EUROPEAN
COMMISSION

Brussels, 26.10.2021
SWD(2021) 307 final

PART 1/5

COMMISSION STAFF WORKING DOCUMENT

Accompanying the document

REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

Progress on competitiveness of clean energy technologies
1 - Macroeconomic

{COM(2021) 950 final} - {COM(2021) 952 final}

CONTENTS

PROGRESS ON COMPETITIVENESS OF CLEAN ENERGY TECHNOLOGIES

1. INTRODUCTION

1.1. An EU climate neutral pathway for the clean energy system

Since 2019, the European Green Deal is the overarching framework for EU clean energy policy. It sets the objective for the EU to have no net emissions of greenhouse gases (GHG) in 2050 and to decouple economic growth from resource use. To operationalise the European Green Deal, the EU Climate Law[1] has enshrined into law the political priority of becoming climate neutral by 2050 and of reducing greenhouse gas emissions by 55% by 2030, compared to 1990 levels. This has been followed by the Fit-for-55 package to deliver on the European Green Deal, adopted by the Commission in July 2021, which proposes to revise existing instruments as well as propose new ones[2] in order to achieve the 2030 target in a fair, cost-effective, and competitive way. This package constitutes the most comprehensive set of proposals the Commission has ever presented on climate and energy. These initiatives will notably contribute to the development of the clean energy sector in the next decades, in particular by spurring innovation and creating new market demand in the EU, cementing EU global leadership by action and by example in the fight against the climate crisis.

The policy context is complemented by a new EU budget (the Multiannual Financial Framework) covering the period 2021-2027. The EUR 1 074 billion[3] envelope sets a clear sustainable direction for the EU, with a target of spending at least 30% of these funds on actions fighting climate change. The clean energy sector is addressed by several EU programmes, notably: the cohesion policy funds, the Horizon Europe framework programme for research and innovation (e.g. through its European Innovation Council and its Cluster on Climate, Energy and Mobility), the Connecting Europe Facility (CEF), and the LIFE programme for environment and climate action. In addition, the revision of the European Emission Trading Scheme (ETS) will increase the allocation of allowances and therefore resources for the Innovation Fund, the Modernisation Fund and the newly created Social Climate Fund. The Innovation Fund, depending on the EU ETS price, could bring an estimated EUR 47 billion, to be invested over 10 years to support the deployment in the market of breakthrough low carbon technologies. The Modernisation Fund, intended to support low income Member States in the modernisation and decarbonisation of their energy systems, would be increased by an additional 2.5% of total allowances. The Social Climate Fund would provide EUR 72.2 billion in financing over seven years, or the equivalent of 25% of expected revenues under the new emissions trading system covering buildings and road transport. It would fund Member States' programmes designed to support investment in increased energy efficiency of buildings, the decarbonisation of heating and cooling and zero- and low-emission mobility and transport, specifically directed at vulnerable households. Finally, the Recovery and Resilience Facility (RRF), created as part of NextGenerationEU and its EUR 750 billion[4], is detailed in section 2.5.

---

[1] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021.

[2] The legislative files include proposals to review the Renewable Energy Directive (RED), the Energy Efficiency Directive (EED), the Energy Tax Directive (ETD), the EU Emissions Trading System (EU ETS), the Effort Sharing Regulation (ESR), the Alternative Fuels Infrastructure Directive (AFID), the Regulation on Land Use, Forestry and Agriculture, the CO2 emission standards for cars and vans, but also proposals to create a Carbon Border Adjustment Mechanism (CBAM), and the ReFuelEU Aviation and FuelEU Maritime initiatives. An EU Forest Strategy and a proposal to create a Social Climate Fund complete the package.

[3] 2018 prices.

[4] 2018 prices. EUR 806.9 billion in current prices.

The clear direction described above, which sets targets, regulation, and funding – notably in energy efficiency, renewable energy, and emissions reductions – enables the clean energy sector to have visibility over future market prospects and opportunities, thus increasing investors' certainty. The foundation on which the framework is built is the EU internal market, which these policies aim to continuously strengthen by removing internal and external investment and trade barriers. Most recently, the European Commission presented its new Industrial Strategy[5] – updating it following the COVID-19 crisis[6] – to provide a roadmap for the EU industry to become more competitive globally. Some highly relevant initiatives to the clean energy sector include the creation of industrial alliances to accelerate activities that would not develop otherwise. To date, relevant alliances in place are the European Batteries Alliance, the Clean Hydrogen Alliance, and the European Raw Materials Alliance. Future alliances will include Zero Emission aviation and renewable and low-carbon fuels alliances.

The dependence on key raw materials, which is relevant for certain technologies covered in this report (e.g. batteries, PV), is also a centrepiece of the new industrial policy, as the EU aims to enhance its strategic autonomy. In addition to policies ensuring the sustainability of raw material production, the EU is also firmly attached to ensuring strong life-cycle and circularity considerations within its internal market, including recyclability, reusability or waste management of its products. Relevant examples include the proposal for a Batteries Regulation and the Circular Economy Action Plan, both presented by the European Commission in 2020. The Clean Energy Industrial Forum (CEIF), set up in 2018 by the European Commission, brings together industrial actors from the renewables, batteries and construction sectors, in order to identify and take advantage of growth opportunities.

Common rules and standards for access to finance are also important for fair and competitive market access. The EU aims to ensure this for example through the revision of state-aid guidelines for research, development and innovation, for energy and environment, and for important projects of common European interest (IPCEI). They will allow Member States to address market failures in very specific situations. At the same time, initiatives such as the EU Taxonomy Regulation and its delegated acts for sustainable finance will aim to steer market uptake of a wide range of technologies, including in the clean energy sector.

Another crucial point affecting the competitiveness of the clean energy industries, are the complex and lengthy administrative and permitting procedures. Permitting delays constitute a major barrier for the transition to a decarbonised energy system, delaying deployment and investments into clean energy infrastructures and technologies by many years. A significant acceleration of deployment is needed to achieve the current 2030 renewable energy target of 32%, and an even greater acceleration will be needed to meet the newly proposed 40% target of the 'Fit for 55' package.

Urgent simplification and streamlining of permitting procedures is needed to create a common market for renewables that facilitates efficient and cost-effective deployment as well as investor certainty, also in view of the massive investments needed. To this end, the Commission plans in 2022 to present guidance on the permitting provisions of the renewable energy directive, to facilitate best practices exchanges and strongly encourages Member States to continue streamlining and simplifying procedures to this end.

Finally, trade policy has a key role to play in driving Europe's economic prosperity and competitiveness, supporting a vibrant internal market and assertive external action. Political and geo-economic tensions are leading to growing unilateralism and distortions of trade and investments. This is also impacting the energy sector, where increasingly EU companies are faced with third country governments putting in place market access barriers, local content requirements or other discriminatory or otherwise trade restrictive measures

---

[5] COM(2020) 102 final.

[6] COM(2021) 350 final.

aimed at promoting their domestic industry. In line with the Trade Policy Review, the European Commission is taking an active role in securing access to third country markets for our renewable energy industry through its bilateral trade agreements and its reinforced enforcement approach, while ensuring undistorted trade and investment in the raw materials and energy goods required for the transition to climate neutral economies.

1.2. Context of the Report

This is the second competitiveness progress report published in the context of the State of the Energy Union report. As competitiveness in the clean energy sector is a broad concept, the first report defined it through a range list of indicators that this report uses to assess competitiveness.

Table 1 List of indicators for the Competitiveness Progress Report

Part 1: Macro section	**Part 2: Technology specific section**		
Macro-economic analysis (aggregated, per MS and per clean technology)	1. Technology analysis Current situation and outlook	2. Value chain analysis of the energy technology sector	3. Global market analysis
Primary and final **energy intensity**; **share of RES; import dependency,** industrial electricity and gas **prices**	**Capacity installed, generation/production** *(today and in 2050)*	**Turnover**	**Trade (imports, exports)**
Turnover of the EU (clean, Fossil Fuel) sector (vs whole economy)	**Cost / Levelised Cost of Electricity (LCoE)**[7] *(today and in 2050)*	**Gross value added growth** Annual, % change	**Global market leaders vs. EU market leaders**
Gross value added of renewable energy production vs Energy Efficiency vs economy	**Public R&I funding (MS and EU)**	**Number of companies in the supply chain, incl. EU market leaders**	**Resource efficiency and dependence**[8]
Employment figures EU vs RoW; gender statistics	**Private R&I funding** (venture capital (value and number of deals) (incl sources backing VC), energy companies)	**Employment in value chain segment**	
COVID-19 disruption of value chains	**Patenting trends** (incl high value patents)	**Energy intensity / labour productivity**	
	Level of scientific Publications	**Community Production** *Annual production values*	

---

[7] And –if available- Levelised Cost of Storage (LCoS).

[8] Segments of the value chain that depend on critical raw materials.

2. OVERALL COMPETITIVENESS OF THE EU CLEAN ENERGY SECTOR

2.1. Energy and resource trends

Over the period 2005-2019, both primary energy intensity and final energy intensity in industry have continued to decrease at an average annual rate of around 2%[9]. In the more recent period (2015-2019) the majority of Member States achieved reductions in energy intensity, with the exception of Belgium[10], Hungary and Poland[11]. In absolute terms, over the same recent period, total primary and final energy consumption increased slightly for the majority of Member States. However, big consumers such as Germany, France and Italy managed to achieve reductions in primary energy consumption (along with Denmark and the Netherlands), leading to a small overall reduction at EU level[12]. The reduced energy intensities demonstrate the decoupling of energy demand from economic growth. However, increased effort will be needed to achieve the new energy efficiency targets proposed by the Commission for 2030.

Table 2 shows the change in these indicators over the recent 5-year period per Member State. The majority of Member States achieved reductions, albeit some at a lower rate than the EU average. Over the same period the GHG intensity has also been decreasing consistently, enabled – among others – by the increasing share of renewable energy in energy consumption.

---

[9] Energy Union indicators EE1-A1: Primary energy intensity EE3: Final energy intensity in industry, DE5: Share of renewable energy in percentage of gross final energy consumption, SoS1: Net import dependency – sources Eurostat: Complete energy balances [nrg_bal_c], Gross value added [nama_10_a10]; GDP: AMECO database

[10] Where there was a small increase in primary energy intensity.

[11] Where the final energy intensity in industry increased.

[12] Even though reductions achieved in recent years have been small, overall, in the period 2005-2019 EU primary energy consumption decreased by 10% and final energy consumption decreased by 5%.

Table 2: Trends per Member State on primary energy intensity, final energy intensity in industry, renewable energy share and targets, and net import dependency (fossil fuels).

Indicators	Primary energy intensity		Final energy intensity in industry		RES in gross final energy consumption		Net import dependency	
Unit	[toe/mn Euro GDP2010]	average annual change [%]	[toe/mn Euro GVA2015]	average annual change [%]	Share [%]	gap to 2020 target [pp]	Net imports [%]	absolute change [pp]
Year	2019	2015-19	2019	2015-19	2019	2019	2019	2015-19
EU	102	-2%	90	-2%	20%	🟡	61%	🔴
BE	111	🔴	137	🟡	10%	🔴	77%	🟢
BG	347	🟢	306	🟢	22%	🟢	38%	🔴
CZ	208	🟢	116	🟢	16%	🟢	41%	🔴
DK	55	🟢	40	🟢	37%	🟢	39%	🔴
DE	87	🟢	72	🟡	17%	🔴	68%	🔴
EE	190	🟢	96	🟢	32%	🟢	5%	🟢
IE	44	🟢	20	🟡	12%	🔴	68%	🟢
EL	132	🟡	141	🟢	20%	🟢	69%	🟢
ES	101	🟡	101	🟡	18%	🔴	75%	🔴
FR	100	🟢	79	🟡	17%	🔴	48%	🔴
HR	163	🟢	136	🟡	28%	🟢	56%	🔴
IT	84	🟡	74	🟢	18%	🟢	77%	🔴
CY	117	🟡	96	🟢	14%	🟢	93%	🟢
LV	165	🟡	184	🟢	41%	🟢	44%	🟢
LT	145	🟡	106	🟡	25%	🟢	75%	🟢
LU	77	🟡	105	🟢	7%	🔴	95%	🟢
HU	186	🟢	147	🔴	13%	🟡	70%	🔴
MT	71	🟡	39	na	8%	🔴	97%	🟢
NL	84	🟢	113	🟢	9%	🔴	65%	🔴
AT	86	🟡	86	🟢	34%	🟡	72%	🔴
PL	191	🟢	135	🔴	12%	🔴	47%	🔴
PT	111	🟡	145	🟡	31%	🟡	74%	🟢
RO	163	🟢	142	🟢	24%	🟢	30%	🔴
SI	144	🟢	111	🟢	22%	🔴	52%	🔴
SK	179	🟡	151	🟡	17%	🟢	70%	🔴
FI	140	🟡	228	🟡	43%	🟢	42%	🟢
SE	93	🟡	115	🟢	56%	🟢	30%	🔴

Legend								
🔴		>0%		>0%		x>0.5 %		x>0
🟡		0%> and >-2%		0%> and >-2%		0.5%> and >0.1%		
🟢		<-2%		<-2%		x<0.1 %		x=<0

Position relative to EU average

Source: Energy Union indicators, based on Eurostat data[13]

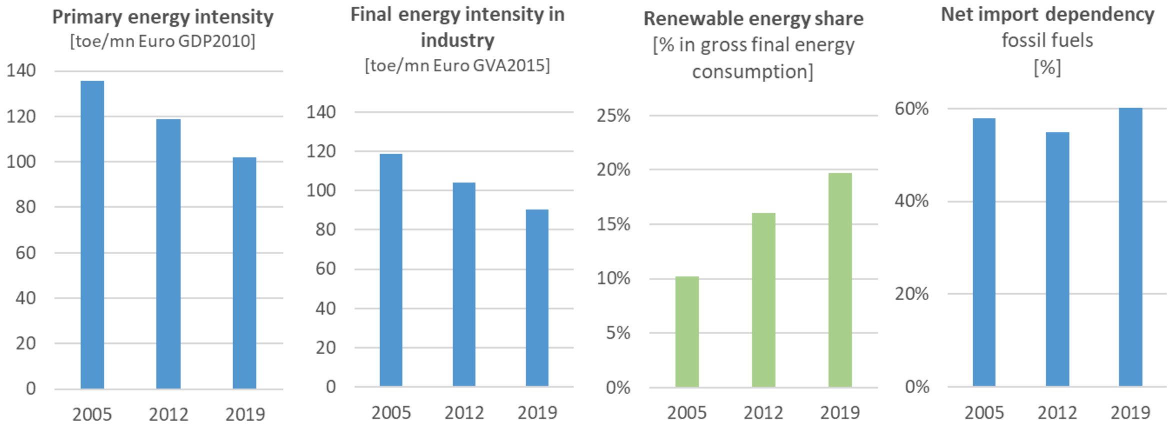
In 2019, the renewable energy share in the EU gross final energy consumption reached 19.7% (Figure below), very close to the 2020 target of 20%, with a renewable share of 34% in electricity generation.

---

[13] Energy Union indicators EE1-primary energy consumption, EE2-Final energy consumption, EE3: Final energy intensity in industry, SoS1: Net import dependency – sources Eurostat: [nrg_bal_c], [nrg_bal_s], Gross value added [nama_10_a10]; GDP: AMECO database.

Bioenergy accounted for 59% of the total renewable energy supplied, followed by wind (14%), hydro (12%), geothermal (8%) and solar (7%)[14]. While more than half of the Member States have already exceeded them, and a few more are very close, there are several countries further away from achieving their targets. The penetration of renewable energy needs to be significantly accelerated in order to achieve the new binding target proposed by the Commission of at least 40% renewable share in final energy consumption by 2030.

Figure 1 EU primary energy intensity and final energy intensity in industry, renewable energy share, and net import dependency (fossil fuels)



Source: Energy Union indicators, based on Eurostat data[15]

Despite a short-term reduction between 2008 and 2013, the EU energy import dependency[16] has since experienced an increase. In 2019, net import dependency reached 60.6%, the highest it has been during the last 30-year period. This is due to reduced domestic production of fossil fuels[17].

Under the package to deliver on the European Green Deal, the Commission has proposed to strengthen the EU Emissions Trading System (ETS) by tightening the cap and increasing the linear reduction factor from 2.2% per year to 4.2%. Furthermore, the EU ETS would be extended to maritime transport. The use of carbon pricing and carbon prices in economies with emissions trading systems and similar carbon pricing systems are increasing as parties put in place measures to meet Greenhouse Gas Emissions reduction targets. 2021 saw the launch of China's national emissions trading system, covering the power sector and due to expand to cover other heavy emitting sectors. Trading began in July 2021 at a price of RMB 50 (6.5 Euros) per tonne CO_2. Since 2019, Canada has a federal carbon pricing system, with a benchmark/ minimum price across all provinces, which will reach 50 CAD (around 34 Euros) per tonne in 2022 and will rise by 15 CAD (10 Euros) per year from 2023 to 2030. Other jurisdictions are also revising their ETS legislation, for example, South Korea and New Zealand where the ETS price rose to 48 NZD (28 Euros)

---

[14] Eurostat Complete energy balances [nrg_bal_c]

[15] Energy Union indicators EE1-primary energy consumption, EE2-Final energy consumption, EE3: Final energy intensity in industry, SoS1: Net import dependency – sources Eurostat: [nrg_bal_c], [nrg_bal_s], Gross value added [nama_10_a10]; GDP: AMECO database.

[16] In the context of this report, net import dependency measures the level of total net imports as a proportion of total gross inland consumption and the energy consumption of maritime bunkers (i.e. what is consumed in a country or region over a year). The indicator is based on Eurostat energy statistics.

[17] Eurostat (sdg_07_10), (sdg_07_11), (nrg_bal_c).

per tonne in July 2021. The EU Emissions Trading System (ETS) prices have risen from about 25 Euros per tonne of CO_2 in 2020 to around 50 Euros per tonne of CO_2 in mid-2021.

The Commission has also reviewed the functioning Market Stability Reserve (MSR) and proposed adjustments to prevent excessive surpluses and deficits in the market. The Commission also proposes a new, separate ETS to cover emissions from fuels used in the road transport and buildings sectors, to provide incentives for decarbonisation. Social impacts on vulnerable households, micro-enterprises and transport users that arise from the new system would be addressed by a new Social Climate Fund. Direct income support would also be made available to vulnerable households, in order for them to absorb the immediate price impact of the new emissions trading system.

Comparing EU[18] to the world's biggest economies in terms of carbon pricing[19,20](based on OECD data from 2018 on pricing carbon emissions of energy use[21]), only South Korea had higher level of pricing, in which over 65% of emissions were priced above 5 EUR/tCO_2, mainly via taxes on fuel use . In the EU, on average, over 41% of emissions were priced above 5 EUR/tCO_2. Also, over 27% was priced above 120 EUR/tCO_2. As mentioned above, since 2018, the EU ETS price has increased significantly. In the US and China, 65% and 91% of emissions respectively were not priced at all or priced at less than 5 EUR/tCO_2. Taking view on industry and electricity sectors shows that emissions were priced generally at lower level. In the industry, over 90% of emissions in South Korea were priced above 5 EUR/tCO_2. In the EU this share was on average about 56%. In contrast in the US and China, 97% and 98% of emissions were not priced at all or priced below 5 EUR/tCO_2. In the electricity sector, South Korea had again the highest pricing, where 72% of emissions were priced at 5-30 EUR/tCO_2 and 25% of emissions priced at 30-60 EUR/tCO_2. In the EU, on average 77% of emissions were priced at 5-30 EUR/tCO_2. In the US and China, 93% and 100% of emissions respectively, were not priced at all or priced below EUR 5 per tCO_2.

Figure 2: Emissions priced at different levels – all sectors[22], industry and electricity (2018)

---

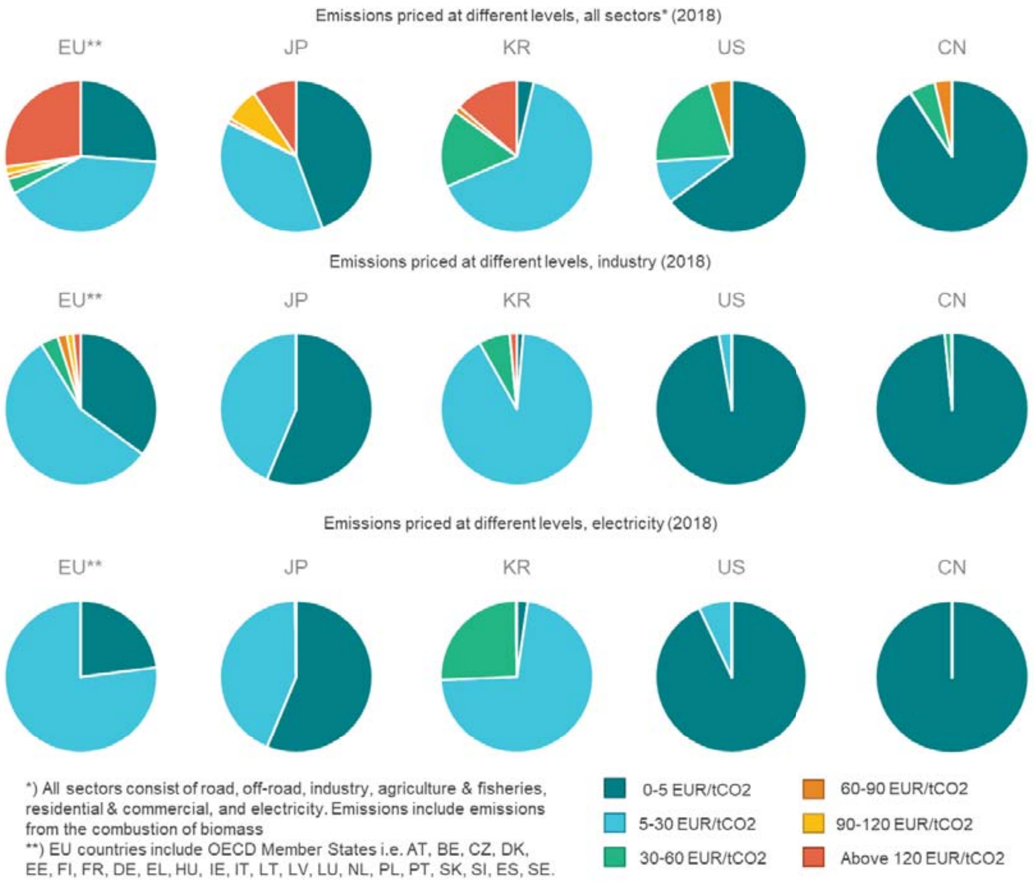
[18] This is based on OECD data which includes the following EU countries: AT, BE, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LT, LV, LU, NL, PL, PT, SK, SI, ES, SE.

[19] Effective carbon rates reported by OECD is the most detailed and comprehensive account of how 44 OECD and G20 countries – responsible for around 80% of global emissions – price carbon emissions from energy use. Effective carbon rates consider emission permit prices (e.g. EU ETS), carbon tax and fuel excise tax.

[20] EU was calculated as simple average of EU countries, as there was no data to do weighted average calculation.

[21] OECD (2021), Effective Carbon Rates 2021: Pricing Carbon Emissions through Taxes and Emissions Trading, OECD Publishing, Paris, https://doi.org/10.1787/0e8e24f5-en.

[22] All sectors include road, off-road, industry, agriculture and fisheries, residential and commercial, and electricity. Emissions include also emissions from the combustion of biomass.



*) All sectors consist of road, off-road, industry, agriculture & fisheries, residential & commercial, and electricity. Emissions include emissions from the combustion of biomass

**) EU countries include OECD Member States i.e. AT, BE, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LT, LV, LU, NL, PL, PT, SK, SI, ES, SE.

Source: JRC elaboration based on OECD[23]

Literature is inconclusive when it comes to the effects of carbon pricing on different elements of competitiveness. Calel and Dechezlepretre (2016)[24] find that EU ETS has increased low-carbon innovation[25] among regulated firms by as much as 10%, while not crowding out patenting for other technologies. Results imply that the EU ETS accounts for nearly a 1% increase in European low-carbon patenting compared to a counterfactual scenario. In another study Ley et al. (2016)[26] investigated patent data and industry specific energy prices for 18 OECD countries over 30 years. They found that 10% increase of the average energy prices[27] over the previous five years results in a 3.4% and 4.8% increase of the number of green innovations and the ratio of green innovations to non-green innovations, respectively. In the meta-

---

[23] OECD. Effective Carbon Rates: Share of emissions priced - Dataset. Availablet at: https://stats.oecd.org/?datasetcode=ecr.

[24] Calel, R & Dechezlepretre, A (2016) Environmental policy and directed technological change: evidence from the European carbon market. The Review of Economics and Statistics 98:1, 173-191, DOI: https://doi.org/10.1162/REST_a_00470.

[25] Patents classified as ‘Technologies and applications for mitigation or adaption against climate change’ (Y02 class) are used as a proxy for low-carbon innovation.

[26] Ley, M, Stucki, T, Woerter, M (2016) The impact of energy prices on green innovation. The Energy Journal, International Association for Energy Economics 37:1.

[27] Energy prices here refer to end-use prices (per tonne of oil equivalent including taxes) for the manufacturing sector for different energy products, such as electricity, light fuel oil, natural gas and different coal products.

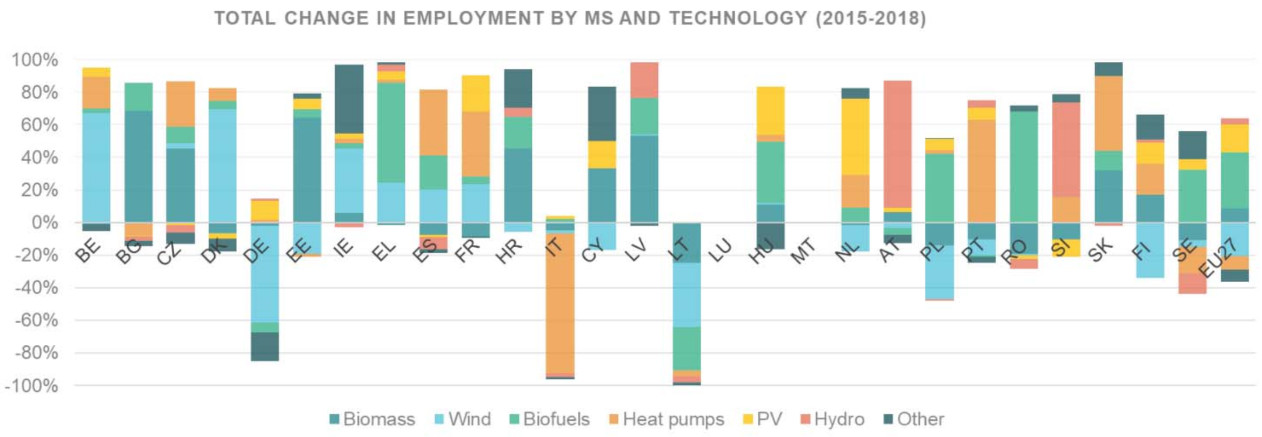
analysis of Venmans et al. (2020)[28] on the impact of carbon pricing on a range of economic indicators[29], positive effect is found on innovation and productivity, while effect on net exports, turnover, and employment remain inconclusive. Carbon prices levied on industry have been low to date, either because of exemptions to carbon taxes, or generous levels of free allowances, which in part explains these findings.

2.2. Human Capital

2.2.1. Employment in clean energy

Looking more closely at direct and indirect jobs[30][31] per renewable energy technologies over the period 2015-2018, shows that overall employment in EU has grown by an average 1% annual growth[32]. However, there are vast differences across different technologies and Member States. In terms of renewable energy technologies at EU aggregate level, the biggest decline has been in the wind sector. Decline of jobs has been biggest in Germany, Lithuania, Poland and Finland. Especially in Germany, the biggest market, decline has been due to the wind installation market slowing down, from annual installed capacity of 5.4 GW in 2016 to 1.7 GW in 2019[33] (see Offshore and Onshore wind sections). In contrast, the biggest overall increase in EU has been in the biofuels and solar PV. Biofuel jobs grew most in the Greece, Poland and Romania. Solar PV jobs grew the most in France, Hungary and the Netherlands.

Figure 3 Total change in employment by technology and by MS over 2015-2018 period



Source: JRC based on EurObserv'ER

Figure 4 (below) shows the average annual growth rate over the period 2015-2018 across Member States and across different technologies. Jobs have grown fastest in solar PV (12%), biofuels (11%), and waste to

---

[28] Venmans F., Ellis J. & Nachtigall D. (2020) Carbon pricing and competitiveness: are they at odds?, Climate Policy, 20:9, 1070-1091, DOI: 10.1080/14693062.2020.1805291.

[29] Net imports, foreign direct investments, turnover, value added, employment, profits, productivity, and innovation

[30] It is important to note that two different data sources are used for employment figures in this report, namely Eurostat Environmental Goods and Services Sector accounts and EurObserv'ER. The figures are not directly comparable as there are methodological differences in approaches. The Annual Single Market Report 2021 estimated the employment and gross value added of Renewables Ecosystem using national accounts and NACE classification.

[31] EurObserv/ER definition – direct employment includes renewable equipment manufacturing, renewable plant construction, engineering and management, operation and maintenance, biomass supply and exploitation. Indirect employment refers to secondary activities such as transport and other services.

[32] EurObserv'ER tracks direct and indirect jobs in renewable energy technologies per Member State. The methodology and scopes in Eurostat EGSS accounts and EurObserv'ER are different, hence the figures should not be compared directly.

[33] Based on EurObserv'ER Wind Energy Barometer.

energy sector (9%), and declined fastest in geothermal (-8%), solar thermal (-6%), in wind (-5%) and biogas (-5%). Jobs have grown overall fastest in Bulgaria (25%), Belgium (20%), Greece (20%), Ireland (16%) and Netherlands (15%). Jobs have declined fastest in Italy (-14%), in Lithuania (-13%) and in Germany (-6%). EU-average is used as a benchmark for ranking the growth rate of Member State in each technology i.e. green – growing faster than EU average, yellow – growing but at lower level than EU average, and red – declining or declining faster than EU average. Benchmarks per each technology are indicated in Figure 4.

Figure 4 Average growth rate per year in jobs (2015-2018) by technology and by Member State

Growth of employment per technology (CAGR) over period 2015-2018

	Biomass	Wind	Biofuels	Heat pumps	Solar PV	Hydropower	Others*	**Total**
BE	↓	↑	→	↑	→	→	↓	20%
BG	↑	→	↑	↓	↓	↓	↓	25%
CZ	↑	↑	→	↑	↓	↓	↓	10%
DK	↓	↑	↑	↑	↓	→	↓	5%
DE	↓	↓	↓	↑	→	↑	↓	-6%
EE	↑	↓	↑	→	↑	→	↑	9%
IE	↑	↑	↑	↑	↑	↓	↑	16%
EL	↓	↑	↑	↑	↑	↑	↑	20%
ES	↓	↑	↑	↑	↓	↓	↓	7%
FR	↓	↑	→	↑	↑	→	→	4%
HR	↑	↓	↑	→	→	↑	↑	7%
IT	↓	→	→	↓	→	↓	→	-14%
CY	↑	↓	→	→	↑	→	↑	11%
LV	↑	↑	↑	→	→	↑	↓	12%
LT	↓	↓	↓	↓	→	↓	↓	-13%
LU	→	→	→	→	→	→	→	0%
HU	↑	↑	→	↑	↑	→	↓	6%
MT	→	→	→	→	→	→	→	0%
NL	↓	↓	↑	↑	↑	→	↑	15%
AT	↑	↓	↓	→	→	↑	↓	13%
PL	↓	↓	↑	↑	↑	↓	↑	0%
PT	↓	↓	↓	↑	↑	→	↓	6%
RO	↓	→	↑	→	↓	↓	↑	9%
SI	↓	→	→	↑	↓	↑	↑	8%
SK	↑	→	→	↑	→	↓	↑	9%
FI	→	↓	→	↑	↑	→	↑	2%
SE	↓	→	↑	↓	↑	↓	↑	1%
EU27	**2%**	**-5%**	**11%**	**-2%**	**12%**	**3%**	**-3%**	**1%**
↑	>2%	>0%	>11%	>0%	>12%	>3%	>0%	
→	<2%	<0%	<11%	<0%	<12%	<3%	<0%	
↓	≤0%	≤-5%	≤0%	≤-2%	≤0%	≤0%	≤-3%	

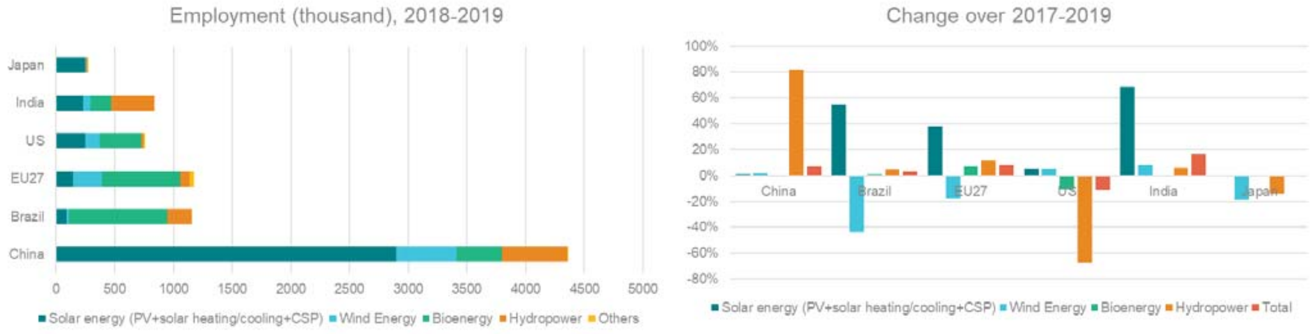
*) Others include biogas, waste, solar thermal and geothermal

Source: JRC based on EurObserv'ER

2.2.1.1.Global comparison

Overall global renewable energy employment increased by 4% from 2018 to 2019, reaching 11.5 million jobs. Solar PV remains the biggest globally with 33% share, followed by bioenergy[34] with 31% share of total jobs. The biggest increase since 2018 has occurred in India (growth of 16%), where jobs, especially in solar energy increased by 68%. In China, the biggest market, jobs in solar energy grew only by 1%, with the biggest growth occurring in hydropower with 82% growth. Also in Brazil growth of jobs was driven by increase in solar energy employment, whereas jobs in wind sector decreased. In the US and Japan overall level of jobs declined.

