects fail[120]. Explicit incorporation of ocean energy in national renewable energy standards and emissions trading schemes will further accelerate growth and deployment of commercial projects.

8.4.1 Drivers and Barriers

Ocean energy is a young industry conducive to innovation and experimentation. Roughly 250 current and past start-ups have proposed or tested devices for wave, tidal, or ocean thermal energy conversion.[121] Just over 60 of these (24%) are headquartered within the EU-27, representing several dozen design pathways.

Key drivers of the market growth and competitiveness include:

- **Renewable energy targets and public funding drive innovation**. Ocean energy is a large and largely untapped source of renewable energy, and the drive to harness that energy has increased with decarbonization and renewable energy targets. Ocean Energy Europe has recently advocated for a target of 100 MW of ocean generation capacity by 2025 across the EU-27[122]. The Horizon 2020 programme, its successor Horizon Europe, and the European Regional Development fund are key sources of public funding for ocean development in Europe.
- **Tidal and wave power are stable and predictable energy sources**. European intra-day electricity markets favour resources that are reliable and predictable. Ocean energy is driven by lunar cycles and can provide this predictability, especially when buffered by co-located storage resources[123].
- **Wave energy devices have not yet converged around a standard design**. While lack of standards can hinder industry growth, it creates a rich environment for competition among start-ups. Wave energy developers have yet to consolidate around a single design pathway—a fact reflected in the larger

[119] Ocean Energy Systems. (2020). Ocean Energy Systems Annual Report 2019. https://tethys.pnnl.gov/publications/ocean-energy-systems-annual-report-2019
[120] Ocean Energy Europe. (2020b). Ocean energy industry calls for European target of 100MW by 2025. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/08/Press-Release-100MW-by-2025-Offshore-RES-strategy.pdf
[121] EMEC. (2020). Marine Energy. http://www.emec.org.uk/marine-energy/
[122] Ocean Energy Europe. (2020b). Ocean energy industry calls for European target of 100MW by 2025. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/08/Press-Release-100MW-by-2025-Offshore-RES-strategy.pdf
[123] IEEE. (2019). A Real Scale Prototype to Smooth Short-Time Power Fluctuations of Marine Renewable Energy Sources – Uliss.EMR Project. https://ieeexplore.ieee.org/document/8867355

number of wave energy patents and companies in this segment of the value chain.

- **Tidal stream technology benefits from advances in the wind industry**. Tidal stream technology is not a perfect analogue to wind power, as marine turbines experience different stresses and challenges than their above-water counterparts, but tidal energy benefits from developments in the wind industry. For example, the US National Renewable Energy Laboratory (NREL) is experimenting with next-generation thermoplastic resin turbine blades for both marine and wind applications. These blades are recyclable, do not require heat to cure, are lighter and stronger than traditional blades, and can be manufactured onsite—reducing manufacturing costs by up to 30%[124].
- **Developers are under pressure to reduce CAPEX and OPEX**. The marine environment poses unique challenges to ocean devices, and yet ocean energy developers must reduce the cost/kWh of marine energy to become cost-competitive with established renewables like offshore wind. This requires innovation at each step of project development: technological and material advancements that protect critical components from corrosion, kinetic damage, and biofouling; supply chain innovations such as shorter turbine blades that reduce upstream costs; and long-term planning for device maintenance over an expected 20- to 30-year useful life.

Marine generation faces substantial challenges in the competition against more established renewable energy resources like onshore and offshore wind. These challenges are offset somewhat by the potential to co-locate marine energy resources near existing marine infrastructure to reduce development costs. Generation resources can also be co-located. For example, German developer Sinn Power has developed a hybrid platform that combines wind, wave, and solar generation in a modular floating platform[125].

Ocean projects in the EU-27 face several numbers of barriers to competition and growth:

- **Uncertain environment for long-term private investment**. As the industry matures, it faces the challenge of re-establishing confidence among large corporations and private investors who fled the industry in the early 2010s.
- **Loss of organizations and expertise due to Brexit**. The UK has a long history of supporting ocean energy development. Its exit from the EU means a loss of some key sources of national funding, especially Wave Energy Scotland. However, collaboration between EU-27 developers and UK test sites will continue, and the EU-27 has its own active testing sites in Belgium, France, Spain, the Netherlands, and elsewhere.
- **High levelized costs relative to other renewables**. Ocean generation technologies are both CAPEX and OPEX intensive. The US DOE (2019) estimates LCOE of the earliest projects at EUR110-EUR396/MWh for wave and EUR110-

[124] US National Renewable Energy Laboratory. (2020). Advanced Thermoplastic Resins for Manufacturing Wind Turbine Blades. https://www.nrel.gov/manufacturing/comet-wind-blade-resin.html

[125] SINN Power. (2020). Ocean Hybrid Platform. https://www.sinnpower.com/floatingplatform

EUR236/MWh for tidal energy, but forecasts cost reductions of 50%-75% and 61% respectively once stable commercial scale is achieved[126]. Recent projects like Waveboost have made progress toward identifying effective pathways to drive down costs, but ocean technology is unlikely to reach cost parity with offshore wind over the next decade.

- **Uncertainty surrounding environmental impacts**. Coastal areas include some of the most biodiverse ecosystems on earth, and there is inevitable overlap between some of these natural communities and attractive sites for wave and tidal generation. Scotland took some initial steps toward outlining guidelines for environmentally responsible site selection and development in 2013[127] and sponsored additional research on the expected impacts of ocean generation on marine plants and animals. However, variation between sites, lack of standards for testing equipment and methodologies, and general lack of information on environmental impacts have led to a fragmented permitting process that drives up project costs.[128]

8.4.2 Raw Material Usage

The ocean industry has yet to consolidate around a single set of design solutions for wave or tidal generation. As no devices are currently in series production, material compositions of converters, turbine blades, anti-corrosion coatings, and balance of system components are still in the development phase[129].

Tidal stream turbines are structurally similar to offshore wind turbines and depend on many of the same materials detailed in section 6.3.1 of this report. Rotor components include boron, molybdenum, niobium, and rare earth elements for which the EU-27 has limited or no sources, which creates a dependency on Chinese exports[130]. Wave converter designs differ across device types but include generators, pumps, mooring materials, and electrical components for which no supply constraints are anticipated.

As in offshore wind turbines, structural components such as monopiles, anchors, and ballast plates that can incorporate steel, concrete, and composites.

8.5 Competitive Landscape

[126] US Department of Energy. (2019). Marine Energy Overview Appendix A. https://www.energy.gov/sites/prod/files/2019/09/f66/73355-Appendices.pdf

[127] Scottish Government. (2013). Planning Scotland's Seas Sectoral Marine Plans for Offshore Wind, Wave and Tidal Energy in Scottish Waters Consultation Draft. Available at: http://www.gov.scot/publications/draft-sectoral-marine-plans-offshore-renewable-energy-scottish-waters-consultation/pages/8/

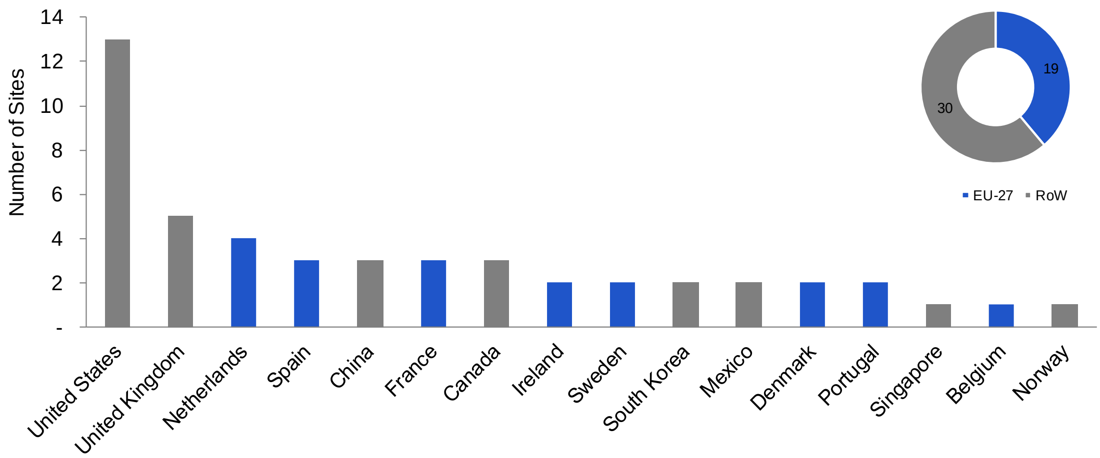
[128] US Department of Energy, Water Power Technologies Office. (2020). 2019 Project Review https://www.energy.gov/sites/prod/files/2020/04/f74/2019-wpto-peer-review-final-report_1.pdf

[129] CorPower Ocean. (2020). https://www.ri.se/sites/default/files/2020-06/WaveBoost-Results.pdf

[130] EC/JRC China Flagship Report (2019): https://ec.europa.eu/jrc/en/publication/china-challenges-and-prospects-industrial-and-innovation-powerhouse

Testing centres are essential to the development and scaling of new ocean energy devices, as they enable equipment to be tested in real-sea conditions at commercial scale, and often in a grid-connected environment. Altogether, the EU-27 is home to 19 of the 49 open ocean testing sites for ocean energy development around the world[131]. The US has the next largest group of sites at 13. In recent years, China has accelerated research and development of energy technologies across multiple sectors, with more than 20 universities focusing on tidal research.[132] It now holds the majority of ocean-related patents.

Figure 52: Open Ocean Testing Sites by Country, EU-27 vs Rest of World



Source: Guidehouse Insights (2020)

8.6 Value Chain Segment Competitiveness

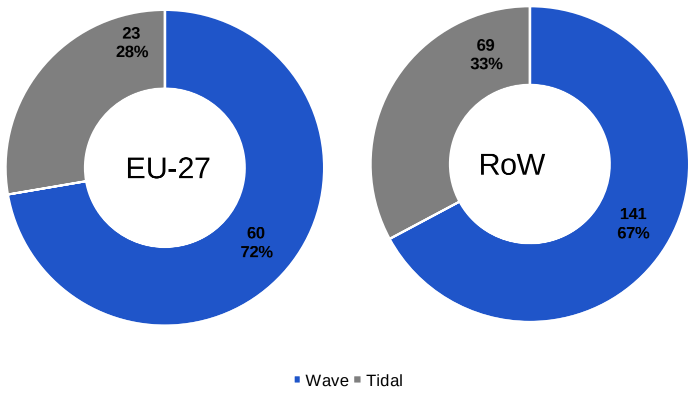
Wave energy is the most competitive value chain segment in terms of company activity with more than 236 companies engaged worldwide according to EMEC's company database[133]. Tidal stream devices have largely converged around a horizontal axis design, though exceptions like the Minesto Deep Green tidal kite have also successfully reached agreements to install tens of megawatts of capacity. More mature technology results in a smaller number of more advanced companies and fewer device designs under development in the tidal segment.

Figure 53: Ocean Energy Devices under Development, EU-27 vs Rest of World

[131] Ocean Energy Systems. (2020). Ocean Energy Systems Annual Report 2019. https://tethys.pnnl.gov/publications/ocean-energy-systems-annual-report-2019

[132] Ocean Energy Europe. (2020). Ocean Energy: Key Trends and Statistics 2019. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE_Trends-Stats_2019_Web.pdf

[133] EMEC. (2020). Marine Energy. http://www.emec.org.uk/marine-energy/



Source: Guidehouse Insights (2020)

Company-level trends are mirrored at the device level. Of 293 ocean energy devices documented by EMEC[134], 201 are wave energy converters and 92 are tidal energy converters—roughly a quarter of which are being built and tested by companies headquartered in the EU-27. Wave devices account for a quarter to a third of all devices planned, tested and deployed in the EU-27 and worldwide.

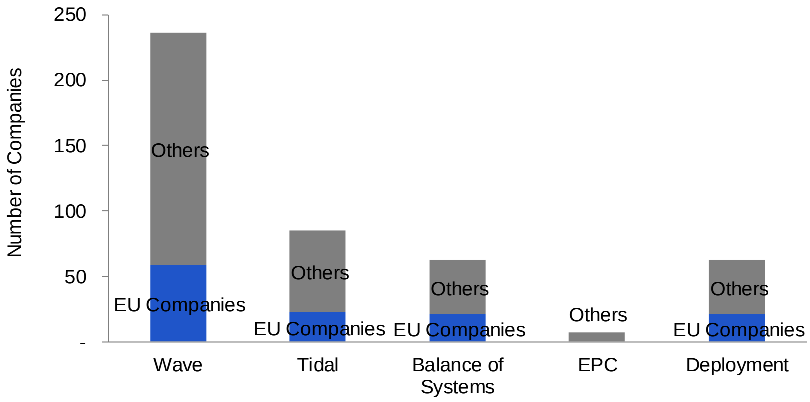
8.6.1 Competitive Intensity

Wave energy converters account for the majority of start-ups, devices in development, and patents registered. However, on a capacity basis, tidal stream technologies are closer to commercialization than wave energy devices and account for 10.4 of 11.9 MW currently "in the water" on the European continent.[135] As the industry matures, supply chains solidify, and companies begin to specialize, the share of companies in the EPC and deployment segments will grow. Currently, testing centres account for the majority of the deployment segment.

[134] EMEC. (2020). Marine Energy. http://www.emec.org.uk/marine-energy/

[135] Ocean Energy Europe. (2020). Key Trends and Statistics 2019. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE_Trends-Stats_2019_Web.pdf

Figure 54: Competitive Intensity across each Value Chain Segmaent, Global, 2020



Source: Guidehouse Insights (2020)

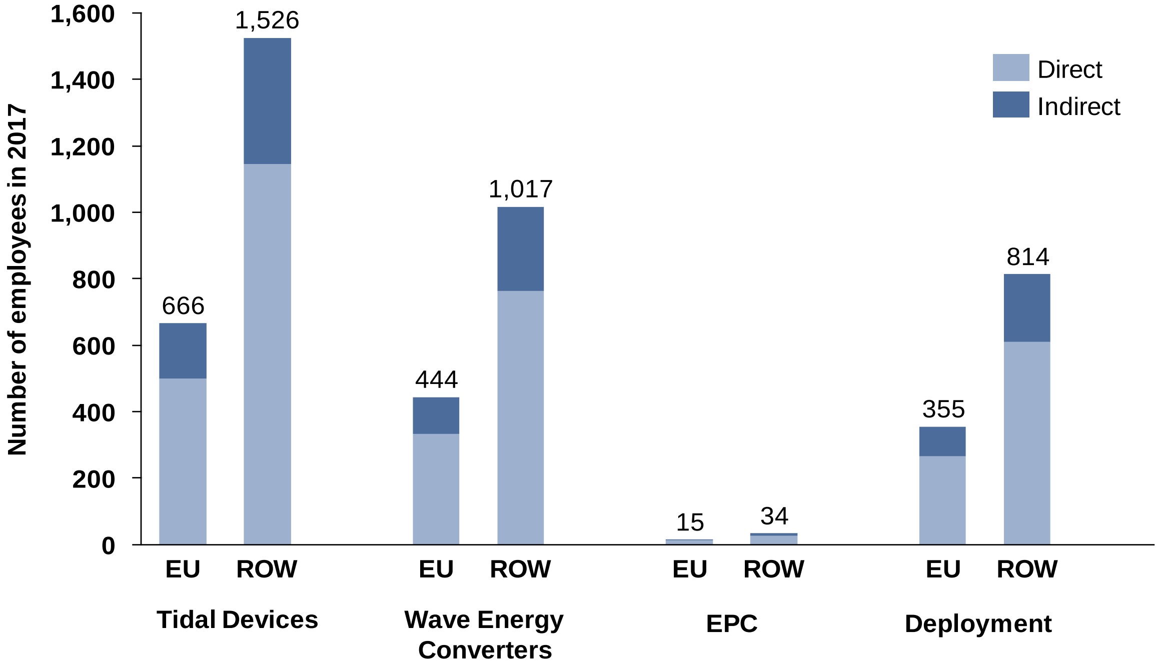
8.6.2 New Entrants

Ocean energy is still an emerging field with few commercially mature competitors. Guidehouse identified only 9 ocean energy start-ups that received private funding in 2019.[136] This partly reflects the technical maturity of ocean energy technologies; many companies remain in an early stage of development. Additionally, the large costs associated with building ocean energy are a barrier to new market entrants.

[136] CBInsights and Crunchbasel

8.6.3 Employment Indicators

Figure 55: Ocean Employment by Value Chain [137] [138]



The largest employment for the Ocean sector was in the tidal devices value chain segment for both Europe and the rest of the world. Overall, Europe makes up a large share of the global employment figure, at around 40%. Direct jobs made up 75% of the total number of jobs, while indirect jobs formed 25% in both Europe and the rest of the world. This is very different from the rest of the renewable technologies, where indirect jobs formed the majority. Europe seems to be in a very good positions when it comes to employment in Ocean energy.