Figure 5 Renewable energy employment in the biggest economies



Source: JRC based on IRENA

2.2.1.2.Skills and training aspects

The clean energy system is entering a new era, where new innovations have been emerging at an accelerated pace. Such acceleration requires re-skilling and up-skilling across all skills levels to deploy and further develop clean energy technologies and solutions across different sectors. Demand for a wide range of occupational categories relevant to the greening economy is expected to increase until 2030. These include blue collar jobs like labourers in mining (covering also the mining of critical materials for clean technologies), construction, manufacturing and transport, building and related trades, as well as white collar jobs like science and engineering professionals[35].

To support the uptake of next-generation skills essential for the EU green transition, the EU launched in 2020 the Pact for Skills[36] where partnerships with industrial ecosystems such as construction and energy intensive industries are being set up through roundtables. There are over 336 signatories to the Pact, with 130 also making commitments for upskilling and reskilling[37]. Signatories can be a rage of different actors: individual companies, regional and local partnerships, industrial ecosystems and cross-sector partnerships. Key principles include the promotion of lifelong learning, monitoring and anticipation of required skills, as well as working for equal opportunity. High-level roundtables with industrial ecosystems in the construction and energy intensive

---

[34] Bioenergy includes liquid biofuels, solid biomass and biogas.

[35] https://www.cedefop.europa.eu/en/publications-and-resources/publications/3077

[36] European Commission, The Pact for Skills – mobilising all partners to invest in skills, 2020.

[37] https://ec.europa.eu/social/main.jsp?catId=1517&langId=en

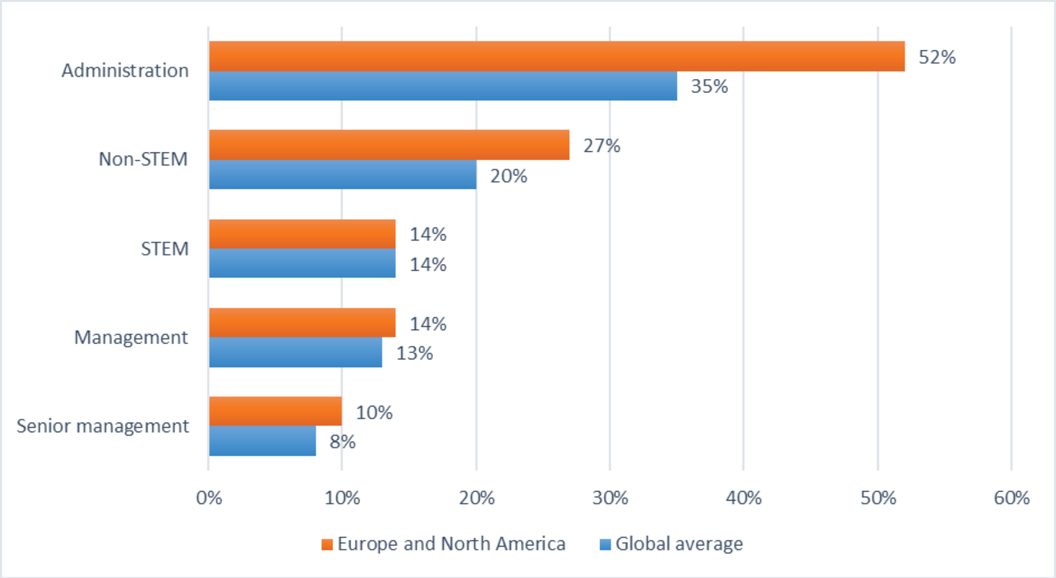
industries sectors have already taken place. These pave the way for partnerships established under the pact to benefit from platforms for networking, expertise, guidance and financial resources.

The composition of training offered in clean energy reflects the need for balance between technical, soft, and transversal skills. EU's BUILD UP Skills initiative aims to equip construction professionals, ranging from manual labourers to design professionals and senior management, with skills for sustainable and energy efficient construction[38]. Various efforts at EU level (DigiPLACE project[39], set up of Digital Innovation Hubs and others) aim at supporting the digital transformation of the construction ecosystem. Digital technologies in construction, buildings and infrastructure can improve sustainability, resource efficiency and the overall management of the assets.

2.2.1.3.Gender aspects

While women accounted for an average of 32% of the workforce in the renewables sector in 2019[40], in wind sector specifically, women represent an estimated 21% of the industry's workforce globally. In Europe and North America, the best performing region, the share is 26%[41]. This is principally due to a heavy representation of women in administration, see Figure 6. The role with the lowest share of female employment (8%) was senior management (e.g. owners or members of the board of directors of an organisation). Women being comparatively less represented in non-administrative functions might attest to the existence of a variety of gender-specific barriers. Conventional energy sectors, including extractive fossil fuel industries are even more male dominated[42].

Figure 6 Shares of women by role in the wind energy sector in Europe and North America and globally



---

[38] CORDIS, New skills for the construction sector to achieve European energy targets, Results Pack, 2020.

[39] Home (digiplaceproject.eu)

[40] IRENA (2019): https://www.irena.org/publications/2019/Jan/Renewable-Energy-A-Gender-Perspective

[41] IRENA (2020), Wind Energy: A Gender Perspective. IRENA, Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jan/IRENA_Wind_gender_2020.pdf

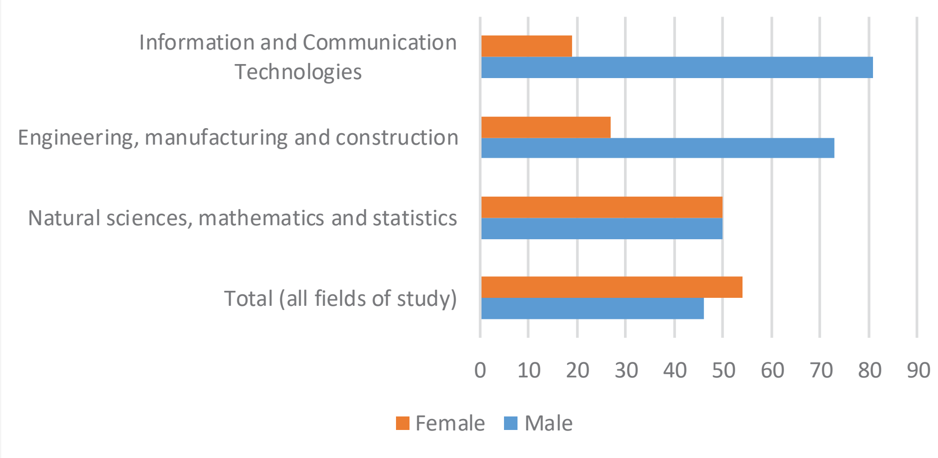
[42] https://publications.jrc.ec.europa.eu/repository/handle/JRC120302.

Source: JRC elaboration based on IRENA (2020)[43]

The energy sector also faces stark gender gaps in innovation and entrepreneurship. In the patent classes closely associated to the energy sector – combustion apparatus, engines, pumps and power – women are listed in less than 11% of applications, and over 15% for climate change mitigation technologies (CCMT), which is comparable to all technologies, including information and communication technologies (ICT)[44]. Highest share (about 25%) of women in patent applications is in chemistry and health sectors.

Gender imbalances both in the energy sector workforce as well as in energy related research and innovation activity, are closely connected to the underrepresentation of women in higher education in some STEM sub-fields. In the EU, women are overrepresented in tertiary education as a whole (54 % across all tertiary education levels and all fields). Within STEM, there is gender balance in the Natural sciences, mathematics and statistics sub-field. However, the sub-fields highly relevant for the energy sector remain strongly male dominated: in 2019 less than a third of Engineering, manufacturing and construction and less than a fifth of ICT higher education students was female.

Figure 7 Distribution of tertiary education students in STEM fields by sex, %, EU-27, 2019



Source: JRC based on Eurostat [EDUC_UOE_ENRT03]

2.2.2. Gross value added in clean energy

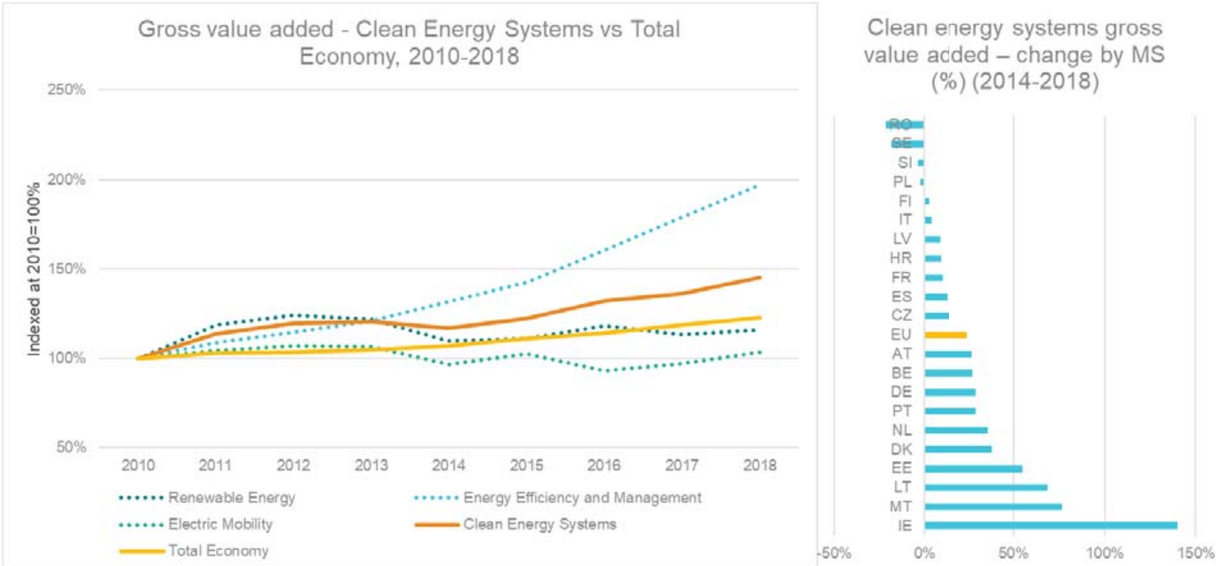
The gross value added of clean energy systems overtook the rest of the economy with an average annual growth of 5% compared to the 3% in the whole economy since 2010. Clean energy (EUR 133 billion) represented 1% of the total value added in the EU in 2018. Within the clean energy systems, gross value added in 'Renewable energy' (EUR 60 billion) has grown with an average annual growth of 2%, while 'Energy efficiency and management systems' (EUR 67 billion) has grown on average by 9% in the same period. Gross value added in the 'Electric mobility' at EUR 7 billion has grown at less than 1% annually.

---

[43] IRENA (2020), Wind Energy: A Gender Perspective. IRENA, Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jan/IRENA_Wind_gender_2020.pdf

[44] IEA (2020), Gender diversity in energy: what we know and what we don't know, IEA, Paris https://www.iea.org/commentaries/gender-diversity-in-energy-what-we-know-and-what-we-dont-know.

Figure 8 Clean energy systems gross value added vs total economy - growth in EU27 2010-2018 and clean energy systems gross value added - change by Member State over 2014-2018



*) No data for Greece, Cyprus, Luxembourg, Hungary or Slovakia. For Finland no data in 2014, so change for 2015-2018. EU27 aggregate is estimated.

Source: JRC based on Eurostat 'env_ac_egss2'[45]

2.2.3. Labour productivity

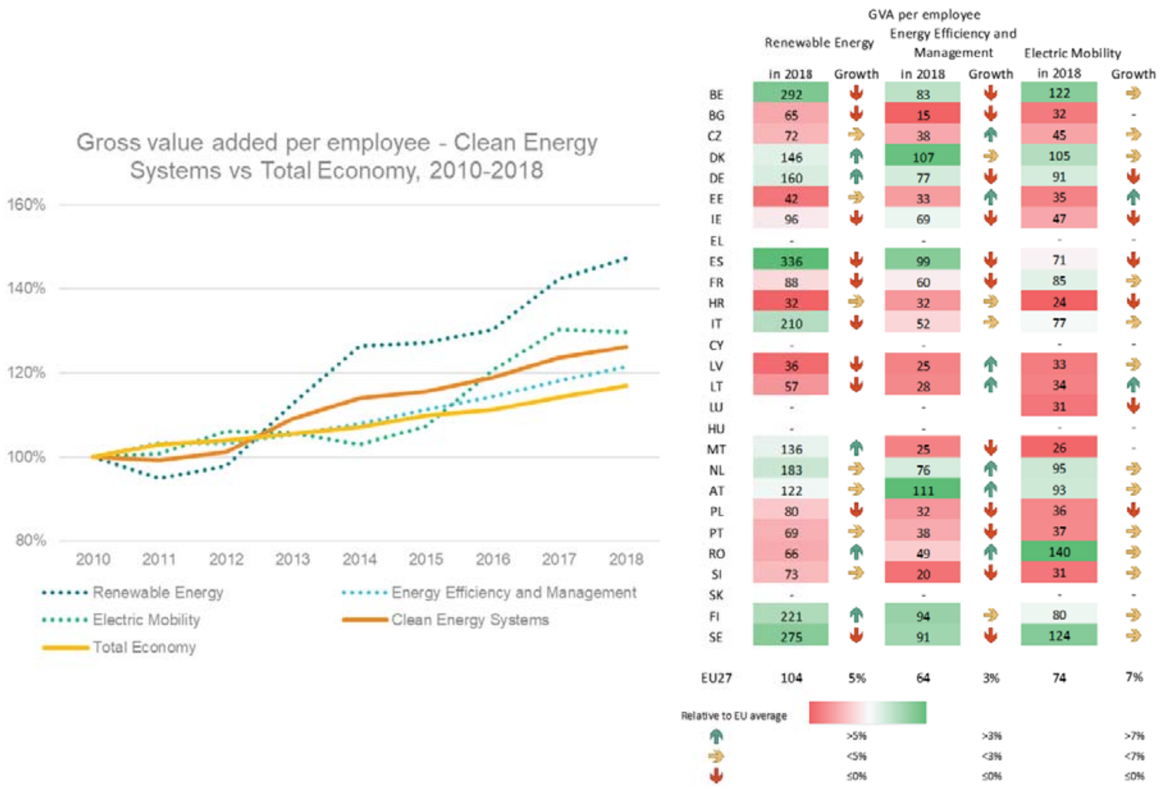
'Renewable energy' jobs created on average EUR 104 000 of gross value added per employee in 2018 with an average annual growth[46] of 5% since 2010. This is nearly twice as much as in the rest of the economy (EUR 64 000 of gross value added per employee). Figure 9 below displays the higher growth in gross value added per employee of multiple components of the clean energy system compared to total economy as well as a break down by Member State.

---

[45] Eurostat 'env_ac_egss2'. Clean energy systems include CReMA 13A - Production of energy from renewable resources, which includes both generation of renewable energy and manufacturing of technologies needed to produce renewable energy ('Renewable energy'); CReMA 13B - Heat/energy saving and management, which includes heat pumps, smart meters, smart grids, energetic refurbishment of buildings, and storage ('Energy efficiency and management'); and CEPA1 - Protection of ambient air and climate, which includes electric vehicles and associated components and the essential infrastructure needed to for the operation of electric vehicles ('Electric mobility').

[46] Compound average growth rate.

Figure 9 Gross value added per employee – Clean energy systems vs Total economy (2010-2018), and gross value added per employee per MS in 2018 and compound average growth rate over 2015-2018 period



GVA per employee

	Renewable Energy		Energy Efficiency and Management		Electric Mobility	
	in 2018	Growth	in 2018	Growth	in 2018	Growth
BE	292	↓	83	↓	122	→
BG	65	↓	15	↓	32	-
CZ	72	→	38	↑	45	→
DK	146	↑	107	→	105	→
DE	160	↑	77	↓	91	↓
EE	42	→	33	↑	35	↑
IE	96	↓	69	↓	47	↓
EL	-		-		-	-
ES	336	↓	99	↓	71	↓
FR	88	↓	60	↓	85	→
HR	32	→	32	→	24	↓
IT	210	↓	52	→	77	→
CY	-		-		-	-
LV	36	↓	25	↑	33	→
LT	57	↓	28	↑	34	↑
LU	-		-		31	↓
HU	-		-		-	-
MT	136	↑	25	↓	26	-
NL	183	→	76	↑	95	→
AT	122	→	111	↑	93	→
PL	80	↓	32	↓	36	↓
PT	69	→	38	↓	37	→
RO	66	↑	49	↑	140	→
SI	73	→	20	↓	31	→
SK	-		-		-	-
FI	221	↑	94	→	80	→
SE	275	↓	91	↓	124	→
EU27	104	5%	64	3%	74	7%

Relative to EU average

	Renewable Energy	Energy Efficiency and Management	Electric Mobility
↑	>5%	>3%	>7%
→	<5%	<3%	<7%
↓	≤0%	≤0%	≤0%

Source: JRC based on Eurostat 'env_ac_egss1' and 'env_ac_egss2'[47]

Labour productivity in 'Renewable energy' is about three times higher in Spain and Belgium than the EU average, though declining. In Spain and Belgium a large share of gross value added in renewable energy, 85% and 64% respectively, comes from generation of renewable electricity. By contrast, more than half of the value added of the renewable energy sector in Denmark, Croatia and Austria is generated by the manufacturing of clean energy technologies. Labour productivity in 'Energy efficiency and management' is highest and growing in Denmark and Austria, and in both over half of the value added is generated by the manufacturing sector. The factors behind high variation of productivity levels among Member States include income, energy prices, subsidies for renewable energy, composition of the renewable energy mix, and the scope of activities covered[48].

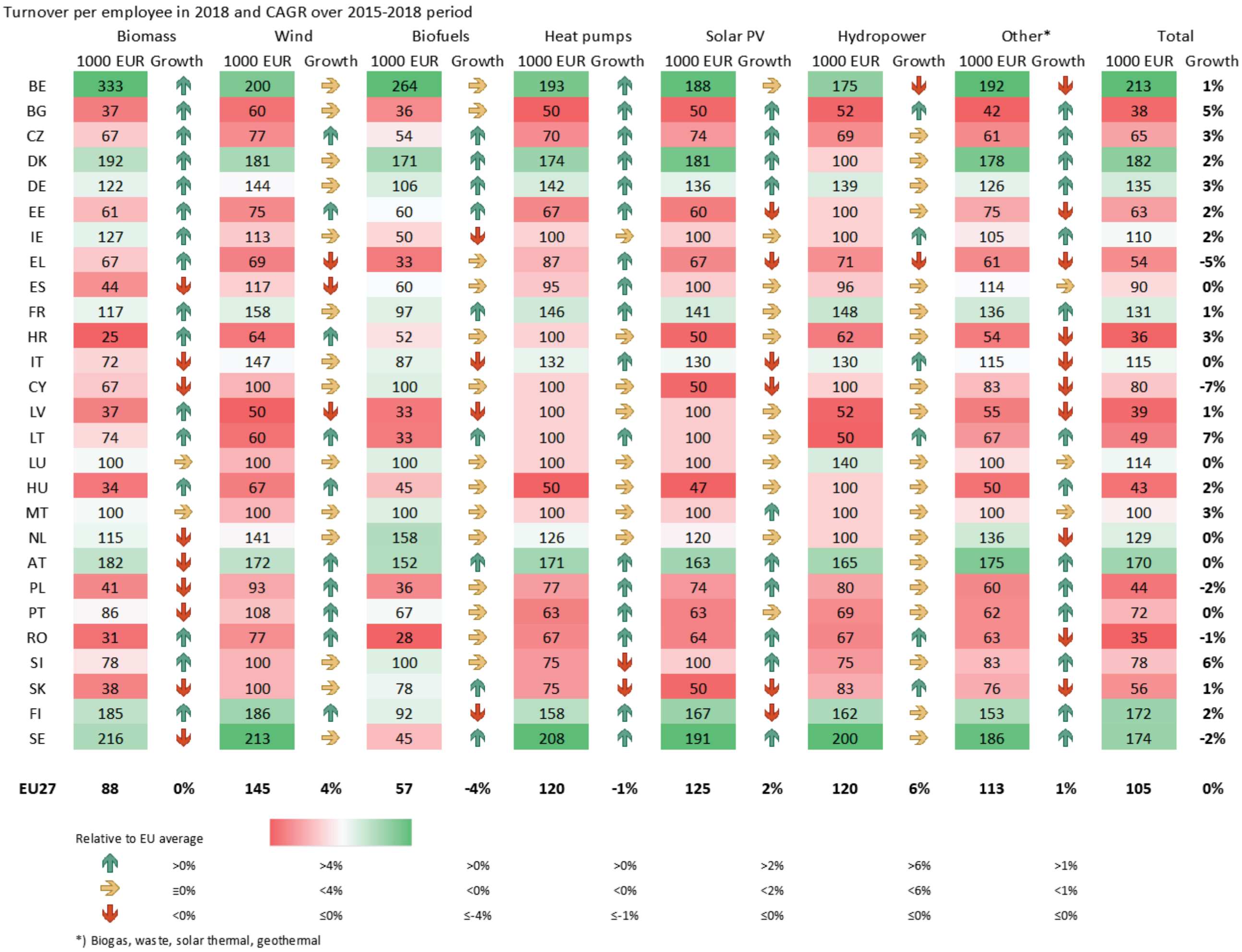
---

[47] Clean energy systems include CReMA 13A - Production of energy from renewable resources, which includes both generation of renewable energy and manufacturing of technologies needed to produce renewable energy ('Renewable energy' – in the graph); CReMA 13B - Heat/energy saving and management, which includes heat pumps, smart meters, smart grids, energetic refurbishment of buildings, and storage ('Energy efficiency and management' – in the graph); and CEPA1 - Protection of ambient air and climate, which includes electric vehicles and associated components and the essential infrastructure needed to for the operation of electric vehicles ('Electric mobility' In the graph).

48Eurostat. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Environmental_economy_%E2%80%93_statistics_by_Member_State#Employment.

While employment in the wind sector has decreased in the EU in the past years, the labour productivity[49] is highest, at EUR 145 000 per employee, and has grown by 4% a year on average. Second highest labour productivity is in the solar PV sector at EUR 125 000 per employee (with 2% average annual growth) and hydropower at EUR 120 000 per employee (with 6% average annual growth). Interestingly, while employment in biofuels has grown, its labour productivity is by far the lowest, at EUR 57 000 per employee and it has been decreasing by 4% a year on average. This is due to a large portion of jobs related to the feedstock procurement component of the value chain. Biomass production in agriculture and forestry sectors is more labour intensive but yields less value than i.e. biomass conversion. While there are differences among Member States and technologies (Figure 10), overall at aggregate EU level there has been no growth in turnover per employee.

Figure 10 Turnover per employee in 2018 and compound average growth rate over 2015-2018 period



Turnover per employee in 2018 and CAGR over 2015-2018 period

	Biomass		Wind		Biofuels		Heat pumps		Solar PV		Hydropower		Other*		Total	
	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth
BE	333	↑	200	→	264	→	193	↑	188	→	175	↓	192	↓	213	1%
BG	37	↑	60	→	36	→	50	↑	50	↑	52	↑	42	↑	38	5%
CZ	67	↑	77	↑	54	↑	70	↑	74	↑	69	→	61	↑	65	3%
DK	192	↑	181	→	171	↑	174	↑	181	↑	100	→	178	↑	182	2%
DE	122	↑	144	→	106	↑	142	↑	136	↑	139	→	126	↑	135	3%
EE	61	↑	75	↑	60	↑	67	↑	60	↓	100	→	75	↓	63	2%
IE	127	↑	113	→	50	↓	100	→	100	→	100	↑	105	↑	110	2%
EL	67	↑	69	↓	33	→	87	↑	67	↓	71	↓	61	↓	54	-5%
ES	44	↓	117	↓	60	→	95	↑	100	→	96	→	114	→	90	0%
FR	117	↑	158	→	97	↑	146	↑	141	→	148	→	136	↑	131	1%
HR	25	↑	64	↑	52	→	100	→	50	→	62	→	54	↓	36	3%
IT	72	↓	147	→	87	↓	132	↑	130	↓	130	↑	115	↓	115	0%
CY	67	↓	100	→	100	→	100	→	50	↓	100	→	83	↓	80	-7%
LV	37	↑	50	↓	33	↓	100	→	100	→	52	→	55	↓	39	1%
LT	74	↑	60	↑	33	↑	100	↑	100	→	50	↑	67	↑	49	7%
LU	100	→	100	→	100	→	100	→	100	→	140	→	100	→	114	0%
HU	34	↑	67	↑	45	→	50	→	47	→	100	→	50	↑	43	2%
MT	100	→	100	→	100	→	100	→	100	↑	100	→	100	→	100	3%
NL	115	↓	141	→	158	→	126	→	120	→	100	→	136	↓	129	0%
AT	182	↓	172	↑	152	↑	171	↑	163	↑	165	→	175	↑	170	0%
PL	41	↓	93	↑	36	→	77	↑	74	↑	80	→	60	↑	44	-2%
PT	86	↓	108	↑	67	→	63	↑	63	→	69	→	62	↑	72	0%
RO	31	↑	77	↑	28	→	67	↑	64	↑	67	↑	63	↓	35	-1%
SI	78	↑	100	→	100	→	75	↓	100	↑	75	→	83	↑	78	6%
SK	38	↓	100	→	78	↑	75	↓	50	↓	83	↑	76	↓	56	1%
FI	185	↑	186	↑	92	↓	158	↑	167	↓	162	→	153	↑	172	2%
SE	216	↓	213	→	45	↑	208	↑	191	↑	200	→	186	↑	174	-2%
EU27	**88**	**0%**	**145**	**4%**	**57**	**-4%**	**120**	**-1%**	**125**	**2%**	**120**	**6%**	**113**	**1%**	**105**	**0%**

Relative to EU average

	Biomass	Wind	Biofuels	Heat pumps	Solar PV	Hydropower	Other*
↑	>0%	>4%	>0%	>0%	>2%	>6%	>1%
→	≡0%	<4%	<0%	<0%	<2%	<6%	<1%
↓	<0%	≤0%	≤-4%	≤-1%	≤0%	≤0%	≤0%

*) Biogas, waste, solar thermal, geothermal

Source: JRC based on EurObserv'ER

---

[49] This is based on turnover per employee figures from EurObserv'ER, hence these should not be compared to labour productivity measured as gross value added per employee above.

2.3. Research and innovation trends

After the last economic crisis, public investments in R&I prioritised by the Energy Union[50],[51] went into a decline for half a decade, only showing signs of recovery after 2016. Since then, the EU MS have invested an average EUR 3.5 billion per year, but spending is still lower than that observed a decade ago. The trend from 2016 is consistent with increased investments in energy in general – and clean energy in particular - globally[52], however these do not seem to keep pace with increases in GDP or R&I spending in other sectors.

Today, at 0.027%, the EU has the lowest R&D investment intensity in the clean energy sector (measured as a share of GDP) of all major global economies, just below the US, though levels seem to be decreasing or stable for all. In 2019 the R&I budget allocated to the socioeconomic objective of energy in the EU was EUR 4.1 billion, representing 4.4% of total spending on R&I[53], having decreased slightly compared to the two previous years. This shows that, while increasing in absolute terms, investments in the technologies needed for decarbonisation are not keeping pace with the growth of the economies themselves, or prioritised as much as other sectors.

EU research funds have been contributing an increasing share of public funding and have been essential in maintaining research and innovation investment levels over recent years, contributing on average an additional EUR 1.5 billion per year. Combined with an estimated average EUR 20 billion of private spending[54], the average annual total investment in the Energy Union R&I priorities over recent years (2014-2018) is in the order of EUR 25 billion[55].

In 2019, total public investment from all EU MS was still 5% lower than 2010, but had increased by 2% compared to 2015. Table 3 shows that there is a mixed picture at Member State level. About a quarter have consistently increased spending overall throughout the 10-year period, with an equivalent number showing a decrease. For the remaining, the trend coincides with the total for all EU MS, or information on R&I spending is not available. While there is a clear need to improve monitoring of R&I investment, there is also increased momentum and engagement from the Member States in view of the reporting foreseen in the Energy Union Governance Regulation. This goes beyond public R&I investment, to also stepping up efforts at national level to monitor R&I investments from the private sector.

---

[50] COM(2015)80; renewables, smart system, efficient systems, sustainable transport, CCUS and nuclear safety.

[51] JRC SETIS https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en.

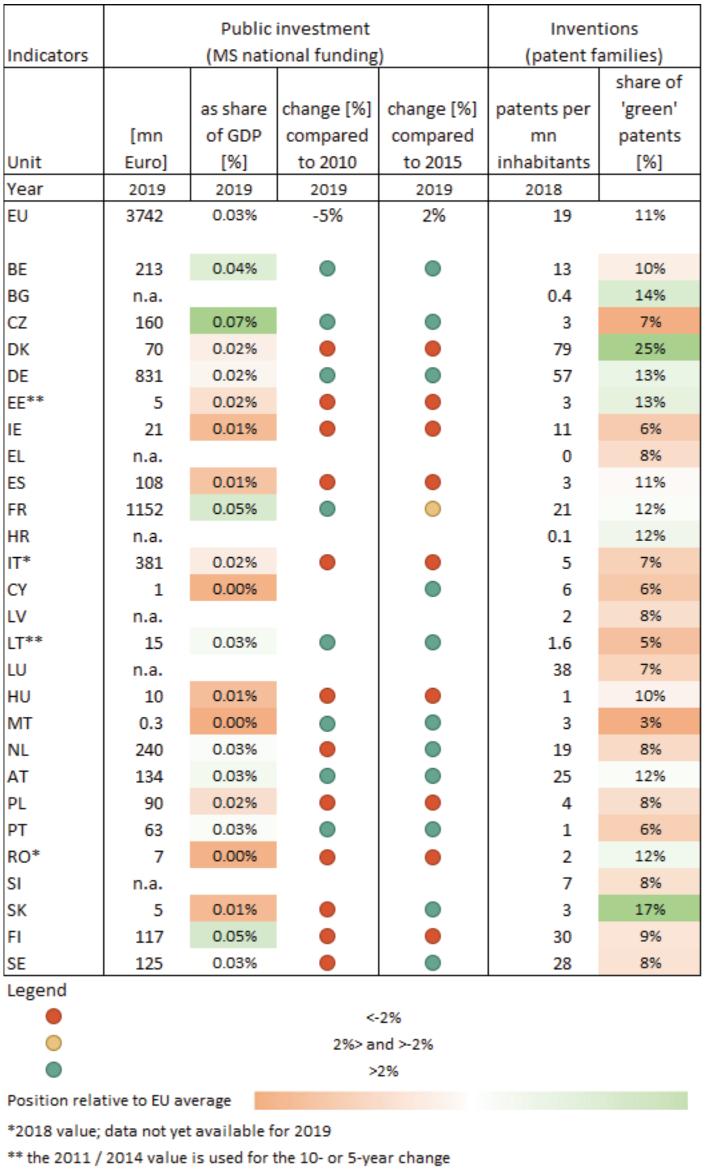
[52] https://www.iea.org/reports/world-energy-investment-2020/rd-and-technology-innovation.

[53] Eurostat, Total GBAORD by NABS 2007 socio-economic objectives [gba_nabsfin07]. The energy socioeconomic objective includes R&I in the field of conventional energy. The Energy Union R&I priorities would also fall under other socioeconomic objectives.

[54] Private investment estimates have been revised upwards, due to changes in classification and the underlying data.

[55] The increased total compared to last year’s reporting is due to the revision of the private investment estimates (see above).

Table 3 Overview of public R&I investment and patenting per Member State .



Indicators	Public investment (MS national funding)				Inventions (patent families)	
Unit	[mn Euro]	as share of GDP [%]	change [%] compared to 2010	change [%] compared to 2015	patents per mn inhabitants	share of 'green' patents [%]
Year	2019	2019	2019	2019	2018	
EU	3742	0.03%	-5%	2%	19	11%
BE	213	0.04%	🟢	🟢	13	10%
BG	n.a.				0.4	14%
CZ	160	0.07%	🟢	🟢	3	7%
DK	70	0.02%	🔴	🔴	79	25%
DE	831	0.02%	🟢	🟢	57	13%
EE**	5	0.02%	🔴	🔴	3	13%
IE	21	0.01%	🔴	🔴	11	6%
EL	n.a.				0	8%
ES	108	0.01%	🔴	🔴	3	11%
FR	1152	0.05%	🟢	🟡	21	12%
HR	n.a.				0.1	12%
IT*	381	0.02%	🔴	🔴	5	7%
CY	1	0.00%		🟢	6	6%
LV	n.a.				2	8%
LT**	15	0.03%	🟢	🟢	1.6	5%
LU	n.a.				38	7%
HU	10	0.01%	🔴	🔴	1	10%
MT	0.3	0.00%	🟢	🟢	3	3%
NL	240	0.03%	🔴	🟢	19	8%
AT	134	0.03%	🟢	🟢	25	12%
PL	90	0.02%	🔴	🔴	4	8%
PT	63	0.03%	🟢	🟢	1	6%
RO*	7	0.00%	🔴	🔴	2	12%
SI	n.a.				7	8%
SK	5	0.01%	🔴	🟢	3	17%
FI	117	0.05%	🔴	🔴	30	9%
SE	125	0.03%	🔴	🟢	28	8%

Legend

🔴	<-2%
🟡	2%> and >-2%
🟢	>2%

Position relative to EU average

*2018 value; data not yet available for 2019

** the 2011 / 2014 value is used for the 10- or 5-year change

Source: JRC[56] based on IEA[57], own work.

Private investment in the Energy Union R&I priorities in the EU is estimated at 0.18% of GDP, above the US but lower than other major competing economies. This represents 12% of the business expenditure on R&D, which is above the 6% estimated for the US, but about half of the share observed for major Asian economies.

---

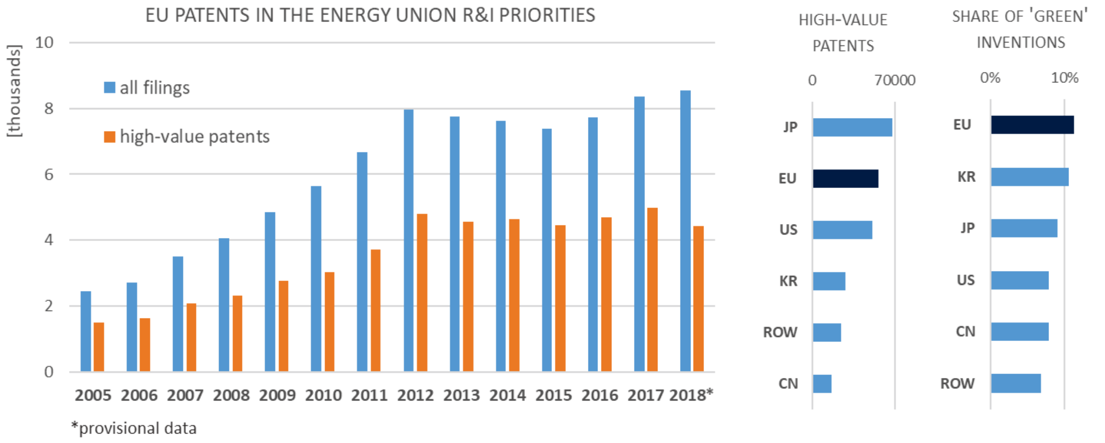
[56] JRC SETIS https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en.

[57] Adapted from the 2021 edition of the IEA energy technology RD&D budgets database.

Following a peak in 2012, overall patenting activity in clean energy technologies[58] decreased[59]. This trend seems to be reversing from 2016, with annual filing levels in the EU (Figure 11), and globally, returning to those observed in 2012. The EU has a greater share of ‘green’ inventions in Climate Change Mitigation Technologies, compared to other major economies (and the world average) indicating greater focus and specialisation of inventive activity in clean energy technologies. This specialisation is not equally shared at Member State level. Larger economies, with traditionally strong innovation ecosystems may have high outputs in terms of patents per capita as part of a large portfolio of innovation; others may not be as strong in terms of output, but show higher specialisation for these technologies within their patenting activity.

Overall, in terms of high-value inventions[60], the EU is second only to Japan, mainly due to Japan’s advantage in transport technologies; however, the EU leads when it comes to renewables and energy efficiency. The EU also continues to host a quarter of the top 100 companies in high-value patents in clean energy over the last 5-years. Nonetheless, there is increasing (global) unease about the impact of state- or subsidy- backed technology domination, closed markets and different intellectual protection rules and policies on innovation and competitiveness in the sector, especially as manifested by China. Despite those concerns, over a quarter of the clean energy inventions protected internationally over the last 5 years by EU applicants have also targeted the Chinese market.

Figure 11: EU patenting trends in the Energy Union R&I priorities, and positioning in high-value patents and share of ‘green’ technologies in patenting activity versus major economies[61]



Source: JRC[62] *based on EPO Patstat*

---

[58] Low-carbon energy technologies under the Energy Union’s R&I priorities. This is the overall trend; there were exceptions for certain technologies (e.g. batteries) which kept increasing throughout the period. The same applies for broad ‘green’ patenting activity in Climate Change Mitigation technologies.

[59] With the exception of China, where local applications keep increasing, without seeking international protection. (See also: Are Patents Indicative of Chinese Innovation? https://chinapower.csis.org/patents /).

[60] High-value patent families (inventions) are those containing applications to more than one office i.e. those seeking protection in more than one country / market.

[61] Cumulative number of high-value patents in Energy Union R&I priorities over 2005-2018; average share of ‘green’ patents in Climate Change Mitigation Technologies for 2017-2018; data for 2018 is provisional.

[62] JRC SETIS https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en.

In terms of collaborations in green innovation, beyond the alliances built within Europe due to geographical proximity, EU firms tend to collaborate most with US counterparts[63]. EU Member States generate 33% of co-inventions in green technologies through Intra-EU connections, 29% with the USA and only 6% with China. France and Germany are the two Member States with the highest number of international partners and co-inventions. The US has the highest number of co-inventions in clean energy technologies, nearly 40% of which are with the EU. East-Asia countries, namely China, Japan, South Korea and Taiwan have strong mutual collaborations.

According to the recent UNESCO Science Report[64], the volume of scientific publications from the EU[65] on nine SDG7[66] renewable energy topics has increased from nearly 60k in the period 2012-2015 to over 70.5k in the period 2016-2019 (18% increase). However, the report also notes that high-income economies are no longer dominating topics related to clean energy and innovation, and some of the strongest growth is instead taking place in lower middle-income countries. For example, the respective publications from East & Southeast Asia increased by 45% and those from South Asia more than doubled.

2.4. The clean technologies funding landscape

2.4.1. Introduction

The Climate Tech domain encompasses a broad set of sectors which tackle the challenge of decarbonising the global economy[67]. It also includes novel technologies e.g. long-duration energy storage, green hydrogen production, storage, and use of hydrogen in heavy industry, carbon management) that, together with more mature generation technologies (e.g. solar and wind) under deployment, will be crucial to achieve carbon neutrality by 2050, if properly developed and scaled-up.

Climate Tech is an emerging and challenging domain for Venture Capital (VC) investors. These novel technologies usually involve high investments in R&I, long lead times to reach maturity and typically require a significant amount of capital in pilot plants[68]. This calls for substantial public support along the start-up lifecycle to de-risk and stimulate further private investments for their development and implementation at scale.

---

[63] JRC118983 Grassano, N., Hernández, H., Tübke, A., Amoroso, S., Dosso, M., Georgakaki, A. and Pasimeni, F.: The 2020 EU Industrial R&D Investment Scoreboard.

[64] UNESCO (2021) UNESCO Science Report: the Race Against Time for Smarter Development. S. Schneegans, T. Straza and J. Lewis (eds). UNESCO Publishing: Paris.

[65] The study refers to EU28 (including the UK).

[66] "Ensure access to affordable, reliable, sustainable and modern energy for all."

[67] Climate Tech encompasses a broad set of sectors which tackle the challenge of decarbonising the global economy, with the aim of reaching net zero emissions before 2050. This includes low-to-negative carbon approaches to cut key sectoral sources of emissions across energy, built environment, mobility, heavy industry, and food and land use; plus cross-cutting areas, such as carbon capture and storage, or enabling better carbon management, such as through transparency and accounting.

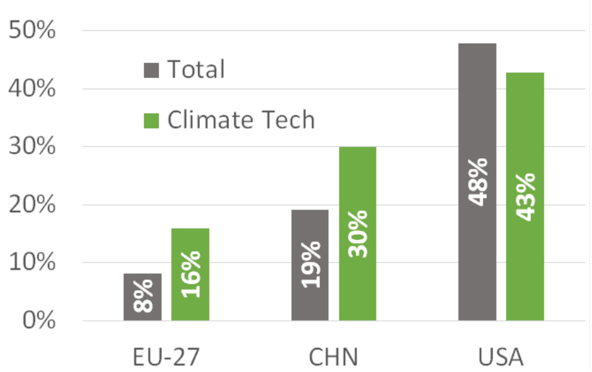
[68] Giving rise to the notion of Deep Green start-ups: cutting edge technologies focused on addressing environmental challenges (e.g. green battery manufacturing, electric aircraft). Deep Green are at the intersection between Climate Tech and Deep Tech, defining the latter as companies building on scientific discovery in engineering, mathematics, physics, and medicine. Characterised by long R&D cycles and untested business models.

2.4.2. VC investment trends in Climate Tech companies (Global and EU)

Worldwide VC investments[69] in climate tech start-ups and scale-ups reached EUR 14 billion in 2020[70], increasing more than 1250% since 2010 (EUR 1 035 million). Within this, VC investments in EU-based climate tech companies have been 11 times higher over the past 5 years than they were between 2009 and 2014, reaching more than EUR 2.2 billion in 2020[71].

EU firms received 16% of global VC funding in the climate tech domain compared to only 8% of overall VC funding (all domains)[72]. Figure 12 highlights the attractiveness of EU climate tech start-ups but also the investment gap in EU start-ups as VC investments range far behind levels in the US and China.

Figure 12: VC funding in Climate Tech vs Total (2020)[73]



Source: JRC elaboration based on PitchBook data.

At the same time, for the first year in 2020, early stage investments in EU climate tech start-ups were higher than those in the US and China.

EU-based climate tech start-ups still trail their counterparts in ability to scale. Over the past 5 years, they only benefited from 7% of all later stage investments in climate tech start-ups, far behind the US (44%) and China (41%)[74]. Furthermore, out of the total number of climate tech Unicorns[75], those based in the EU account for only 6%, compared to US (56%) and China (26%)[76].

---

[69] Investments include Early stages (Accelerator/Incubator, Angel, Seed and early stage VC) and later stages (later stage VC and Private Equity Growth).

[70] Accounting for: i) between 4 to 6 % of total VC funding according to JRC elaboration based on PitchBook data and ii) PwC data based on Dealroom data.

[71] JRC elaboration based on Pitchbook data 2021.

[72] JRC elaboration based on Pitchbook data 2021.

[73] Where Climate Tech is expressed as % of global Climate Tech investments and total is expressed as % of all global VC investments.

[74] JRC elaboration based on PitchBook data.

[75] The standard definition of unicorn is a privately held start-up valued at more than USD 1 billion.

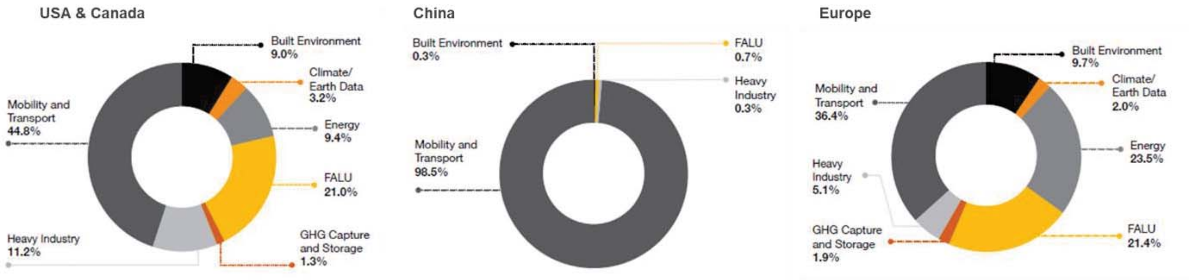
[76] JRC elaboration based on PitchBook data.

2.4.2.1.Climate Tech investments in the Energy Sector

Worldwide, the Energy domain[77] accounted for 8.2% of total VC Climate Tech investment between 2013 and 2019, far below the Mobility and Transport domain (63%) and Food, Agriculture and Land use (13.6%)[78]. Global investment in Energy start-ups has grown at a moderate pace, recording a Compound Annual Growth Rate (CAGR) of 41%, which is substantially lower than the overall growth rate of climate tech investment). This reflects the relative maturity of two of the major sources of renewable energy – wind and solar – which are now being deployed globally at scale, and are increasingly financed through traditional project, debt and other finance rather than venture capital.

Europe (EU and UK) is investing a higher share of VC in Energy domain (23.5%) compared to the US (9.4%) and China (less than 1%). Most investment is taking place in developing the core technologies for renewable energy generation (predominantly PV cells) and the energy storage (batteries) to support their proliferation[78].

Figure 13 Area-specific VC funding as % share of the overall Climate Tech VC investments in the US, China and Europe



Source: PwC analysis on Dealroom data

2.4.2.2.The Digitalisation of Energy and VC funding dynamics

As the digitalisation of energy is a crucial enabler of the energy transition, understanding the trend of VC investments in digital start-ups entering the energy sector is key to support the development of a more integrated, interconnected, secure, transparent and competitive energy system, where not only energy but also data need to flow freely in the system.

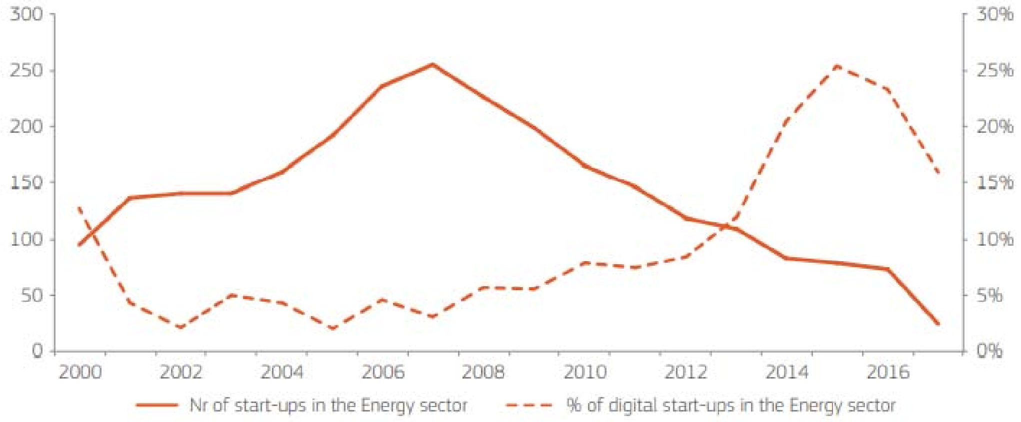
Figure 14 shows that, despite considerable decrease in number of VC-backed energy start-ups worldwide at the beginning of the last economic crisis, the share of digital start-ups in the Energy sector has increased and reached its maximum in 2015.

---

[77] Identified by the PwC report as one of the key sectors contributing to the majority of global GHG emissions – together with Mobility & Transport, Food, Agriculture and Land Use, Heavy Industry, Built environment (vertical areas), GHG Capture and Storage, and Climate and Earth Data generation (horizontal areas).

[78] PwC, The State of Climate Tech 2020. The next frontier for venture capital, 2020.

Figure 14: Total number of Energy start-ups and the percentage of digital start-ups[79] *in the Energy sector that received VC funding between 2000 and 2017*



Source: JRC analysis based on Venture Source, Dow Jones data

2.4.3. The Clean Tech funding landscape in EU

Both the overall Climate Tech VC funding dynamics in the EU and the attraction of VC investors for EU-based Climate Tech are strongly related to the number of overarching policy goals in the climate and energy sector established at EU and Member States level (see section 1.1), together with tools supporting Climate Tech (e.g. fund of funds, grants, equity and debt co-investment, R&D tax credit), and the overall EU support for a R&I green innovation ecosystems.

The EU public funding institutions have shown they can lead green innovation excellence. The Horizon Europe pillar III on “Innovative Europe” aims at supporting the development of disruptive and market-creating innovations through three distinctive and complementary instruments:

The European Innovation Council (EIC)[80], with a budget of EUR 10.1 billion, is a one stop shop for scaling up the next European’s unicorns, providing financial support, investment opportunities and coaching to breakthrough and disruptive innovation projects[81]. So far, the EIC pilot has achieved 90% of innovations addressing Sustainable Development Goals (SDG), in particular in the field of Green Deal, Digital and Health.

The European Institute of Innovation & Technology (EIT), with a budget of EUR 2.965 billion, aims at strengthening Europe’s innovation ability by powering solutions to pressing global challenges and by nurturing entrepreneurial talent. Supporting the development of EIT Knowledge and Innovation Communities (KICs), EIT has the scope to increase the collaboration between business, education and research organisations, public authorities and civil society.

---

[79] Digital start-ups in the Energy sector: this set includes start-ups in the Energy sector whose description of activity includes any digital-related keyword.

[80] European Innovation Council (europa.eu)

[81] Through the EIC Pathfinder, Transition activities, Accelerator, and Business acceleration services. So far, the EIC pilot has achieved 90% of innovations addressing Sustainable Development Goals (SDG), in particular in the field of Green Deal, Digital and Health.

The European Innovation Ecosystems initiative, with a budget of EUR 527 million, focuses on building an interconnected, inclusive, innovation ecosystem, complementing the actions carried out by the EIC and the EIT, as well as activities managed under other pillars of Horizon Europe and initiatives developed by Member States and Associated Countries.

Furthermore, the InvestEU programme and cohesion policy aims at supporting access to and availability of finance primarily for SMEs, including innovative ones and those operating in the cultural and creative sectors, as well as for small mid-cap and other companies. In addition, the European Investment Fund (EIF) invests in European VC funds, providing venture debt directly to start-ups and connects investors with start-ups, and the European Investment Bank (EIB), beyond loans, provides venture debts, invests in private equity funds, provides guarantees to improve the costs of financing for strategic projects or sectors.

While some of their offerings overlap, these institutions are designed to complement each other across the start-up's life-cycle[82]. As an example, the EIB played a role in attracting private investments in Northvolt - the Swedish green battery company founded in 2016 - which is building the first European commercial-scale battery plant in Sweden and raised EUR 1.4 billion in financing in June 2020 . EIT InnoEnergy supported the company to put together a consortium of investors and access EIB funding: the EUR 350 million loan from EIB is accompanied by EUR 886 million from private investors[83]. After the first plant in Sweden, Northvolt plans a joint venture with Volkswagen to build a battery plant in Germany.

Moreover, additional funding programmes exist to convey revenues from climate-related policies in support of the energy transition. The Innovation Fund supports the deployment in the market of breakthrough low carbon technologies. The Modernisation Fund intends to help low income Member States in the modernisation and decarbonisation of their energy systems. The Social Climate Fund would fund Member States' programmes designed to support investment in increased energy efficiency of buildings, the decarbonisation of heating and cooling and zero- and low-emission mobility and transport.

Despite these innovation ecosystem support instruments, EU-based climate tech start-ups still trail their counterparts in ability to scale, thus hindering the EU from reaping the climate and competitiveness benefits of EU innovation as well as preventing movement of promising ventures to the US or Asia to reach scale. For example, while Northvolt is a success, it dwarves the rest of EU investments, thus illustrating the need of public funding for the development of commercial scale pilot plants.

Overall, the significant difference in regional VC funding, including climate tech, across geography is partially due the different VC funding culture. As an example, the US institutional investors have traditionally been more willing to engage in VC, and the US has a stronger history of start-ups and scale-up success, thus creating a more favourable start-ups ecosystem.

In addition, key structural barriers are holding back the EU-based climate tech scale-ups compared to US and China, such as:

- Innovation performance barriers: difficulty in translating a strong EU research performance into innovation; lack of breakthrough/disruptive innovations creating new markets.
- Innovation funding barriers: i) transition from lab to enterprise, ii) scaling up for high risk innovative start-ups. The more difficult access to finance reported by EU scale-ups is consistent

---

[82] World Economic Forum in collaboration with KPMG, Bridging the gap in European scale-ups funding: the green imperative in an unprecedented time, 2020.

[83] VW, BMW, Goldman Sachs, AMF, Folksam Group and IMAS Foundation.

with a higher reliance on internal funds among these firms, as well as a relatively under-developed venture capital market in EU compared to US[84].

- Innovation ecosystem barriers: despite many national and local ecosystems exist, the EU's market and regulatory fragmentation hinders growth and leads to different maturity of VC ecosystems; there is a pressing need to include all regions and all talent. Within this, the lack of labour force with the right skills can represent an obstacle to growth among scale-ups.

2.4.4. New generation of financial mechanisms to support Climate Tech scale up in EU and EU supporting initiatives

Filling the gap in scale-up between EU and other major economies requires mobilising private investors to participate more actively in the European VC market and in the funding of climate tech and Deep Climate Tech start-ups[85]. This is still a poor fit for the business model of "traditional" VC funds.

As an example, blended finance[86] structures could address the mismatch of the VC model and deep-tech investment and scaling up EU's industrial transformation, by mobilising private investments or incentivising patient capital from the private sector. While blended finance is rare in the EU, successful examples exist (Estonian EIC-funded start-up Skeleton[87] and the German "Future Fund"[88])[89]. The future success of SPACs faces uncertainty.

The recent lackluster aftermarket performance for SPACs could intensify the downward pressure on new SPAC IPO issuance and general enthusiasm for the product. A related decline of investor sentiment around SPACs is to be expected if returning capital due to failure to find a target becomes a regular occurrence. Regulation and litigation risks are also looming, which may discourage new SPAC activity. [90]

In view of the Green Deal's objectives and recognising the role of technological innovation as key enabler for climate neutrality, the EU has put a number of relevant support mechanisms in place. For example, the 2020 European Industrial Strategy package sets key actions to improve access to finance for Small and Medium Sized Enterprises (SMEs), including a mechanism to boost the scale of VC funds, increase private investment and facilitate the cross-border expansion and scale-up of SMEs. Furthermore, the joint fund

---

[84] EIB, Investment report 2019/2020: accelerating Europe's transformation

[85] Deep Tech start-ups build on scientific knowledge and are characterised by long R&D cycles and untested business models. Deep Climate tech start-ups are companies using cutting edge technology to address environmental challenges. As they rely on large capex investments in pilot plants for new technologies to be able to scale their revenues, they require even a higher levels of investments – compared to Climate Tech.

[86] Blended finance is a structuring approach which uses public funding to de-risk private investments and, by doing so, acclimatize private investors with a new technology, sector, region or asset class. It leverages a combination of grant with equity, debt investments or insurance-like products from either the public or private sectors and mobilizes consortium of investors to meet the funding needs of deep tech start-ups.

[87] One of the largest European manufacturers ultracapacitor-based energy storage. The products are used to power and save energy in various applications in the automotive, transportation, grid, and renewable energy industries. the Clean Tech solutions have caught the attention of new industrial investors and top European entrepreneurs, and the company raised EUR 41.3 million in equity round, bringing its total capital raised to over EUR 93 million. The investment is in the top five funding rounds of the cleantech sector in the EU in 2020 and will further accelerate Skeleton's growth.(https://community-smei.easme-web.eu/articles/green-innovations-eic-funded-company-skeleton-technologies-raised-eu413-million-equity).

[88] The German federal government is providing EUR 10 billion for an equity fund for technologies of the future (Zukunftsfonds or "future fund"). The fund will primarily benefit start-ups in the growth phase with high capital requirements. Together with further private and public partners, the fund projects to mobilise at least EUR 30 billion in venture capital for start-ups in Germany, and combined with existing financial instruments, over EUR 50 billion in venture capital are expected to be mobilised for start-ups in the next few years, together with private investors. (Federal Ministry of Finance, 2021).

[89] World Economic Forum, Bridging the gap in European scale-up funding: the Green Imperative in an unprecedented time, 2020.

[90] PitchBook SPAC market update Q3 2021, Uncertainty Clouds Future for SPACs

between EIB, EC and Breakthrough Energy Ventures Europe (BEV-E) allows for the blending of institutional (risk-averse) with a VC (less risk-averse) investment approaches[91]. Next Generation EU financing and the EU Sustainable Finance Regulation may further accelerate clean energy VC support.

Further scaling up can be achieved by streamlining existing mechanisms, making use of synergies across instruments at EU and MS level, further exploring new funding solutions (creation of funds directing private savings towards VC-funded firms, blended instruments) and introducing further funding incentives (e.g. government financing/co-financing for start-ups). The European Scale-up Action for Risk capital (ESCALAR), a pilot programme launched by the European Commission and managed by the EIF, is a good example for a new investment approach.[92] It is also crucial that policy initiatives, EU programmes and related instruments maintain and increase the attractiveness of EU Climate Tech firms for VCs. Furthermore, public and corporate procurement opportunities could foster long-term growth in strategic sectors or even kick-start emerging markets, while involvement of investment management firms could improve perspectives for VC firms. Finally, involving universities could attract highly skilled workers and encourage entrepreneurship.

2.5. Covid-19 impact and recovery

2.5.1. Impact

2.5.1.1.Impact on clean energy generation, investments and R&I

The renewable energy sector generally proved to be resilient during the pandemic[93]. As displayed in Figure 15, while electricity generation from coal, gas and nuclear decreased, renewables overtook fossil fuels for the first time as the EU's main power source for the year 2020 (renewables 38% of EU electricity, versus 37% fossil fuels and 25% nuclear)[94]. Wind (14%) and solar (5%) generated one fifth of EU's electricity in 2020, the remaining 19% came mainly from hydropower and bioenergy which have stagnated the past few years[95]. In all IEA global post-pandemic scenarios, renewables grow rapidly – mainly solar due to its high-cost reductions (followed by onshore and offshore wind).

---

[91] The European Commission, European Investment Bank and Breakthrough Energy Ventures establish a new EUR 100 million fund to support clean energy investments (eib.org)

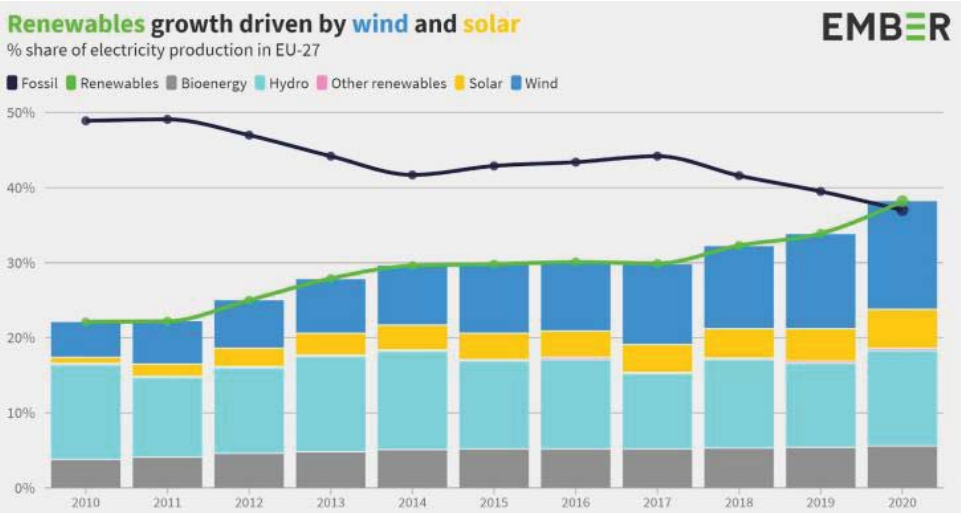
[92] https://ec.europa.eu/growth/content/escalar-%E2%82%AC12-billion-help-high-potential-companies-grow-and-expand-europe_en

[93] IEA, World Energy Outlook, 2020.

[94] Agora Energiewende and Ember (2021), The European Power Sector in 2020: Up-to-Date Analysis on the Electricity Transition, https://ember-climate.org/wp-content/uploads/2021/01/Report-European-Power-Sector-in-2020.pdf.

[95] Ibid.

Figure 15 Growth of renewables share in electricity production compared to fossil fuels



Source: Agora Energiewende and Ember, 2021

2020 was also a year of unprecedented global spending on the deployment (excluding investments in companies, R&D and manufacturing) of low-carbon technologies, reaching USD 501.3 billion, a growth of 9% compared to 2019[96]. Falling capital costs enabled a record number of solar and wind to be installed globally, while investment in heat pump installation increased 12%, energy storage (esp. batteries) remained level with respect to 2019, despite falling prices, and CCS investments tripled. Hydrogen investments dropped 20% but 2020 was still the second highest annual investment ever[97].

Europe and China are currently vying for top position among markets active in energy transition investment[98]. Europe accounted for the biggest part of the global investment in 2020, with USD 166.2 billion (up 67%), China at USD 134.8 billion (down 12%) and the US as USD 85.3 billion (down 11%). Europe's performance was driven by a i) record year for electric vehicle sales, and ii) the best year in renewable energy investment since 2012.[99].

Early trends indicate general resilience in global R&I spending for renewable energy as well. Growth in global public spending on energy R&D slowed from 7-10% in 2017 and 2018 down to 2% in 2020, but the renewable component grew more quickly, achieving 83% of total energy R&D spending. Similarly, while overall corporate R&D energy spending dropped in 2020, the renewable component continued to grow[100]. Worldwide, in spite of an overall downward investment dynamic and despite the fact that significant VC funding was redirected to pandemic-related industries such as pharmaceuticals and healthcare, Climate Tech domain is proving to be resilient to the COVID-19 outbreak and remained attractive to the VC funding. Examples include Amazon's USD 2 billion "Climate pledge" venture fund, Microsoft's USD 1 billion Climate Innovation Fund.

---

[96] BloombergNEF, Energy Transition Investment Hit $500 Billion in 2020 – For First Time, 2021.

[97] Ibid.

[98] BloombergNEF, Energy Transition Investment Trends – Tracking global investment in the low-carbon energy transition, 2021.

[99] BloombergNEF, Energy Transition Investment Hit $500 Billion in 2020 – For First Time, 2021.

[100] IEA, World Energy Investment, 2021.

2.5.1.2. Impact on supply chains and installed capacity

EU energy technology supply chains have generally been resilient to the impacts of the pandemic. Covid-induced restrictions temporarily disrupted supply chains and delayed construction of renewable energy installations in key markets (especially onshore wind and solar PV). Yet, since mid-May 2020, renewables-based construction projects, equipment supplies, policy implementation (permitting, licensing, auctions) and financing have returned to near normal levels in many countries because project developers and manufacturers have modified their operations to adapt to ongoing social-distancing rules[101].

In addition to bottlenecks due to disruptions in production, logistics and transportation sectors, operating costs of some energy technology supply chains increased due to price increases in products and services such as transportation. Yet these impacts were common to all economic sectors[102]. While important EU suppliers in China and other Asian countries generally were able to limit impacts, supply chains faced greater impacts from intra-EU measures such as border closures and lockdowns. Intra-EU difficulties were therefore often more important than manufacturing and logistics challenges in non-EU countries. Supplier concentration exacerbated these impacts, while global supply chains provided advantages such as supply diversification and access to global markets[103].

2.5.2. Recovery

The analysis of the 22[104] RRPs approved by the Commission by 5 October 2021[105] shows that EUR 177 billion have been allocated to climate-related investments, representing 40% of the total of EUR 445 billion of RRF funds allocated to these Member States. Nearly all Member States are using RRF funds for investments in building renovation and clean transport (around 62 billion is dedicated to sustainable mobility), and many are using it to invest in renewable energy. In this context, Member States[106] have significantly built on the ‘flagship initiatives’ put forward by the Commission in relation to the green transition, in particular the ‘Power up’, ‘Renovate’ and ‘Recharge and refuel’ flagship initiatives. About 43% of climate-related investments (EUR 76 billion) is dedicated to energy efficiency (27.9%) and renewable energy and network (14.8%).

Research and innovation also represented an important share within the climate-related investments , as Members States allocated nearly EUR 12.3 billion to investment in R&I in climate change mitigation and adaptation and the circular economy in their Recovery and Resilience Plans. The timely implementation of the RRPs can help Member States achieve the more ambitious targets for 2030 in line with the European Green Deal Package[107].

---

[101] IEA, Renewables 2020 – Analysis and forecast to 2025, 2020.

[102] Study on Resilience of the critical supply chains for energy security and the clean energy transition during and after the COVID-19 crisis (2021).

[103] Ibid.

[104] AT, BE, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, IE, IT, LT, LU, LV, MT, PT, RO, SI, SK.

[105] The expenditures reported for the RRF are estimates processed by the Commission based on the information on climate tracking published as part of the Commission’s analyses of the recovery and resilience plans. The data reported cover the 22 national recovery and resilience plans assessed and approved by the Commission by 05 October 2021 and the amount will evolve as more plans are assessed.

[106] Annual Sustainable Growth Strategy 2021, COM(2020) 575 final, 17 September 2020, section IV.

[107] The Commission has already disbursed EUR 52.4 billion in pre-financing from the RRF to Austria, Belgium, Croatia, Cyprus, Czechia, Denmark, France, Greece, Italy, Latvia, Lithuania, Luxembourg, Portugal, Slovenia, Slovakia and Spain, equivalent to 13 % of the grant and (where applicable) loan component of those Member State's financial allocation, except for Germany where it corresponds to 9%.

2.6. Innovative and cooperative business models

The energy transition changes the way the energy system operates. Distributed renewables, proactive consumers, the opportunity to track and trace energy sources, monitor energy consumption and energy efficiency in real time and provide flexibility services to the system create new innovations, actors, and type of business. The section below explores three key business models that help creating markets for new technologies, services and innovations, in a decentralised energy system: energy communities, one stop shops for building renovation, and energy service companies (ESCOs). Many of these new business models are enabled by smart grid technologies analysed in the next section.