8.6.4 Trade (EX, IM)

The ocean energy market is nascent and driven by the activities of individual developers who source components largely from within Europe. As no devices have yet reached series production and supply chains have not formalized or solidified, macroeconomic indicators such as import and export data are not available.[139]

The EU-27 is a knowledge centre for ocean energy development and a net exporter of technology and best practices to the rest of the world. European companies test their

[137] 2018 Annual economic report on Blue economy, - https://www.researchgate.net/publication/326033424_2018_Annual_Economic_Report_on_Blue_Economy#:~:text=The%20Annual%20Report%20on%20the,oceans%2C%20seas%20and%20coastal%20resources.

[138] IRENA (2017). Renwable Jobs annual review. https://www.irena.org/documentdownloads/publications/irena_re_jobs_annual_review_2017.pdf

[139] Guidehouse Interview with Industry Expert. (2020).

devices in facilities around the world (Canada's Bay of Fundy, the US Navy Test Centre in Hawaii, etc)[140], and cross-border collaboration is a hallmark of the industry. Of 60 ocean-related projects funded by Horizon 2020 between 2014 and 2020, 33 involved more than one participant country.[141]

As one example, the MeyGen project is operated by SIMEC Energy Atlantis, a UK company, but three of its four turbines were built by the Austrian Manufacturer Andritz HYDRO Hammerfest. The Andritz turbines included cables built in the UK, Italian and German blades and hub, a Finnish-designed gearbox, and various other components from a total of 10 countries.[142]

The ocean industry has many opportunities to benefit from advancements in from analogous industries, especially offshore wind; this includes supply chains for rotors, generators, subsea cables, and project development. European companies have the opportunity to fill gaps in the wave and tidal industry as global supply chains for ocean energy projects develop[143].

[140] Ocean Energy Europe. (2020). Ocean Energy: Key Trends and Statistics 2019. https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE_Trends-Stats_2019_Web.pdf

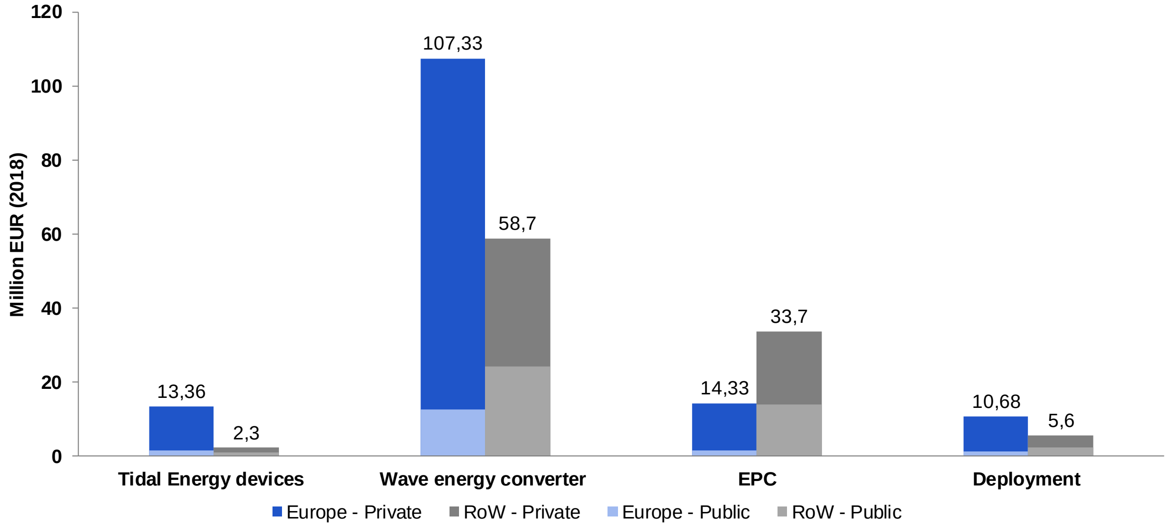
[141] EU Publications Office. (2020). CORDIS – EU Research Projects Under Horizon 2020 (2014-2020). https://data.europa.eu/euodp/en/data/dataset/cordisH2020projects

[142] Guidehouse Interview with Industry Expert. (2020).

[143] BVG Associates. (2019). Ocean Power Innovation Network Value Chain Study: Summary Report. https://www.nweurope.eu/media/8935/bvga-21187-summary-report-for-value-chain-study-r2-final.pdf

8.6.5 R&I activities

Figure 56: Ocean R&I investments by value chain step [144] [145]

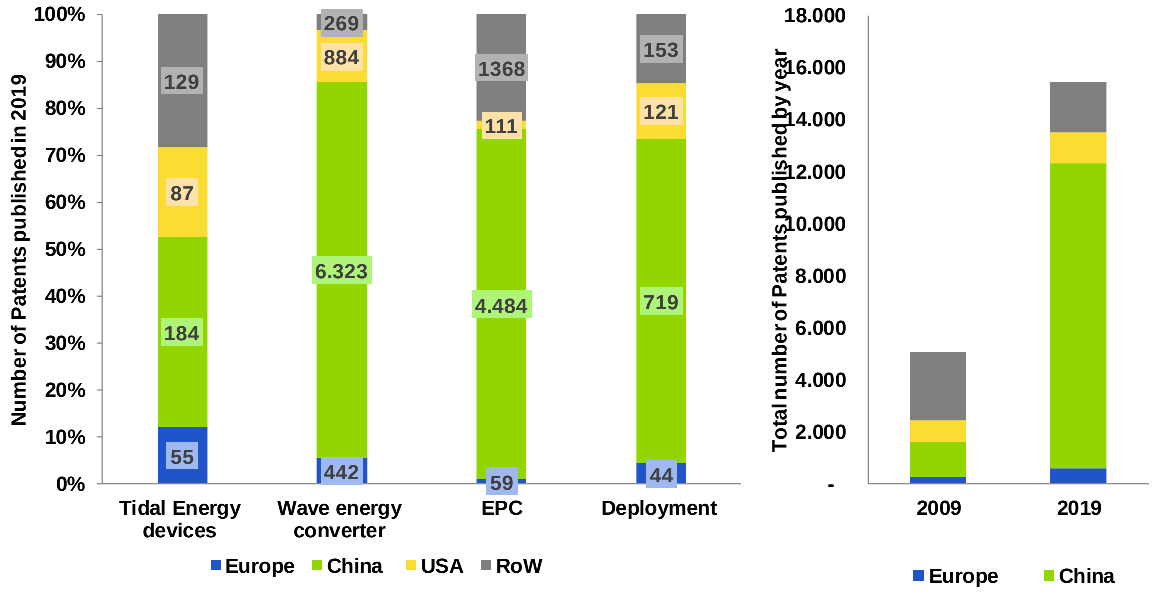


There are 320 ocean organisations in Europe and 140 were part of the H2020 research and development programme. The EU also holds 50% of the world's tidal developers, and 60% of the world's energy developers. This investment data was obtained from the report on Europe's Blue economy and from IRENA for the rest of the world. Europe dominated the overall investments for ocean energy. This is mainly due to private investment, which formed a much larger share in Europe when compared to the rest of the world. However, the rest of the world is leading Europe in only the EPC sector.

[144] 2018 Annual economic report on blue economy. https://www.researchgate.net/publication/326033424_2018_Annual_Economic_Report_on_Blue_Economy#:~:text=The%20Annual%20Report%20on%20the,oceans%2C%20seas%20and%20coastal%20resources.

[145] IRENA (2020). Investment trends in Renwable energy. https://www.irena.org/Statistics/View-Data-by-Topic/Finance-and-Investment/Investment-Trends

Figure 57: Ocean Patents by Value Chain / Ocean Patent Trends by Region[146]



Although the overall investments were higher in Europe, this was not reflected in the patenting figures. Europe only formed 3-11% of patents published in 2019 across the value chain. This is likely due to the large number of ocean energy products being produced in China. Note that patents being published in China could belong to European companies. The total number of patents more than doubled between 2009 and 2019 for both Europe and the rest of the world. The Wave energy converter segment had the largest number of patents published in all regions.

Considering research publications and institutions, the US is the dominant player with about 80 research institutions active in ocean power research, being responsible for 180 publications. Overall, there are about 170 research institutions from Horizon2020 member states active in this research field, compared to 270 in the rest of the world. These institutions' efforts resulted in about 390 (Horizon2020), respectively 510 (ROW) publications in a 5-year timeframe.[147]

8.7 Company profiles

Company & key financials	Short description	Operational footprint & geographic focus	
SIMEC ATLANTIS ENERGY	▪ Tidal Energy Conversion	*HQ*	▪ Edinburgh, Scotland, United Kingdom
SIMEC Atlantis Energy **Turnover: EUR6.7 million**	▪ SIMEC Atlantis Energy ("Atlantis") is the leading tidal energy developer behind MeyGen, the world's largest grid-connected tidal stream array.	*R&I or Production*	▪ Supply chain concentrated in the United Kingdom

[146] Google Patents database (2020)
[147] Navigant (2020) - International Strategic Partnerships in Energy

Profit: N/A	▪ Major products are the AF-1000 and AF-1500 horizontal axis turbine ▪ MeyGen generated €4.5 million in 2019, 85% of the company’s turnover ▪ Turnover doubled from €2.4 million to €4.8 million between 2018 and 2019 ▪ As of August 2020, Atlantis claimed an investment pipeline of £350 million (€387 million) and 100 MW of tidal projects under development.	*Sales*	▪ Current markets are England, Northern Ireland, France, Canada, India ▪ Planned expansion to Japan, China, and Indonesia

Company & key financials	Short description	Operational footprint & geographic focus	
Minesto	▪ Tidal Energy Conversion	*HQ*	▪ Gothenburg, Sweden
Minesto	▪ Minesto is a Swedish developer of tidal energy conversion devices that can also be used in ocean currents ▪ Its major product is the 0.5 MW Deep Green Tidal Kite (DG500), currently deployed at testing sites in Holyhead Deep (Wales) and Taiwan	*R&I or Production*	▪ Sweden ▪ United Kingdom
Turnover: EUR0.0039 million			
Loss: EUR -9.8 million		*Sales*	▪ Sweden, Wales, Northern Ireland (Faroe Islands, Strangford), Taiwan ▪ Minesto is in discussions to establish two grid-connected devices in Taiwan as part of ocean-based microgrids

Company & key financials	Short description	Operational footprint & geographic focus	
	▪ Wave Energy Conversion	*HQ*	▪ Gauting, Germany
SINN Power GmbH	▪ SINN Power is a startup that develops wave energy conversion devices, grid and mobility solutions, generators and electrical system components, and hybrid ocean platforms (solar PV and wind) ▪ The company’s major ocean product is the SP Single Module	*R&I or Production*	▪ Greece
Turnover: N/A			
Profit: N/A		*Sales*	▪ N/A

	point absorber, designed to be deployed in modular arrays. It is currently being tested at 1:1 scale in Iraklio, Greece. ▪ SINN Power had secured roughly €7.6 million in funding as of August 2020 and is participating in the Horizon 2020 MUSICA hybrid platform project		

Company & key financials	Short description	Operational footprint & geographic focus	
SEABASED	▪ Wave energy conversion	*HQ*	▪ Brevik, Norway
Seabased	▪ Seabased develops a wave energy converter based on a linear generator ▪ It signed a 100 MW deal with TC's Energy to develop wave capacity in Ghana in 2018. The project was reportedly on schedule as of April 2020, with plans to scale to 1000 MW by 2040	*R&I or Production*	▪ Norway ▪ Finland ▪ Ghana ▪ Sweden
Turnover: EUR8.7 Million (est)			
Profit: N/A		*Sales*	▪ Ghana

Company & key financials	Short description	Operational footprint & geographic focus	
Wello	▪ Wave energy conversion	*HQ*	▪ Espoo, Finland
Wello Oy	▪ Wella Oy develops the Penguin rotating mass wave energy device, which produces grid-ready electricity and has an expected 30-year useful life ▪ The company raised EUR1,710,078 in its latest funding round in 2019	*R&I or Production*	▪ UK ▪ Estonia ▪ Indonesia
Turnover: EUR8.5 Million			
Profit: N/A		*Sales*	▪ N/A

Company & key financials	Short description	Operational footprint & geographic focus	
ORBITAL MARINE POWER	▪ Tidal energy conversion	*HQ*	▪ Orkney, Scotland, United Kingdom

Orbital Marine Power	▪ Also known as Scotreneawables tidal power. Orbital Marine Power develops the floating 2 MW SR200 tidal turbine.	*R&I or Production*	▪ Orbital Marine Power is primarily active in Scotland
Turnover: EUR12.75 Million (EST)			
Profit: N/A		*Sales*	▪ The SR2000 provided 3,250 MWh of power to the Orkney grid in 2018

Company & key financials	Short description	Operational footprint & geographic focus	
	▪ Tidal energy conversion	*HQ*	▪ Graz, Austria
Andritz Hydro Hammerfest	▪ Andritz HYDRO develops and supplies tidal stream arrays, as well as associated services and products ▪ It supplied three of the four turbines that comprise SIMEC Atlantis' MeyGen project. ▪ Andrtiz HYDRO's turbine has a site-dependent rated power of 500-2000 kW and an expected useful life of 25 years.	*R&I or Production*	▪ UK ▪ Canada ▪ Indonesia
Turnover: ERU237.9 Million			
Profit: EUR122.8 Million		*Sales*	▪ UK

Company & key financials	Short description	Operational footprint & geographic focus	
	▪ Tidal energy conversion	*HQ*	▪ Quimper, France
Sabella	▪ Sabella is a French developer of tidal current turbines and arrays ▪ It produced the first marine turbine to export power to the French grid (the D10-1000). Turbine designs are site-specific. ▪ Sabella focuses on off-grid development at remote communities where electricity costs are high and fossil-fuel dependent	*R&I or Production*	▪ France ▪ UK
Turnover: EUR10 Million (EST)			
Profit: N/A		*Sales*	▪ France ▪ UK ▪ Philippines

8.8 List of Abbreviations

BoS	Balance of Systems
CAPEX	Capital Expenditures
DER	Distributed Energy Resources
DOE	United States Department of Energy
EU-27	European Union
EMEC	European Marine Energy Centre
EPC	Engineering, Procurement & Construction
GW/GWh	Gigawatt/Gigawatt-hour
LCOE	Levelized Cost of Energy
MW/MWh	Megawatt/Megawatt-hour
OPEX	Operational Expenditures
OTEC	Ocean Thermal Energy Conversion
PPA	Power Purchase Agreement
RoW	Rest of World
UK	United Kingdom
US	United States
WPTO	United States Water Power Technologies Office

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US DEPARTMENT OF ENERGY. (2019). US DEPARTMENT OF ENERGY AWARDS $25 MILLION FOR NEXT-GENERATION MARINE ENERGY RESEARCH PROJECTS. HTTPS://WWW.ENERGY.GOV/ARTICLES/US-DEPARTMENT-ENERGY-AWARDS-25-MILLION-NEXT-GENERATION-MARINE-ENERGY-RESEARCH-PROJECTS

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9 Energy Management (Digital Technologies)

9.1 Summary

Scope	• Home Energy Management systems (HEMS) and Building Energy Management systems (BEMS) are hardware, software, and services platforms that facilitate monitoring and management of energy in residential and commercial buildings. Both HEMS and BEMS range widely in sophistication and have evolved significantly with advancement in new technologies, including advanced sensors, IoT, AI, and others.
Market	• According to Guidehouse Insights, the EU-27 market for energy management technologies is expected to grow from EUR 2.5 billion in 2020 to EUR7.0 billion in 2030 at a CAGR of 10.9% during this period[148].
Competitive-ness of EU-27 companies	• EU-27 is a global leader in BEMS. Many companies headquartered in the EU have reached global BEMS leader market status in commercial energy management solutions. These include Schneider Electric, Siemens, Trane Technologies, Johnson Controls, and others. These companies' leadership role in BEMS is primarily driven by their legacy role as building controls and HVAC hardware providers. These companies have successfully leveraged their expertise in building systems to move into digital technologies and applications. • EU-27 companies do not hold the same leadership position in HEMS. The most scaled HEMS solutions offered by companies such as Oracle, Bidgely, Uplight, Itron, and others originate in North America. There is significant HEMS activity in the European market as well, especially in comparison to other regions of the world, but local companies have yet to reach significant traction.

9.2 Introduction

Home Energy Management systems (HEMS) and Building Energy Management systems (BEMS) are hardware, software, and services platforms that facilitate monitoring and management of energy in residential and commercial buildings. Both HEMS and BEMS range widely in sophistication and have evolved significantly with advancement in new technologies, including advanced sensors, IoT, AI, and others. HEMS and BEMS aggregate increasingly growing data streams to facilitate integrated management of energy technologies and resources beyond energy efficiency.

[148] Guidehouse Insights. (2019). Home Energy Management Overview. Retrieved at https://guidehouseinsights.com/reports/home-energy-management-overview
Guidehouse Insights. (2019). Intelligent Buildings Overview. Retrieved at https://guidehouseinsights.com/reports/intelligent-buildings-overview

EU-27 is a global leader in BEMS[149]. Many companies headquartered in the EU have reached global BEMS leader market status in commercial energy management solutions. These include Schneider Electric, Siemens, Trane Technologies, Johnson Controls, and others. These companies' leadership role in BEMS is primarily driven by their legacy role as building controls and HVAC hardware providers. These companies have successfully leveraged their expertise in building systems to move into digital technologies and applications.

EU-27 companies do not hold the same leadership position in HEMS. The most scaled HEMS solutions offered by companies such as Oracle, Bidgely, Uplight, Itron, and others originate in North America. There is significant HEMS activity in the European market as well, especially in comparison to other regions of the world, but local companies have yet to reach significant traction. As described in detail below, the HEM market has been transforming in the past 5 years to integrate new data streams coming from consumer smart home devices. Many key brands in smart home originated in North America, and the region is the largest market for smart home IoT, thus driving innovation in the HEM market.

[149] Guidehouse Insights. (2020). *Guidehouse Insights Leaderboard: Intelligent Building Software*. Retrieved at https://guidehouseinsights.com/reports/guidehouse-insights-leaderboard-intelligent-building-software

Figure 58: Introduction on Energy Management Value Chain

	Home energy management software (HEMS)	Commercial building energy management software (BEMS)	Commercial BEMS deployment
Key activities	Software platforms to support utilities in customer engagement, home energy analytics, alerts, etc.	Software ranging from simple building automation to advanced IoT and AI-enabled systems that enable proactive management	Integration of new hardware and software with existing building systems and legacy automation controls.
Market Size (M€)	Global: 869 EU: 299	Global: 4.095 EU: 1.164	Global: 3.648 EU: 1.037
Market Growth Outlook	**Global:** **EU:** • Emphasis on personalization and holistic view of customer • Global CAGR outpacing EU-27 growth	**Global:** **EU:** • Growth in intelligent building solutions beyond energy management • Global CAGR outpacing EU-27 growth	**Global:** **EU:** • Integration across building systems drives deeper efficiencies • Global CAGR outpacing EU-27 growth
Key players EU	• Schneider Electric	• Schneider Electric • Siemens • Trane	• Schneider Electric • Siemens • Trane
Key players Rest of the World	• Bidgely • Itron • Oracle • Uplight	• Honeywell • Johnson Controls	• Honeywell • Johnson Controls
Critical materials	• N/A	• N/A	• N/A

Legend: (10 year CAGR) >15% >10% >5% >0%

Source: Guidehouse Insights (2020)

9.2.1 Definitions and Market Trends

Building Energy Management Systems (BEMS) have evolved from simple controls to sophisticated intelligent building applications over the years. BEMS currently range in sophistication from simple tracking of energy consumption to proactive management of energy use and integration with other commercial building systems. Simple energy reporting applications may start with utility bill or utility data analysis. Heating, Ventilation, and Air Conditioning (HVAC) and lighting are the next biggest areas for energy consumption analysis because they are the largest energy-consuming equipment in a building. Deeper savings come from a more holistic approach to building energy management where all equipment works together toward better efficiency. Finally, more complex energy management systems employ sensor-driven insights that combine energy and operational efficiencies in the areas of facilities management, occupancy, asset and space management, wayfinding, and others. The current BEMS market is primarily driven by a proliferation of behind-the-meter sensor technologies, enabling more advanced analytics and visibility into a wider range of assets and technologies. Advanced metering infrastructure (AMI), typically referred to as smart meters, has not been playing a significant role in market growth.

Likewise, the home energy management (HEM) market has been undergoing significant change. Smart meters, and managing energy via the meters, home area networks (HANs), and smart appliances never materialized at scale. Instead, other technologies behind the meter have grown in importance. Smart meters still matter for HEM; the data flowing from these meters remains an important tool for utilities. But the number of other HEM information channels has grown in the past 5 years and that has altered the market's dynamics. These new data streams come from smart thermostats, smart plugs, smart lighting, as well as DERS such as solar PV, EVs, and other technologies.

More channels have meant not only an increase in the amount of energy management data but also data that is more nuanced. For instance, combining data from a smart meter, a smart thermostat, and a home's physical aspects means the insights and potential actions can be much more personal to a home and its occupants. Additionally, residential customers now also have options for efficiently managing their energy consumption without a smart meter.

As a result, utilities have had to change their thinking about how they play in the HEM space in order to engage consumers. Utilities now emphasize advanced analytics, personalization, and targeted engagement with energy users. These features have become mainstream elements of HEM solutions. Current HEM solutions range from direct-to-customer energy monitoring apps to white-label software platforms for utility customers that are then rolled out to end users[150]. All solutions support basic energy monitoring functionality, alerts, and report features. More advanced platforms support personalization and disaggregation and help identify faulty equipment or similar appliance-level data.

9.3 Industry Value Chain Analysis

9.3.1 Value Chain Segmentation

Software is the central part of the value chain within both HEMS and BEMS. Software here is defined as money spent on the digital programs, platforms, and analytics tools used to provide customers the data and processes for managing energy consumption, including interactive web portals.

Market players that have advanced software capabilities have a market advantage. Within both segments, that entails advanced data analysis capabilities, including data stream integration, predictive analytics, trend identification, and other features. All market leaders in BEMS have both advanced hardware and software capabilities. They have built on their expertise in building systems and controls to layer on analytics, IoT, AI, and other advanced digital technologies to support energy management. HEMS market leaders offer a mix of solutions. Some offer both hardware and software to enable customers to manage consumption more efficiently, while others offer software only, or a combination of software and services. The trend is toward more emphasis on advanced software as the market matures and the hardware becomes more commoditized[151].

Deployment (system integration) is critical in the BEMS value chain, facilitating integration of new hardware and software with existing building systems and legacy automation controls. BEMS market leaders hold similar market share in both software

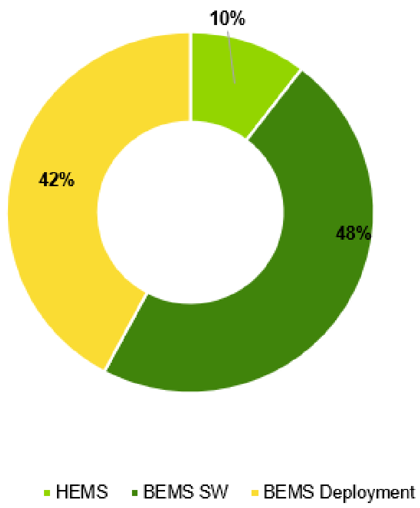
[150] Guidehouse Insights. (2019). *Home Energy Management Overview*. Retrieved at https://guidehouseinsights.com/reports/home-energy-management-overview

[151] Ibid.

and deployment segments as most advanced software BEMS solutions require system integration across different building systems. However, there are also market players that specialize in systems integration or software.

Deployment is not a separate value chain segment in HEMS, as market players bundle software and deployment services. There is opportunity to develop a separate system integration part of the value chain, as interoperability between systems and communication protocols remain a barrier in the market. Moreover, deployment of many HEMS solutions is handled behind-the-meter where consumers buy HEMS devices and software on their own, and then operate these with or without connecting to grid resources or services.

Figure 59: Value Chain Segmentation, Global, 2020[152]

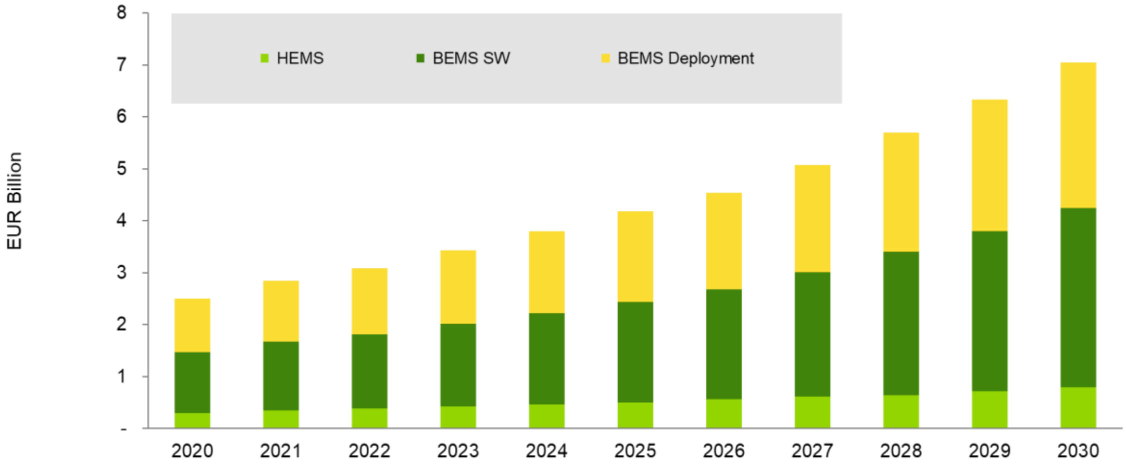


9.3.2 Market Size Analysis

The following market size forecasts for HEMS and BEMS SW include just the software revenue associated with HEMS and BEMS offerings. The forecasts do not capture hardware revenue. The BEMS Deployment forecast captures systems integration services for BEMS, including, HVAC, lighting, controls, and IoT integration.

[152] Source: Guidehouse Insights, 2020.

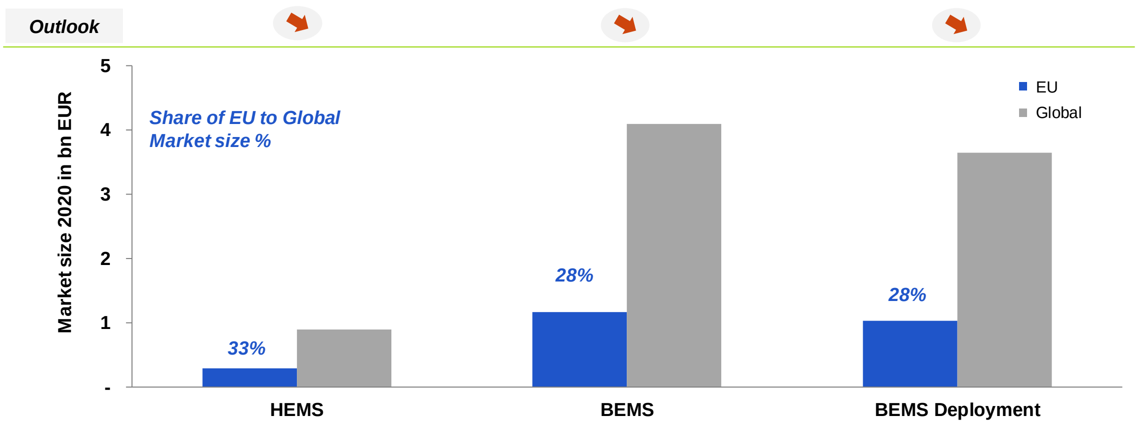
Figure 60: Total Annual Market Size, EU-27: 2020-2030[153]



9.3.3 Share of the EU Market

EU-27 holds around one third market share in HEMS, BEMS SW, and BEMS Deployment. EU-27's market share is expected to decrease over the forecast period due to more aggressive growth in other regions of the world, primarily Latin America, Middle East and Africa, but also Asia Pacific. These are currently smaller markets, but they are expected to grow at a faster pace, therefore reducing EU-27's market share.

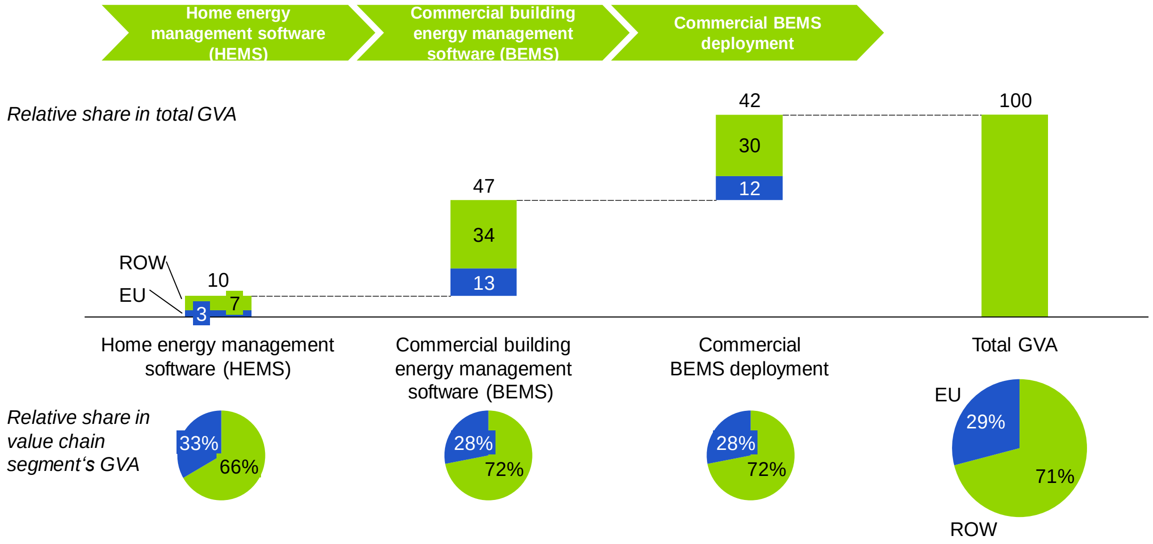
Figure 61: Share of EU-27 Market Size to Global Market, Value Chain Segment: 2020[154]



153 Source: Guidehouse Insights, 2020.
154 Source: Guidehouse Insights, 2020.

9.3.4 Gross Value Added

Figure 62: Breakdown of GVA throughout energy management value chain



Source: Guidehouse Insights (2020)

The gross value added in general resembles the market sizes for the respective value chain segment and region, adjusted for a trade surplus/deficit and the value of input material. For the energgy management sector, no input material is considered since the value chain predominantly relies on digital technologies. The largest share of the GVA is captured by the BEMS segment, out of which the EU captures a relative share slightly lower than for the HEMS segments.

9.4 Market Outlook

9.4.1 Drivers and Barriers

A wide range of forces drives the BEMS market. These drivers include:

- Energy savings and ROI improvements: Reductions in an energy bill remain the main driver in the market. Energy efficiency is a clear and transparent measure of ROI. Vendors cite examples of positive ROI from software spend, with gains in the single to low double-digit percentage range in areas such as energy consumption improvement or lower costs through predictive maintenance instead of traditional scheduled maintenance work.
- Technological advancement: BEMS software continues to evolve with advances in technology. The latest solutions use cloud and edge computing processes, and employ advanced tools and methods, such as data analytics, artificial intelligence (AI), or machine learning (ML). These technological advances result in deeper savings and additional benefits, such as proactive maintenance or space management, driving consumer interest.
- Growing acceptance among customer: Pressure is mounting for building owners and managers from occupants, customers, and even shareholders who want connected, customized, sustainable, and automated commercial spaces. Occupants are interested in healthier, more comfortable, tech-

enabled spaces – a set of expectations built on personal use of smart technologies from the smart thermostat to productivity cell phone apps. The result is a new focus on the commercial building as a business asset—a way to showcase measures of brand that create loyalty and support the bottom line.

- Energy efficiency and greenhouse gas (GHG) regulations: A driver that is unique in strength to the EU market is energy efficiency regulation. Aggressive energy efficiency and GHG targets support growth in BEMS as more and more customers become motivated by monitoring and reducing their energy use and GHG impact.

Barriers holding back adoption of BEMS market solutions include:

- Costs and ROI expectations: While ROI has been improving, customers across many segments are still reluctant to spend CAPEX or OPEX on energy efficiency improvements[155]. Multiple industries have quicker ROI expectations across all building technologies. For example, manufacturing and retail have shorter planning timeframes, and therefore are expecting much quicker returns. In contrast, education, healthcare, or government facilities engage in longer-term planning and are more open to solutions that do not demonstrate an immediate return.
- Customer scepticism: A common barrier in the market is sceptical buyers that have little experience with digital tools or need clear validation before agreeing to purchase. BEMS represents a relatively large market. However, solution penetration is lower among multiple customer segments, such as small and medium-sized buildings. With low awareness of how the technologies might works and what results they deliver, customers can be hesitant to invest in BEMS. This barrier is strongest for most cutting-edge BEMS applications that are part of broader intelligent building solution platforms. BEMS systems that consist of basic automation are less susceptible to this barrier.

A wide range of forces drives the HEMS market. These drivers include:

- Customer engagement: Utilities are moving away from a traditional centralized hub-and-spoke model toward a customer-centric approach. Increasingly, utilities are adopting digital tools for connecting with customers, reaching out more frequently than the sluggish monthly arrival of the paper electricity bill. Ongoing customer engagement is taking place via mobile, online, voice, and social network channels. Utilities now have numerous touch points to stay engaged with customers with timely and relevant information related to saving

[155] Guidehouse Insights. (2019). Energy Efficient Buildings Overview. Retrieved at https://guidehouseinsights.com/reports/energy-efficient-buildings-overview

energy. Customer engagement has become a top strategic priority for utility executives, and not simply an operational check box[156].