2.6.1. Energy communities

Under the Clean Energy Package, extensive provisions were introduced in the Electricity Directive ('citizen energy communities') and the Renewable Energy Directive[108] ('renewable energy communities') to promote energy communities and prosumers, thereby allowing consumers to take an active role in the energy market and strengthening energy production from renewable sources. In particular, energy communities in EU legal framework have been conceptualised in Article 2 (11) Electricity Market Directive ('citizen energy communities') and in Article 2 (16) Renewable Energy Directive ('renewable energy communities'), and linked to an enabling framework to facilitate their participation on the relevant energy markets (Article 16 Electricity Market Directive; and Article 22 Renewable Energy Directive). Both legal concepts share a common core: they need to be organised through a legal entity, are effectively controlled by non-professional actors, have an open and voluntary participation structure and have as a purpose to provide social, economic and environmental benefits rather than financial profits. However, there are also some fundamental difference in terms of energy source, ownership and participation:

- 'renewable energy communities' (REC) are about all sources of renewable energy. 'Citizen energy communities' (CEC) are about all sources of electricity, but not other forms of energy. Note that both concepts overlap when an energy community is active in 100% renewable electricity, in which 'renewable energy communities' become a subset of 'citizen energy communities';
- members or shareholders that effectively control the 'renewable energy community' need to be located in proximity of the renewable energy projects that are owned and developed by that community. As such, renewable energy communities are 'local' energy communities. This is not the case for 'citizen energy communities', allowing for more flexibility and thus both local communities and communities-of-purpose;
- all types of actors can participate in 'citizen energy communities', whilst for 'renewable energy communities' this is limited to citizens, SMEs and local authorities.

Note that energy communities are in essence not about technology, smart grids, etc. Developments in this field can be useful for energy communities, but this is not a technological concept.

In border regions, there can be a significant added value of a cross-border approach, allowing to benefit from local complementarities across borders in areas such as renewable energy production or storage solutions, taking into account the 'energy efficiency first' principle. However, energy markets do not yet function across borders as seamlessly as they do within a country. For example, cross-border electricity

---

[108] In RED II, introduction of enabling frameworks by Member States to facilitate their development, to ensure inter alia that unjustified barriers to renewable energy communities (RECs) are removed and relevant distribution system operators cooperate with the RECs, but also that RECs are regulated according to the activities they engage in. Member States also have to take the characteristics of RECs into consideration when they design their support schemes.

transactions are frequently limited because legal frameworks do not allow for low-voltage exchanges of electricity across the border. Energy communities can play a significant role in charting the way ahead. Both the Electricity Market Directive and the Renewable Energy Directive set the conditions for Member States to include options for cross-border implementation of energy communities in their national transpositions[109].

In terms of enabling framework, both ‘citizen energy communities’ and ‘renewable energy communities’ benefit from set of rights and responsibilities to facilitate their market integration, most notably related to enabling activities (generate, store, sell, share, aggregate or other energy services), and ensuring non-discriminatory treatment in terms of charges and procedures (e.g. supply licensing; grid access procedures). For ‘renewable energy communities’ there are some additional set of privileges. In this regard, it is important to understand that the criteria of the legal concept of ‘renewable energy communities’ are more narrow than for ‘citizen energy communities’, so harder to fulfil. The latter forms the basis to justify the privileges included in the enabling framework of Article 22 Renewable Energy Directive, including but not limited to the requirement for Member States to consider the characteristics of ‘renewable energy communities’ when designing support schemes.

Whilst only recently conceptualised in EU legislation, Energy communities are not a new phenomenon. Nowadays, there are thousands of these initiatives scattered across Europe, each with different scales and use of technology, ownership structures and actors involved.

Currently, at least two million European citizens collectively engage in more than 8400 energy communities, having realized a minimum of 13000 projects since 2000[110]. They support the energy transition and contribute to the competitiveness of renewable energy technologies in various ways. Energy communities raise technology awareness and acceptance, promote energy efficiency, produce and distribute renewable-based electricity, provide services around e-mobility, and run energy consulting services. They experiment innovatively with business models and self-sufficiency concepts for the benefit of local communities.

Figure 16 details the number of initiatives and projects per country. Differences across countries can be explained by varying strength of governmental support and incentives schemes, historic path dependencies of the energy system, and social and technological preferences. Current total renewable capacities installed by energy communities in Europe can be estimated at least as high as 6.3 GW, contributing up to 7% to the nationally installed capacities. The lion’s share is taken by solar PV (~50%), followed by onshore wind (~10%). A conservative estimate of the total invested finances amounts to at least 2.6 billion EUR[111]. The continuation and extension of energy communities in Europe depend on favorable legislation and financial incentives as well as on the competitiveness of technologies that are accessible to citizens (i.e., granular technologies, such as roof-top solar, small- to medium-size wind and solar parks, heat pumps, micro hydro, biomass furnaces, and biogas installations).

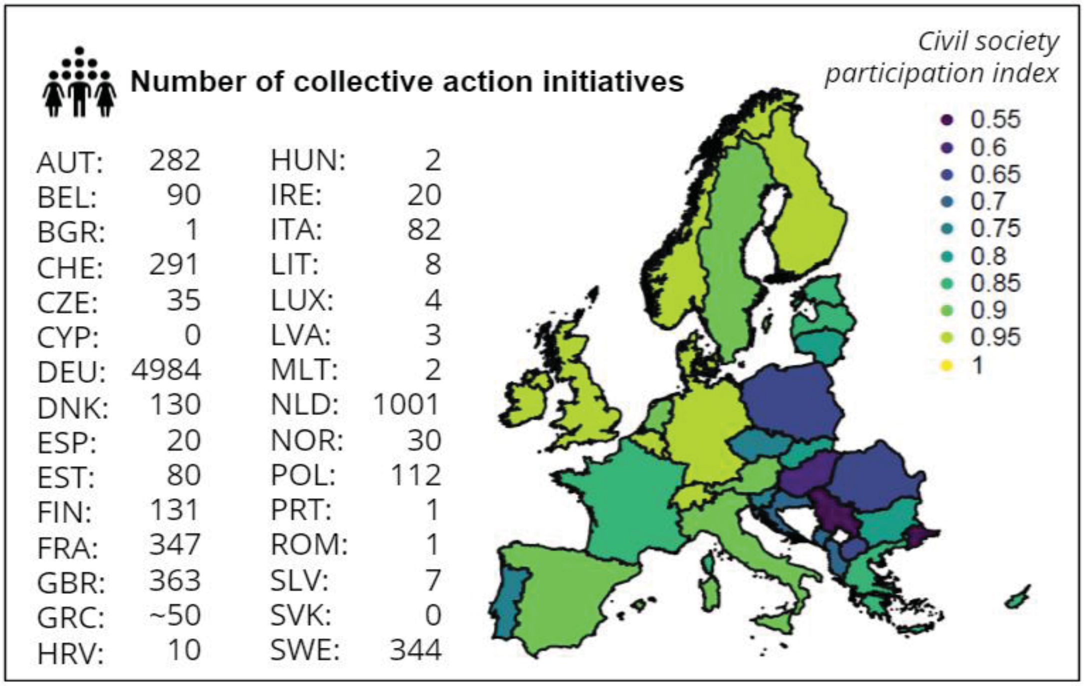
---

[109] “EU Border Regions: Living labs of European integration”, COM(2021) 393 final, 14.7.2021.

[110] Schwanitz, V. J., Wierling, A., Zeiss, J. P., von Beck, C., Koren, I. K., Marcroft, T., … Dufner, S. (2021, August 22). The contribution of collective prosumers to the energy transition in Europe - Preliminary estimates at European and country-level from the COMETS inventory.

[111] ibid

Figure 16 Collective action initiatives in Europe



AUT:	282	HUN:	2
BEL:	90	IRE:	20
BGR:	1	ITA:	82
CHE:	291	LIT:	8
CZE:	35	LUX:	4
CYP:	0	LVA:	3
DEU:	4984	MLT:	2
DNK:	130	NLD:	1001
ESP:	20	NOR:	30
EST:	80	POL:	112
FIN:	131	PRT:	1
FRA:	347	ROM:	1
GBR:	363	SLV:	7
GRC:	~50	SVK:	0
HRV:	10	SWE:	344

Source Schwanitz, V. J., Wierling, A., Zeiss, J. P., von Beck, C., Koren, I. K., Marcroft, T., … Dufner, S. (2021, August 22). The contribution of collective prosumers to the energy transition in Europe - Preliminary estimates at European and country-level from the COMETS inventory.

Many of the above-identified energy communities are member of REScoop.eu[112] the European federation for energy cooperatives.
Whilst the legal organizational form of cooperative is by far the most prominent for energy communities across the EU, there are various types of legal entities (partnerships, limited liability companies, associations etc.), as well as organizational and social arrangements that have developed in the different Member States of the EU. Indeed, various member states will have different experiences with energy communities. For example, in the Netherlands community actors are usually individuals or small businesses, whilst in Germany and Greece municipalities have played a crucial role.

Until today, less than half of Member States have notified the full transposition of the Electricity Market Directive rendering it difficult to establish a causal relation between the surge in energy communities and the EU legal frameworks for ‘citizen energy communities’. So far, no Member State has notified full transposition of the Renewable Energy Directive (REDII). Whilst the EU frameworks provide a good basis to trigger the development of energy communities across the EU,[113] much will depend on how Member States will implement the enabling framework for these types of energy communities, notably how Member States translate the right to non-discriminatory, proportionate, fair and transparent procedures. For ‘renewable energy communities’ the implementation of Article 22 (7) RED II will be of particular importance as energy communities today struggle to build their business case without financial support. Partly due to the phase-out of feed-in-tariffs and transition to premium price auctions, the development of

---

[112] *www.REScoop.eu.*

[113] Energy Communities under the Clean Energy Package - REScoop.

energy communities in Germany have stagnated as they experience difficulties competing for subsidies with large undertakings.[114] In response, energy communities are exploring new activities and services such as electro-mobility sharing, optimizing collective self-consumption, interacting with dynamic pricing and providing flexibility services to the public network. Especially the latter is a promising activity to create an additional source of revenue for energy communities, provided existing barriers are removed (complexity of ITC services, lack of local flexibility markets at DSO level, difficulties with aggregating different devices due to lack of data interoperability, lack of standardization etc.). Some of these barriers are already addressed through the Electricity Market Directive.[115]

The NECP framework already has a requirement for Member States to report on renewable energy communities, however only a few Member States included (voluntarily) quantitative targets or concrete measures for the development of energy communities in their NECPs (most demonstrate awareness but no planning). Member States with early legal frameworks in place for energy communities, including the Netherlands, Denmark and Germany today have the highest number of energy communities (see graph above).[116] Outdated regulatory frameworks and administrative procedures adjusted to large vertically integrated undertakings have also been identified as one of the major barriers for the development of energy communities.[117]

In order to boost the development of energy communities in the sense of the EU Directive, the Commission is in the process of setting up an Energy Community Repository. The Energy Community Repository will contribute to the dissemination of best practices and provide technical assistance for the development of concrete energy community initiatives across the EU. The aim of this project is to assist local actors and citizens willing to set up REC and CEC in rural and urban areas, through technical and administrative advice and encourage their development. The data collected through this project would constitute a very important source of information for European institutions and national, regional and local authorities. It will contribute to the identification and dissemination of best practices and know-how for communities that wish to set up a sustainable energy project, in particular in Member States that do not have so far strong tradition of energy community initiatives. The projects that will receive targeted technical assistance under this repository will serve as examples of positive local actions that should inspire widespread efforts for citizen-driven initiatives through the development of energy communities. . Energy community initiatives could also be supported by cohesion policy funding, including through the Community Led Local Development (CLLD) instrument. In addition, the Commission is in the process of setting up an Advisory Hub for rural energy communities, i.e. ‘citizen energy communities’ and ‘renewable energy communities’ in rural areas in order to remedy the disproportionate impact of the energy transition on communities in rural areas by supporting the development of sustainable energy action that can be conducive to the local economy and increase security of energy supply. Special emphasis will be put on the involvement to local authorities, linked to the Covenant of Mayors.

---

[114] Entwicklung und Umsetzung eines Monitoringsystems zur Analyse der Akteursstruktur bei Freiflächen-Photovoltaik und der Windenergie an Land (umweltbundesamt.de).

[115] Article 32 on local flexibility markets; Article 23 juncto 24 on data management and interoperability.

[116] One of the drivers for the heterogeneous picture of energy communities across Member States have been the varying national legislative frameworks in place for energy communities. See Frontiers, ‘Assessment of policies for gas distribution networks, gas DSOs and the participation of consumer’, pp. 8-9; Ronne, A., and F.G. Nielsen, ‘Consumer (Co-)Ownership in Denmark’, Energy Transition - Financing Consumer Co-Ownership in Renewables, Palgrave Macmillan, Cham, 2019.

[117] Benjamin Huybrechts and Sybille Mertens, ‘The relevance of the cooperative model in the field of renewable energy [2014] Annals of Public and Cooperative Economics, pp. 199-201; Binod Prasad Koirala, ‘integrated community energy systems’ (DPhilthesis, Delf University of Technology 2017, p.1; Stakeholder interview with Cormac Walsh from Energy Cooperatives Ireland, 12th of June 2021; Frontier et al’s report (2019), ‘Potentials of sector coupling for decarbonisation – Assessing regulatory barriers in linking the gas and electricity sectors in the EU - Final report’, p. 49.

2.6.2. Renovation of buildings - One stop shop

The market-based model of one-stop shops (OSSs) is among the most prominent recent approaches aimed at supporting building renovation decisions. OSSs work as a market place, offering integrated renovation solutions, encouraging action, guiding building owners through the entire renovation journey, providing technical and administrative assistance and helping secure the right financial solutions. While all energy efficiency projects could be good candidates, OSSs are particularly well equipped in addressing the renovation market fragmentation barriers on both demand and supply sides, overcoming some of the sociotechnical barriers surrounding the decision to renovate in a holistic way. For these reasons, OSSs are especially well suited to support small-scale renovation projects (e.g. individual buildings or apartments).

OSSs are only recently appearing in Europe. From a recent analysis of the current OSSs present in Europe conducted by the JRC[118], 62 OSSs have been identified across the EU in 2020, located in 22 countries, 57 were found to be operating or planned to be launched soon across the EU and Norway, and 6 have been closed. Around two third of the Member States have at least one OSS on the national renovation market. Regionally, Western Europe has the most abundant OSS markets, centred in France, the Netherlands, the UK, Belgium, Spain and Denmark.

Overall, OSSs have been found to be a promising approach to bring together homeowners and actors from the construction supply side and increase demand in energy renovations because they i) are locally embedded; ii) establish a trust-based relationship with the clients; iii) simplify the renovation decision process, informing, motivating, and providing support from the start to the end; iv) boost the interest of not yet committed energy users through awareness raising; facilitate access to financing and occasionally offer better rates; v) follow-up on finished projects; vi) and reach out to vulnerable populations, contributing to tackle energy poverty.

2.6.3. ESCOs

Energy Service Companies (ESCOs) are another business model that plays an important role in energy efficiency and functioning of energy services markets by providing turnkey services, addressing several market barriers on the ground and unlocking the energy savings potential[119]. Their distinct feature is associated with their incentive/remuneration structure; ESCOs assume performance risks by linking their compensation to the performance of their implemented projects, thus incentivising themselves to deliver savings-oriented solutions.

The EU's legislative framework contributes to fostering the energy services market. The Energy Efficiency Directive (EED)[120] provides the key requirements for promoting energy services and energy performance contracting in the Member States. The revised EED[121] strengthens the role of energy services and notably use of Energy Performance Contracts (EnPC) in contributing to the renovation wave with specific focus given to the public sector to lead by example.

---

[118] Boza-Kiss, B., Bertoldi, P., Della Valle, N. and Economidou, M., One-stop shops for residential building energy renovation in the EU, EUR 30762 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-40100-1, doi:10.2760/245015, JRC125380.

[119] Boza-Kiss, et al. 2017, 2019; Moles-Grueso, et al. 2021.

[120] Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018.

[121] Proposal for Directive (EU) 2021/0218 of the European Parliament and of the Council of 14 July 2021.

The average ESCO market of the European Union has been on a steady rise for the last decades, and the growth and maturity has continued or even increased slightly between 2015 and 2018. However, important barriers still remain: lack of technical knowledge and experience in procurement, lack of financing and low level of awareness of energy performance contracting which have contributed to the low level of trust to energy services providers￼. The drivers and barriers determining ESCO markets are distinctly local and specific to the legal, policy, fiscal, financial and cultural context in each Member State. With the recent revision of the EED, it is expected that persisting barriers can be better overcome to ensure necessary conditions and incentives for the uptake of the EnPC and energy services markets.

Figure 17 The speed and direction of development between 2015 and 2018 in national ESCO markets

Source: The assessment is purely based on own research data (JRC survey 2018)

It is therefore important that Member States continue promoting the uptake of energy services and energy performance contracting through clear and transparent rules including certification of energy services providers, and also capacity building. Dissemination of experience of implemented projects and best practices are necessary to increase trust and ensure better understanding of energy performance contracting and ESCO's role in contributing to the renovation wave and bringing multiple benefits including new and innovative business models.

Table 4. Size of the ESCO and EnPC markets of the EU in JRC reports.[122]

---

[122] Boza-Kiss Benigna, Zangheri Paolo, Bertoldi Paolo, Economidou Marina, Practices and opportunities for Energy Performance Contracting in the public sector in EU Member States, EUR 28602 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-68832-4, doi:10.2760/49317, JRC106625.

	Number of active ESCOs (2018)[123]	Number of EnPC providers (2016)[124]	Number of EnPC providers to the public sector (2020)[125]	Number of EnPC contracts signed (2016)[126]	Number of EnPC contracts signed in the public sector (2020)[127]	Value of the EnPC contracts signed in the public sector (m€) (2020)[128]
EU	**1383**	**261**	**246**	**559**	**617**	**975**
AT	36	17.5	5	26.5	11	6.5
BE	9	>7	9	5	11	20
BG	12	12.5	5.8	2	10	3
HR	12.5	5	10.5	3	50	25
CY	22	19	0	0	0	0
CZ	15	9	7.2	45	25	21
DK	4	7	2.7	11	9	70
EE	4	0	2	"few"	1	1
FI	15	6	3	4	5	3.5
FR	45	10	10	40	50	70; 50[129]
DE	560 (Service suppliers)	8.5; 138[130]; 50[131]	8	30	58	90; 7,700[132]
GR	6	3[133]	12	5	8	100
HU	10	5[134]	4	1.5	20	2.8
IE	25	n/a	10.8	n/a	4	16.6
IT	3400	4.5-20(?)	20	50	230	250
LV	4.5	3	0	0	6	12.6
LT	n/a	4.5	2	3.5	6	3.2
LU	n/a	1(?)	n/a	1	n/a	n/a
MT	n/a	0	n/a	0	n/a	n/a
NL	57 (EnPC only)	15; 57[135]	40	27	n/a	n/a
PL	25	12.5; 20[136]	7.5	15	13	39

---

[123] When not stated the contrary, data is about 2018. Main source:
Boza-Kiss, B., Toleikyté, A., Bertoldi, P. 2019. Energy Service Market in the EU - Status review and recommendations 2019. Scientific and Technical Report. European ESCO Market Reports series. EUR 29979 EN, European Commission, Luxembourg, 2019, ISBN 978-92-76-13093-2, doi:10.2760/768, JRC118815.

[124] When not stated the contrary, data is about 2016. Main source: Boza-Kiss et al. (2017).

[125] Source: Moles-Grueso, S., Bertoldi, P., Boza-Kiss, B. Energy Performance Contracting in the Public Sector of the EU – 2020, EUR 30614 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-30877-5, doi:10.2760/171970, JRC123985.

[126] Source: Boza-Kiss et al. (2017).

[127] Source: Moles-Grueso, et al. (2021).

[128] When not stated the contrary, data is about 2020. Main source: Moles-Grueso, et al. (2021).

[129] Value for 2018, in Boza-Kiss et al. (2019).

[130] Value for 2018, in Boza-Kiss et al. (2019,

[131] Value for 2020, in Moles-Grueso et al. (2021).

[132] Value for 2018, in Boza-Kiss et al. (2019).

[133] Value for 2018, in Boza-Kiss et al. (2019).

[134] Value for 2018, in Boza-Kiss et al. (2019).

[135] Value for 2018, in Boza-Kiss et al. (2019).

[136] Value for 2018, in Boza-Kiss et al. (2019).

PT	13.4	12.5	15	n/a	13	50
RO	10	<10	4	0	0	0
SK	40	10[137]	8.5	45	25	25
SI	10	4[138]	6	15	44	96, 25[139]
ES	70	25	>50	250	59	60
SE	20	4.5	3	6	1	10

Country values are calculated using average values of estimates reported in a specific year (i.e. 2016, 2018 or 2020). For Total EU values, the most recent values reported were selected.

---

[137] Value for 2018, in Boza-Kiss et al. (2019).

[138] Value for 2018, in Boza-Kiss et al. (2019).

[139] Value for 2018, in Boza-Kiss et al. (2019).

EUROPEAN
COMMISSION

Brussels, 26.10.2021
SWD(2021) 307 final

PART 2/5

COMMISSION STAFF WORKING DOCUMENT

Accompanying the document

REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

Progress on competitiveness of clean energy technologies
2 & 3 - Windpower

{COM(2021) 950 final} - {COM(2021) 952 final}

OFFSHORE WIND

INTRODUCTION

Today, offshore wind produces clean electricity that competes with, and is sometimes cheaper than existing fossil fuel-based technology. It is a story of European technological and industrial leadership.

With the European Climate Law now in force, the EU's new and significantly more ambitious 2030 climate target – of a net domestic reduction of at least 55% in greenhouse gas emissions compared to 1990 levels – is now a legal obligation, which must be implemented through binding legislation applicable across all Member States and sectors of the economy. This will require a scale up of the offshore wind industry. In the offshore renewable energy strategy, it is foreseen that 60 GW offshore wind capacity will be installed by 2030 and 300 GW by 2050, which is estimated to require less than 3% of the European maritime space and can therefore be compatible with the goals of the EU Biodiversity Strategy[140].

3. TECHNOLOGY ANALYSIS – CURRENT SITUATION AND OUTLOOK

3.1. Introduction/technology maturity status (TRL)

The world's first offshore wind farm was installed in Vindeby, off the southern coast of Denmark, in 1991. At the time, few believed this could be more than a demonstration project[141]. 30 years later, offshore wind energy is a mature, large-scale technology providing energy for millions of people. New installations have high capacity factors up to 65% and the costs have steadily fallen over the last 10 years.

The Communication on the "EU strategy to harness the potential of offshore renewable for a climate neutral future"[142] proposes a strategy to make offshore renewable energy a core component of Europe's energy system by 2050. The strategy presents a general enabling framework, addressing barriers and challenges common to all offshore technologies and different sea basins but also sets out specific policy solutions adapted to the different state of development of technologies and regional contexts.

3.2. Capacity installed, generation/production

The cumulative installed capacity of the entire wind energy sector (both onshore and offshore wind) in the EU increased by 123% from 80 GW in 2010 to 178.7 GW in 2020. On a global level, the EU ranks second, only superseded by China (288 GW) since 2015[143].

The increase in deployment was even more pronounced for the offshore wind sector, surging form 1.6 GW in 2010 to 14.6 GW in 2020.

The European Commission estimates wind producing half of Europe's electricity by 2050, with wind energy capacity rising from 178.7 GW today to up to 1 300 GW (EU in 2050, CTP-MIX: 1 253GW). That entails a 25x increase in offshore wind in the EU between 2020 and 2050. The committed capacity of offshore wind installations in Member States' National Energy Climate Plans (NECPs) until 2030 amounts

---

[140] EU Biodiversity Strategy for 2030. Bringing nature back into our lives. COM/2020/380 final.

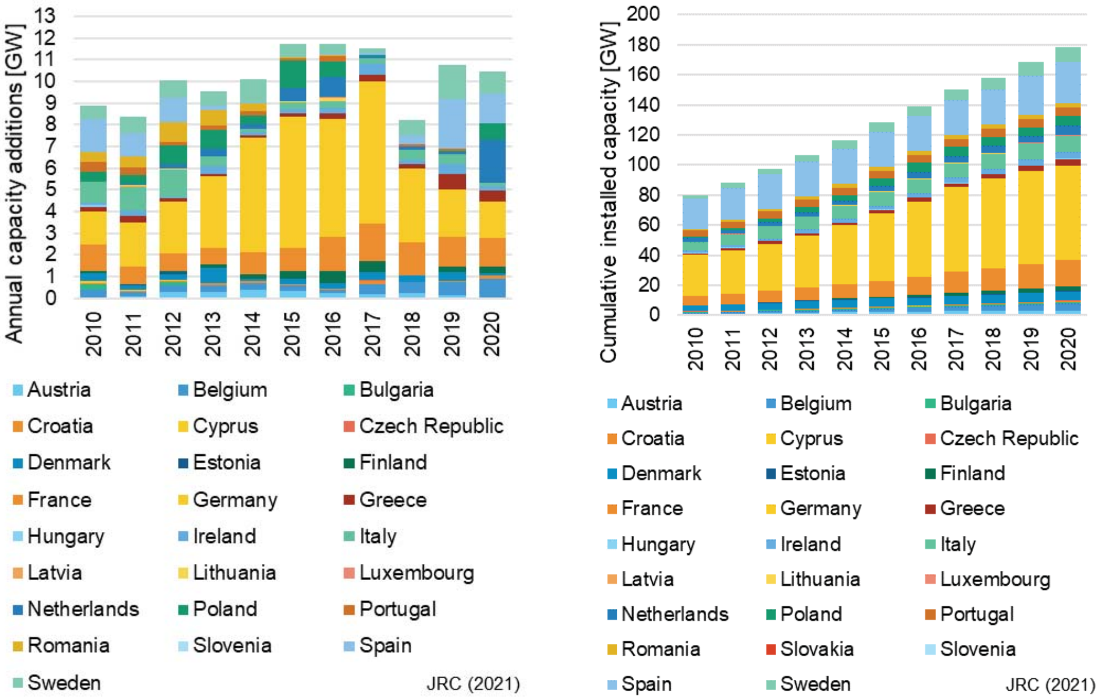
[141] The farm generated 5MW and covered the annual energy consumption of 2 200 households during 25 years.

[142] COM(2020) 741 final.

[143] GWEC (2021), Global Wind Statistics 2020.

to (at least) 62.5 GW, while the expected offshore wind projects in EU sea basins based on latest announcements/industry is 84.2 GW.

Figure 1: Annual capacity additions (left) and cumulative installed capacity (right) of wind energy (both onshore and offshore) in the EU.



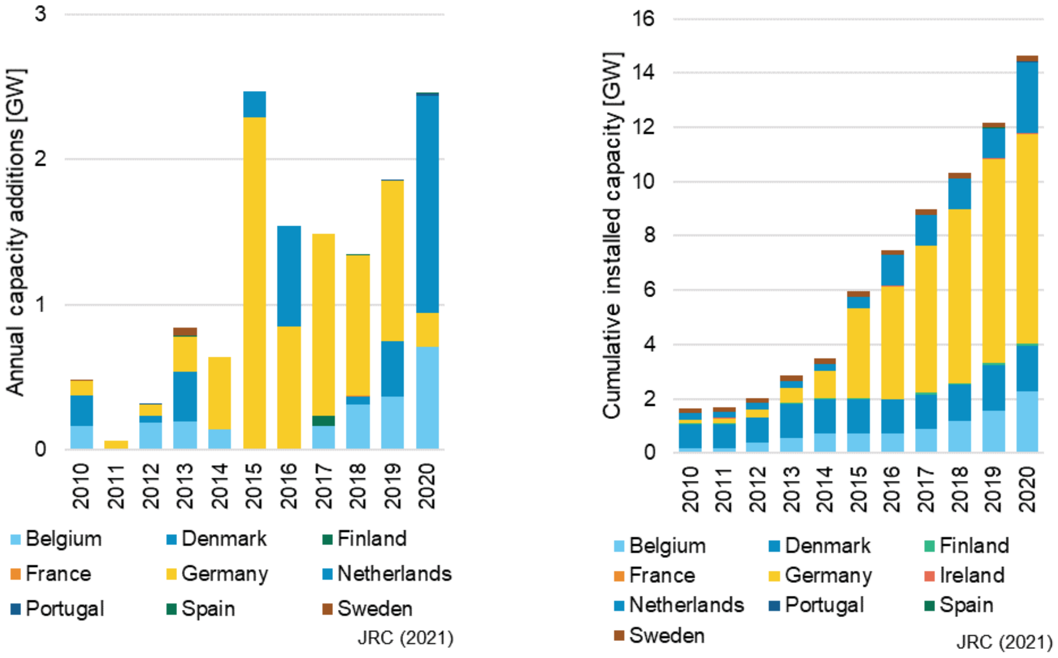
Source: JRC based on GWEC (2021)

In 2020, the entire European offshore wind market represented 71% (24.8 GW) of the global market in terms of cumulative installed capacity. The global installed capacity of the EU MSs accounts for about 42% (or 14.6 GW). Stimulated by the ending of its Feed-in-Tariff by end of 2021, China saw another record year in capacity additions (3.1 GW) resulting in a cumulative offshore wind capacity of about 9.9 GW, ranking second behind the United Kingdom (10.2 GW). EU Member States installed 2.5 GW in 2020, making it the second best year in deployment in the last decade. In 2020 the Netherlands (1.5 GW), Belgium (0.7 GW), the UK (0.5 GW) and Germany (0.22 GW) were the leading countries in terms of the capacity deployed in European waters. The remaining capacity (0.017 GW) was deployed in Portugal, when two of the three floating offshore wind turbines of the Windfloat Atlantic demonstration project were connected to the grid in the beginning of 2020.[144]

---

[144] JRC, Telsnig T: Wind Energy - Technology Development Report 2020, JRC123138. EUR 30503 EN. Luxembourg. URL: https://ec.europa.eu/jrc/en/publication/wind-energy-technology-development-report-2020 (updated 2020 data)

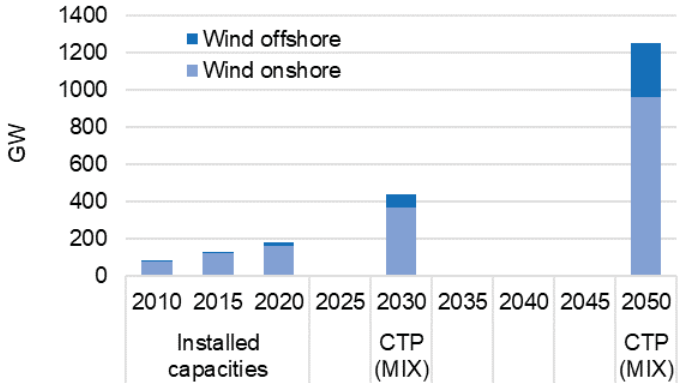
Figure 2: Annual capacity additions (left) and cumulative installed capacity (right) of offshore wind energy in the EU.



Source: JRC based on GWEC (2021)

Projected capacities in onshore wind and offshore wind according to CTP-MIX scenario: Onshore: 366 GW in 2030, 963 GW in 2050; OFFSHORE: 73 GW in 2030, 290 GW in 2050.

Figure 3: Installed wind capacities and wind capacity targets in the EC CTP-MIX scenario



Source: JRC based on 2030 Climate Target Plan Impact Assessment[145]

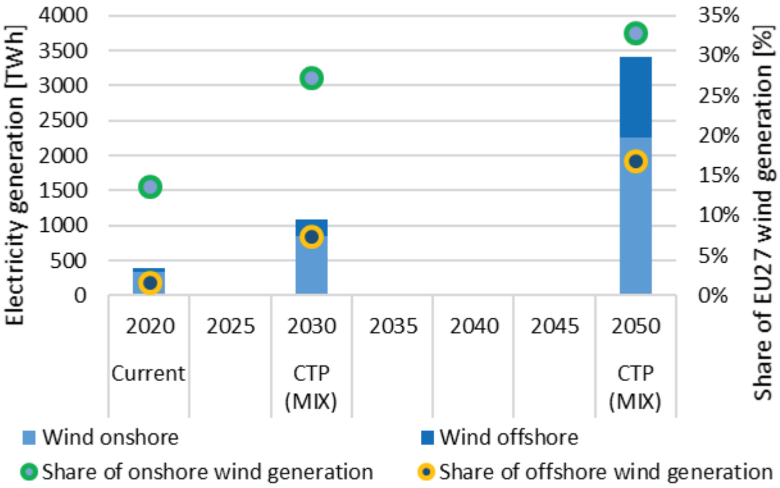
Projected electricity generation in onshore wind and offshore wind according to CTP-MIX scenario: Onshore: 847 TWh in 2030 (share of total electricity generation: 27.3%), 2 259 TWh in 2050 (share:

---

[145] SWD(2020) 176 final, PART 2/2

32.9%); Offshore: 229 TWh in 2030 (share: 7.4%), 1 154 TWh in 2050 (share: 16.8%). Current share of total electricity generation (2020): Onshore wind 13.7%; Offshore wind (1.7%)[146] [147] [148]

Figure 4: Current and future electricity generation from onshore and offshore wind and its share in total electricity generation of the EU



Source: JRC based on 2030 Climate Target Plan, BEIS and WindEurope[149],[150],[151]

The EU Strategy on Offshore Renewable Energy (ORES) proposes to increase Europe's offshore wind capacity from its current level (14.6 GW in 2020) to at least 60 GW by 2030 (and to 300 GW by 2050)[152]. Following current national targets as expressed in the MSs National Energy Climate Plans (NECPs) suggest that the ORES target for 2030 can be achieved. Multiple NECPs do not differentiate between onshore and offshore wind, however limiting to those countries that formulated a specific offshore wind target for 2030 would lead to a cumulated offshore wind capacity of 62.5 GW. With 20 GW in 2030, Germany is the country with the highest NECP offshore wind target followed by the Netherlands, Denmark, France, Ireland, Belgium and Poland. Offshore wind targets at limited scale were formulated by Portugal, Lithuania and Italy. Even though not explicitly mentioned in their NECPs, a set of MSs is expected to deploy substantial offshore wind capacities until 2030. If all MSs targets and expected offshore wind projects are commissioned until 2030 a total of about 84.2GW could go online in EU Member States.