- Regulatory: In many jurisdictions, regulators have set energy efficiency goals or targets for utilities or energy providers to meet as they deliver service to residential customers yet do so in newer ways. These utilities are encouraged to move beyond traditional EE programs to include customer engagement approaches that involve non-traditional channels, such as mobile, that can deliver specific energy consumption alerts or cy7u90 connect[157] with the more granular functionality of smart thermostats.
- Personalization: Because of digital online channels and processes, a broad range of customers, and not just Millennials, has come to expect a more personalized engagement experience with companies. Call it the Amazon-effect, energy customers expect a similar experience when interacting with their utility, one that personalizes every touch point. For example, using a utility web portal should have the residential customer's key billing and usage information that is up to date, and enables for immediate interaction. Customers expect recommendations specifically tailored to their home for specific steps that can be taken to reduce energy use.
- Accessible hardware: Homeowners and renters now have access to more advanced hardware that provides improved energy monitoring and more granular control of energy use. For instance, smart thermostats are common and provide greater control of HVAC systems, which can lead to lower energy bills.
- Environmental concerns: A growing number of consumers have a strong desire to protect the environment and are willing to spend money on HEM solutions as a means of reducing energy consumption and simultaneously reducing their carbon footprint.

Barriers holding back adoption of HEMS market solutions include:

- Lack of standardization: Some HEM devices and the accompanying software lack the necessary standards to interoperate with other products or are part of point solutions that limit their usefulness.
- Slow-to-adopt utilities, energy providers: A long sales cycle at many utilities means advanced HEM solutions must wait for approval. Solutions can get stuck in lengthy trials, delaying the value to customers.
- Cost: Advanced HEM devices cost well beyond the price of a traditional product, meaning people of more modest means are likely to hold off adopting until prices soften. Smart thermostats are a key device for HEM. For example, a programmable thermostat costs around EUR26-EUR53 (USD30-USD60). A typical smart thermostat ranges in price from EUR150 -193EUR (USD170 to

[156] Guidehouse Insights. (2019). *Home Energy Management Overview*. Retrieved at https://guidehouseinsights.com/reports/home-energy-management-overview

[157] Ibid.

USD220)[158]. Other HEM devices, such as smart lighting or smart plugs, also come with higher costs. This price difference can be a big hurdle for many customers.

- Tepid consumer demand: Not all customers are motivated to go out of their way to reduce energy consumption by adopting HEM products or solutions. They cannot justify the added expense or hassle for new hardware when the ROI can be uncertain.

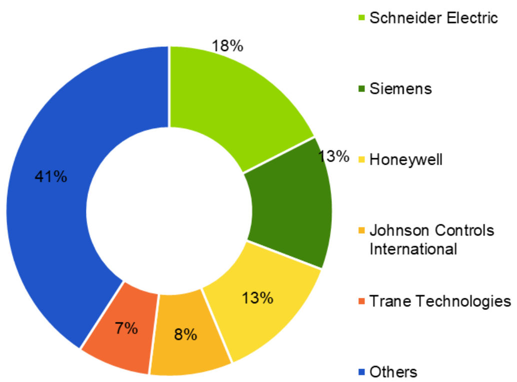
9.4.2 Raw Material Usage

There are no critical raw materials used.

9.5 Competitive Landscape

EU companies are strongest in the BEMS value chain segments. Multiple market leaders are headquartered and do a large part of their business in Europe. These include Schneider Electric, Siemens, Trane Technologies, and Johnson Controls. These companies have leveraged their legacy role as building systems hardware providers, including HVAC, controls, fire safety, access, and automation to evolve their business towards digital technologies, including advanced BEMS solutions. By having established relationships and brand recognition in the building systems market, they have been successful in expanding to software and services solutions in Europe and beyond.

Figure 63: Top 5 BEMS Market Players, Global, 2020[159]

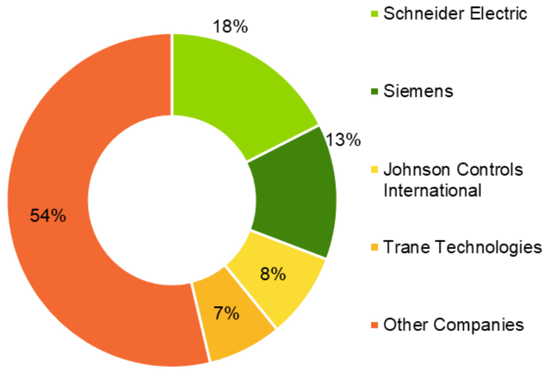


In total, EU-27-headquartered market leaders hold 46% of the global market revenue. Schneider Electric and Siemens are the largest BEMS market players, together accounting for over 30% of the BEMS market. Johnson Controls and Trane Technoogies are two other EU-27 leaders in BEMS solutions, with a cumulative market share estimated at 15%.

[158] Guidehouse Insights. (2020). *Market Data: Smart Home IoT*. Retrieved at https://guidehouseinsights.com/reports/market-data-smart-home-iot

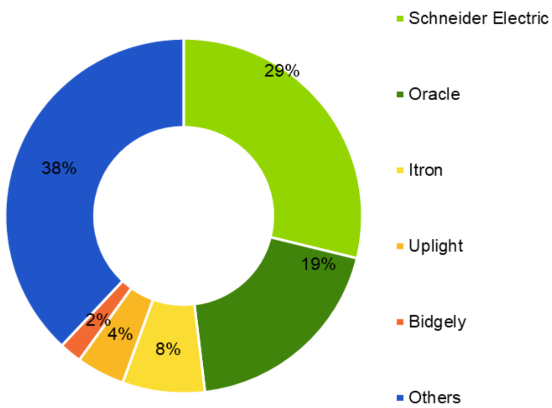
[159] Source: Guidehouse Insights, 2020.

Figure 64: Share of Top BEMS EU-27 Market Players in the Total Market, Global, 2020[160]



EU hosts fewer market leaders among HEMS players, many of which are in the United States. There is significant HEMS market activity in Europe, but fewer large established players with proven solution offerings that are utilized by many utility customers. Innovation in the HEMS market has been driven in the past few years by a proliferation of smart home devices and corresponding new data streams that consumers and utilities can leverage to improve energy management. The smart home market has had its beginning in the United States, and North America currently leads the world in smart home IoT device adoption. Consequently, most innovative HEMS solutions that emphasize data aggregation and personalization have evolved in the United States to capitalize on data-driven opportunities for efficiency.

Figure 65: Top 5 HEMS Market Players, Global, 2020[161]

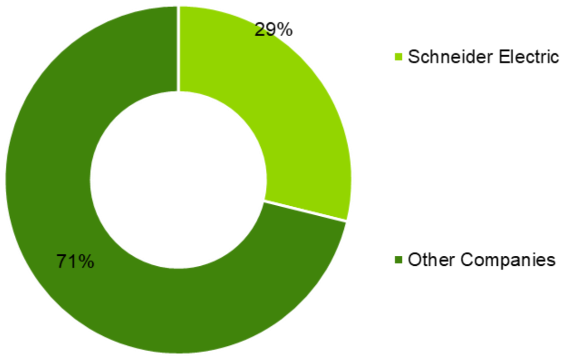


Schneider Electric is the only HEMS market leader that is headquartered in EU-27. However, it holds significant market share, estimated at 29%. Other global market

[160] Source: Guidehouse Insights, 2020.
[161] Source: Guidehouse Insights (2020).

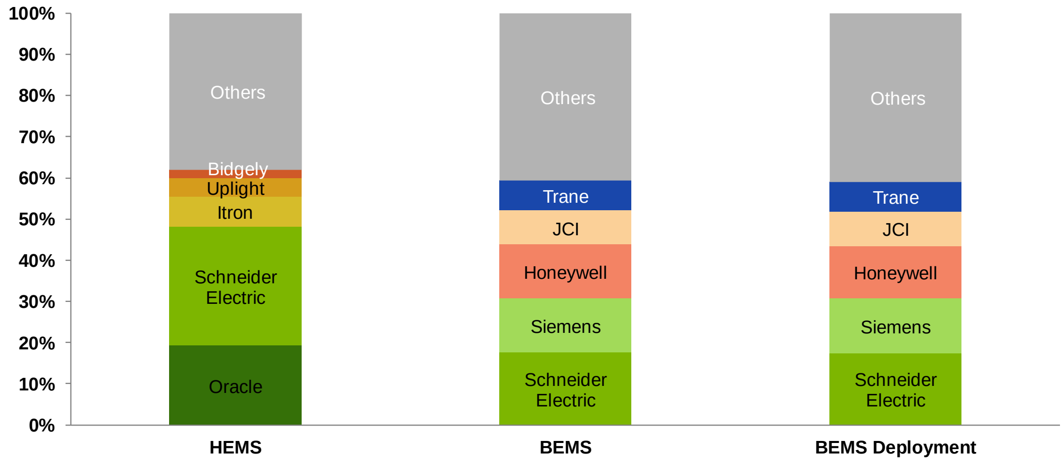
leaders, including Oracle, Itron, Uplight, and Bidegly are headquartered in the US and account for an estimated 33% of the market.

Figure 66: Share of Top HEMS EU-27 Market Players in the Total Market, Global, 2020[162]



HEMS and BEMS have a similar market share distribution between top 5 market leaders and other companies. In all segement, market leaders account for about 60% of the global market. Leading companies capture 20-30% of the total market.

Figure 67: Top Key Market Players and Market Share, Global, 2020[163]

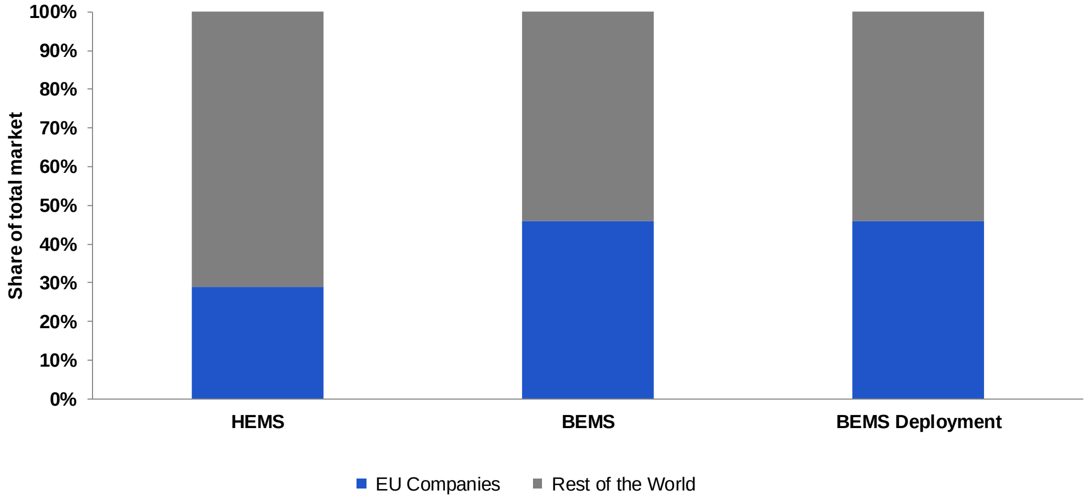


[162] Source: Guidehouse Insights (2020).
[163] Source: Guidehouse Insights, 2020.

9.6 Value Chain Segment Competitiveness

9.6.1 Competitive Intensity

Figure 68: Competitive Intensity across each Value Chain Segment, Global, 2020[164]



9.6.2 New Entrants

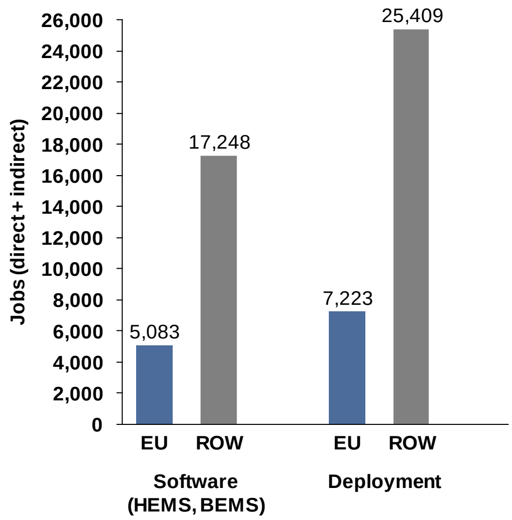
As a primarily digital environment, the energy management market has lower capital requirements than generation-based clean energy markets. Guidehouse identified 46 start-ups that received private funding in 2019.[165] Of these 46 companies, funding amount was disclosed for 40 totalling EUR 175 million. These companies are concentrated in the HEMS and BEMS value chain segments rather than the deployment segment. Indeed, the software-based nature of HEMS and BEMS creates an environment where new entrants are able to compete with low capital investment.

Of the start-ups that received private funding in 2019, 28% were headquartered in the EU-27. This is roughly in line with the share of EU-27 in the overall global market, which stands at 29% in 2020.

[164] Source: Guidehouse Insights, 2020.
[165] CB Insights and Crunchbase

9.6.3 Employment Indicators

Figure 69: Energy management Employment by Value Chain[166]



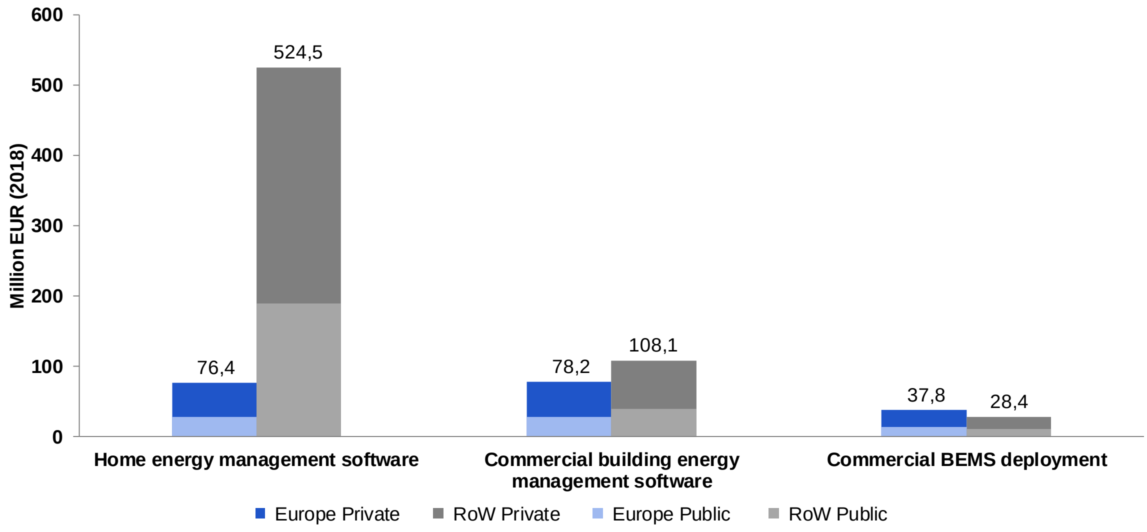
The first part of the value chain employment consisted of software development and the deployment consisted of downstream operation and management. The employment figures were based on a multiplying factor provided by the source [167], and the market sizes for Europe and the rest of the world. Figure 58 shows that most employment lies on the deployment side of the value chain rather than software development, which is what is expected in jobs for digital technologies. Overall, Europe seems to be in a very good position.

9.6.4 R&I activities

[166] Robert Atkinson, Daniel Castro and Stephen Ezell (2009). The digital road to recovery: A stimulus plan to create jobs, boost productivity and revitalize America. https://itif.org/files/roadtorecovery-details.pdf?_ga=2.55192171.1383099122.1595350138-1426202233.1595350138

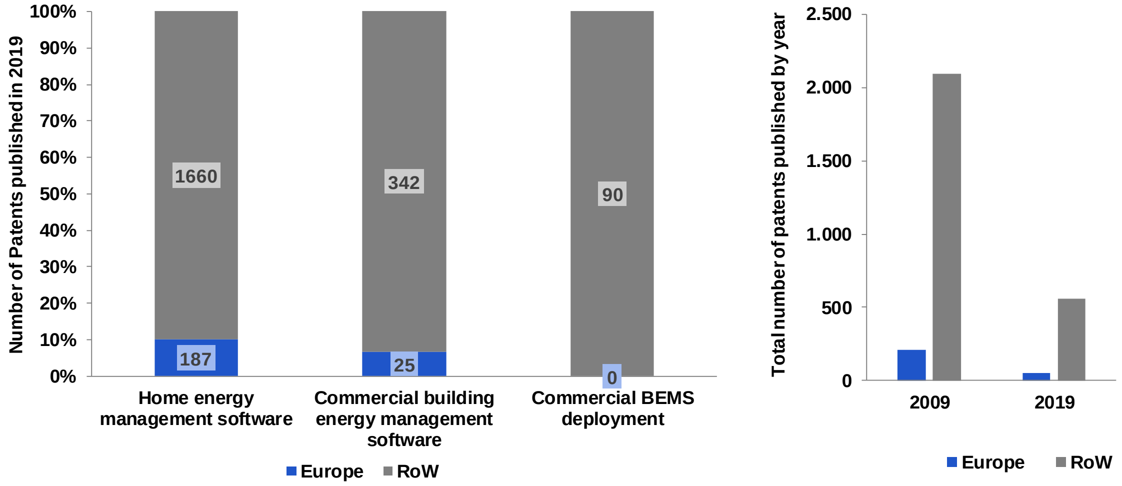
[167] Robert Atkinson, Daniel Castro and Stephen Ezell (2009). The digital road to recovery: A stimulus plan to create jobs, boost productivity and revitalize America. https://itif.org/files/roadtorecovery-details.pdf?_ga=2.55192171.1383099122.1595350138-1426202233.1595350138
Note: We used an employment factor (jobs per invested dollar), taken from this source. The employment figures have been calculated using this factor from literature and the current market size estimations by GHI.