Following this path EU countries would still see most of the offshore wind installations deployed until 2030 in the North Sea (47 GW), yet substantial capacities can be expected in other sea basins particularly in the Baltic Sea (21.6 GW) and in the Atlantic Ocean (11.1 GW). Moreover, first offshore wind capacities are expected in the Mediterranean Sea (2.7 GW) and the Black Sea (0.3 GW). The move to new sea basins is

---

[146] WindEurope ,Wind energy in Europe – 2020 Statistics and the outlook for 2021 – 2025, 2021

[147] BEIS (2021), National Statistics Energy Trends: UK renewables, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables

[148] UK shares in onshore and offshore electricity generation were deducted from figures given in WindEurope (2021) based on reported data in BEIS (2021)

[149] SWD(2020) 176 final, PART 2/2

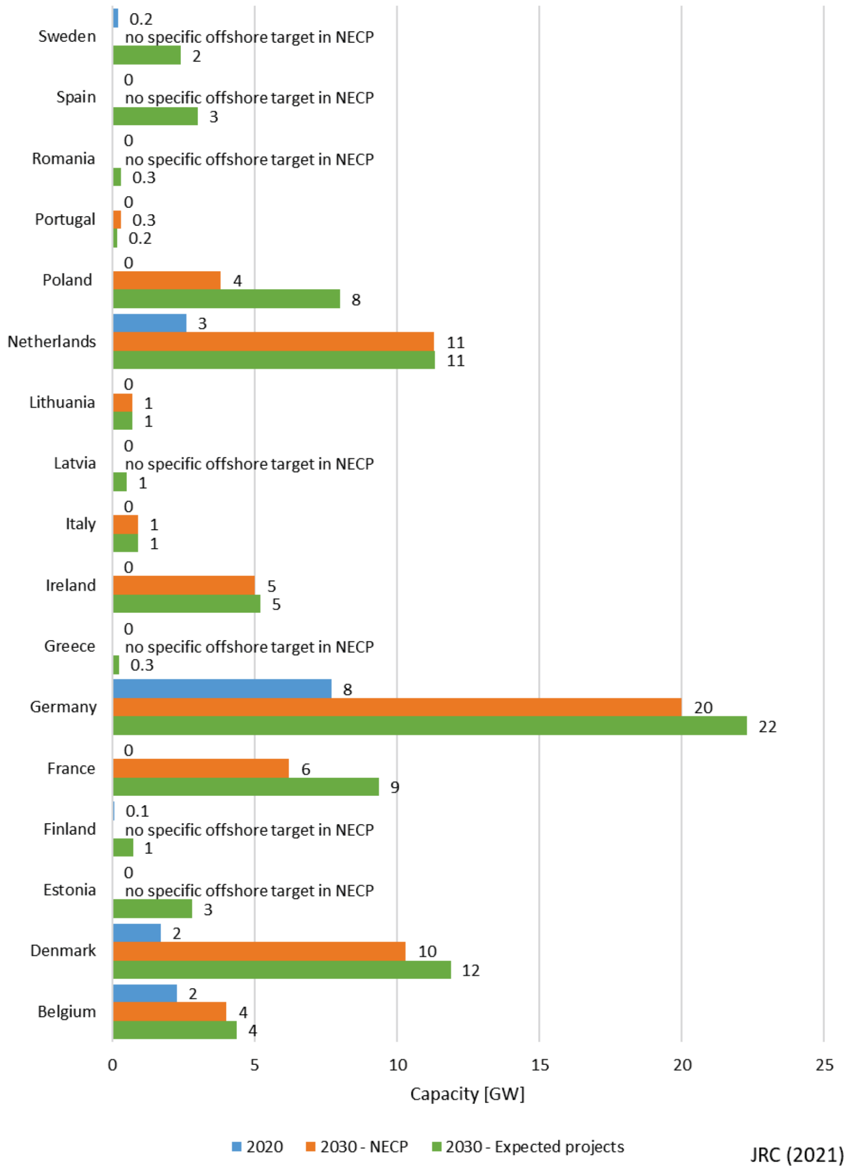
[150] WindEurope (2021), Wind energy in Europe - 2020 Statistics and the outlook for 2021-2025.

[151] UK share was deducted based on: BEIS Energy Trends - Statistical Release 25 March 2021, https://www.gov.uk/government/collections/renewables-statistics#digest-of-uk-energy-statistics-(dukes):-annual-data

[152] COM(2020) 741 final

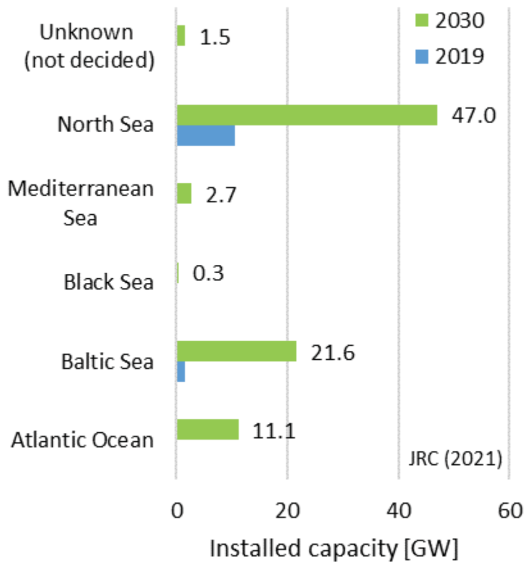
expected to bring an uptake of floating offshore wind projects. About 3 to 4.4 GW of floating offshore wind capacity is expected in EU MSs (France, Greece, Ireland, Italy, Portugal and Spain) by 2030.

Figure 5: Offshore wind capacities as committed in EU MSs National Energy Climate Plans (NECPs) until 2030 versus expected offshore wind projects in EU MSs based on latest announcements/industry



Sources: JRC analysis of NECPs and future expected offshore wind projects (2021)

Figure 6: Expected offshore wind projects in EU sea basins until 2030 based on latest announcements/industry



Sources: JRC analysis of NECPs and future expected offshore wind projects (2021)

3.3. Cost / Levelised Cost of Electricity (LCoE)

Offshore LCoE (bottom fixed): Bottom-fixed offshore wind LCoE declined rapidly to today's values ranging from EUR 67 per MWh to EUR 140 per MWh (Figure 7). Particularly since 2014 an upscaling in project and turbine size can be observed in order to capitalise on the decrease of the unit costs (economies of size). Following current projections on the future costs of bottom-fixed offshore wind expects LCoE levels in the range of EUR 30 EUR per MWh to EUR 60 EUR per MWh by 2050. The cost of offshore wind installations is therewith reaching similar levels as the one of onshore installations.

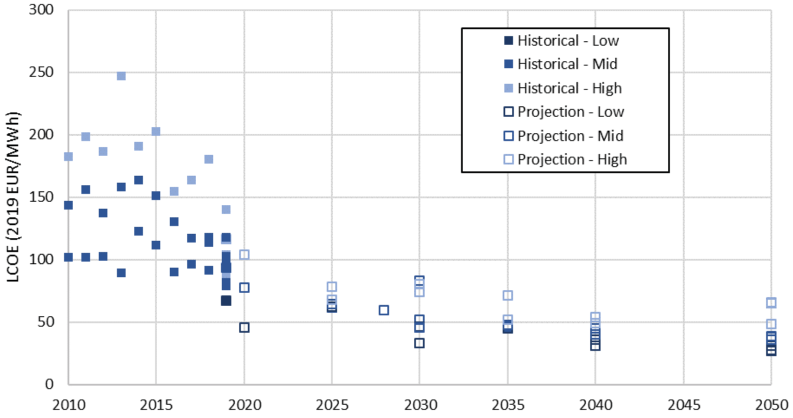
As for all other capital intensive RES technologies the cost of finance (weighted average cost of capital (WACC)) impacts LCoE considerably. The WACC is mainly influenced by country risks and interest rates (see also section 1.3 of onshore wind chapter). Although there is not much data on offshore wind WACC, a recent study finds generally higher values for offshore wind (ranging from 3.5% to 9%) than for onshore wind as the technology is at an earlier stage of development thus having a higher risk profile. Evidence suggests that a further decrease (and convergence among countries) in WACC could be achieved by focusing on de-risking debt financing of wind energy projects by policies that implement support schemes decreasing the volatility of a projects cash flow (e.g. a sliding feed-in premium scheme (Contract for Difference))[153] [154].

---

[153] AURES II (2021), Renewable energy financing conditions in Europe: survey and impact analysis, D5.2, March 2021, H2020 project: No 817619

[154] JRC, Low Carbon Energy Observatory, Wind Energy Technology Market Report, European Commission, 2019, JRC118314.

Figure 7: Range of historical and projected offshore wind LCoE estimates



Source: Chart reproduced from Beiter et al. 2021[155]

Operation & maintenance costs[156] (O&M) are decreasing. Global average annual O&M costs for offshore wind were about USD 90[157]/kW in 2018, and are projected to go down by one-third by 2030 and further decline towards USD 50[158]/kW in 2040 (a decrease of 40% compared to 2018). These reductions will mainly be due to economies of scale, industry synergies, along with digitalisation and technology development, including optimised maintenance concepts [159].

CAPEX for offshore wind projects are declining rapidly and depend on the rated turbine capacity, depth of the site (and the foundation technology pursued) and the size of a project and range in the established European markets between EUR 2 500 per kW and EUR 3 900 per kW[160]. IEA estimates CAPEX in 2018 of EU projects averaging around EUR 3 400 per kW[161,162].

Globally, investment in offshore wind would need to grow substantially over the next three decades, with overall cumulative investment of over USD 2 750 billion[163] from now until 2050. Annually, average investment would need to increase more than three-fold from now until 2030 and five-fold until 2050. Major investments are required for rapid installation of new OW power capacities[164].

More recent studies calculate with an offshore wind deployment ranging between 177 GW and 346 GW in European waters by 2050 and estimate offshore and wind investments at EUR 360 billion to EUR 750

---

[155] Beiter P., Cooperman A., Lantz E., Stehly T., Shields M., Wiser R., Telsnig T., Kitzing L., Berkhout V., Kikuchi Y. (2021) Wind power costs driven by innovation and experience with further reductions on the horizon, WIREs Energy Environ. 2021;e398. https://doi.org/10.1002/wene.398.

[156] These usually represent about 25 to 30% of total lifecycle costs for offshore wind farms (source: Röckmann C., Lagerveld S., Stavenuiter J. (2017) Operation and Maintenance Costs of Offshore Wind Farms and Potential Multi-use Platforms in the Dutch North Sea. In: Buck B., Langan R. (eds) Aquaculture Perspective of Multi-Use Sites in the Open Ocean. Springer, Cham).

[157] EUR 75.83 (1 USD = 0.84 EUR).

[158] EUR 42.13 (1 USD = 0.84 EUR).

[159] IEA, Offshore Wind Outlook 2019 - World Energy Outlook Special Report, 2019.

[160] BNEF 2020 Interactive Datasets.

[161] IEA, Offshore Wind Outlook 2019 - World Energy Outlook Special Report, 2019.

[162] Excluding transmission costs.

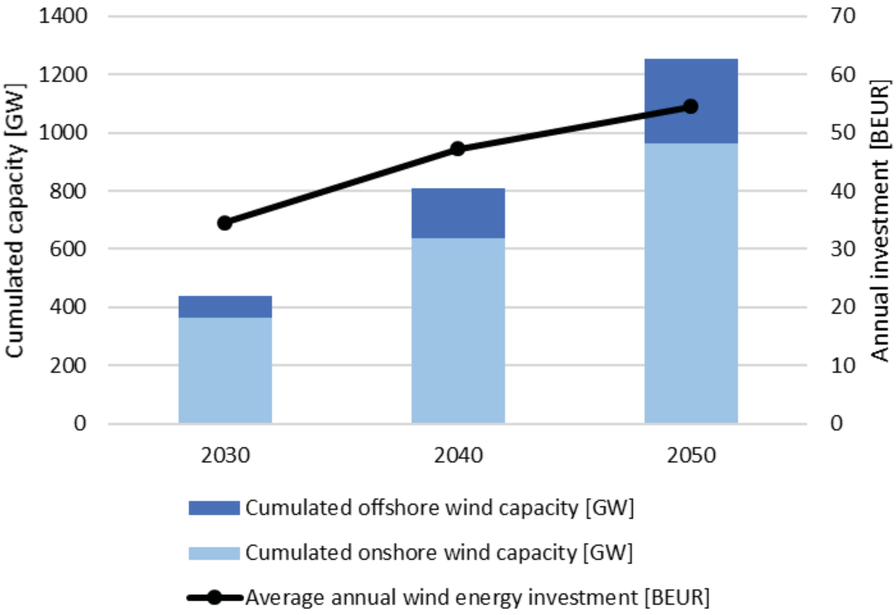
[163] EUR 2310 billion (1 USD = 0.84 EUR).

[164] IRENA, Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation paper), International Renewable Energy Agency, Abu Dhabi, 2019.

billion (of which EUR 200-500 billion are the grid part transmission and interconnection; and EUR 160-250 billion are the generation assets) being in line with the EU Offshore [165]Strategy estimating EUR 800 billion.

The clean energy transition and 2050 climate target will require a total EU investment in wind energy of up to EUR 1 360 billion in the period 2020-2050 under current policy projections. [166,167, 168].

Figure 8: Investment needs until 2050 for both onshore and offshore wind in the EC CTP-MIX scenario



Source: JRC analysis based on the EC CTP—MIX scenario

3.4. Public R&I funding

At the EU level, the R&I priorities include all aspects aimed to provide secure, cost-effective, clean and competitive energy supply, such as new turbine materials and components, resource assessment, grid integration, offshore technology, floating offshore wind, logistics, assembly, testing and installation, maintenance and condition-monitoring systems and airborne wind energy systems.

Offshore wind energy received the largest part of funding awarded to the wind energy related projects. Within the offshore wind funded projects, one area that is still in the early stages of development globally

---

[165] Guidehouse/Sweco (2020), R Recommendations for an integrated framework for the financing of joint (hybrid) offshore wind projects Final report Prepared for the European Commission, Reference No.: 212597.

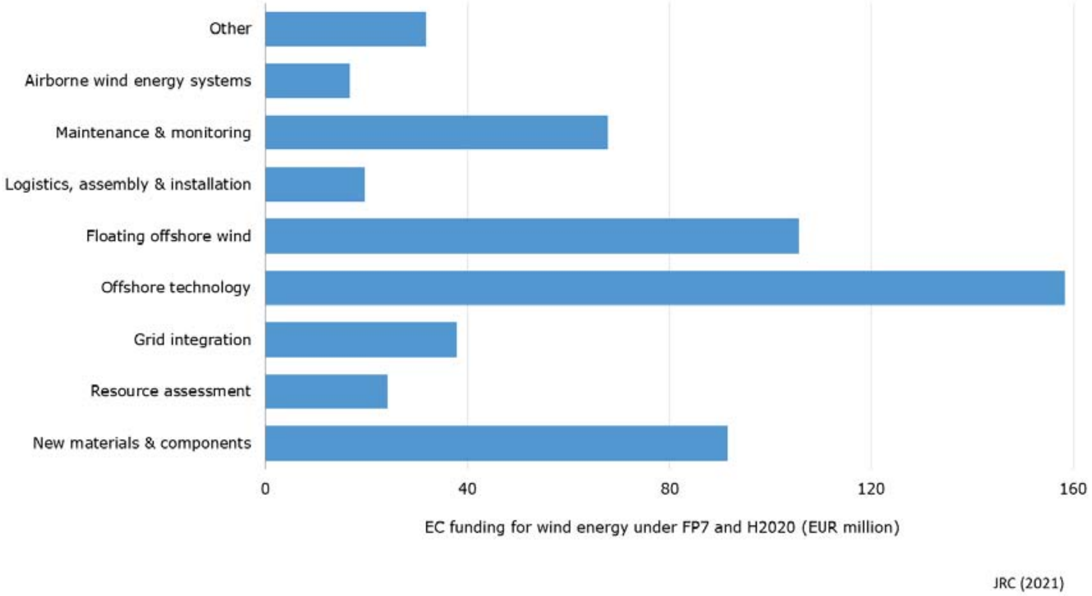
[166] These figures are based on the capacity deployment of the CTP-MIX scenario and the average of the investment expenditure assumptions for onshore and offshore wind towards 2050 as reported in the EU Reference Scenario 2020.

[167] COM(2021) 557 final, Amendment to the Renewable Energy Directive to implement the ambition of the new 2030 climate target, July 2021.

[168] DG ENER, EU Reference Scenario 2020, Energy, transport and GHG emissions - Trends to 2050, Accompanying excel file on technology assumptions, https://ec.europa.eu/energy/data-analysis/energy-modelling/eu-reference-scenario-2020_en.

but carries significant environmental and economic upsides, floating offshore wind, was mostly targeted. [169] [170].

Figure 9: EC funding on wind energy R&I priorities in the period 2009 -2020 under FP7 and H2020.



Source: JRC

Apart from EC-funded projects, the EC-funded SET plan Implementation Working Group (IWG) for Offshore Wind reported a significant number of nationally funded projects (17 out of 24, with single project budgets up to EUR 35 million) with a main focus on the R&I priorities 'Wind Energy Offshore Balance of Plant', 'Floating Offshore Wind' and 'Wind Turbine Technology'[171,172]. Other joint industry programmes related to the SET-Plan include projects from the Dutch GROW programme, and DNV GL's Joint Industry Projects (JIP) on Wind Energy.

Cost reduction through increased performance and reliability, development of floating substructures for deeper waters and the added value of offshore wind energy (system value of wind) were pivotal elements of the SET plan Implementation Plan (IP). In order to achieve these targets, the IP proposes to focus R&I activities on system integration, offshore wind energy – Balance of Plant, floating offshore wind, wind energy O&M, wind energy industrialisation, wind turbine technology, basic wind energy sciences, ecosystem and social impact and the human capital agenda. The IWG estimated that projects addressing these priorities need a combined investment of EUR 1090 million until 2030 with a split in contributions of Member States 34%, EU 25% and Industry 41%.

In 2020 the IWG Offshore Wind updated the targets in its second SET-Plan Implementation Plan for Offshore Wind. Based on current developments in industry, policy and research, the IWG Offshore Wind foresees the main challenges to be addressed by offshore wind energy R&I in the areas of cost reduction,

---

[170] JRC, Telsnig T: Wind Energy - Technology Development Report 2020, JRC123138. EUR 30503 EN. Luxembourg. URLt: https://ec.europa.eu/jrc/en/publication/wind-energy-technology-development-report-2020 (updated 2020 data).

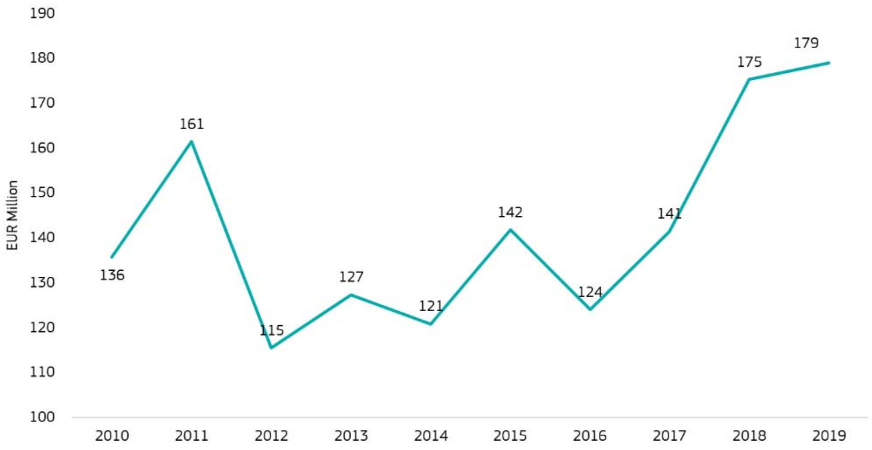
[171] https://setis.ec.europa.eu/system/files/setplan_wind_implementationplan_0.pdf.

[172] JRC, Implementing the SET Plan - Progress from the Implementation working groups, 2020, JRC118272.

the increase of the system value of wind, the need to fully integrate sustainability (both from an environmental and social perspective) and the adaptability to regional conditions and regional cooperation (e.g. the North Seas Energy Cooperation, the Baltic Sea Offshore Wind, the Atlantic Action Plan, the Blue-Med). This is in line with the scientific challenges for R&I in the wind energy domain which aim for a) an improved understanding of atmospheric and wind power plant flow physics, b) the interaction between aerodynamics, structural dynamics and hydrodynamics of enlarged floating wind turbines and c) research on systems science for integration of wind power plants into the future electricity grid[173].

EU public investment has remained roughly constant, between 2012 and 2016 around EUR 120-145 million with an increasing trend since then, reaching EUR 179 million by 2019 (Figure 10). Preliminary numbers for 2020 on selected EU MSs indicate that this increase of public investments continues [174].

Figure 10: Public R&I investments in wind energy in the EU



Source: JRC

Japan led the public RD&D investments in wind energy, for the period 2017-2019, followed by Germany. The Netherlands, Denmark, Spain and France were also amongst the top ten countries investing in wind energy [175].

---

[173] Veers P. et al, 2019, Grand challenges in the science of wind energy, Science, doi: 10.1126/science.aau2027.

[174] JRC, commissioned by DG GROW - European climate-neutral industry competitiveness scoreboard(CIndECS) (Draft, 2021). IEA codes: 32 Wind Energy.

[175] JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard(CIndECS) (Draft, 2021). IEA codes: 32 Wind Energy.

Figure 11: R&I investments in wind energy of the top EU countries compared to global competitors in the period 2017-2019[176]

Source: JRC

3.5. Private R&I funding

In Europe around 90% of the R&I funding in (onshore and offshore) wind energy comes from the private sector[177]. R&I investments in Europe are highly concentrated in Germany, Denmark and Spain, accounting for 77% and 69% of EU corporate and total R&D funding respectively[178].

Private investment into wind rotors is responsible for 1% of total investment in wind in RoW markets but ~ 20% in European markets over a 5-year period[179].

Private investment in wind energy in the EU follow closely the one of China and are much higher compared to the other major economies.

Over the last decade private R&D spending held a relatively constant level between EUR 1.6 billion and EUR 1.9 billion. Moreover, private R&D investments topped public R&D investments by a factor of 10 during this period.[180]

Patenting trends - including high value patents

With its annual growth rate of 50% in 2000-2016, China ranks first in wind energy inventions after overtaking from the EU in 2009, which had been world leader since 2006. However, Chinese patenting

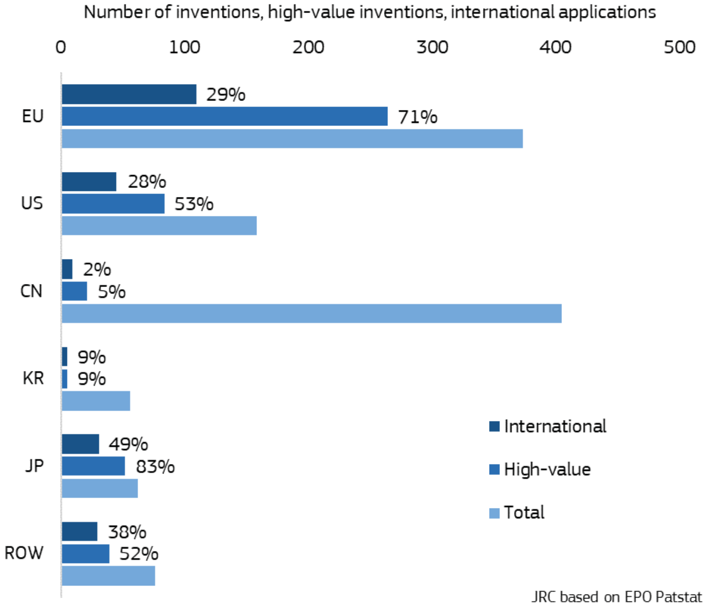
---

[176] IEA reporting countries. IEA data on wind energy public R&I investments does not include China.
[177] JRC, Low Carbon Energy Observatory, Wind Energy Technology Market Report, European Commission, 2019, JRC118314.
[178] JRC, Low Carbon Energy Observatory, Wind Energy Technology Market Report, European Commission, 2019, JRC118314.
[179] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020).
[180] WindEurope, Local Impact Global Leadership (2017, 2020 data update).

activity is aimed for protection in its national market. Of the more than 70% of patenting inventions filed on wind energy technologies, about 5% were high value inventions[181] (vs around 71% of high value inventions for Europe).

Europe has the highest specialisation index (indicating the patenting intensity) in wind energy compared to the rest of the world[182]. The EU wind rotors accounted for most of the high value patent application between 2015 and 2017[183].

Figure 12: Number of inventions and number/share of high-value inventions and international activity[184] in the period 2015 - 2017



Source: JRC

In the period 2015 – 2017, Denmark and Germany are the leading countries in terms of high-value inventions followed by the United States, Japan and China. 71% of all EU's inventions are high value inventions, a value only matched by Japan (83%) which however shows significantly lower invention counts in absolute terms. In this period the EU share in high-value inventions accounts for 57% followed by the US (18%), Japan (11%), China (5%) and Korea (1%). However, the EU's leadership position in high-value patents (with the major EU OEMs filing most of the inventions) is experiencing a decrease since 2012, due to strong performance in high-value patents by major companies from the US (e.g. General Electric) and Japan (e.g. Mitsubishi Heavy Industries, Hitachi).

---

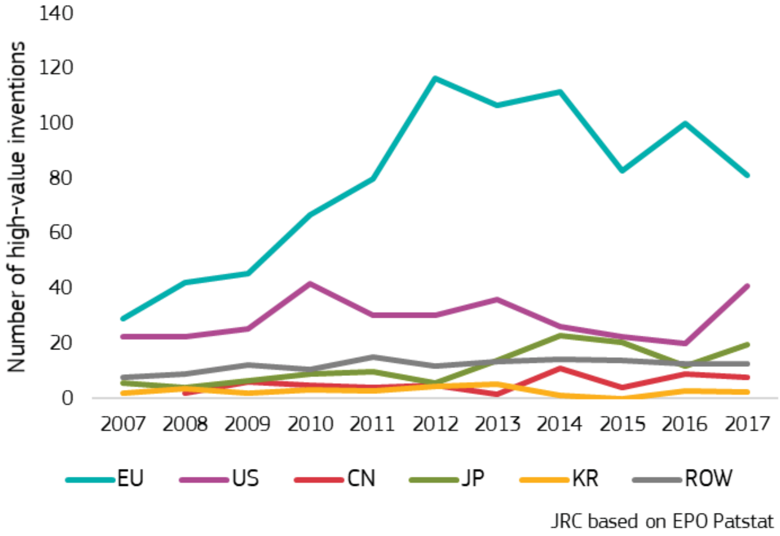
[181] This means that the patents are protected in other patent offices outside of issuing country and refer to patent families that include patent applications in more than one patent office.

[182] JRC, Low Carbon Energy Observatory, Wind Energy Technology Market Report, European Commission, 2019, JRC118314.

[183] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020).

[184] An invention is considered of high-value when it contains patent applications to more than one patent office. Patent applications protected in a country different to the residence of the applicant are considered as international.

Figure 13: Number of high value inventions in wind energy by country



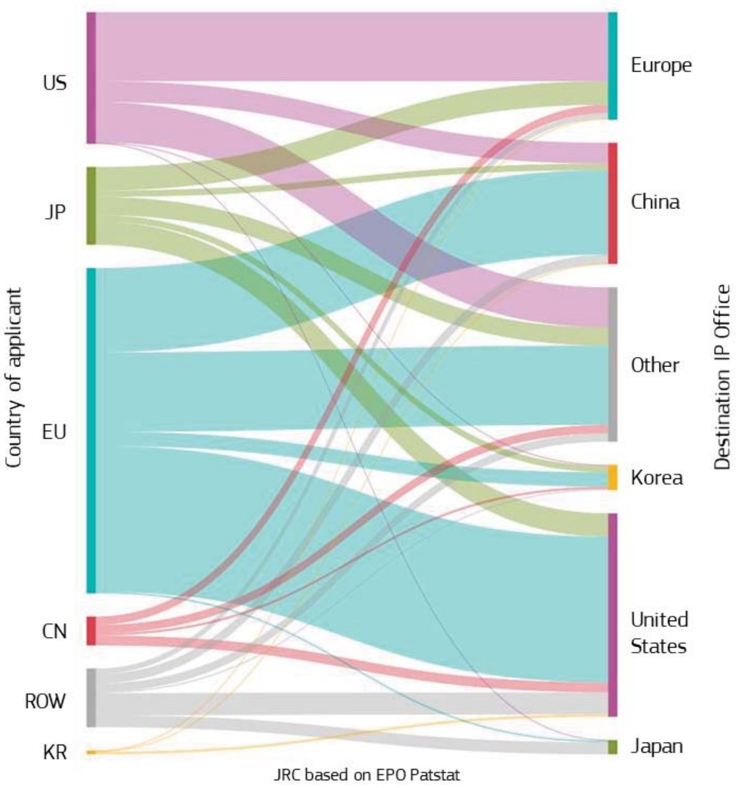
Source: JRC

Figure 14 shows the flow of high value inventions from the major economies to the main patent offices in the period 2015-2017. EU applicants show the highest share of inventions protected in United States and China, whereas the United States and Japan protect a substantial share of their inventions in Europe[185].

---

[185] JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2021).

Figure 14: International protection of high-value inventions (2015-2017)



Source: JRC

3.6. Level of scientific publications

Publications in the wind sector are based on data from Scopus in the period 2015 to 2019[186,187].

The overall number of wind energy publications grew from 3 526 publications in 2015 to 4 299 publications in 2019 (+22%).

Although publication counts seem to indicate a stronger activity outside the EU countries on country level, the EU as a whole ranks first (5 406 publications, 27%). Moreover, publications from the EU countries leading in wind energy deployment and research show high citation impacts indicating a higher recognition of their scholarly outputs than those from their global competitors. Exemplarily the field weighted citation impact (FWCI)[188,189] of wind energy publications in Germany, Denmark, France, Italy, Spain and the

---

[186] Data from Scopus, the world's largest abstract and citation database for peer reviewed publications. 2019 is the latest complete year for Scopus. Based on a citation network-based approach the research performance in the wind energy sector is measured by three main metrics: the prominence of a topic cluster, its scholarly output and the relative citation impact (FWCI) to identify relevant topic clusters to define the field of energy research.

[187] JRC/Elsevier 2020, Energy research - A bibliometric analysis of topic clusters A report commissioned by the Knowledge for the Energy Union Unit (C.7) of the European Commission Joint Research Centre, Invitation to tender - JRC/PTT/2020/VLVP/1016.

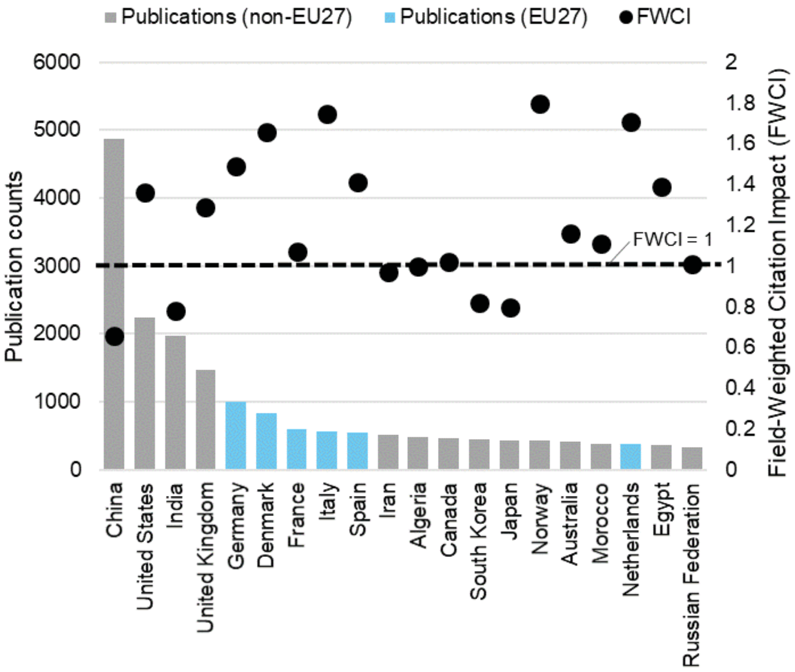
[188] Field-Weighted Citation Impact is the ratio of the total citations actually received by the denominator's output, and the total citations that would be expected based on the average of the subject field.

[189] Field Weighted Citation Impact (FWCI) is an indicator of the citation impact of a publication. It is calculated by comparing the number of citations actually received by a publication with the number of citations expected for a publication of the same

Netherlands ranges between 1.1 and 1.75, whereas only the United States (1.36), Norway (1.8) and the United Kingdom (1.3) show comparable values. Notably research from major other global wind markets such as China (0.66), India (0.78), South Korea (0.82) and Japan (0.8) perform significantly below the average FWCI (Figure 15).

Among EU countries, Germany (1 002) ranks first in terms of publication counts, followed by Denmark (828) and France (599). Moreover multiple Member States are recognised as having a high impact with their publication activity, with 12 Member States scoring above the average FWCI (Figure 16).

Figure 15: Global wind energy research outputs and their respective recognition (based on FWCI) in the period 2015 to 2019

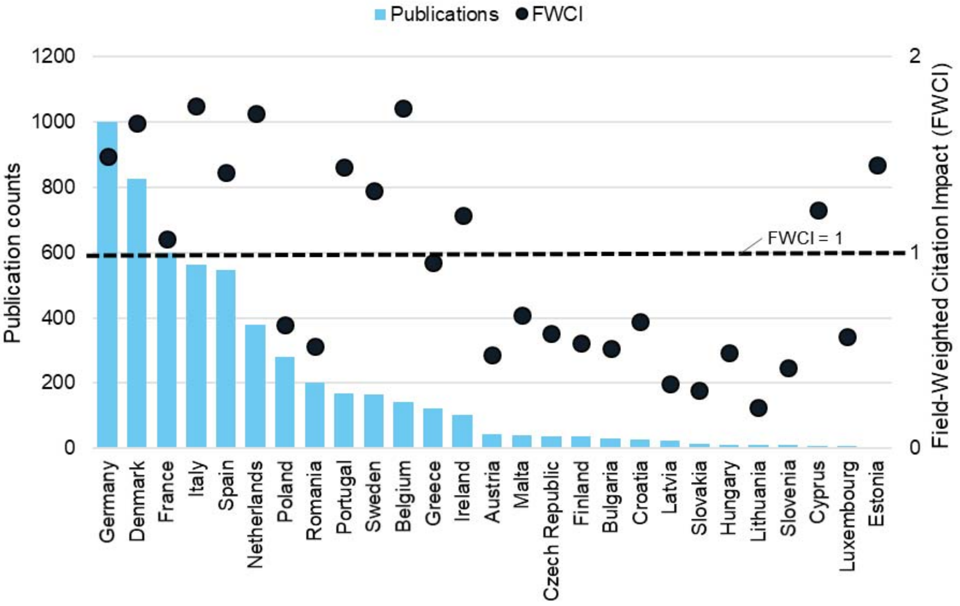


Source: JRC/Elsevier 2020

---

document type, publication year, and subject. The indicator is always defined with a world average baseline of 1.0. An FWCI of 1.0 indicates that the publications have been cited the same amount, on average, as the world average for similar publications.

Figure 16: Wind energy research outputs in EU countries and their respective recognition (based on FWCI) in the period 2015 to 2019



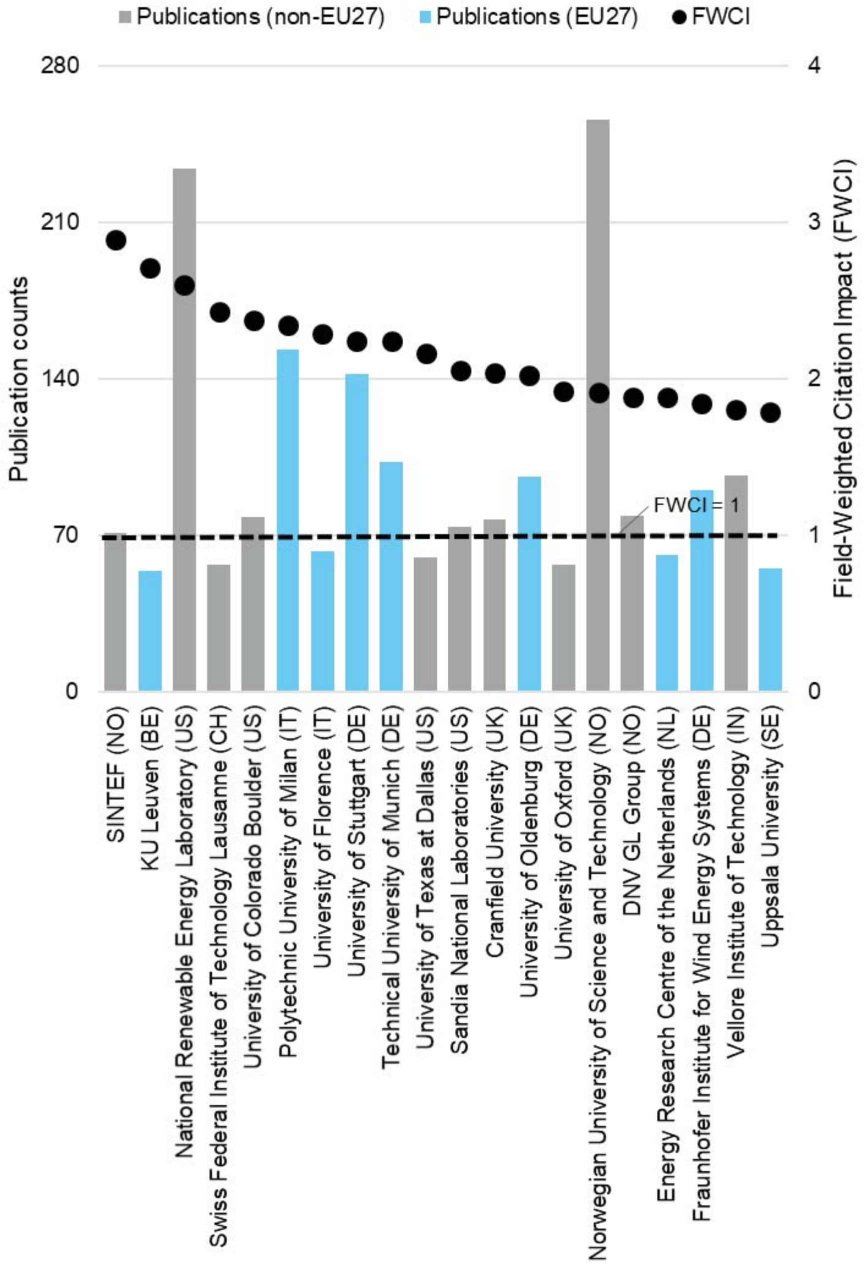
Source: JRC/Elsevier 2020[190]

Research of EU organisations active in wind energy are among the most recognised in the field. In terms of citation impact 9 organisations within the Top20 stem from the EU countries. The Norwegian SINTEF (2.89) ranks first in terms of FWCI followed by KU Leuven (2.71) from Belgium and the US National Renewable Energy Laboratory (NREL) (2.6).

---

[190] JRC/Elsevier 2020, Energy research - A bibliometric analysis of topic clusters A report commissioned by the Knowledge for the Energy Union Unit (C.7) of the European Commission Joint Research Centre, Invitation to tender - JRC/PTT/2020/VLVP/1016.

Figure 17: Recognition of scientific output (based on FWCI) of the leading wind energy research organisations in the period 2015 to 2019



Source: JRC/Elsevier 2020[191]

Within the wind sector, offshore wind related research is the most published in the period 2015 to 2019. Topics containing offshore wind related key-phrases (e.g. combinations of 'offshore wind farm', 'offshore

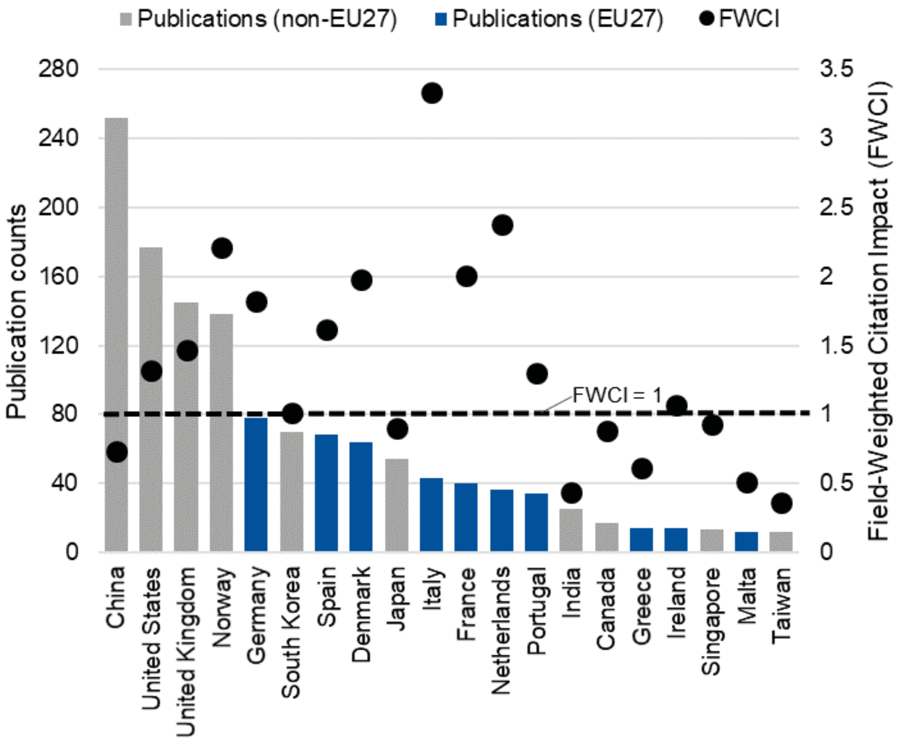
---

[191] JRC/Elsevier 2020, Energy research - A bibliometric analysis of topic clusters A report commissioned by the Knowledge for the Energy Union Unit (C.7) of the European Commission Joint Research Centre, Invitation to tender - JRC/PTT/2020/VLVP/1016[191] Publications which include the three keyphrases 'offshore wind turbine' 'semisubmersible', tension leg platform'.

wind turbine', 'condition monitoring, 'semisubmersible', tension leg platform') see an increased publication activity (about 2 200 scholarly outputs) and have a relatively high citation impact as compared to the average world citation impact.

As an example, the number of publications which include the three key-phrases 'offshore wind turbine' 'semisubmersible', tension leg platform' are depicted in Figure 22 and Figure 23. Similar as in the entire wind energy topic the leading countries can be found outside the EU, with China, the United States, the United Kingdom and Norway publishing significantly more than single EU countries. Again the EU as a whole outnumbers its competitors with about 420 publications in the period 2015 -2019. Moreover 8 out of 10 MSs are recognised as high impact publishers which can only be matched by competitors from the United States, the United Kingdom and Norway (Figure 18).

Figure 18: Global offshore wind energy research outputs (in the area of WT and support structures) and their respective recognition (based on FWCI) in the period 2015 to 2019[192]



Source: JRC/Elsevier 2020[193]

This trend can be also be observed when analysing the leading organisations publishing scientific output in offshore wind in the period 2015 to 2019. The Norwegian University of Science and Technology (NO) leads with 93 publications followed by Shanghai Jiao Tong University (CN, 87) and University of Strathclyde (UK, 43). With SINTEF (NO) a Norwegian organisation is also leading in terms of citation

---

[192] Publications which include the three keyphrases 'offshore wind turbine' 'semisubmersible', tension leg platform'.

[193] JRC/Elsevier 2020, Energy research - A bibliometric analysis of topic clusters A report commissioned by the Knowledge for the Energy Union Unit (C.7) of the European Commission Joint Research Centre, Invitation to tender - JRC/PTT/2020/VLVP/1016

impact (3.86), followed by National Renewable Energy Laboratory (NREL) (2.76) and the Technical University of Denmark (DK) (2.51).

3.7. Final Considerations

In 2020, the EU installed 10.5 GW of wind power capacity (both onshore and offshore), bringing its cumulative wind power capacity to 178.7 GW.

The increase in deployment was even more pronounced for the offshore wind sector surging from 1.6 GW cumulative capacity in 2010 to 14.6 GW in 2020. Projected capacity in offshore wind according to CTP-MIX scenario is of 73 GW in 2030, 290 GW in 2050. Following current national targets as expressed in the MSs National Energy Climate Plans (NECPs) suggest that the ORES targets for 2030 (at least 60 GW) can be achieved. Most of the offshore wind installations deployed until 2030 will be located in the North Sea (47 GW), yet substantial capacities can be expected in other sea basins particularly in the Baltic Sea (21.6 GW) and in the Atlantic Ocean (11.1 GW) and to some extent in the Mediterranean Sea (2.7 GW) and the Black Sea (0.3 GW). The move to new sea basins will require further developments of floating technology and the development of port infrastructure.

4. VALUE CHAIN ANALYSIS OF THE ENERGY TECHNOLOGY SECTOR

4.1. Introduction/summary

This section includes the EU subsidiaries of non EU multinationals (as they also create employment and value added here); this section excludes non-EU subsidiaries of the EU multinationals; for companies manufacturing a large portfolio of products, it includes only the part of their activities related to the segment.

Since the value chains of offshore and onshore wind largely overlap, this section addresses both of them. For the onshore-specific part of the value chain, please refer to Value chain analysis in the chapter on onshore wind.

Europe is a recognized market leader in the wind energy: 48% of active companies in the wind sector are headquartered in the EU compared to the RoW[194]. European manufacturers capture around 35% to 40% of the global wind turbine value chain (China almost 50%). The European OEMs in the wind energy sector have held a leading position in the last few years although their market share has decreased in 2018 mainly in favour of the Chinese OEMs. Within the next decade, Europe will maintain its leadership position in annual growth, yet China, Asia Pacific and North America are expected to develop a significant market size (i.e. installed capacity) of more than 50%[195]. Among the top 10 OEMs in 2018, European OEMs led with 43 % of market share, followed by the Chinese (32 %) and North American (10 %) companies. EU offshore wind turbine OEMs held a leading market share (in terms of WT deployed) in the last decade, however in 2020 China overtook EU for the first time securing a market share of 47% compared to EU OEMs with 39%.

A recent study estimates the annual market size (in terms of revenues) of the EU in offshore wind to almost double from about EUR 31.3 billion in 2020 to about EUR 59.2 billion in 2030. In 2020 this represents

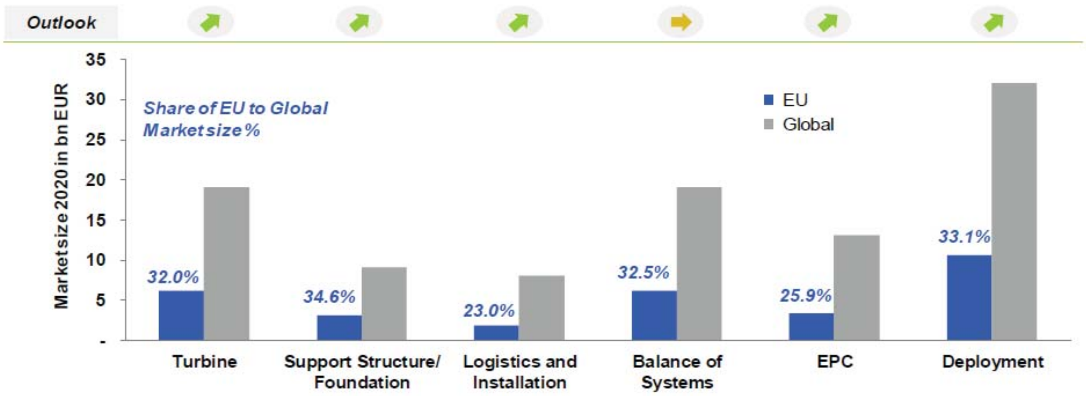
---

[194] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020).

[195] GWEC, Global Offshore Wind Report 2020, 2020.

about 31.2% of the global market. Across the different value chain segments the global share of the EU market ranges from 23% (Logistics & Installation) to 34.6% (Support Structures) (Figure 19)[196].

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



Source: Guidehouse Insights (2020)

Source: ASSET Study commissioned by DG ENERGY - Gathering data on EU competitiveness on selected clean energy technologies (Draft, 2020)

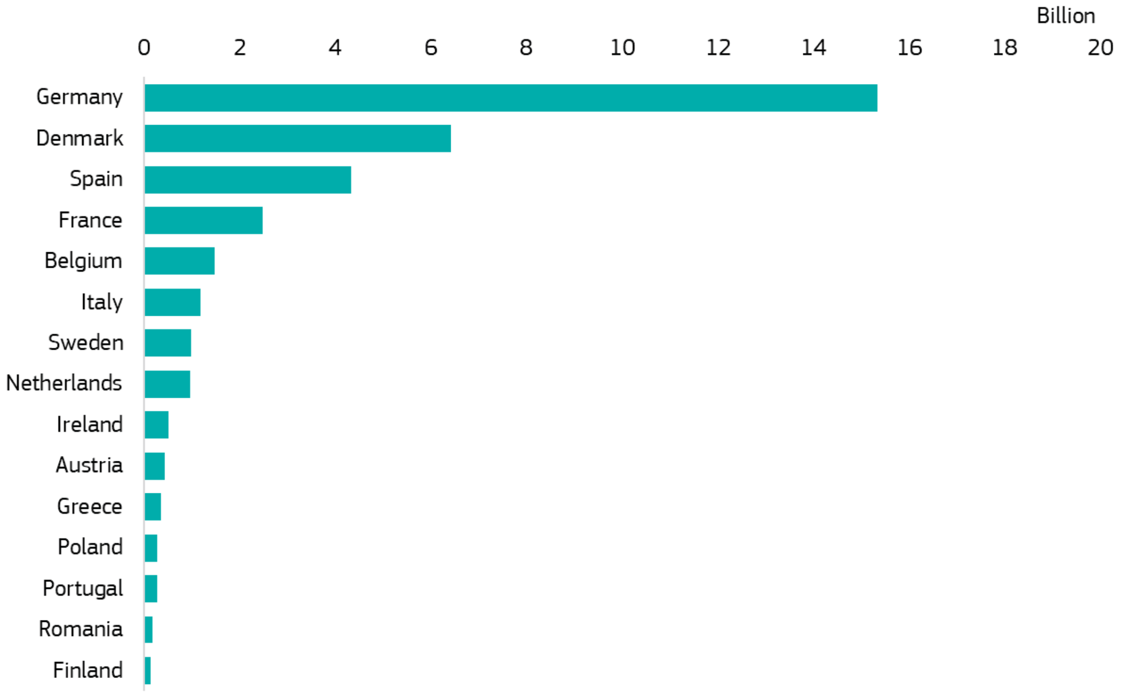
4.2. Turnover

In 2018, the EU turnover amounted to EUR 36 billion, a 2% drop since 2015.

---

[196] EC/Guidehouse 2020, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, ISBN 978-92-76-27325-7 doi: 10.2833/94919 MJ-03-20-496-EN-N.

Figure 20: Turnover of the wind energy value chain in the Top15 EU countries in 2018



Source: JRC[197]

4.3. **Gross value added growth**

Most European manufacturing facilities are located in the country of the company's headquarter or countries with increased wind energy deployment. 48% of active companies in the wind sector are headquartered in the EU. Specifically for wind rotors, the share of EU companies is 58%, with most headquartered in Germany, Denmark and France. Europe is leading in all parts of the value chain for sensing and monitoring systems for onshore wind turbines, including research and production[198].

OEMs also locate their manufacturing facilities in countries where they supply wind turbine components and services, except for Gamesa (ES) and Senvion SE (DE), whose manufacturing facilities are only placed in their country of origin. Smaller OEMs tend to locate their facilities around their headquarters[199] [200].

The EU wind sector has shown its ability to innovate: the EU is leading in the parts of the value chain dealing with sensing and monitoring systems for onshore wind turbines, including research and production. Also, the EU wind industry has high manufacturing capabilities in components with a high value in wind turbine cost (towers, gearboxes and blades), as well as in components with synergies to other industrial sectors (generators, power converters and control systems).

---

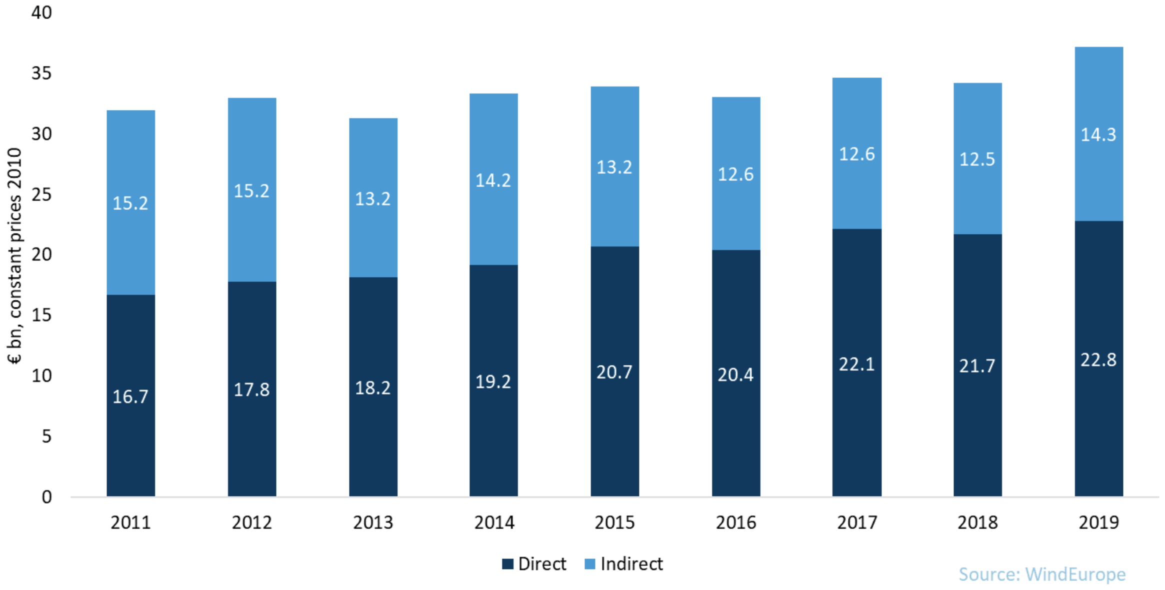
[197] JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2021). IEA codes: 32 Wind Energy.

[198] ASSET Study commissioned by DG ENERGY - Gathering data on EU competitiveness on selected clean energy technologies (Draft, 2020).

[199] WindEurope.

[200] WindEurope, Local Impact Global Leadership (2017, 2020 data update).

Figure 21: Gross Value Added of the European wind energy industry



Source: WindEurope

4.4. Number of EU companies

In the last years the EU offshore market further consolidated following Senvion's insolvency at the end of 2019 and Vestas buying out Mitsubishi Heavy Industries (MHI) from their offshore wind joint venture in 2020 [201] [202]. With SiemensGamesa RE, Vestas and General Electric RE there are currently three offshore original equipment manufacturers (OEMs) with manufacturing capabilities in EU waters. So far, offshore wind OEMs located their factories mainly around the North Sea and Baltic Sea; however, suppliers of subcomponents can be found all over Europe, even in landlocked countries (Figure 24). In January 2021, Chinese offshore wind manufacturer MingYang entered the EU offshore wind market by securing a deal to supply 10 offshore wind turbines to the 30MW Port of Taranto (Beleolico) offshore wind project (replacing the previously planned Senvion turbines) which will be the first commercial EU offshore wind farm in the Mediterranean Sea (end of 2021). MingYang will execute the project from its EU HQ in Germany while turbines seem to be shipped from China. Moreover, monopiles will be provided by a Spanish manufacturer (Haizea Wind Group)[203] [204].

---

[201] WPM 2020a, Windpower Monthly review of 2019 -- part 2 https://www.windpowermonthly.com/article/1669604/windpower-monthly-review-2019-part-2#Senvion, (accessed on 04/01/2021)

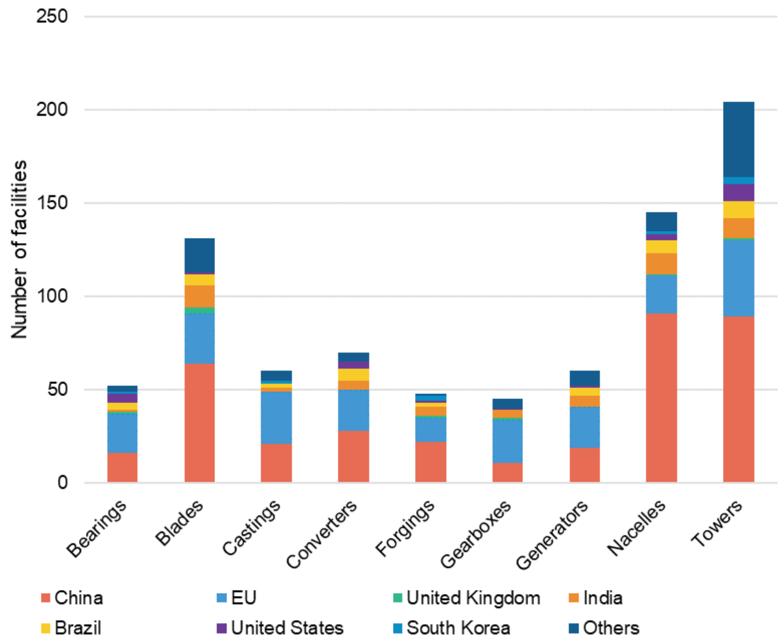
[202] WPM 2020b, Vestas closes deal to buy out MHI from offshore wind venture https://www.windpowermonthly.com/article/1698632/vestas-buys-mhi-offshore-wind-joint-venture, (accessed on 04/01/2021)

[203] https://www.offshore-energy.biz/first-mediterranean-sea-offshore-wind-project-switches-turbine-supplier/ (accessed on 28/01/2021).

[204] https://www.windpowermonthly.com/article/1705391/mingyang-enters-european-offshore-wind-market (accessed on 28/01/2021).

In total, 155 facilities are dedicated to onshore wind and a further 66 supply to both onshore and offshore wind.[205, 206, 207].

Figure 22: Operational manufacturing facilities of wind energy components in 2019



Source: WindEurope

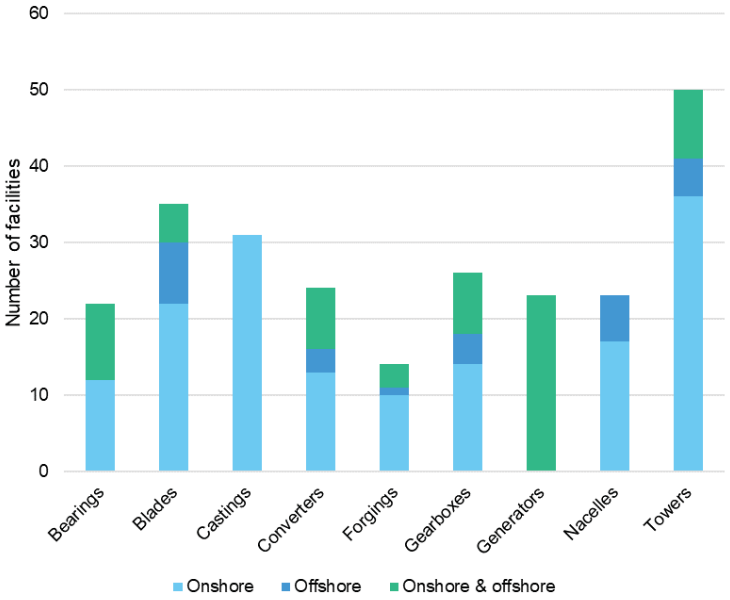
---

[205] WindEurope/Wood Mackenzie (2020), Wind energy and economic recovery in Europe - How wind energy will put communities at the heart of the green recovery, October 2020.

[206] WindEurope, Local Impact Global Leadership (2017, 2020 data update).

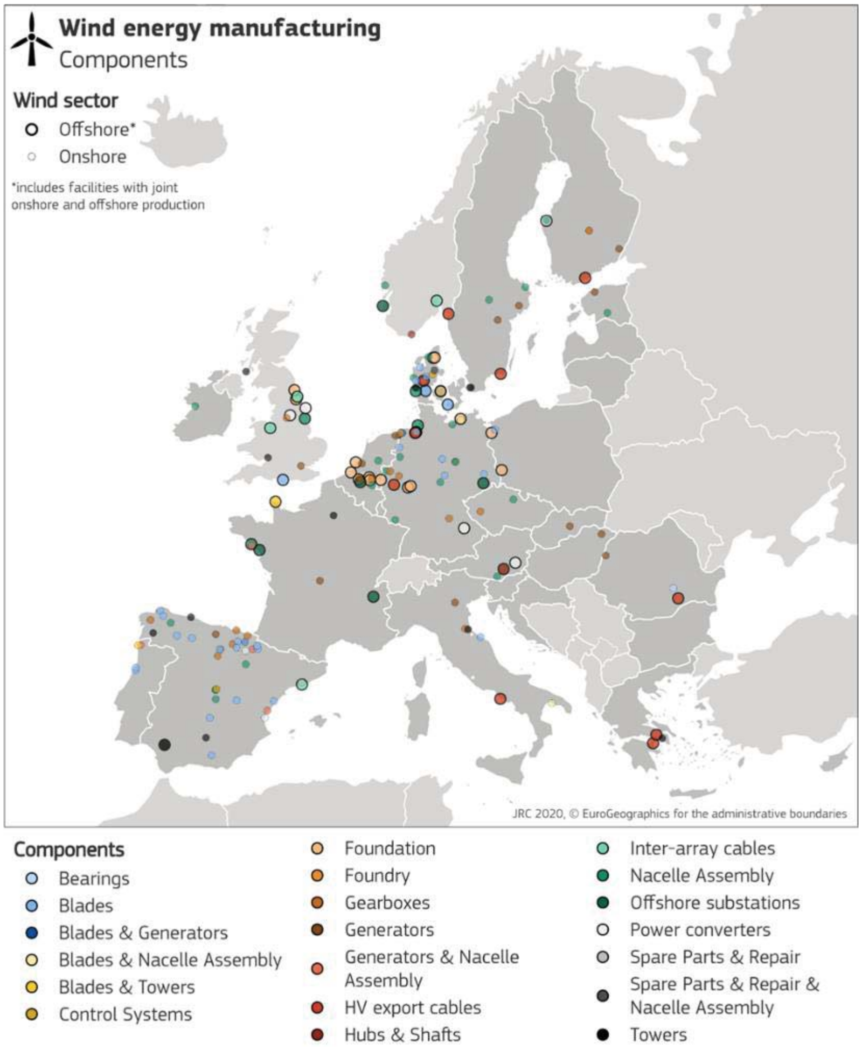
[207] JRC, Low Carbon Energy Observatory, Wind Energy Technology Market Report, European Commission, 2019, JRC118314 (data update July 2020).

Figure 23: Number of European facilities split by value chain segment in 2019



Source: WindEurope

Figure 24: Location of manufacturing facilities of onshore and offshore wind energy components in Europe in 2020



Source: JRC

The increase in rated capacity and blade size of offshore wind turbines further amplifies the need to upsize the infrastructure in existing and future ports hosting manufacturing facilities of large subcomponents (blades and nacelles) or final nacelle assembly. Today the three main offshore OEMs have an estimated 6.5 to 8 GW of nacelle assembly capacity at European ports[208].

This means that European offshore manufacturing at ports will need to grow substantially to serve annual capacity additions up to an estimated 16 GW to satisfy the demand in the period 2030-2050.

---

[208] WindEurope/Wood Mackenzie (2020), Wind energy and economic recovery in Europe - How wind energy will put communities at the heart of the green recovery, October 2020.

Table 1: Location and production capacity of the leading offshore wind manufacturers (nacelles and blades).

Offshore manufacturer	Location/port of Blade or Nacelle assembly factories	Country	Sea basin	Offshore nacelle production capacity estimate [GW/year]
Siemens Gamesa	Bremerhaven	Germany	North Sea	4
	Cuxhaven	Germany	North Sea	
	Aalborg	Denmark	North Sea (Kattegat)	
	Alexandra -Green port Hull	United Kingdom	North Sea	
Vestas	Port of Lindø (Munkebo)	Denmark	Baltic Sea (Danish straits - Great Belt)	2
	Nakskov (Zealand)	Denmark	Baltic Sea	
	Esbjerg (Sydjylland)	Denmark	North Sea	
	Isle of Wight	United Kingdom	North Sea (English Channel)	
GE Renewable & LM Wind Power	Cherbourg	France	North Sea (English Channel)	0.5 (2)
	Saint Nazaire	France	Atlantic Ocean	
	Lunderskov	Denmark	Baltic Sea (not at coast, close to Kolding)	
	Castellón	Spain	Mediterranean Sea (not at coast)	

Sources: JRC Wind manufacturer database (2021) and WindEurope (2020)

Critical raw material dependence

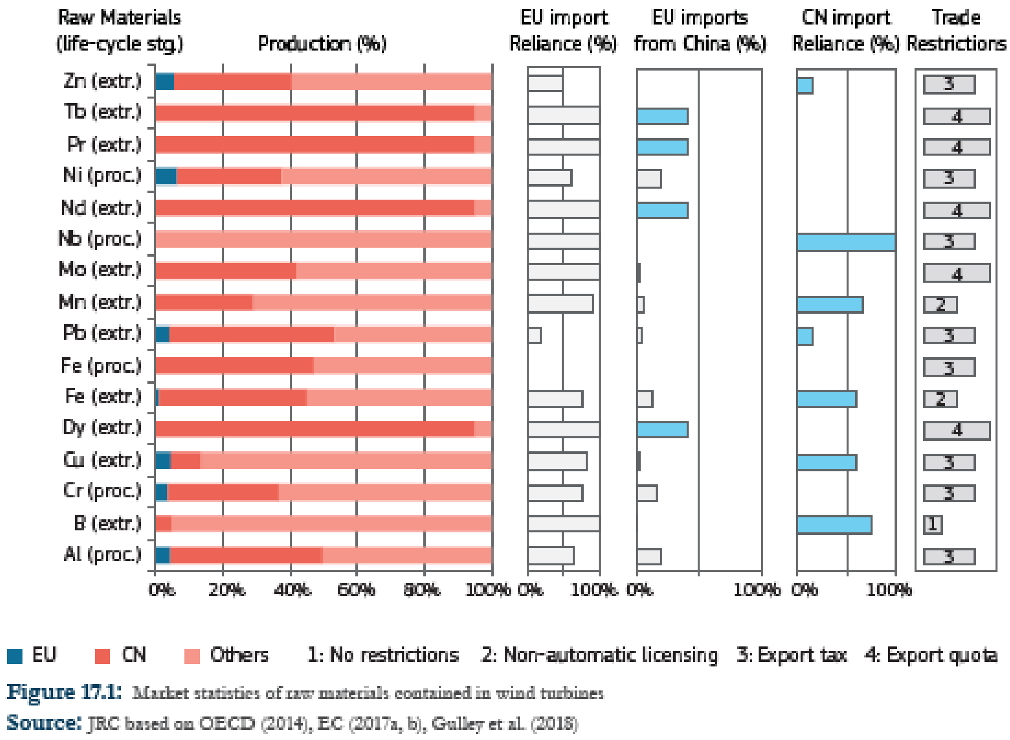
A potential risk of offshore wind energy concerns the supply of raw materials. This paragraph considers the critical raw material dependence of both offshore and onshore wind energy since their raw material usage is similar to a large extent. EU companies are ahead of their competitors in providing offshore generators of all power ranges, due to a well-established European offshore market and the increasing size of newly installed turbines[209]. Wind turbine blades are often made up of composite materials, which are difficult to recycle/re-manufacture. 2.5 million tonnes of composite material are in use in the wind sector globally. 14 000 wind turbine blades will be decommissioned in Europe the next five years. This is a major challenge, both environmentally and economically. Because there is a need to reduce polluting extraction of raw materials and to decrease dependency of the European economy may on raw materials produced in third countries. Applying circular economy approaches, along the life-cycle of installations, is of key importance.