Figure 70: R&D investments Energy management [168] [169] [170]



The investment figures for Europe were obtained from ETIP SNET and are based on the demonstration projects in Europe. There projects are coordinated by Research & Innovation stakeholders (research centres, universities, consultants, etc.), regulated operators (TSOs and DSOs), energy technology providers, ICT and software providers and energy suppliers. For the rest of the world, an estimation was made based on the market size. In Europe, the public investments are part of the H2020 programme and are estimated at 35% according to ETIP SNET in 2018. Overall, the research investments in both Europe and the rest of the world are very similar, where Europe leads commercial BEMS deployment research while the rest of the world leads HEMS and BEMS software research.

Figure 71: Patents [171]



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168 ETIP SNET (2018), Presentation of recent and ongoing R&I projects in the scope of the ETIP SNET. https://www.etip-snet.eu/wp-content/uploads/2018/11/Project_monitoring_Part1-Final-1-1.pdf

169 ETIP SNET (2020), R&I roadmap 2020-2030.

170 IEA (2019), World Energy Investment https://www.iea.org/reports/world-energy-investment-2019

171 Google Patents (2020).

On the patenting side, Europe seems to have a share of 5-10% of the patents published over the 10-year period. Both Europe and the rest of the world have seen a decline in the number of patents being published over the 10-year period. Home energy management software segment had the most patents in the value chain.

Considering R&D activities in Europe, an important player is the ETIP SNET.[172] The members of this platform range from research & innovation stakeholders (research centres, universities, consultants, etc.) to system operators (TSOs and DSOs), energy technology providers, ICT and software providers, as well as energy suppliers. In total, more than 250 projects in Europe for digital technologies research are ongoing. According to a survey amongst these projects (121 participants) about a third are funded by FP7 or Horizon 2020, whilst the remainders are funded through other instruments.

9.7 Company profiles

Company & key financials	Short description	Operational footprint & geographic focus	
Life Is On Schneider Electric	BEMS software, BEMS deployment	*HQ*	France
Schneider Electric **BEMS Turnover: est. EUR 1,360 million**	Schneider Electric is a global buildings market incumbent that provides end-to-end energy and automation products and services to a variety of commercial and industrial clients. The focus is on energy management and automation in homes, buildings, data centers, infrastructure, and industries. It has a presence in more than 100 countries, and key products include EcoStruxure, an IoT-enabled, plug-and-play, open, interoperable architecture and platform.	*R&I or Production*	United States, China, EU
Profit: EUR244 million[173]		*Sales*	Global

Company & key financials	Short description	Operational footprint & geographic focus

[172] Members of ETIP SNET are : ENTSO-E, EDSO, CEDEC, EUELECTRIC, GEODE, EERA, EUROBAT, HEA, SEDC, EPPSA, COGEN&EUGINE, EUTurbines, COGEN&ETN, ESMIG, EUTC, Europacable, Orgalime, T&D Europe, Deep Geothermal TP -EGEC, ETIP Photovoltaics, ETIP RES Heating and Cooling, ETIP Wind, Euro Heat&Power and Eruopean Hydrogen Association.

[173] Overall company EBITDA margin applied to estimated technology revenue

SIEMENS	• BEMS Software, BEMS Deployment	*HQ*	▪ Germany
Siemens	Siemens is an incumbent energy management, automation, and digital solutions provider spanning all building segments, industrial sites, data centers, and power management. The company is intimately involved with developing and promoting intelligent digital building technologies from design/construction to the end of the building's life. Desigo and Apogee are Siemens' leading building management software platforms.	*R&I or Production*	▪ United States, China, EU
BEMS Turnover: est. EUR1,022 million			
Profit: EUR116 million[174]		*Sales*	▪ Global

Company & key financials	Short description	Operational footprint & geographic focus	
Honeywell	▪ BEMS software, BEMS deployment	*HQ*	▪ United States
Honeywell	Honeywell is a Fortune 100 software-industrial company that delivers industry-specific solutions including aerospace and automotive products and services, control technologies, and performance materials globally. Key products include Enterprise Building Integrator, WEBS Building Automation System, Ascent Building Management System, CentraLine Integrated Building Management, ComfortPoint Open BAS, and Trend BMS.	*R&I or Production*	▪ China
BEMS Turnover: est. EUR1,000 million			
Profit: EUR239 million[175]		*Sales*	▪ Global

Company & key financials	Short description	Operational footprint & geographic focus	
Johnson Controls	▪ BEMS software, BEMS deployment	*HQ*	▪ Ireland

[174] Overall company EBITDA margin applied to estimated technology revenue

[175] Overall company EBITDA margin applied to estimated technology revenue

Johnson Controls **BEMS Turnover: est. EUR643 million**	Johnson Controls provides HVAC, building automation and controls, security, fire detection and suppression, digital, and other solutions for intelligent buildings. The company focuses on intelligent buildings, efficient energy solutions, integrated infrastructure, and next generation transportation systems. Metasys, Verasys, York, Hitachi HVAC, and SIMPLEX are brand names associated with the offerings.	*R&I or Production*	▪ United States, China, EU
Profit: EUR74 million[176]		*Sales*	▪ Global

Company & key financials	Short description	Operational footprint & geographic focus	
	▪ BEMS software, BEMS deployment	*HQ*	▪ Ireland
Trane Technologies **BEMS Turnover: est. EUR560 million**	Trane is a global HVAC equipment and controls manufacturer and service provider that has transformed into a leading intelligent building system product and service provider. Trane Intelligent Services and Trane Building Advantage brands use analytics to extract useful insights from building data to improve overall building performance.	*R&I or Production*	▪ China, United States, Belgium
Profit: EUR85 million[177]		*Sales*	▪ Global

Company & key financials	Short description	Operational footprint & geographic focus	
	▪ HEMS software, services	*HQ*	▪ United States
Oracle Opower **HEMS Turnover: est. EUR172.6 million**	▪ Opower's solutions include a suite of customer digital engagement tools and communications, energy insights and alerting, energy efficiency, and DR. Engaging customers with actionable	*R&I or Production*	▪ North America, Europe, Asia

176 Overall company EBITDA margin applied to estimated technology revenue
177 Overall company EBITDA margin applied to estimated technology revenue

Profit: EUR72 million[178]	information, energy usage insights, and consumption comparisons has made it the largest provider of behavioral energy efficiency and DR programs, with more than 100 utility clients across North America, Europe, and Asia.	*Sales*	▪ Global

Company & key financials	Short description	Operational footprint & geographic focus	
bidgely	▪ HEMS software, services	*HQ*	▪ United States
Bidgely	▪ Bidgely's UtilityAI platform enables utilities to target all customers, regardless of whether they have a smart meter installed. The platform is capable of delivering personalized insights from actual customer data. In April 2019, Bidgely expanded the UtilityAI platform when it launched CARE, an AI-powered call center solution aimed at helping improve the customer experience. Bidgely's overall solutions also help with customer engagement across multiple channels, including mobile apps, web portals, text messaging, email, and paper reports.	*R&I or Production*	▪ US, Europe, Asia
HEMS Turnover: est. EUR18.1 million			
Profit: EUR3 million[179]		*Sales*	▪ US, Europe, Asia

Company & key financials	Short description	Operational footprint & geographic focus	
uplight	▪ HEMS software, services	*HQ*	▪ United States
Uplight	▪ The Tendril platform supports engagement through home energy reports (HERs), electronic HERs, a customer engagement portal, high usage alerts, rates marketing and calculators, activation through	*R&I or Production*	▪ North America, Europe, Asia
HEMS Turnover: est. EUR39.3 million			

[178] Overall company EBITDA margin applied to estimated technology revenue
[179] Average Technology EBITDA margin applied to estimated company revenue

Profit: EUR7 million[180]	marketplace integrations, online home energy audits, HER advertising, smart speaker-voice integration, next-best actions, non-residential engagement and analytics, and program enrolment. The platform also offers a demand management solution via smart thermostats that works with the customer to better optimize energy consumption while maintaining comfort.	*Sales*	▪ US, Europe, India

Company & key financials	**Short description**		**Operational footprint & geographic focus**
	▪ HEMS hardware, software	*HQ*	▪ United States
Itron **HEMS Turnover: est. EUR66.9 million**	▪ The company's flagship HEM product for its utility customers is the IntelliSOURCE platform, which includes capabilities for demand management, energy efficiency, and customer engagement. IntelliSOURCE enables utilities to deepen residential customer engagement by adding integrated energy efficiency capabilities to DR programs while providing tools to better manage customer participation, such as a utility-branded mobile app, smart thermostat control, automated price response, and actionable tips. Itron is furthering its customer engagement and HEM capabilities through third-party partnerships and deploying solutions with utilities to orchestrate a variety of DER, including electric vehicles, storage, HVAC, water heaters, PV, and water heaters in conjunction with time-of-use (TOU) rates.	*R&I or Production*	▪ US, Europe, Asia
Profit: EUR7 million[181]		*Sales*	▪ Global

180 Average Technology EBITDA margin applied to estimated company revenue
181 Overall company EBITDA margin applied to estimated technology revenue

Company & key financials	Short description	Operational footprint & geographic focus	
	▪ HEMS hardware, software	*HQ*	▪ France
Schneider Electric **HEMS Turnover: est. EUR258.4 million**	▪ The company's HEM strategy is based on its Wiser Energy management system. The Wiser system continuously monitors a home's electrical consumption and can detect inefficiencies that needlessly boost energy bills. For residential users with solar PV, the system can also help them take advantage of cheaper, off-peak energy. The Wiser system consists of a hardware device sold by Schneider Electric subsidiary Square D that gets professionally installed to a home's electrical service panel. The device connects to a home Wi-Fi network for transferring usage data. The system includes a mobile app for monitoring usage, and is compatible with devices such as Phillips Hue, Wemo Insight, and Kasa smart plugs.	*R&I or Production*	▪ US, EU
Profit: EUR46 million[182]		*Sales*	▪ Global

9.8 List of Abbreviations

AI	Artificial Intelligence
AMI	Advanced Metering Infrastructure
BEMS	Building Energy Management System
CAPEX	Capital Expenditure
DER	Distributed Energy Resources
EV	Electric Vehicle
GHG	Greenhouse Gas
GVA	Gross Value Added
HANs	Home Area Networks
HEMS	Home Energy Management System
HVAC	Heating, Ventilation, Air Conditioning
IoT	Internet of Things
ML	Machine Learning
OPEX	Operating Expense
ROI	Return on Investment

[182] Overall company EBITDA margin applied to estimated technology revenue

SW	Software

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ROBERT ATKINSON, DANIEL CASTRO AND STEPHEN EZELL (2009). THE DIGITAL ROAD TO RECOVERY: A STIMULUS PLAN TO CREATE JOBS, BOOST PRODUCTIVITY AND REVITALIZE AMERICA. HTTPS://ITIF.ORG/FILES/ROADTORECOVERY-DETAILS.PDF?_GA=2.55192171.1383099122.1595350138-1426202233.1595350138

10 Grid Management (Digital Technologies)

10.1 Summary

Scope	• Grid Management Technologies segment can be subdivided into distributed energy resource management systems (DERMS) software, virtual power plant (VPP) software, distributed energy resource (DER) analytics software, and deployment services. • The digital grid management technologies will be critical as the grid evolves from centralized generation toward a mix of two-way communicating distributed energy resources (DER).
Market	• According to Guidehouse Insights, the EU-27 market for grid management technologies is expected to grow from EUR197.7 million in 2020 to EUR1.2 billion in 2030 at a CAGR of 19.6% during this period[183].

183 Guidehouse Insights (1Q 2020). *Global DER Deployment Database.*

Competitive-ness of EU-27 companies	• The EU holds the strongest competitive position in the VPP segment of the value chain. As DER analytics are often coupled with VPP offerings, the EU also is relatively strong in the DER Analytics component of the value chain. • While DERMS capabilities are more sought after in North America, EU-27 companies like Siemens & Schneider Electric are leading DERMS providers globally. There are, however, several other major operational technology (OT) vendors headquartered outside of the EU and several innovative start-ups coming out of the North American market.

10.2 Introduction

Digital grid management technologies will be critical as the grid evolves from centralized generation toward a mix of two-way communicating distributed energy resources (DER). Digital grid management technologies discussed in this section serve a variety of use cases including device optimization and control. As more DER connect to the grid, operators are looking to manage grid networks as efficiently and effectively as possible. Historically, centralized generation and one way power flows did not require grid operators to engage in this degree of active management, but as the grid becomes more dynamic optimization can result in reduced utility and end-customer costs and improved customer engagement whilst maintaining secure and reliable networks. Grid management technologies enable operators to actively management dynamic networks of two-way power flows.

In 2020, the EU-27 holds the strongest competitiveness in the VPP segment of the value chain[184]. As DER analytics are often coupled with VPP offerings, the EU also is relatively strong in the DER Analytics component of the value chain. While DERMS capabilities are more sought after in North America, EU companies like Siemens & Schneider Electric are leading DERMS providers (see more detail below) globally. There are, however, several other major operational technology (OT) vendors headquartered outside of the EU and several innovative start-ups coming out of the North American market.

The digital grid management technologies will be critical as the grid evolves from centralized generation toward a mix of two-way communicating distributed energy resources (DER). Digital grid management technologies discussed in this section serve a variety of use cases including device optimization and control. The Grid Management (Digital Technologies) segment can be subdivide into DERMS software, VPP software, DER analytics software, and deployment services.

[184] Guidehouse Insights (2Q 2020). *Virtual Power Plant Overview.*

Figure 72: Introduction to Grid Management Value Chain

	DERMS Software	DER Analytics Software	VPP Software	DERMS Deployment	DER Analytics Deployment	VPP Deployment
Key activities	• Software License Fees	• Software License Fees • SaaS Spending	• Software License Fees	• Implementation & Integration Services • Operations & Maintenance	• Implementation & Integration Services • Operations & Maintenance	• Implementation & Integration Services • Operations & Maintenance
Market Size (M€)	Global 22 EU 12	Global 54 EU 23	Global 86 EU 39	Global 168 EU 36	Global 71 EU 33	Global 145 EU 65
Market Growth Outlook	Global: EU: DER Proliferation & Network Constraints	Global: EU: Smart Meter (Load) and PV (Solar) Growth	Global: EU: DER Proliferation & Economic Optimization	Global: EU: Integration with growing number of systems	Global: EU: Integration with growing number of systems	Global: EU: Integration with growing number of systems
Key Players EU	SIEMENS Schneider Electric	SIEMENS Landis+Gyr Schneider Electric	centrica Business Solutions enel x NEXT Kraftwerke Schneider Electric	SIEMENS Schneider Electric	SIEMENS Landis+Gyr Schneider Electric	centrica Business Solutions enel x NEXT Kraftwerke Schneider Electric
Key Players Rest of the World	AutoGrid OSI enbala ABB GE	Itron GE ORACLE	enbala ABB limejump AutoGrid kiwipower	AutoGrid OSI enbala ABB GE	Itron GE ORACLE	enbala ABB limejump AutoGrid kiwipower
Critical materials	• n/a	• n/a	• n/a	• n/a	• n/a	• n/a

Legend: (10 year CAGR) >15% >10% >5% >0%

Source: Guidehouse Insights (2020)

10.3 Industry Value Chain Analysis

10.3.1 Value Chain Segmentation

Figure 73: Software Platform Overview & Use Cases[185]

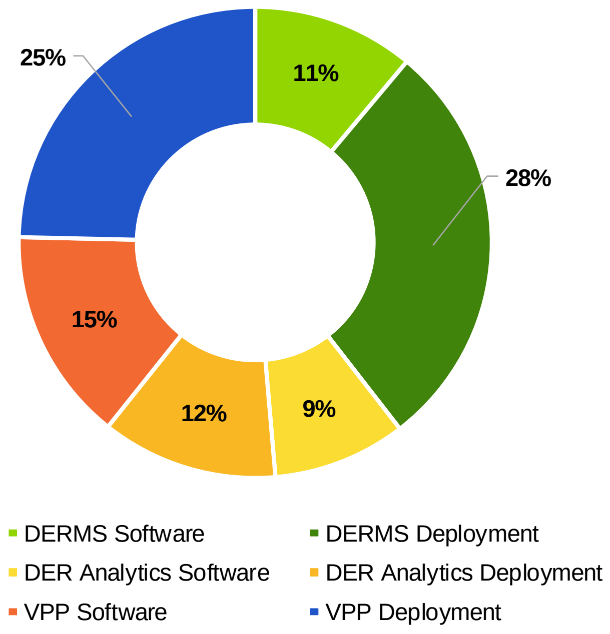
DERMS Software	VPP Software	DER Analytics Software
• Control system that enables optimized control of the grid and DER (to the extent that a utility may be able to dispatch and control DER) • Common use cases include VVO, power quality management, and the coordination of DER dispatch (when possible) to support operational needs	• Remotely and automatically optimize DER dispatch via an aggregation and optimization platform linking retail to wholesale markets • Enable energy trading in wholesale markets on behalf of DER owners who would otherwise not be able to participate on their own; VPPs can act as an arbitrageur between DER and diverse energy trading floors	• Consists mainly of load and solar forecasting capabilities • May suffice for low levels of DER integration, however, growing DER penetration may call for more capabilities • DER analytics are being integrated into competitive VPP software and grid DERMS platforms and are less frequently a standalone offering

DER analytics, DERMS, and VPP companies themselves typically perform systems integrations with a variety of DER hardware vendors. All major companies profiled in this chapter as DERMS, VPP, or DER Analytics Software providers offer deployment services (ABB, Centrica Business Solutions, GE, Next Kraftwerke, Schneider Electric,

[185] Guidehouse Insights (2020).

and Siemens) As DER can operate independently of DERMS, VPP, and DER Analytics, which increase grid operators' situational awareness and management capabilities with regard to the devices, Guidehouse does not consider individual DER assets as part of the Digital Grid Management value chain segment. Similarly, very few grid management software providers, and none of those reviewed in this report rely on hardware to enable their solutions. For this reason, the value chain segmentation begins with grid management software itself. Different solutions, or combinations of software solutions may be deployed to utilities and grid operators in the global market. The majority share of grid management (digital technologies) solution thus lies in deployment, consisting of the platform provider services needed to launch and maintain continuous operations.

Figure 74: Value Chain Segmentation, Global, 2020[186]



DER analytics for understanding DER characteristics and impacts: DER analytics support utilities in planning and forecasting or micro-forecasting load and solar generation. DER can cause tremendous disruptions to traditional supply and demand patterns and heavily affect the processes of resource, capital, and operational planning. Utilities need to understand and forecast DER-affected demand and DER output. They also need to anticipate, understand, and predict locational effects on the grid to effectively perform these processes. For the purposes of this analysis, DER analytics refers to load and solar forecasting technologies. The clear segmentation between DER analytics, DERMS software, and VPP software continues to blur. DER analytics can be offered as a standalone package or under an ADMS or DERMS module. These analytics applications are already integrated across most major ADMS (load forecasting) and DERMS (solar forecasting) vendors.

DERMSs for DER and grid management: DERMSs are control systems that enable optimized control of the grid and DER to the extent that a utility can dispatch and control DER. To minimize disruptions and the presence of phantom loads, utilities need to manage the grid more proactively. Common use cases include volt/voltampere reactive (Volt/VAR) optimization (VVO), power quality management and the coordination of DER

[186] Guidehouse Insights (2020).

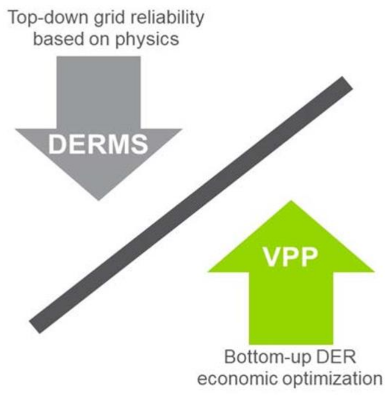
dispatch (when possible) to support operational needs[187]. For the purposes of this analysis, DERMS refers to systems for grid management & control. Primary applications include DER modeling and visualization, estimation & forecasting, and DER scheduling & dispatch. These systems are offered by a number of traditional operational technology (OT) vendors (e.g., ABB, GE, OSI, Schneider, Siemens). Companies that apply a DR management philosophy to DER management have frequently classified it as DERMS or VPP control systems rather than DR management system; these are excluded from the scope of analysis. Incumbent IT/OT vendors, new entrants, and startups have approached product development from different perspectives. IT/OT incumbents approach the market for DER as if is an addition to a distribution management system (DMS) or advanced DMS (ADMS).

Virtual power plants (VPPs) for market interfacing: VPP control systems remotely and automatically optimize DER dispatch via an aggregation and optimization platform linking retail to wholesale markets[188]. Though not fully mature, there is growing development in support of DER participation in capacity and energy services markets at the wholesale and retail levels. To date, the VPP solution is more widely applied and is particularly common in the European region. VPP platform purchasers can include either grid operators or DER aggregators actively bidding into the wholesale market. As VPP portfolios grow in complexity and diversity, they also pose increased challenges to the distribution utilities with a grid that underpins the VPP value proposition. VPPs alone cannot solve the DER integration challenges facing the energy ecosystem today. While markets may help unpack previously unrealized value in DER assets, there must be a parallel effort to ensure that the physics of electricity exchanges are respected and responded to in real time. This is where the VPP journey can lead to DERMS. As global energy markets rely more on DER assets to provide the fundamentals of energy and capacity - and the finer adjustments revolving around voltage and reactive power - the need for tighter integration between economics and physics is expected to grow.

Deployment: Deployment consists of implementation and integration services to enable DER management solutions and provide ongoing maintenance activities. Offered by system providers or third-party systems integrators, deployment makes up the majority of the value chain as services often cost more than initial software licenses. Once the solution is deployed, platform providers provide ongoing operations and maintenance; this may consist of back-end operations support, integration of new devices, and updates to security or communications protocols.

[187] National Renewable Energy Laboratory (2018). "Coordinating Distributed Energy Resources for Grid Services: A Case Study of Pacific Gas & Electric."
[188] Guidehouse Insights (2Q 2020). *Virtual Power Plant Overview.*

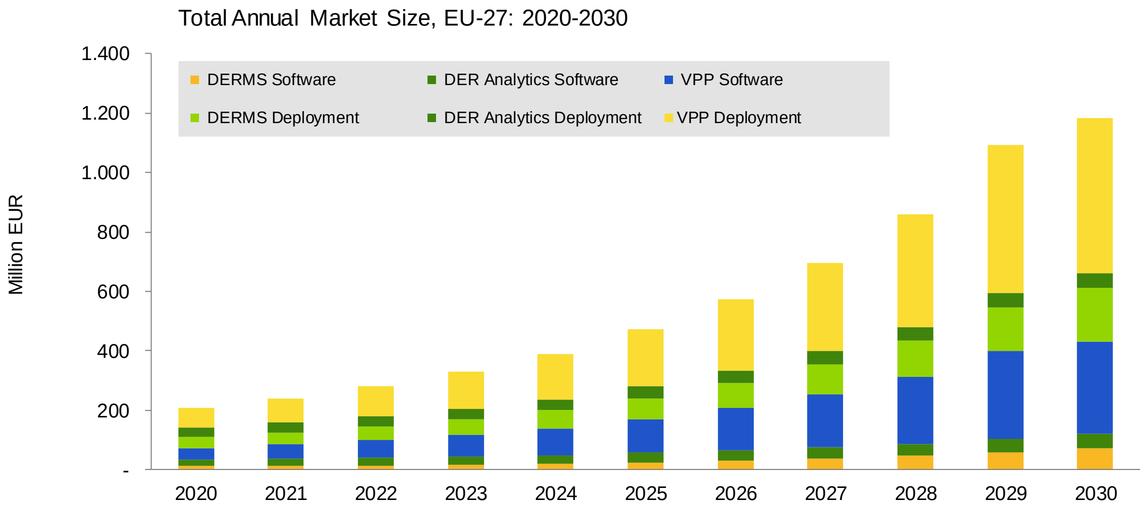
Figure 75: Top-Down and Bottom-Up Control Strategies Merge with VPP-DERMS Hybrid[189]



10.3.2 Market Size Analysis

The EU-27 market for grid management technologies is expected to show strong growth across the forecast period, with particularly high demand for VPP solutions. Smart meter deployments are expected to drive advanced analytics spending, with a focus on granular and dynamic forecasting techniques. DERMS will also show strong growth as a function of DER proliferation and network constraints. The grid management technology market is forecast at EUR197.7 million in 2020, growing to nearly EUR1.2 billion in 2030, at a compound annual growth rate (CAGR) of 19.6%[190].

Figure 76: Total Annual Market Size, EU-27: 2020-2030[191]



10.3.3 Share of the EU Market

When examining the global grid management market, Europe holds particularly strong market shares across DER analytics and VPP software, as well as a moderate share of DERMS.

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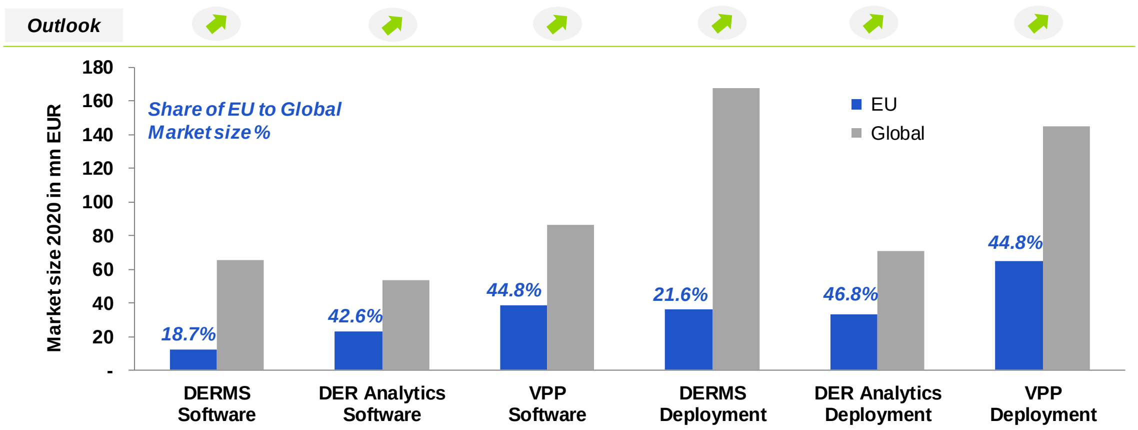
[189] Guidehouse Insights (2020).
[190] Guidehouse Insights (1Q 2020). *Global DER Database.*
[191] Guidehouse Insights (1Q 2020). *Global DER Database.*

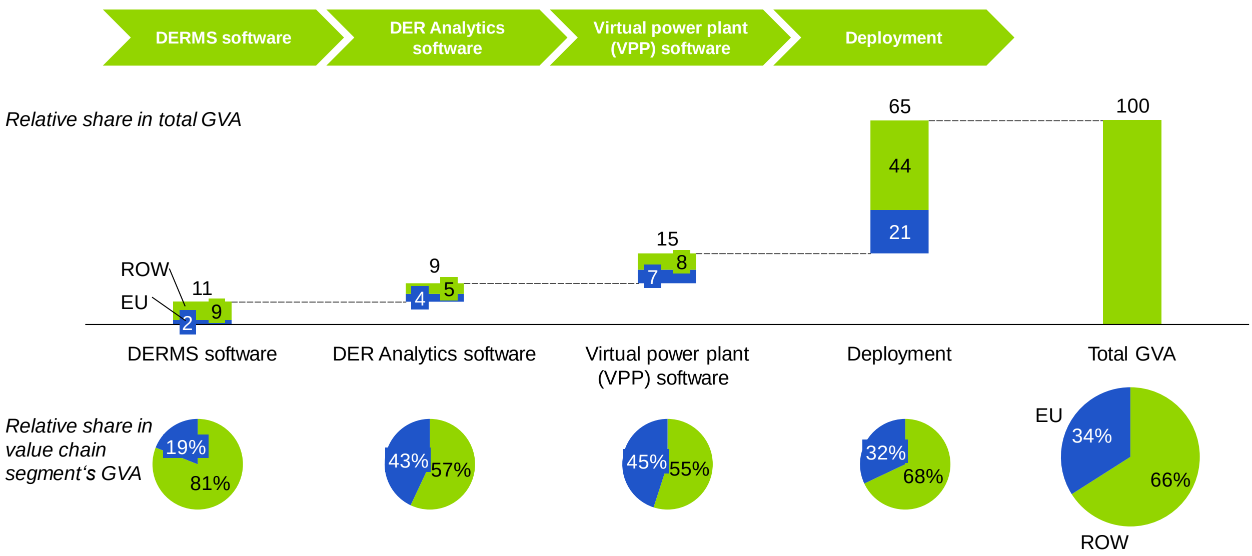
High DER analytics share is largely a function of smart meter deployments and DER growth. Outside of China, Western Europe can be considered the global leader in smart metering; load forecasting is a natural analytics extension of these deployments given the granular data streams. As DERs continue to grow, solar forecasting will expand beyond its still relatively nascent market position. Europe has also been the driving force behind VPP spending, accounting for nearly 45% of global spending in 2020[192]. This is a function of several factors, including DER growth, market opening, valuation of non-traditional assets, and carbon reduction and efficiency goals.

Figure 77: Share of EU-27 Market Size to Global Market, Value Chain Segment: 2020[193]



10.3.4 Gross Value Added

Figure 78: Breakdown of GVA throughout grid management value chain



Source: Guidehouse Insights (2020)

192 Guidehouse Insights (2Q 2020). *Virtual Power Plant Overview.*
193 Source: Guidehouse Insights, 2020.

The gross value added in general resembles the market sizes for the respective value chain segment and region, adjusted for a trade surplus/deficit and the value of input material. For the grid management sector, no input material is considered since the value chain predominantly relies on digital technologies. The largest share of the GVA is captured by the deployment segment, out of which the EU captures a relative share lower than its share in DER analytics and VPP software.

10.4 Market Outlook

This section trends in the flexibility market as related to and enabled by grid management software platforms.

10.4.1 Drivers and Barriers

A number of drivers are coalescing to drive demand for grid management technologies in global markets and in the EU-27. These drivers are a result of natural market and technology evolution, as well as top-down initiatives by policymakers and utilities to support growth in DER.

- European Green Deal and COVID Relief Package - In Europe, the May 2020 €750 billion recovery package proposal devotes 25% of its budget to low-carbon infrastructure projects[194]. European officials are also working to integrate the COVID-19 stimulus effort with the European Green Deal, which emphasizes the development of projects that decouple resource use from economic growth and reach zero net emissions of greenhouse gases (GHG) by 2050[195]. To reach zero carbon emissions, more utility-scale and distributed renewable energy resources will have to interconnect with the grid. Intermittent generation will boost the use case for digital grid manage technologies in European balancing markets.
- Rapid Rise in DER Penetration – Globally, DER have differing levels of positive and negative effects on grid stability and health. In DER saturated areas, utilities are struggling with a number of issues related to reverse power flows, voltage issues, DER intermittency, switching flexibility, and load masking/phantom loads. To operationalize this data and mitigate negative grid effects, advanced software solutions are required.
- Digitization and Enhanced IT Investment - DERs, automation, communications networks, and monitoring devices proliferate in the grid, utility operations managers and executives have access to mountains of new data—on consumption patterns, device health and stresses, power quality and stability metrics, etc. Without sophisticated software and analytics solutions, utilities are unlikely to maximize the returns on these large investments—both financial and operational.
- Market Opening - Growing renewable penetration may also help to drive the continued opening of global ancillary service markets to resources optimized via grid management software, particularly VPP[196]. Deregulated markets in Europe and around the globe allow non- generation utility providers to make available

[194] World Resources Institute (2020). "Europe Charts a Course for Sustainable Recovery from COVID-19." https://www.wri.org/blog/2020/06/europe-charts-course-sustainable-recovery-covid-19

[195] European Commission (2019). "A European Green Deal." https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[196] International Renewable Energy Agency (2019). *Innovative Ancillary Services: Innovation Landscape Brief.*

capacity to balance the grid, the opening and increase of value of balancing and ancillary services markets can incentivize DER participation.

- Growing Interest in Transactive Energy (TE) Markets - TE is a power/energy system in which economic- or market-based platforms are used to make decisions involving the generation, distribution, and consumption of power. TE is predicated on the changing value of any form of DER that is connected to a network[197], and customer load flexibility and has already piloted in some European countries[198]. To allocate this value, system orchestrators must have visibility into every load and source on the network at all times of the day.
- Partnership Opportunities - As utilities and network operators look for integrated solutions to address their evolving grid needs, grid management providers are positioned to grow their market by partnering to provide comprehensive service offerings. A rich partner ecosystem has driven their success.[199] Technology vendors, platform providers, and energy service companies may devote ample resources to building out one or two core competencies.

Global energy markets have begun a transition driven largely by optimization of DER management. However, outdated energy regulation serves as a barrier to more rapid deployment, utility organizational structures, and the high cost and complexity of large-scale technology deployments.