---

[209] JRC, Low Carbon Energy Observatory, Wind Energy Technology Market Report, European Commission, 2019, JRC118314.

Currently, there is no European production of the four main materials used for the production of wind rotors (i.e. boron, molybdenum, niobium and Rare Earth Elements (REEs)). For other raw materials, the EU share of global production is below 1%[210]. China is the largest global supplier for about half of the raw materials needed for wind generators. The EU import reliance for processed REEs (especially neodymium, dysprosium, and praseodymium) used for permanent magnets, is 100%, with 98% being supplied by China (Figure 25). Future materials shortage or supply disruptions could prove to be a risk, given the low substitutability for many raw materials, especially those in high-tech applications[211]. The European Commission proposes an action plan in its communication on critical raw materials[212] to address the issues of overdependence on single supplier countries. Likewise, circularity, recycling and substitution are key R&I technological priorities. In 2022, a call for projects is expected under the Horizon Europe programme, particularly dealing with the R&I challenges of the wind community on large-scale recycling and innovative substitution approaches towards full circularity.

Figure 25: Market statistics of raw materials contained in wind turbines



Source: JRC[213]

---

[210] JRC, China – Challenges and Prospects from an Industrial and Innovation Powerhouse, 2018, JRC116516.

[211] JRC, interactive tool: Materials that are critical to our green future.

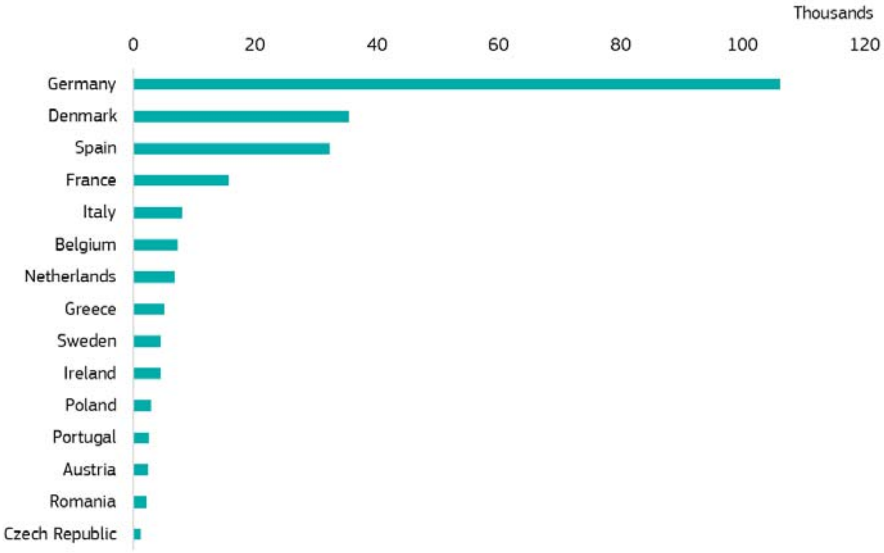
[212] COM(2020) 474 final.

[213] JRC, China – Challenges and Prospects from an Industrial and Innovation Powerhouse, 2018, JRC116516.

4.5. Employment in the selected value chain segment(s)

Wind is a strategic industry for Europe. It is estimated the sectors offers between 240 000 and 300 000 quality jobs[214], 77 000 of which related to offshore wind, contributing EUR 37 billion to EU GDP. Each new turbine generates on average EUR 10 million economic activity. Its 248 factories are all over Europe including in economically-deprived regions. Wind is a major European exporter: half the world's wind power comes from turbines made by European companies. A growth of 2% was observed between 2015 and 2017[215].

Figure 26: Direct and indirect jobs in the EU wind energy value chain in 2018



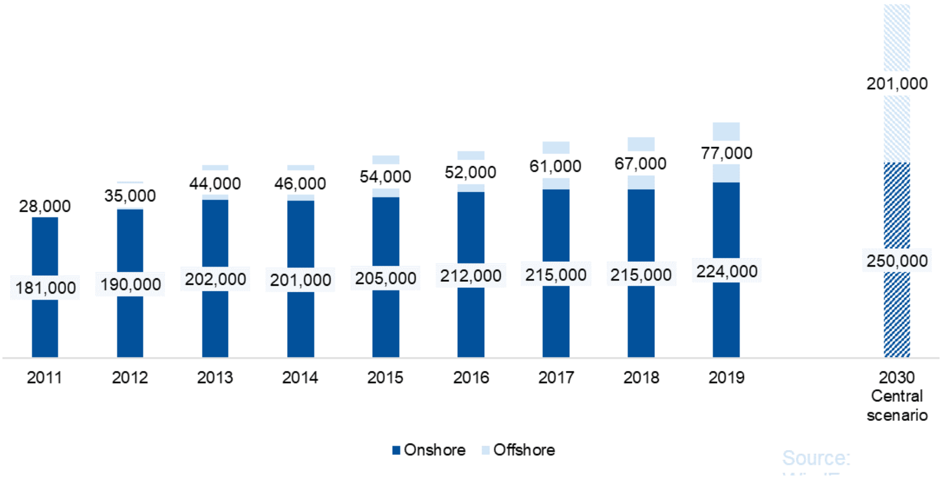
Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard(CIndECS) (Draft, 2021). IEA codes: 32 Wind Energy

---

[214] These are estimates using different methods WindEurope estimates the figure to be 300 000 (https://windeurope.org/about-wind/wind-energy-today/) while Eurobarometer estimates the figure to be 243 000 jobs.

[215] JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard(CIndECS) (Draft, 2021). IEA codes: 32 Wind Energy.

Figure 27: Jobs in the European onshore and offshore wind energy industry (in full-time equivalents)



Source: WindEurope

4.6. Energy intensity considerations, and labour productivity considerations

Labour productivity

Figures on labour productivity in the offshore wind sector measured in direct full term equivalents (FTE) per MW installed are declining over the latest years as the learning effect improves with more capacity installed in the sector. Yet the scope and boundary conditions of these studies differ significantly ranging from case studies on project level to econometric models and scenario based projections estimating the employment factor on country or sector level (Figure 28). Direct job estimates on single projects (given in full time equivalent years) range from 16.3 – 15.8 $FTE/MW_{project}$ for projects in the period 2013-2016[216] [217]. Due to productivity improvements some studies estimate a further decrease in specific direct labour requirements to 9.5 $FTE/MW_{project}$ by 2022[218]. Although these numbers show the expected learning effect they cannot directly be used to estimate the number of total jobs in the entire industry as the extrapolation from project-level capacity to installed capacity in the market would lead to double counting and thus an overestimation.

Current econometric models estimating the number of jobs using employment factors, trade data and/or contribution to the GDP of the sectors involved show direct employment figures declining from about 4 $FTE/MW_{Installed}$ in 2010 to a range of 1.8 to 2.9 $FTE/MW_{Installed}$ in 2020. When including indirect

---

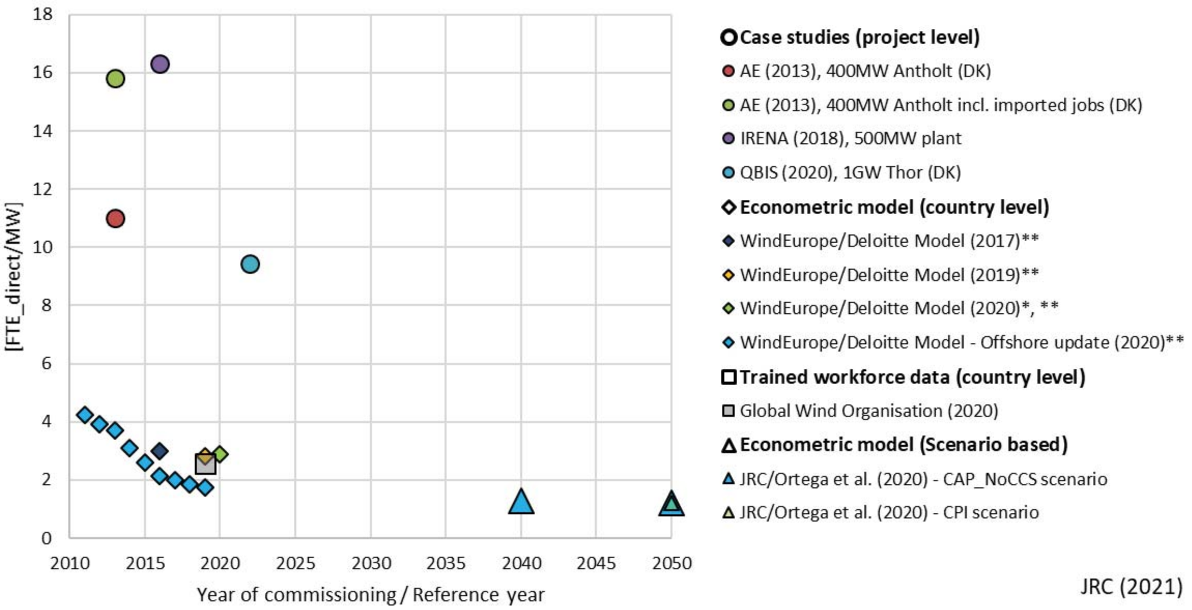
[216] QBIS (2020) Socio-economic impact study of offshore wind.

[217] IRENA (2018), Renewable Energy Benefits: Leveraging Local Capacity for Offshore Wind, IRENA, Abu Dhabi.

[218] QBIS (2020), Socio-economic impact study of offshore wind.

employment effects range between 2.2 to 5.1 $\text{FTE/MW}_{\text{Installed}}$ seems plausible[219] [220] [221] [222] [223]. Scenario-based analyses estimate a further decline in direct labour productivity to about 1.2 $\text{FTE/MW}_{\text{Installed}}$ by 2050.

Figure 28: Estimated direct person years (FTE/MW) for offshore wind based on different case studies and modelling approaches



** Includes direct jobs from wind turbine component manufacturers where a split between onshore& offshore is not possible*
*** Direct jobs estimated based on contribution to the GDP of the sectors involved in the industry and annual reports*

Source: JRC

Energy intensity

The energy intensity is analysed based on the cumulated energy demand (CED) along the lifecycle of offshore wind. The majority of life cycle analyses finds the cumulated energy demand between 0.1 and 0.19 $\text{MJ}_{\text{input}}/\text{kWh}_{\text{el}}$, a comparable order of magnitude when compared with the cumulated energy demand of current onshore wind turbines (see grey dots in Figure 29). Notably data points on floating offshore show higher values than bottom fixed offshore wind in terms of cumulated energy demand. However, a decisive factors influencing the CED, besides the life cycle inventory data used, is the chosen system boundary and assumed geographical reference (e.g. countries electricity mix and wind resource, which becomes apparent in the outlier value of Wagner et al (2011) which includes also the connection of the Alpha Ventus wind farm to the electricity grid). Given the small amount of available LCA data in offshore wind no clear trend

---

[219] Deloitte/WindEurope (2017), Local impact, global leadership – The impact of wind energy on jobs and the EU economy.

[220] WindEurope (2020), The EU Offshore Renewable Energy strategy, June 2020. Updated figures on employment using the Deloitte/WindEurope model.

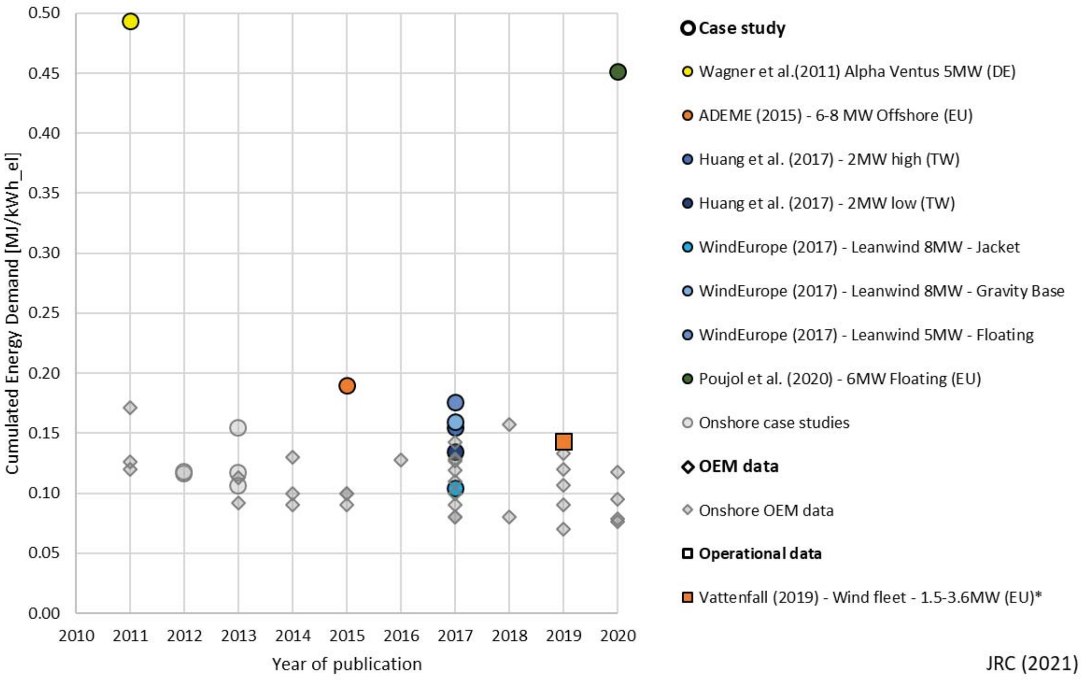
[221] Ortega et al. (2020), Analysing the influence of trade, technology learning and policy on the employment prospects of wind and solar energy deployment: The EU case. Renewable and Sustainable Energy Reviews 122 (2020) 109657, Available https://doi.org/10.1016/j.rser.2019.109657.

[222] JRC 2020, Facts and figures on Offshore Renewable Energy Sources in Europe, JRC121366.

[223] GWO (2020), Powering the Future – Global Offshore Wind Workforce Outlook 2020-2024.

in the CED can be observed, neither in terms of evolution in time nor in respect to the growth in turbine size (Figure 29).

Figure 29: Evolution (top) of Cumulated Energy Demand (MJ_primary energy/kWh_el) of offshore wind turbines and the respective rated capacity (bottom) based on different case studies and OEM data



* includes 57% electricity generation from offshore wind

Source: JRC

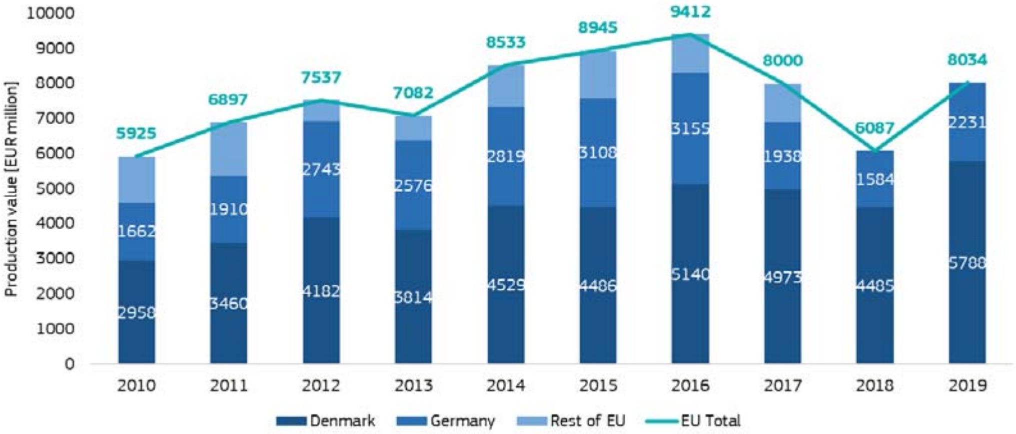
4.7. Community Production (Annual production values)

The total production value of the wind energy value chain in the EU is shown in Figure 30. It remains at a relatively high level in the order of EUR 8 billion per year, since 2014[224].

---

[224] JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard(CIndECS) (Draft, 2021). IEA codes: 32 Wind Energy.

Figure 30 Total Production Value of the wind energy value chain in the EU



Source: JRC[225]

4.8. Final Considerations

Wind is a strategic industry for Europe. It is estimated the sectors offers between 240 000 and 300 000 jobs. Most European manufacturing facilities are located in the country of the company's headquarter or countries with increased wind energy deployment. 48% of active companies in the wind sector are headquartered in the EU. There are 248 operational manufacturing facilities in Europe (30% of all facilities). 155 facilities are dedicated to onshore wind and a further 66 supply to both onshore and offshore wind.

In 2018 the wind energy value chain in the EU produced a turnover of EUR 36 billion.

The EU wind sector has shown its ability to innovate: the EU is leading in the parts of the value chain dealing with sensing and monitoring systems for onshore wind turbines, including research and production. Also, the EU wind industry has high manufacturing capabilities in components with a high value in wind turbine cost (towers, gearboxes and blades), as well as in components with synergies to other industrial sectors (generators, power converters and control systems).

IWG Offshore Wind foresees the main challenges to be addressed by offshore wind energy R&I in the areas of cost reduction, the increase of the system value of wind, the need to fully integrate sustainability (both from environmental and social perspective) and adaptability to regional conditions and regional cooperation (e.g. the North Seas Energy Cooperation, the Baltic Sea Offshore Wind, the Atlantic Action Plan, the Blue-Med).

5. GLOBAL MARKET ANALYSIS

5.1. Trade (imports, exports)

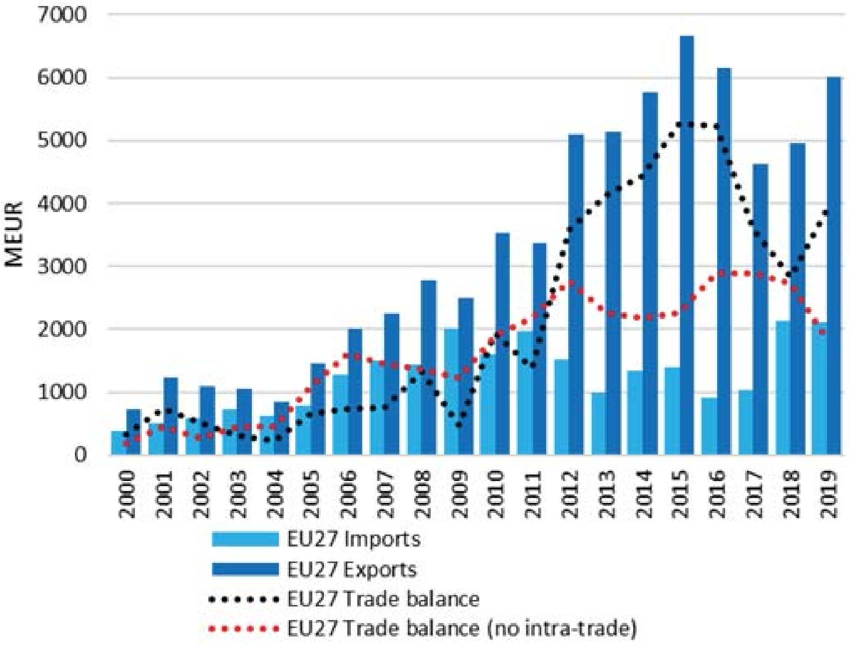
The EU has had a positive trade balance in wind energy related equipment in the last 20 years. Yet there is some stagnation in the growth of this indicator (Figure *31*). This is partially explained by third countries catching up on the EU's first mover advantage, but also by third country policies aimed at protecting their

---

[225] JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard(CIndECS) (Draft, 2021). IEA codes: 32 Wind Energy.

domestic market or forcing EU companies to localise production capacity (e.g. through local content requirements). To illustrate, exports of wind generating sets to China have fallen drastically since 2007 after local content requirements were introduced, and have not recovered. On the opposite, 21% of Chinese wind-related exports in 2018 were destined for the EU market.

Figure 31: Import, export and trade balance in wind energy related equipment (850231, Electric generating sets; wind-powered) of the EU

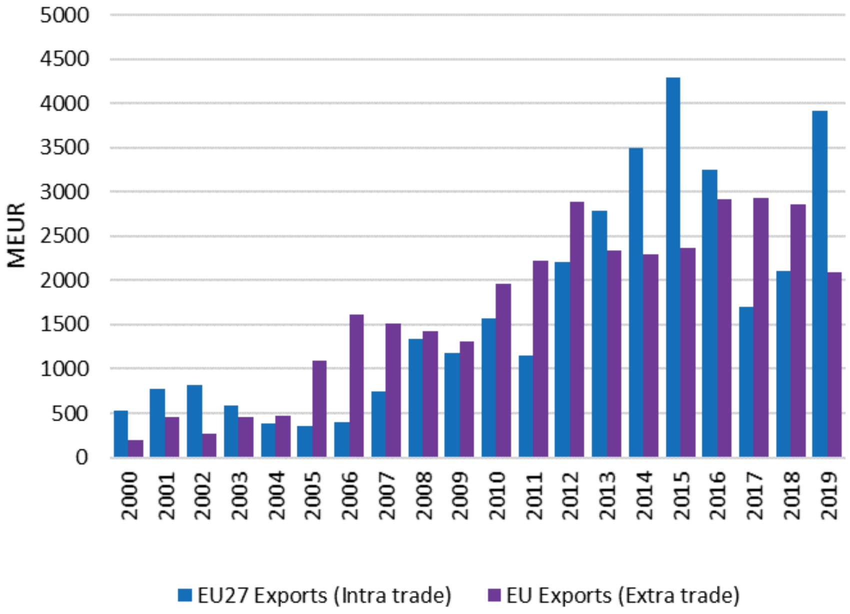


Source: JRC based on Eurostat (Comext)

Imports of wind related goods is mainly done among EU countries (intra trade). In 2019 only 11% of wind related goods came from countries outside the EU, with the majority stemming from China (87%) and India (12%). Imports from the US ranging in the last decade from 3% to 9% dropped in 2019 to 0.2%.

Exports of wind related goods to countries outside the EU (extra trade) show a positive development since 2000. However in the last decade some stagnation can be witnessed (Figure 32). Since 2010 most EU exports are shipped to the UK (25%) followed by the United States (13%), Turkey (9%) and Canada (9%). Only 0.6% of all EU exports on wind related goods are exported to China in the period 2010-2019.

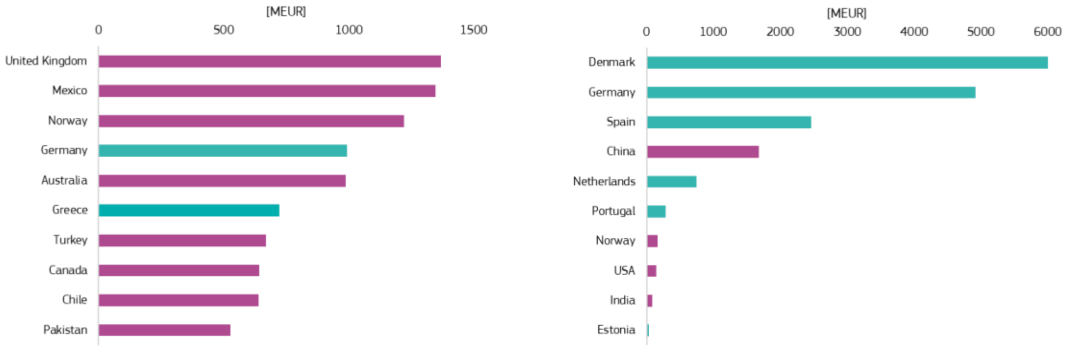
Figure 32: Export of wind energy related equipment (850231, Electric generating sets; wind-powered) among EU countries (intra-trade) and export to countries outside the EU (extra-trade)



Source: JRC based on Eurostat (Comext)

On a single country level the United Kingdom, Mexico and Norway rank among the top importers of wind related goods in the period 2017 – 2019. On the contrary six EU countries can be found among the Top10 global exporters of wind related goods during that period (Figure 33)[226].

Figure 33: Top10 global importers (left) and Top10 global exporters of wind energy related equipment (850231, Electric generating sets; wind-powered) in the period 2017 - 2019



Source: JRC

---

[226] JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2021).

5.2. Global market leaders vs. EU market leaders (market share)

The European Original Equipment Manufacturers (OEMs) in the wind energy sector have held a leading position in the last few years. In 2020 they lost for the first time their first rank to the Chinese OEMs when analysing the Top10 OEMs in terms of market share. Among the top 10 OEMs in 2020, Chinese OEMs led with 42 % of market share, followed by the European (28 %) and North American (12 %) companies. [227]

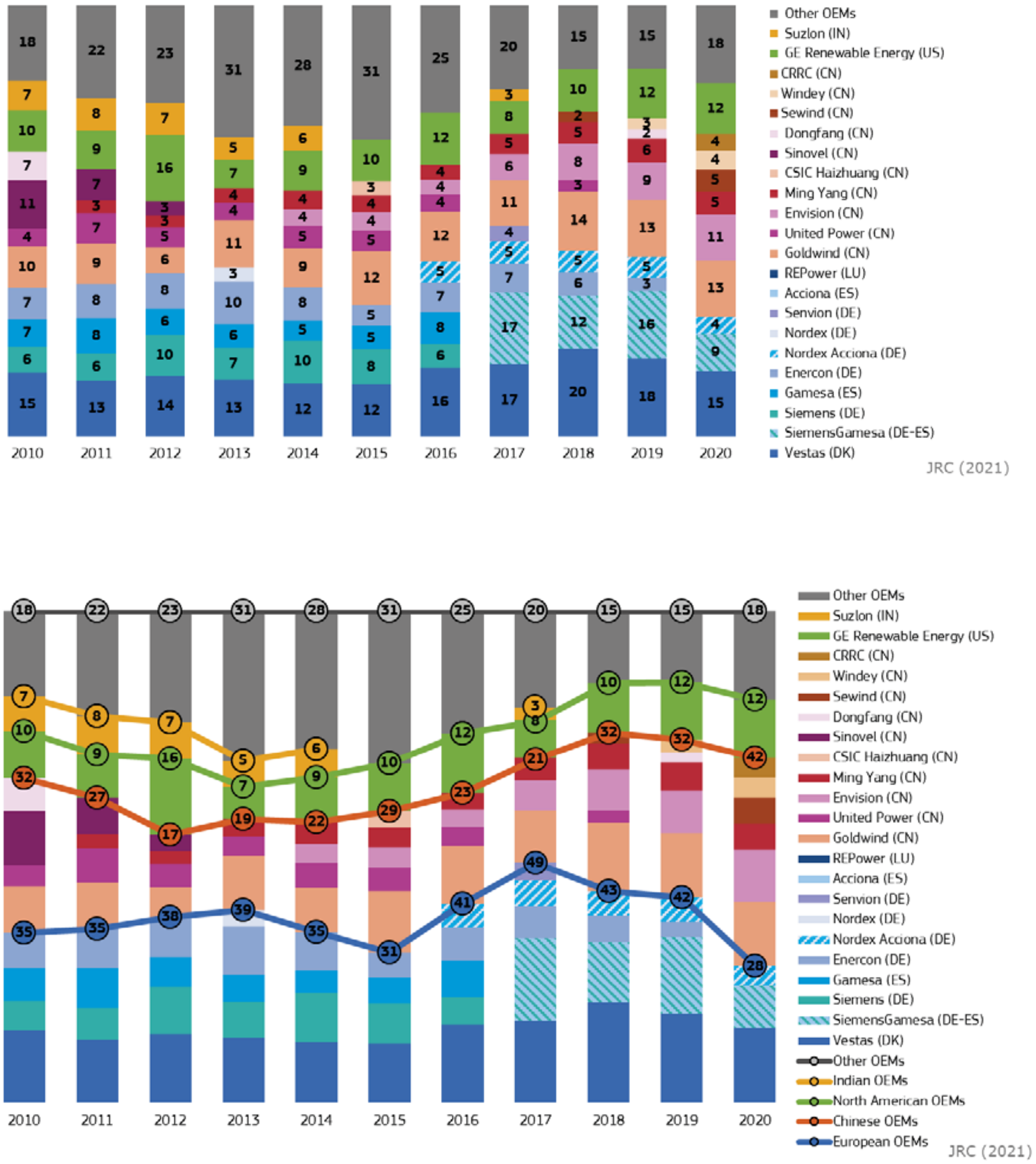
Danish Vestas remained in first place, yet a strong increase in new deployments using turbines from both Chinese OEMs and GE Renewable Energy from the US can be witnessed. This can be explained by a surge in new installations in the Chinese and US wind market.

This latest surge in Chinese wind deployment can, to some extent, be explained through a set of new policies targeting renewable energy integration and a shift from Feed-in-Tariffs towards a tender-based support scheme. This necessitates projects approved before 2018 to be grid-connected latest by the end of 2020 in order to receive the expiring Feed-in-Tariff.

---

[227] JRC, Low Carbon Energy Observatory, Wind Energy Technology Market Report, European Commission, 2019, JRC118314 (data update May 2021).

Figure 34: Market share (%) of the top 10 OEMs in wind energy (top) over the period 2010 – 2020 and their respective origin (bottom)



Source: JRC

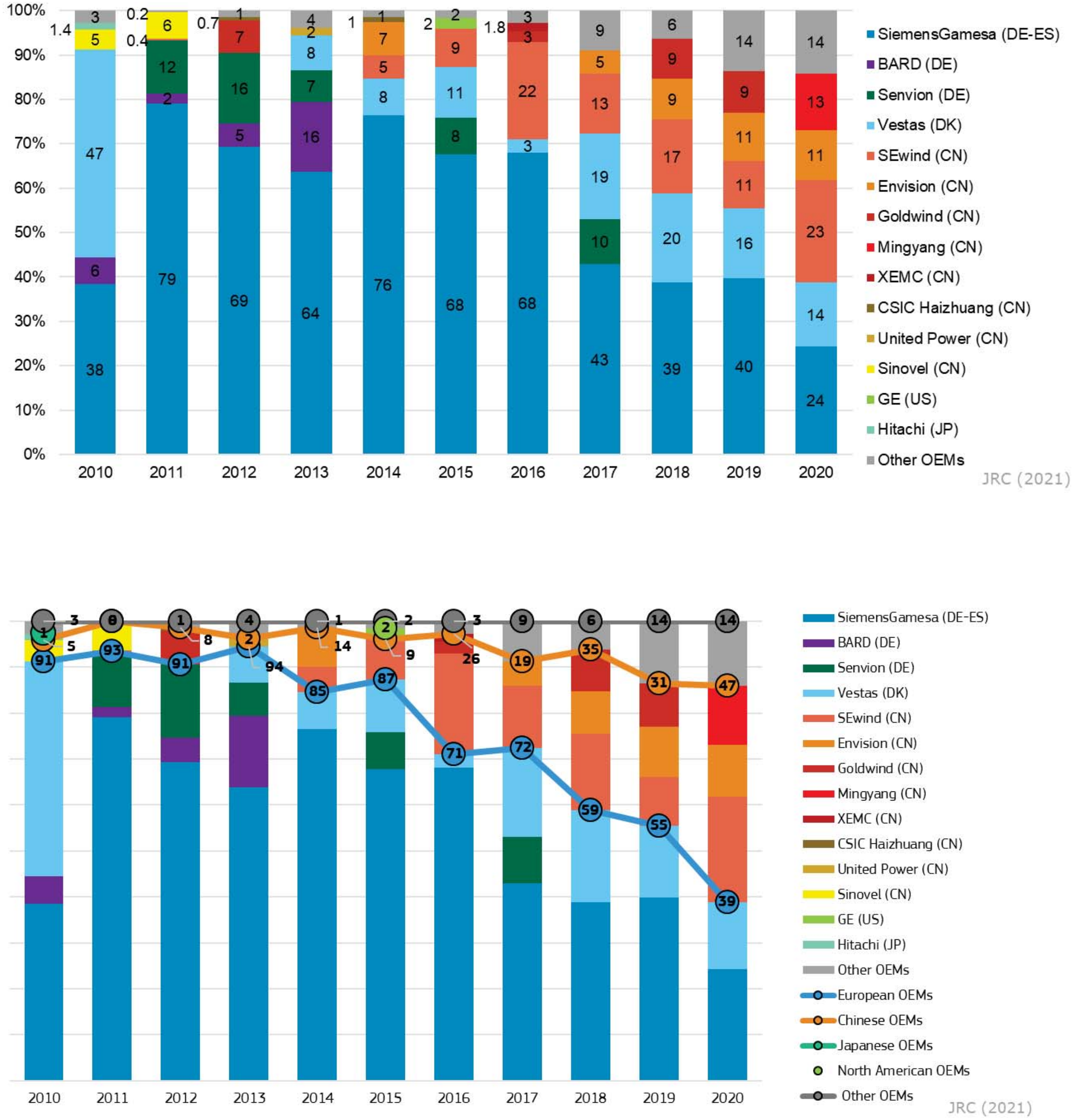
Similarly as in the onshore case, offshore wind projects approved before 2018 and grid connected by end of 2021 still receive a Feed-in-Tariff whereas auctions in the following two years will implement a price cap. Thus an increased deployment activity in China (more than 3GW) led to a strong increase in the market share of Chinese OEMs (47%) leading ahead of the European manufacturers (39%) when assessing their cumulative market share[228].