- System Costs - Advanced software systems require extensive product investments and integration efforts for both software and communications as well as organizational restructuring and human capital investment. Digital grid management technologies, particularly DERMSs, are naturally expensive due to their control system capabilities and number of integration points. System costs are often project-specific and vary based on the scope of the deployment (number of DERs, substations, constraint points, system integration points) and level of system functionality (modelling, forecasting, dispatch)[200].
- Communications Requirements - The ability to monitor and control DER under a DERMS solution relies on connectivity and visibility at the DER level[201]. DER deployments have been sparse, making it difficult for utilities to justify the establishment of dedicated networks. Communications investments in the short term are likely to be small and incremental, using public cellular networks and past investments as much as possible.
- Data Quality Remains a Concern - To adapt to the complex operating environment experienced today, utilities need to further invest in data integrity, most notably connectivity model correction and accuracy. Poor connectivity models have significant implications for utility IT/OT systems, particularly ADMSs and DERMSs that rely on this data[202].
- Availability of System Alternatives - Most major utilities do not require a DERMS at this time to enable granular control of DER. Use cases have tended

[197] Gridwise Architecture Council (2020). "Transactive Energy." https://www.gridwiseac.org/about/transactive_energy.aspx
[198] Brenzikofer et. al (2019). *25th Conference on Electricity Distribution.* "Quatierstrom: A Decentralized Local P2P Energy Market Pilot on a Self-Governed Blockchain."
[199] Guidehouse Insights (3Q 2020). *Market Data: Mixed-Asset Virtual Power Plants.*
[200] Guidehouse Insights (2Q 2020). *DER Management Technologies.*
[201] Guidehouse Insights (2Q 2020). *DER Management Technologies.*
[202] Guidehouse Insights (2Q 2020). *DER Management Technologies.*

to revolve around modeling and forecasting, with control still seen as a forward-looking application. ADMS can mitigate the disruptive effects of DER at low penetrations[203].

10.4.2 Raw Material Usage

As software-based digital technologies, raw material usage is not a component of the grid management value chain as it relates to leading companies in the EU or in other global regions.

10.5 Competitive Landscape

While software platforms are reaching maturation, the applications for digital technologies to provide grid services continue to push innovation in the market space. Leading companies clearly differentiate themselves from the competition through exceptional software platform development, robust portfolios in diverse markets, and a sustainable business model. In particular, there are a number of technology-specific differentiators, including:

- **DER Analytics**
  - Total-cost-of-ownership
  - Scalability
  - Cloud/managed service offerings
  - Dynamic applications
  - Number of input data streams (e.g. cloud cover, business parameters)
  - Advanced scenario and simulation engines
  - Strong data management capabilities
- **DERMS & VPPs**
  - Total cost-of-ownership
  - Product performance
  - Product portfolio (ADMS [and related modules], GIS, etc.)
  - Granularity of DER modeling
  - Forecasting and visualization engines
  - Scalability
  - Real-time control capabilities
  - Value chain integration strategies
  - Trading optimization algorithms

Leaders are currently in the strongest position for long-term success in the grid management markets. There is still ample room for growth in the grid management (digital technologies) market, and to date the EU holds the strongest competitiveness in the VPP segment of the value chain. As DER analytics are coupled with many VPP offerings, it is relatively strong here. While DERMS capabilities are more sought after in North America in terms of demand[204], Siemens & Schneider Electric are leading DERMS providers (see more detail below) globally. There is fierce competition among major OT vendors, including ABB, GE, and OSI. There are also several innovative start-ups in this space currently coming out of the North American market.
The global electricity grid is transitioning from centralized generation toward two-way communicating distributed generation supported by flexible capacity. Recognizing this, several oil and gas (O&G) and other energy providers are making strategic investments

[203] Guidehouse Insights (2Q 2020). *DER Management Technologies.*
[204] Guidehouse Insights (2Q 2020). *Virtual Power Plant Overview.*

in grid management technologies and have acquired or made strategic investments in smaller startups in European and US market. Some, though not all, companies acquired or invested in are headquartered in the EU. Three examples include:

- **Next Kraftwerke (Cologne, Germany)-** Dutch natural gas and electricity producer Eneco invested minority stake (34%) in VPP platform provider Next Kraftwerke in 2017. The investment is undisclosed but estimated to be at least 20 mn. EUR.[205] The investment release noted Eneco's desire to become a leader in the progression toward decentralized energy.
- **Kiwi Power (London, UK)-** In 2014, the company began a partnership with ENGIE while branching out into the frequency response markets. ENGIE then made major investments in the company as it expanded into France. Ultimately, ENGIE acquired just under 50% of the company, buying out the original two founders and becoming its largest stakeholder (investment sum undisclosed).
- **Limejump (London, UK) -** Using artificial intelligence (AI) and machine learning, Limejump's end-to-end solution includes advanced trading strategies and its clients span electricity generators, energy consumers, developers, and investors. Limejump became a wholly owned but independent subsidiary of Shell in 2019 (investment sum undisclosed).

The exact financial disclosures for these transactions have not been publicly disclosed.

VPP software platforms are agile; their attributes are being tested and expanded upon in Europe. Although the names of products, services, and markets are different across each regional market, they tend to have strikingly similar requirements for market participation. Germany is the largest and most mature VPP market, it leads the region in current deployments and is expected to continue holding that position over the next decade. Germany is anticipated to capture about one-third of the total VPP market's annual capacity by 2028, reaching over 4,000 MW of incremental annual capacity additions[206]. Increased VPP-related trading activity is also opening up in the Netherlands, Belgium, the Nordic countries, and across certain Italian energy retailers. With its Eurocentric focus on energy trading, technologies used for financial transactions, tracking, and settlements are setting the stage for future VPPs throughout Europe.

The grid management space is still somewhat convoluted as technologies and terminologies continue to evolve. Across the different management technologies, several key players overlap (ABB, Siemens, Schneider Electric) in their DERMS and VPP offerings. There are also a handful of stand-alone DERMS (GE, OSI) and VPP (Centrica, Next Kraftwerke) providers. DER analytics can be offered as embedded capabilities within DERMS and VPP or as stand-alone deployments. For example, smart metering providers have long offered load forecasting modules to leverage AMI data; this introduces a more diverse competitive value chain.

As mentioned previously, the grid management market is largely characterized by a small pool of overall vendors. Figure 799 shows the respective market shares of the top

[205] https://ecosummit.net/articles/inven-invests-in-cloud-and-heat-and-eneco-invests-in-next-kraftwerke

[206] Guidehouse Insights (3Q 2019). *Market Data: Virtual Power Plants*.

six providers across all value chain segments (DERMS, Analytics, VPP, Deployment). ABB leads the overall market given its footprint in each of the technology segments; most companies only play in two or three of the overall value chain segments.

Figure 79: Competitive Intensity across each Value Chain Segment, Global, 2020[207]

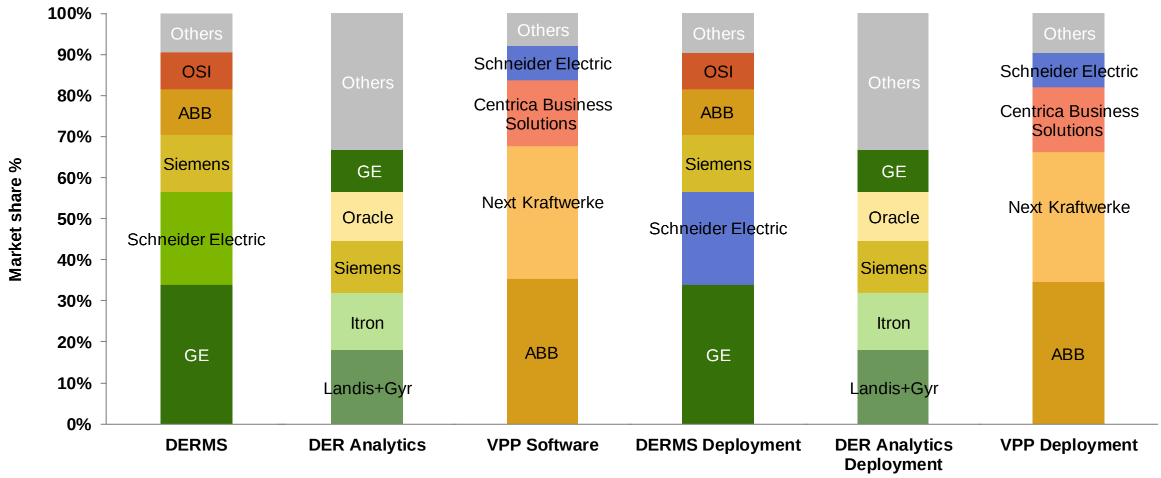


Figure 80: Top Key Market Players and Market Share, Global, 2020[208]

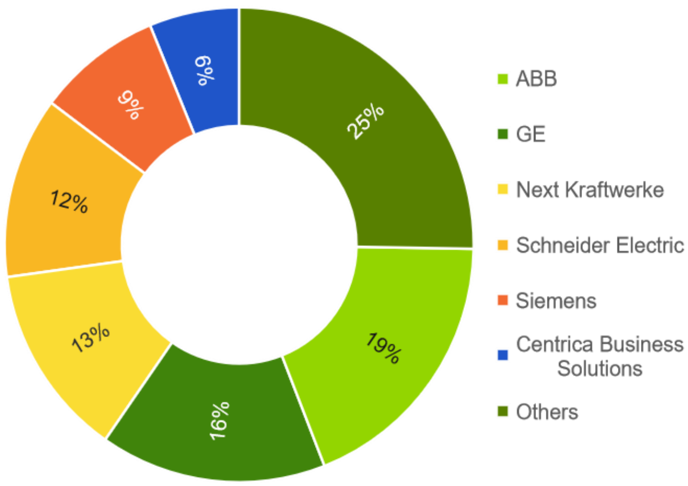
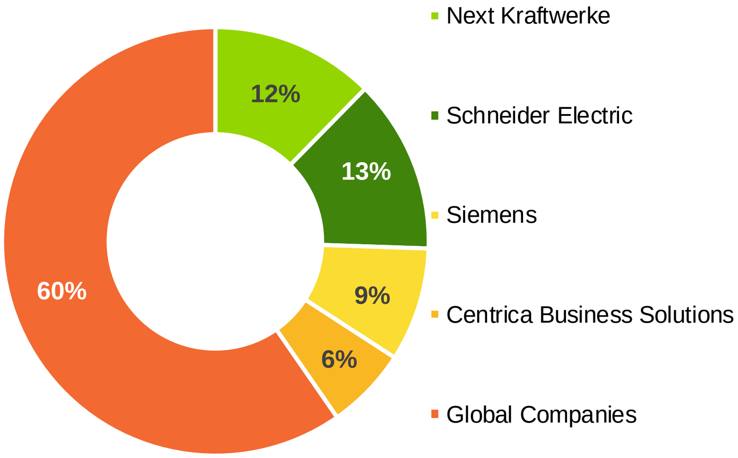


Figure 80 shows the EU share of global spending, with Next Kraftwerke, Schneider Electric, Siemens, and Centrica Business Solutions accounting for ~40% of the overall market. Of note, while Centrica is based in the UK, the Business Solutions unit is located in Belgium, and is thus included in the analysis. Overall market shares are constrained by the Swiss-based ABB and a number of North American vendors (GE, OSI) holding moderate market shares.

[207] Guidehouse Insights (2020).
[208] Guidehouse Insights (2020).

Figure 81 – Share of EU Market Players in the Total Market, Global, 2020[209]



10.6 Value Chain Segment Competitiveness

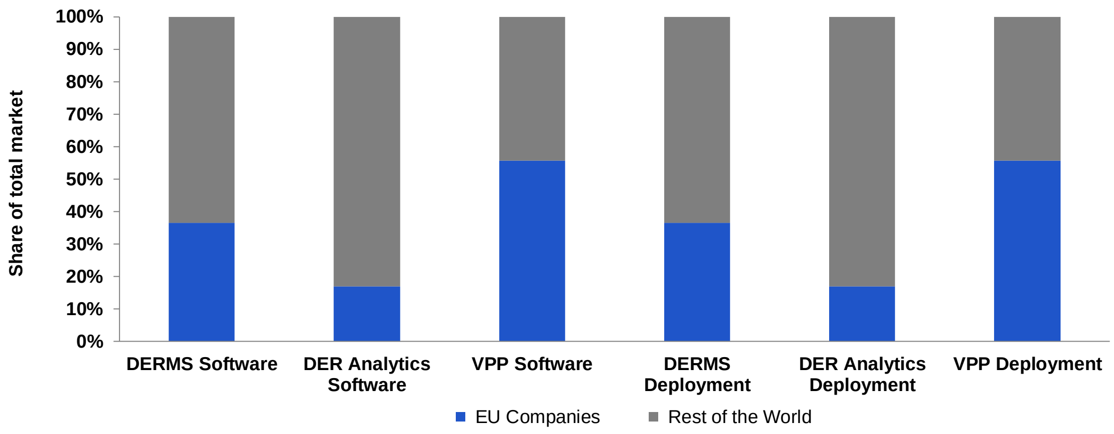
There are a handful of major OT software vendors and stand-alone VPP providers leading the grid management market. Outside of DER analytics, where smart meter providers may be providing load forecasting tools, there is a relatively small pool of vendors vying for competition. Deployment is also largely led by this pool of vendors. While some deployments may leverage a third-party systems integrator, these larger OT and VPP providers typically have the requisite expertise for implementation and integration services, along with annual operations and maintenance.

10.6.1 Competitive Intensity

Figure 9 shows the high competitive intensity across the grid management space. The market is characterized by a few overlapping providers, typically larger OT vendors, and several stand-alone providers within the respective technology segments. As mentioned above, deployment services and ongoing maintenance are also typically offered by software providers, leading to similar competitive dynamics across that segment.

[209] Guidehouse Insights (2020).

Figure 82 – Competitive Intensity across each Value Chain Segment, Global, 2020[210]



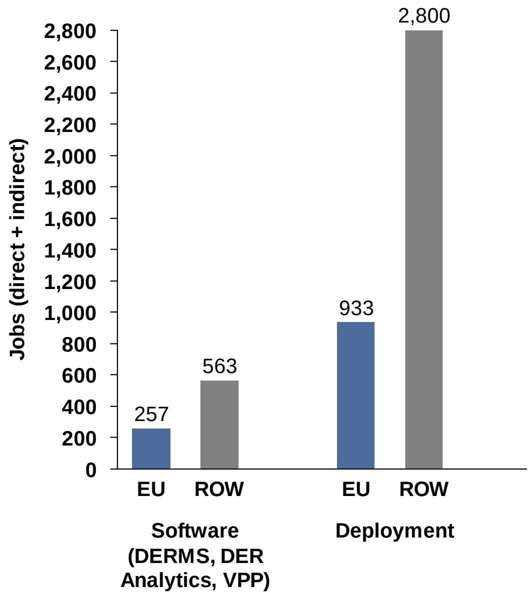
10.6.2 New Entrants

Though incumbent smart meter and OT software vendors can leverage established relationships and economies of scale to create an advantage, the digital nature of grid management technologies creates an environment where new entrants can develop software solutions to compete against these incumbents. Indeed, Guidehouse identified 37 start-ups that received private funding in 2019.[211] With DERMS and VPP value chain segments accounted for the most activities with 18 and 16 funding announcements, respectively. Start-ups in the EU-27 represented 19% of all start-ups receiving funding in 2019. The share of the EU-27 in the overall global market for grid management is 24%, suggesting that EU-27 start-ups could be under-represented.

210 Source: Guidehouse Insights, 2020.
211 CB Insights and Crunchbase

10.6.3 Employment Indicators

Figure 83: Grid management Employment by value chain[212]



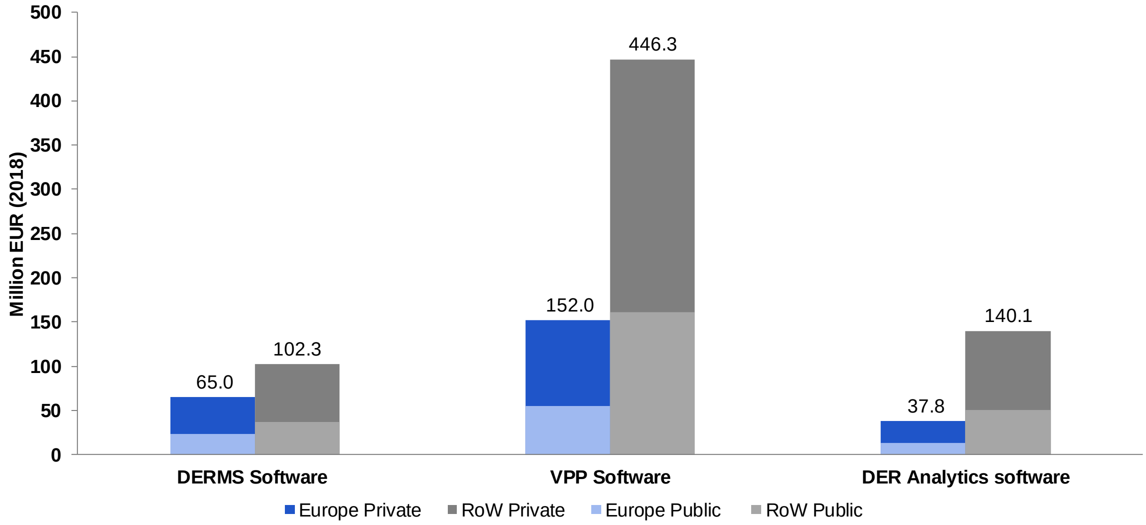
The employment figures were based on a multiplying factor provided by the source [213], and the market sizes for Europe and the rest of the world. Figure 83 shows that most employment lies on the deployment side of the value chain rather than software development, which is what is expected in jobs for digital technologies. Overall, Europe seems to be in a very good position.

[212] Robert Atkinson, Daniel Castro and Stephen Ezell (2009). The digital road to recovery: A stimulus plan to create jobs, boost productivity and revitalize America. https://itif.org/files/roadtorecovery-details.pdf?_ga=2.55192171.1383099122.1595350138-1426202233.1595350138

[213] Ibid.

10.6.4 R&I activities

Figure 84: R&I investments in Grid management[214] [215] [216]



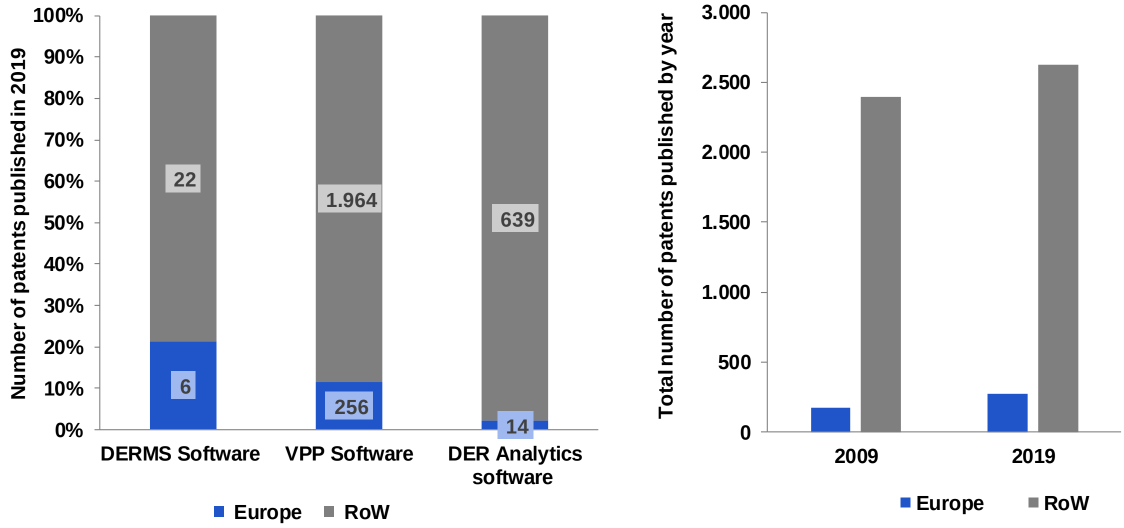
The investment figures for Europe were obtained from ETIP SNET and are based on the demonstration projects in Europe. For the rest of the world, an estimation was made based on the market size. In Europe, all the public investments are part of the H2020 programme and are estimated at 35% according to ETIP SNET in 2018. Overall, the research investments in both Europe and the rest of the world are very similar, where Europe has a higher share in the DERMS software compared to the other value chain segments, while the rest of the world still leads all segments, including VPP software and DER analytics.

[214] ETIP SNET (2018), Presentation of recent and ongoing R&I projects in the scope of the ETIP SNET. https://www.etip-snet.eu/wp-content/uploads/2018/11/Project_monitoring_Part1-Final-1-1.pdf

[215] ETIP SNET (2020), R&I roadmap 2020-2030.

[216] IEA (2019), World Energy Investment https://www.iea.org/reports/world-energy-investment-2019

Figure 85: Grid management by Value Chain / Grid management Patent Trends by Region [217]



On the patenting side, Europe seems to have a share of 10-20% of the patents published over the 10-year period. Europe has seen a significant growth in the grid management patents, while the rest of the world has only seen a slight increase. Most patents were in the VPP software segment, which is in line with the research spending figures in Figure 85. For DERMS software, much of the research investment may not be reflected in the number of patents published due to the nature of the value chain.

10.7 Company profiles

Company & key financials	Short description	Operational footprint & geographic focus	
ABB	▪ DERMS ▪ VPP	*HQ*	▪ Zurich, Switzerland
ABB **Turnover: EUR7.17 million (DERMS); EUR2.06 million (DER Analytics);EUR29.96 (VPP); EUR68.5 million (Deployment)**	▪ ABB promotes four core functionalities: resource management, resource optimization, market participation, and commercial settlement. ▪ The company's ABB Ability DERMS Network Manager includes volt/volt-ampere reactive optimization, cloud-based registration capabilities for end users, and BTM forecasting data using middleware application	*R&I or Production*	▪ ABB completed divestment of its Power Grid business to Hitachi in July 2020 (Japan) • VPP/DERMS reside largely in ABB's Digital Business and remain with ABB.

[217] Google Patents (2020).

Profit: EUR 14 million[218]	programming interface to import data into the network manager.	*Sales*	▪ Belgium, France, Germany, Italy, Poland ▪ United States

Company & key financials	Short description	Operational footprint & geographic focus	
centrica Business Solutions	▪ VPP	*HQ*	▪ Antwerp, Belgium
Centrica Business Solutions **Turnover: EUR13.64 million (VPP); EUR23.84 million (Deployment)** **Profit: EUR2.8 million**	▪ Founded in 2010, REstore was acquired by Centrica in 2017 as part of the company's Distributed Energy & Power division. It is now part of Centrica Business Solutions. ▪ The company's FlexPond patented VPP solution allows utilities to engage with clients through automated DR (ADR) programs and mixed asset VPP. ▪ The company also offers a FlexTreo platform, a cloud-based energy management system for large C&I customers to reduce power costs and maximize income from demand-side management programs ▪ Centrica's grid management products allow clients to cover trading needs across the entire electricity market value chain. ▪ Centrica is also integrating residential customers into its platform, with 50,000 homes enrolled via its 15 partnerships in this space, primarily focused on energy storage as DER grid assets.	*R&I or Production* *Sales*	▪ In September 2019, it announced that smart electric water tanks could be folded into its VPPs through a partnership with Mixergy, a small UK-based startup. ▪ Centrica Business Solutions claims it is developing the world's most advanced VPP for National Grid in partnership with sonnen, in the UK ▪ Centrica Business Solutions' clients include: • EDF • 50Hertz • National Grid • TEPCO

Company & key financials	Short description	Operational footprint & geographic focus	
enbala YOUR GRID. IN BAL	▪ DERMS ▪ VPP	*HQ*	▪ Vancouver, British Columbia, Canada
Enbala	▪ Enbala provides a real-time energy balancing platform for		▪ Enbala continues to grow, recently doubling

[218] Overall company EBITDA margin applied to estimated technology revenue

Turnover: EUR1.29 million (VPP); EUR2.26 (Deployment)	utilities, grid operators, and energy service providers that can toggle between VPP and DERMS applications (instantaneous switching enabled by ABB). ▪ Enbala has broadened its client portfolio with more diverse assets, delving into EV charging as a VPP asset, for example, while expanding the type and size of other DER load assets, including aggregated residential customers.	*R&I or Production*	the total number of contracts from 2018 by shifting focus from primarily C&I to residential markets and announcing a key partnership with Honeywell International Inc. in 2019.
Profit: EUR 0.5 million[219]		*Sales*	▪ North America ▪ The company has focused recent market development activity in Europe and Japan while simultaneously nurturing its foothold in Australia, which it deems as the world's current best VPP market.

Company & key financials	Short description	Operational footprint & geographic focus	
enel x	▪ VPP	*HQ*	▪ Rome, Italy
Enel X **Turnover: EUR1.73 million (VPP); EUR3.02 million (Deployment)**	▪ In the flexibility market closely aligned with VPPs, Enel X has activities in all open wholesale markets in North America and in many countries in Europe and Asia Pacific. ▪ The company acquired eMotorWerks in 2017, the US-based mobility platform technology firm, offering its customers residential EV charging infrastructure (JuiceBox) running on an IoT charging management platform (JuiceNet). ▪ Through its proprietary energy management system platform (DER.OS), which has the ability to serve as both a microgrid controller and a VPP platform, Enel X has the ability to increase the economic returns	*R&I or Production*	▪ This presence is driven in part by the 2017 acquisition of EnerNOC. ▪ In 2017, Enel X acquired Demand Energy Networks, a US-based company specializing in advanced control solutions for storage and DER. ▪ The company acquired eMotorWerks in 2017, the US-based mobility platform technology firm, offering its customers residential EV charging infrastructure (JuiceBox) running on an IoT charging

[219] Average Technology EBITDA margin applied to estimated company revenue

	of storage and other DER across multiple applications. ▪ Enel X estimates that two years are needed to integrate the three platforms from EnerNOC (DR), Demand Energy (DER), and eMotorWerks (EVs) to offer a comprehensive mixed asset VPP solution		management platform (JuiceNet).
Profit: EUR1 million[220]		*Sales*	▪ The Enel Group is an Italian multinational company operating in more than 30 countries with more than 42 GW of capacity. ▪ Projects in: United States, Italy, Poland, Japan ▪ Non-DERMS/VPP: Argentina, Brazil, Colombia, Peru

Company & key financials	**Short description**		**Operational footprint & geographic focus**
	▪ DERMS ▪ Limited VPP offering	*HQ*	▪ Boston, Massachusetts, United States
General Electric	▪ GE DERMS offering is a DER orchestration software solution that encompasses technologies such as advanced energy management, ADMSs, real-time insights, DER orchestration, and geospatial services. ▪ GE aims to cover energy value chains beginning with GIS asset mapping, distribution operator services, transmission operator services, and market operator and player solutions. ▪ This solution is technology-agnostic, allowing energy companies to integrate small-scale renewables produced at the distribution-level, connect new smart buildings to the grid, manage energy storage systems (ESSs) to adjust offers with demand. It also enables EVs charging in an optimized	*R&I or Production*	▪ GE's smart grid offerings are grouped under the GE Digital and Grid Solutions. ▪ Grid Solutions was organized as a GE/Alstom joint organization, which followed GE's acquisition of Alstom Grid in 2015 for EUR12.5 billion.
Turnover: EUR22.17 million (DERMS); EUR5.47 million (DER Analytics);EUR48.03 million (Deployment)			
Profit: EUR7.8 million[221]		*Sales*	▪ Grid Solutions operations in 80 countries

[220] Average Technology EBITDA margin applied to estimated company revenue
[221] Overall company EBITDA margin applied to estimated technology revenue

	way, and to manage and shave end-user consumption via its DR function.		

Company & key financials	Short description	Operational footprint & geographic focus	
	▪ DERMS	*HQ*	▪ Madrid, Spain
Indra – Advanced Control Systems **Turnover: EUR1.96 million (DERMS); EUR3.42 million (Deployment)**	▪ The addition of ACS to Indra's portfolio provides Indra a combined IT/OT value proposition for the first time. • This extends Indra's overall offering with an OT solution composed of real-time software solutions such as SCADA, feeder automation, and DERMS ▪ ACS focused on DERMS as an extension of its ADMS, while Indra's offered other capabilities, specifically an Internet of Things platform to manage and optimize DER assets in the grid. It is still early in the integration process, but the combined solution could develop into a competitive edge-to-edge DERMS.	*R&I or Production*	▪ Indra's Minsait subsidiary bought Advanced Control Systems (ACS) in September 2018. ▪ In July 2019, Indra announced it will partner with Monash University in Australia for the Smart Energy City project
Profit: EUR1 million[222]		*Sales*	▪ ACS primarily targeted US mid-market utilities; Indra acquisition brings global presence

Company & key financials	Short description	Operational footprint & geographic focus	
	▪ VPP	*HQ*	▪ Cologne, Germany
Next Kraftwerke **Turnover: EUR27.19 million (VPP); EUR47.53 (Deployment)**	▪ In 2012, Next Kraftwerke helped launch and operate NEXT Pool, now the largest VPP in Europe (and the world), covering Germany, Austria, Belgium, France, Netherlands, Poland, Switzerland, and Italy. ▪ Next Kraftwerke's in-house developed VPP platform (NEMOCS) is offered to utilities,	*R&I or Production*	▪ The Dutch distribution system operator, Eneco, acquired a minority interest of 34% in Next Kraftwerke in 2017. ▪ The company's other investors are High-Tech Gründerfonds and Neuhaus Partners.

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Profit: EUR 10 million[223]	C&I customers, and aggregators not operating within the NEXT Pool markets. ▪ NEMOCS trading portal is dubbed NEXTRA. ▪ NEMOCS offers monitoring, asset optimization based on market and weather data, and fully automated control based on individual asset rules and is offered as a software as a service (SaaS) product.	*Sales*	▪ To date, NEMOCS has only one officially announced customer, the British supplier Ecotricity, and has several pilots running in South Korea and Japan. ▪ Next Kraftwerke recently announced a partnership with Toshiba to jointly develop VPP solutions and offerings revolving around mixed asset VPPs.

Company & key financials	**Short description**	**Operational footprint & geographic focus**	
	▪ DERMS	*HQ*	▪ Medina, Minnesota
OSI **Turnover: EUR5.87 million (DERMS); EUR0.97 million (DER Analytics);EUR11.94 million (Deployment)**	▪ Key components of OSI's DERMS include real-time system interfaces, cybersecurity with North American Electric Reliability Corporation (NERC)/Federal Energy Regulatory Commission (FERC) standards, and extensive management functionality beyond generation and distribution.	*R&I or Production*	▪ The company has a 3-year, multimillion-dollar roadmap in place to enhance the Integra DERMS solution with added functionality.
Profit: EUR2.8 million[224]		*Sales*	▪ OSI has more US-based ADMS deployments than all other vendors combined. ▪ Ramping up international efforts (currently ~15% of sales) ▪ Offices in Australia New Zealand, China, India, Latin America, Europe, Middle East & Africa

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224 Average Technology EBITDA margin applied to estimated company revenue

Company & key financials	Short description	Operational footprint & geographic focus	
	▪ DERMS ▪ VPP	*HQ*	▪ Paris, France
Schneider Electric **Turnover: EUR14.67 million (DERMS); EUR2.41 million (DER Analytics);EUR7.25 million (VPP); EUR42.53 million (Deployment)**	▪ Schneider Electric SE offers integrated energy solutions across multiple market segments. Segments include residential and commercial buildings, industries and machines manufacturers, utilities and infrastructure, and data centers and networks. ▪ Schneider Electric has partnered with AutoGrid to serve as a global reseller of the AutoGrid Flex platform; this joint solution integrates Schneider's EcoStruxure ADMS. The company thus has vast VPP share in Europe despite not serving as a standalone VPP provider. ▪ Schneider Electric SE's DERMS solution can serve as a standalone solution or be embedded with existing ADMS. Embedding it with ADMS allows complete visualization of DER in the distribution network in geographic, schematic, and substation internal views.	*R&I or Production*	▪ Investment in AutoGrid, led by Schneider Electric Ventures.
Profit: EUR 13.1 million[225]		*Sales*	▪ Operations in more than 100 countries ▪ Strong coverage across Europe; making successful inroads across US

Company & key financials	Short description	Operational footprint & geographic focus	
	▪ DERMS ▪ VPP	*HQ*	▪ Munich, Germany
Siemens AG **Turnover: EUR9.13 million (DERMS); EUR6.76**	▪ Siemens, based in Munich, Germany, is a global technology provider positioned in the electric power value chain by offering solutions for generation, transmission	*R&I or Production*	▪ North America ▪ Europe ▪ Africa

[225] 225 Overall company EBITDA margin applied to estimated technology revenue

(DER Analytics);EUR0.86 million (VPP); EUR29.27 million (Deployment)	and distribution, smart grids, smart cities, and energy efficiency. ▪ Siemens offers its Decentralized Energy Management System (DEMS)—a DERMS which has also been applied to VPPs. *Although Siemens offers a comprehensive solution for grid-to-edge customer management, it does not offer a specific VPP solution offering and sees more near-term opportunities with microgrids in the DER space.* ▪ The system includes optimization features like forecasting, scheduling, real-time optimization, process connection, modelling environment, and comprehensive recording of operating resources.		
Profit: EUR 5.1 million[226]		*Sales*	▪ It has been successful in the market, with deployments in a wide range of geographies and regulatory environments, giving it top marks.

10.8 List of Abbreviations

ADMS	Advanced Distribution Management System
CAGR	Compound Annual Growth Rate
DER	Distributed Energy Resources
DERMS	Distributed Energy Resource Management System
DMS	Distribution Management System
GHG	Greenhouse Gas
OT	Operational Technology
O&G	Oil & Gas
TE	Transactive Energy
Volt/VAR	Volt/Volt Ampere Reactive
VPP	Virtual Power Plant
EPC	Engineering, Procurement and Construction
FIT	Feed-in-tariffs
REE	Rare Earth Elements
LCOE	Levelized Cost of Electricity
ROC	Renewables Obligation Certificates
CfD	Contracts for Difference
OEM	Original Equipment Manufacturer
C&I	**Commercial & Industrial**

[226] Overall company EBITDA margin applied to estimated technology revenue

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