Yet the European Original Equipment Manufacturers in offshore wind rank among the Top 3. SiemensGamesa RE is leading in first place (24%), closely followed by Goldwind (23%) from China while the second European manufacturer Vestas ranks in third position (14%).

---

[228] JRC, Low Carbon Energy Observatory, Wind Energy Technology Market Report, European Commission, 2019, JRC118314 (data update May 2021).

Figure 35: Market share (%) of the top 5 OEMs in offshore wind energy (top) over the period 2010 – 2020 and their respective origin (bottom)



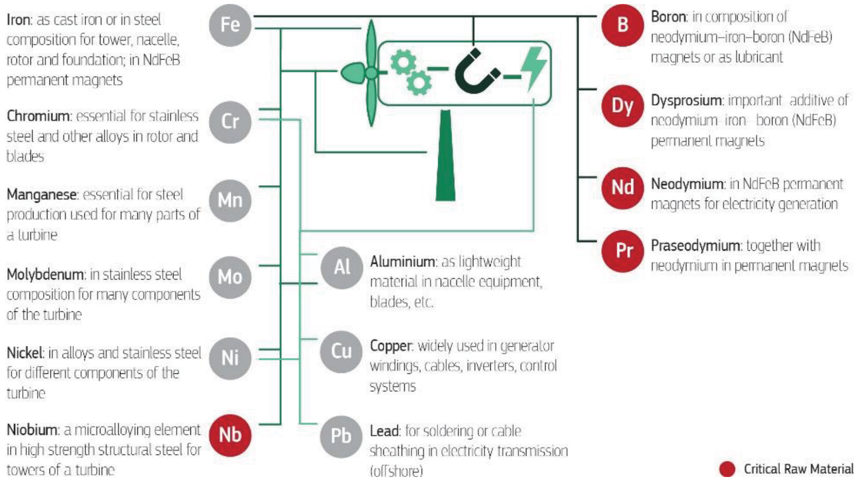
Source: JRC

5.3. Resource efficiency and dependence

A key component of a wind turbine is the generator, which converts the mechanical energy to electrical energy. There are three main types of wind turbine generators: direct current, alternative current synchronous and asynchronous. Considering the fluctuating nature of wind, it is advantageous to operate the generators at variable speed to reduce the mechanical stress on the turbine blades and drive train. Permanent magnet (PM) generators have been introduced in the recent decades in wind turbines applications due to their high power density and low mass. In particular, the Direct Drive PMSG offers certain advantages in terms of efficiency, weight, dimension and maintenance. However, this type of turbine is associated with a high demand for Rare Earth Elements (REEs).

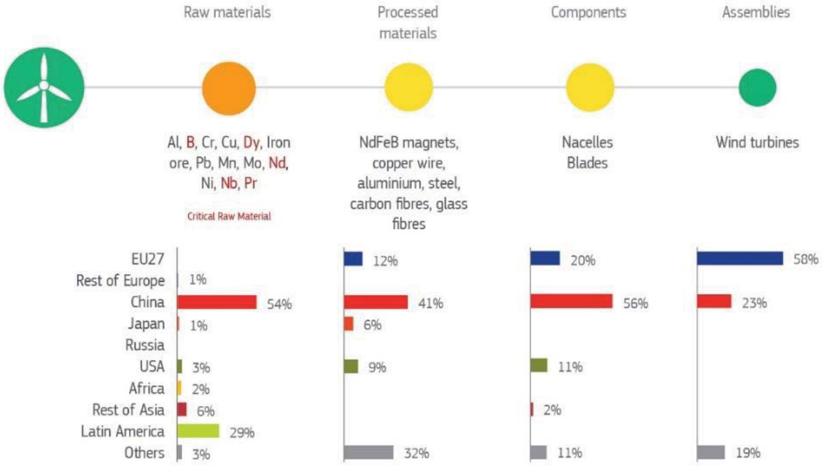
The REEs, i.e. neodymium, praseodymium and dysprosium, are key ingredients in the most powerful magnet material, namely neodymium-iron-boron (NdFeB). This magnet is used to manufacture permanent magnet synchronous generators (PMSG), which are used in the major wind turbine configurations. The most relevant materials required in wind power generation are listed in Figure 36.

Figure 36: Critical raw materials used in wind turbines



Source: European Commission, Critical Raw Materials in strategic technologies and sectors – a foresight study, 2020

Figure 37: Supply risks, bottleneck along the supply chain of wind turbines



Source: European Commission, Critical Raw Materials in strategic technologies and sectors – a foresight study, 2020

A bottleneck assessment performed in EC (2020)[229] for wind turbines shows that the risk to the supply of raw materials is the highest along the supply chain. This risk diminishes downstream through a medium risk for the supply of processed materials and component, until an undetectable risk for assemblies. Indeed, the European share increases from 1% for the raw materials, to 12% for processed materials, 18% for components, until 58% for assemblies.

The blade is another key component of a wind turbine. Its performance requirements lead to a selection of materials that combine high strength-to-weight with high stiffness and fatigue resistance (Reinforced composites such as glass-fibre composites or carbon fibres)[230]. It is estimated that about 4 700 turbines (or 14 000 blades) could be decommissioned by 2023 and would need to be sustainably disposed. Although several recycling routes for glass fibre and carbon fibres exist (e.g. fluidised bed, solvolysis, high voltage pulse fragmentation, pyrolysis, mechanical grinding) and are at a high TRL, competitiveness as compared to new material sourcing has not been reached yet. The current preferred route for composites recycling is co-processing in the cement industry to produce clinker cement, thus not a recovery of the initial material. Future innovation in composite blade recycling might necessitate large scale demonstration plants, synergies with other sectors (e.g. use of recycled blades in manufacturing processes) among others [231] [232]. Moreover new 100% recyclable materials replacing composites gain more attention (e.g. blade manufacturer LM Wind Power and chemical company Arkema using a thermoplastic resin to produce 60 to 80 meter fully recyclable blade prototype).[233] Lately a Vestas led consortium announced a novel chemical recycling process which would allow to fully recycle thermoset composites[234].

5.4. Final Considerations

For offshore wind fixed-bottom and floating installations, the challenge is to create the optimum environment to maintain and accelerate the momentum created in the North Sea, extending best practice and experience to other sea basins, starting from the Baltic Sea, and supporting global expansion.

Making a success of offshore wind energy can yield great benefits for Europe, it can ensure the EU delivers a sustainable energy transition, and bring the Member States on a realistic path to zero pollution and climate neutrality by 2050. It can also make a major contribution to the post COVID-19 recovery, as a sector where Europe's industry has world leadership and which is forecast to grow exponentially in the coming decades.

6. SWOT AND CONCLUSIONS

Strengths:

Wind energy is one of the most promising, clean energy source, a reliable, cost effective, large-scale technology with a steadily increasing installation rate, and with the potential of substantial contribution to the European energy mix and to and the achievements of the EU climate and energy targets.

---

[229] European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020.

[230] European Commission, Critical materials for strategic technologies and sectors in the EU – a foresight study, 2020.

[231] WindEurope, Cefic and EuCIA, Accelerating Wind Turbine Blade Circularity May 2020, https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Accelerating-wind-turbine-blade-circularity.pdf

[232] ETIPWind (2019), How wind is going circular blade recycling, https://etipwind.eu/files/reports/ETIPWind-How-wind-is-going-circular-blade-recycling.pdf

[233] LMWind Power (2020) https://www.lmwindpower.com/en/stories-and-press/stories/news-from-lm-places/zebra-project-launched.

[234] Vestas (2021), New coalition of industry and academia to commercialise solution for full recyclability of wind turbine blades, https://www.vestas.com/en/media/company-news?l=22&n=3974601#!NewsView

Weaknesses:

In order to be viable, wind energy installations should be placed in high wind potential sites, therefore there are geographical limitations which should be taken into account. In addition, important wind potential is often observed in sites where the grid is not strong enough or is not existent, necessitating important investment in grid infrastructure. Concerns of environmental, visual and noise impact of wind installations still exist, and in some cases, like offshore installations, are not well known. The intermittent and variable nature of wind is also a concern when wind reaches high grid penetration levels, nevertheless this can be managed through grid interconnection, wind forecast and transmission planning. For offshore wind, the multiple uses of the ocean (e.g. fisheries, biodiversity, energy production) is a matter of concern, which requires Maritime Spatial Planning and collaboration between Member States.

Opportunities:

With the world markets shifting to green energy and away from conventional energy sources there will be an increasing market for wind turbines in the coming years. The growth of smart grids infrastructure and interconnections will permit higher penetration levels of wind energy. Floating offshore structures offer the potential of economic sustainability and improved public acceptance. With 48% of the active companies in the wind sector headquartered in the EU, holding a leading market position, the above present a unique opportunity for further expansion and competitiveness. The age structure of the EU onshore and offshore wind fleet indicates that repowering will also play a crucial rule in the coming years.

Threats:

Despite the numerous examples showcasing that wind can be competitive compared to conventional energy sources, the technology is still perceived as being expensive. It also requires a high initial investment. There is intensive competition from manufacturers based in China and the US. Differing and changing rules, regulations and support schemes in different countries also poses a threat to the expansion of wind energy. In addition, EU companies are increasingly faced with third country governments putting in place market access barriers, local content requirements or other discriminatory or otherwise trade & investment restrictive measures aimed at promoting their domestic industry. A further risk for wind energy is the supply of raw materials which are mainly imported from China. Circularity of wind installations is still to be further developed. Wind blades, for instance, are often made in composite materials hard to re-use or recycle. Circularity requires R&I and deployment, but the industry is already very committed for circularity.

WIND ONSHORE

7. TECHNOLOGY ANALYSIS – CURRENT SITUATION AND OUTLOOK

7.1. Introduction/technology maturity status (TRL)

Onshore wind is a crucial part of the energy mix, as it is a highly cost-effective renewable technology, set to grow further as more sites are under development. It is expected to deliver the main part of EUs renewable electricity by 2030[235]. EU onshore wind deployment in deep decarbonisation scenarios until 2050 range from about 370 GW to 950 GW[236] Deploying and integrating this amount of wind energy will bring about both environmental benefits and economic opportunities; stimulating research and innovation is key in this regard.

7.2. Capacity installed, generation/production

Cumulative installed onshore wind capacity in the EU increased by 109% from 78.4 GW in 2010 to 164.1 GW in 2020. Since 2018 reduced annual onshore wind additions can be observed mainly originating from moderate deployments in Germany due to complex permitting rules and potential exposure to legal challenges (regional siting plans are not robust). Moreover Germany's Renewables Law aims for a relatively modest increase in onshore wind (to 71 GW as compared to today's 55 GW) until 2030.

The cumulative installed capacity of wind energy globally grew from 198 GW in 2010 to about 743 GW in 2020. Since 2015, the majority of global installed capacity is located in China (39% in 2020), followed by the EU (24%) and the US (16%)[237] [238]. The global wind power industry is expected to install more than 600 GW of new capacity over the next ten years, becoming a market worth EUR 77 billion in 2019 to EUR 1 trillion over the next decade[239].

In 2020, the EU installed 10.5 GW of wind power capacity, bringing its cumulative wind power capacity to 178.7 GW[240]. Based on the ambitions set in European Member States' National Energy and Climate Plans (NECPs), in 2030 the installed capacity of EU should be 295 GW.

The age structure of the EU onshore wind fleet indicates that repowering will play a crucial rule in the coming years. About 18% of the EU onshore fleet is older than 15 years, approaching quickly their design lifetime (20-25 years). This trend is even more pronounced for the leading MS in terms of installed capacity (e.g. Germany, Spain) and first-mover countries (Denmark) (Table 2) [241]. Repowering of onshore wind plays a crucial role in reaching the countries NECP targets and offers the possibility to optimise the resource potential of onshore wind sites with the best wind resource while using more powerful but fewer turbines.

---

[235] Wind Europe.

[236] BNEF NEO.

[237] JRC, Telsnig T: Wind Energy - Technology Development Report 2020, JRC123138. EUR 30503 EN. Luxembourg. URL: https://ec.europa.eu/jrc/en/publication/wind-energy-technology-development-report-2020 (updated 2020 data).

[238] GWEC (2021), Global Wind Statistics 2020.

[239] Guidehouse Insights Estimates (from ASSET study, 2020).

[240] GWEC (2021), Global Wind Statistics 2020.

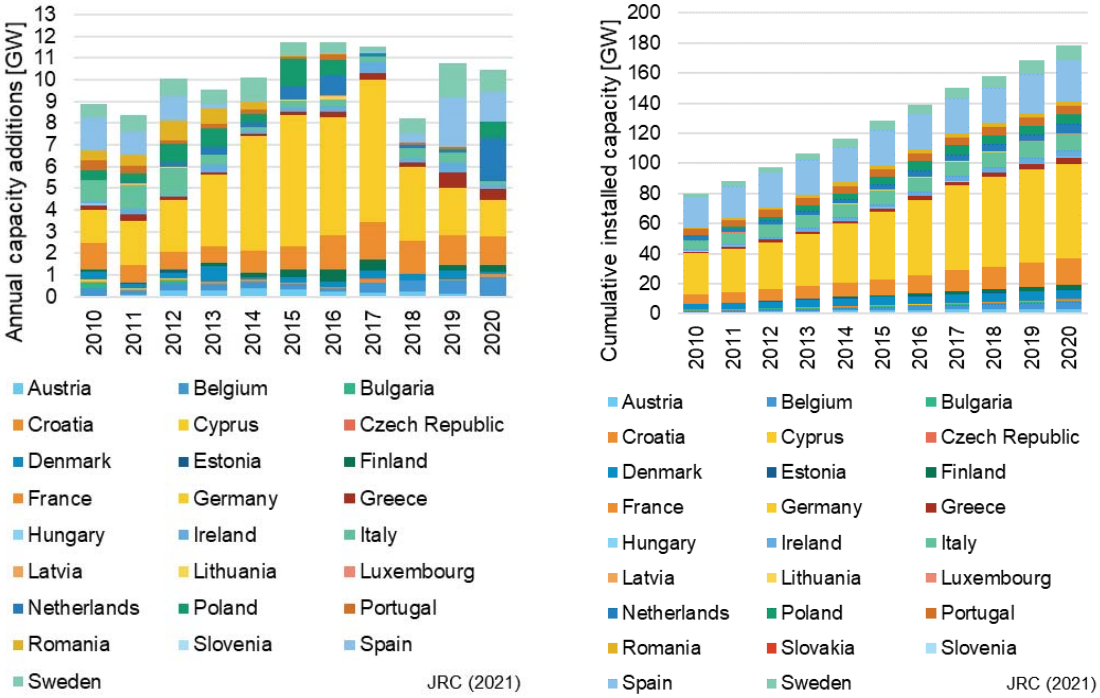
[241] JRC (2019) Uihlein, A., Telsnig, T. & Vazquez Hernandez, C. JRC Wind Energy Database.

Table 2: Onshore wind fleet age structure and the EU, China and the United States

	EU	**Selected EU Member States**					**China**	**United States**
		Germany	Spain	France	Italy	Denmark		
Share of cumulative capacity (%)								
older than 10 years	41%	43%	73%	22%	45%	55%	7%	25%
older than 15 years	18%	26%	27%	2%	9%	53%	0.4%	6%
older than 20 years	3%	4%	3%	0%	1%	23%	0.2%	1%

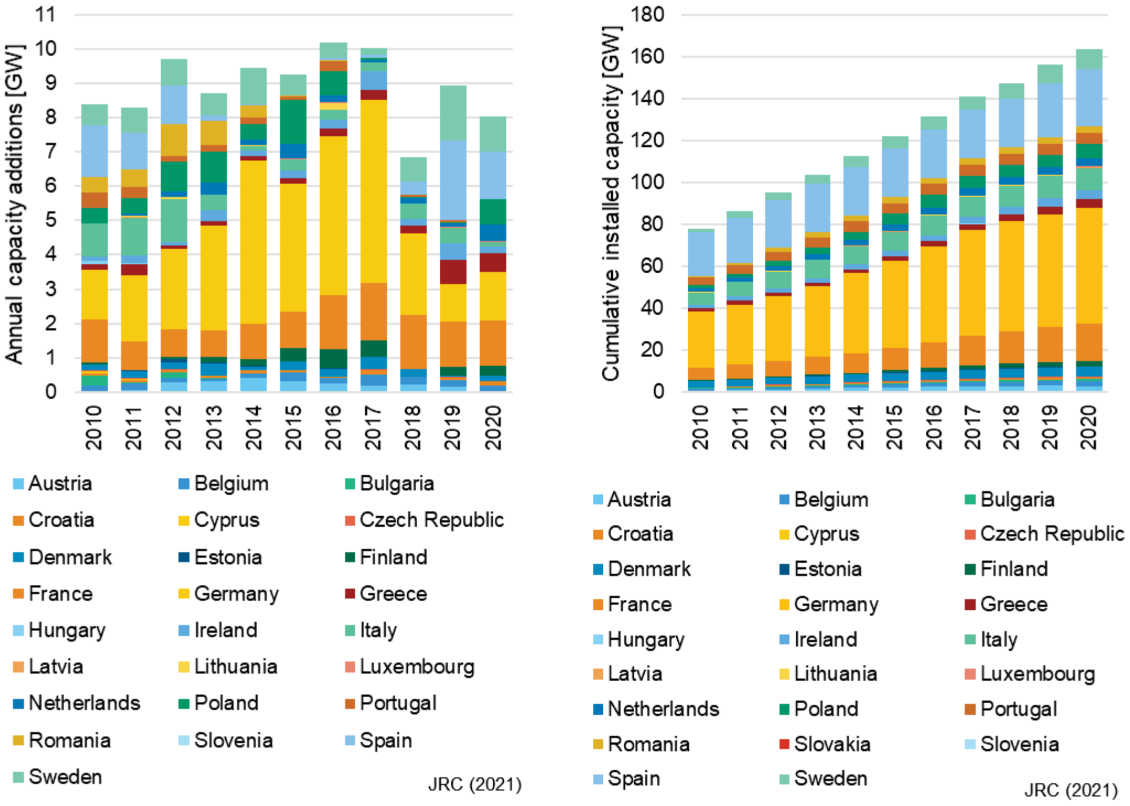
Source JRC

Figure 38: Annual capacity additions (left) and cumulative installed capacity (right) of wind energy (both onshore and offshore) in the EU.



Source JRC based on GWEC (2021)

Figure 39: Annual capacity additions (left) and cumulative installed capacity (right) of onshore wind energy in the EU.



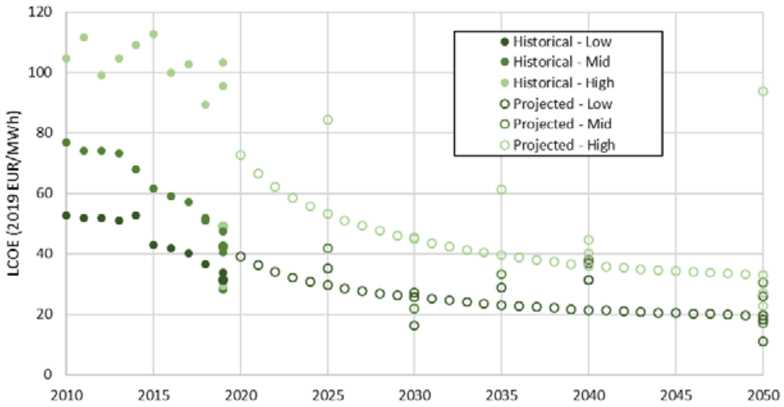
Source JRC based on GWEC (2021)

Projected electricity generation in onshore wind and offshore wind according to CTP-MIX scenario: Onshore: 847 TWh in 2030 (share of total electricity generation: 27.3%), 2 259 TWh in 2050 (share: 32.9%).

The current share of onshore wind in total electricity generation (2020) is 13.7%.

7.3. Cost / Levelised Cost of Electricity (LCoE)

Figure 40: Range of historical and projected onshore wind LCoE estimates



Source Chart reproduced from Beiter et al. 2021[242]

Based on the main cost estimates and projections on onshore wind, Figure 40 identifies a LCoE range spanning from EUR 34 per MWh to EUR 74 per MWh in 2019 which is expected to further decline to values between EUR 19 per MWh to EUR 33 per MWh in 2050.

According to WindEurope data, the LCOE of onshore wind will decrease from EUR 40 per MWh in 2019, to EUR 26 per MWh in 2030, to EUR 19 per MWh in 2050. BNEF estimates the LCOE of onshore wind in EU countries between EUR 24 and 55 per MWh, depending on for example location and financing conditions[243].

Although a decrease in the cost of finance (weighted average cost of capital (WACC)) of onshore wind projects can be observed in the last years this indicator varies considerably among EU countries. Whereas many central EU countries benefit from low WACC (1.3%-4.3%), less developed markets such as Greece, Romania and the Baltic States show a WACC range of about 7% to 10%. This spread can to some extent be explained by diverging interest rates and country risks faced by investors. Evidence suggests that a further decrease (and convergence among countries) in WACC could be achieved by focussing on de-risking debt financing of wind energy projects by policies that implement support schemes decreasing the volatility of a projects cash flow (e.g. Contracts for Difference)[244].

Cost assumptions on onshore wind within the PRIMES model see investment costs dropping to about EUR 850 per kW until 2050. According to WindEurope data, investment costs are expected to decrease from EUR 1300 per kW in 2019, to EUR 1 000 per kW in 2030, to EUR 850 per kW in 2050[245].

---

[242] Beiter P., Cooperman A., Lantz E., Stehly T., Shields M., Wiser R., Telsnig T., Kitzing L., Berkhout V., Kikuchi Y. (2021) Wind power costs driven by innovation and experience with further reductions on the horizon, WIREs Energy Environ. 2021;e398. https://doi.org/10.1002/wene.398.

[243] BNEF, Interactive datasets - LCOE data, 2020.

[244] AURES II (2021), Renewable energy financing conditions in Europe: survey and impact analysis, D5.2, March 2021, H2020 project: No 817619.

[245] WindEurope.

7.4. Public R&I funding

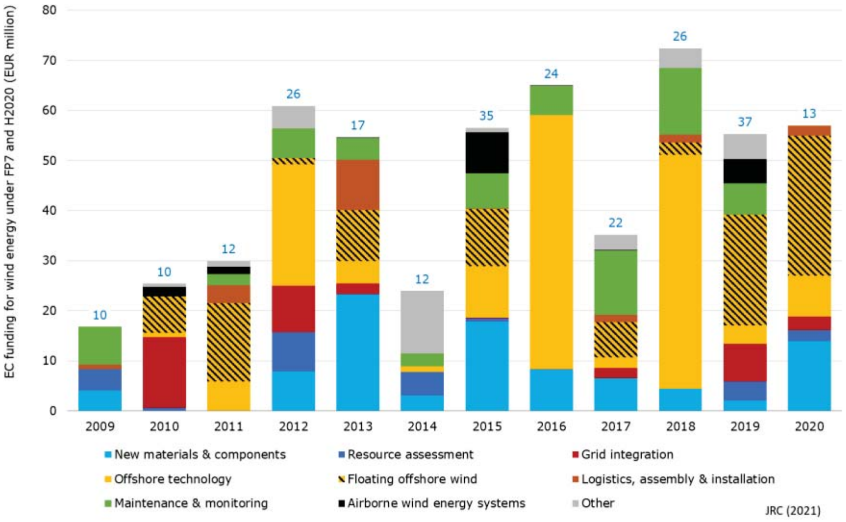
According to the JRC-TIMES 'Zero Carbon' scenario, investment in wind energy clearly dominates among the different low carbon energy technologies with about EUR 2 640 billion until 2050 (of which EUR 1851 billion are deployed onshore).

EU public investment has remained roughly constant, between 2012 and 2016 around EUR 120-145 million with an increasing trend since then, reaching EUR 179 million by 2019 (Figure 41). Preliminary numbers for 2020 on selected EU MSs indicate that this increase of public investments continues.

Although most of the EU R&I funds was spent of offshore or floating offshore wind in 2020, about 37% of the EU R&I funding was also awarded to projects addressing the broader wind categories which also facilitate innovations in the onshore wind sector. Since 2009 about 52% of the EU R&I funding was granted through FP7 and H2020 to these projects addressing R&I priorities apart from the offshore dimension (see Figure 9 in offshore chapter).

Japan is by far the largest investor, followed by Germany the US, and Norway. Total investment of EU countries over the past 3 years totalled EUR 496 million. Five out of the ten top countries where these investments occurred are in the EU.

Figure 41: Evolution of EU R&I funding categorised by R&I priorities for wind energy under FP7 (2009-2013) and H2020 (2014-2020) programmes and the number of projects funded in the period 2009-2020



Source: JRC[246]

7.5. Private R&I funding

This section is common with the offshore wind chapter.

---

[246] JRC, Telsnig T: Wind Energy - Technology Development Report 2020, JRC123138. EUR 30503 EN. Luxembourg. URL: https://ec.europa.eu/jrc/en/publication/wind-energy-technology-development-report-2020 (updated 2020 data).

7.6. Patenting trends - including high value patents

The patenting trends indicators are for the entire wind sector and cannot be split between onshore and offshore wind. Please see the offshore chapter.

7.7. Level of scientific publications

The indicators are for the entire wind sector and cannot be split between onshore and offshore wind. Please see the offshore chapter.

7.8. Final Considerations

Over the last decade private R&D spending held a relatively constant level between EUR 1.6 billion and EUR 1.9 billion. Moreover, private R&D investments topped public R&D investments by a factor of 10 during this period.

The EU is leading in high value patents (with the major EU OEMs filing most of the inventions), yet experiencing a decrease since 2012, due to strong performance in high-value patents by major companies from the US (e.g. General Electric) and Japan (e.g. Mitsubishi Heavy Industries, Hitachi).

Although publication counts seem to indicate a stronger activity outside the EU countries on country level, the EU as a whole ranks first (5 406 publications, 27%). Moreover, publications from the EU countries leading in wind energy deployment and research show high citation impacts indicating a higher recognition of their scholarly outputs than those from their global competitors.

8. VALUE CHAIN ANALYSIS OF THE ENERGY TECHNOLOGY SECTOR

8.1. Introduction/summary

Europe is a recognized market leader in the wind energy: 48% of active companies in the wind sector are headquartered in the EU compared to the RoW[247]. The European OEMs in the wind energy sector have held a leading position in the last few years although their market share has decreased in 2018 mainly in favour of the Chinese OEMs. Within the next decade, Europe will maintain its leadership position in annual growth, yet China, Asia Pacific and North America are expected to develop a significant market size (i.e. installed capacity) of more than 50%[248]. Among the top 10 OEMs in 2018, European OEMs led with 43 % of market share, followed by the Chinese (32 %) and North American (10 %) companies. In 2020 Chinese OEMs (42%) overtook for the first time their competitors from EU-27 (28%) and the US (12%), following the ongoing transition in China from a Feed-In Tariff towards a tender based support system.

A recent study estimates the annual market size (in terms of revenues) of the EU in onshore wind to grow from about 25.3 BEUR in 2020 to about 35.4 BEUR in 2030. In 2020 this represents about 15.2% of the global market. Across the different value chain segments the global share of the EU market ranges from 9.6% (Logistics & Installation) to 18.7% (Turbine) (Figure 42)[249].

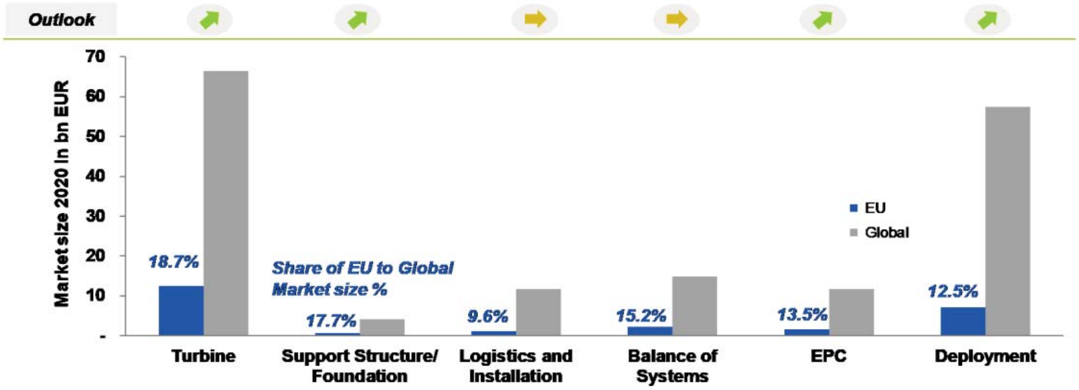
---

[247] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020).

[248] GWEC, Global Offshore Wind Report 2020, 2020.

[249] EC/Guidehouse 2020, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, ISBN 978-92-76-27325-7 doi: 10.2833/94919 MJ-03-20-496-EN-N.

Figure 42: Share of EU Market Size to Global Market, Onshore Wind Value Chain Segment: 2020



Source ASSET Study commissioned by DG ENERGY - Gathering data on EU competitiveness on selected clean energy technologies (2020)

8.2. Turnover

The turnover indicators are for the entire wind sector. Please see the offshore chapter.

8.3. Gross value added growth

The gross value added growth trends indicators are for the entire wind sector and are not split between onshore and offshore wind. Please see the offshore chapter.

8.4. Number of EU companies

There are 248 operational manufacturing facilities in Europe (30% of all facilities, 214 (26 %) in EU countries). 155 facilities are dedicated to onshore wind and a further 66 supply to both onshore and offshore wind.[250] Onshore wind projects necessitate large investments with strong pricing competition, which drives down margins. As a consequence, economies of scale provide a competitive advantage, meaning that the incumbents of the established industry create an adverse environment for newcomers throughout the value chain: in 2019, only 15 start-ups received private funding. 40% of these companies were headquartered in the EU[251].

8.5. Employment in the selected value chain segment(s)

This section concerns the entire wind sector and is not split between onshore and offshore wind. Please see the offshore chapter.

8.6. Energy intensity considerations, and labour productivity considerations

Labour productivity:

---

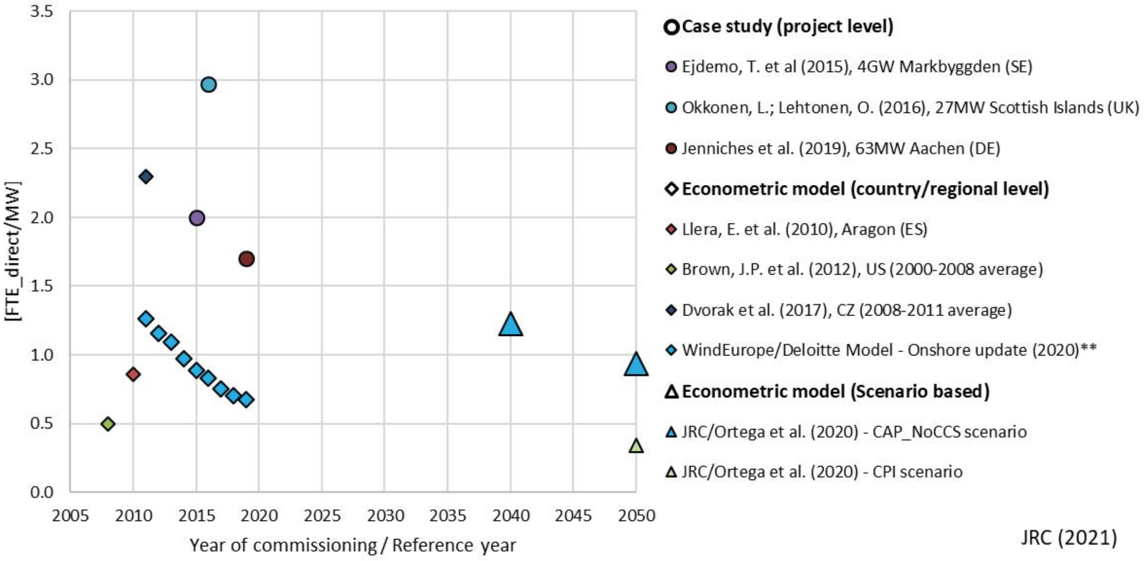
[250] WindEurope/Wood Mackenzie (2020), Wind energy and economic recovery in Europe - How wind energy will put communities at the heart of the green recovery, October 2020.

[251] ASSET Study commissioned by DG ENERGY - Gathering data on EU competitiveness on selected clean energy technologies (Draft, 2020).

As compared to offshore wind, the onshore wind sector shows a lower specific labour productivity when referring to latest case studies and econometric models (Figure 43). Direct job estimates on single onshore wind projects (given in full time equivalent years) range from 1.7 – 3.0 FTE/$MW_{project}$ for projects in the period 2015-2019. Differences in this spread seem to originate from project size and geographical scope[252] [253].

Econometric models on regional and national level estimate the number of direct jobs between 0.5 to 2.3 FTE/$MW_{Installed}$ with European estimates declining to about 0.7 FTE/$MW_{Installed}$ in 2019 [254] [255] [256] [257]. Long term scenario models estimate future labour productivity for onshore wind at a similar scale with values ranging from 0.35 to 0.9 FTE/$MW_{Installed}$[258].

Figure 43: Estimated direct person years (FTE/MW) for onshore wind based on different case studies and modelling approaches



*** Direct jobs estimated based on contribution to the GDP of the sectors involved in the industry and annual reports*

Source JRC

---

[252] Ejdemo T., Söderholm P., (2015) Wind power, regional development and benefit-sharing: The case of Northern Sweden, Renewable and Sustainable Energy Reviews, Volume 47, 2015, https://doi.org/10.1016/j.rser.2015.03.082.

[253] Lasse Okkonen, Olli Lehtonen, Socio-economic impacts of community wind power projects in Northern Scotland, Renewable Energy, Volume 85, 2016, https://doi.org/10.1016/j.renene.2015.07.047.

[254] Eva Llera S. E. et al. (2010), Local impact of renewables on employment: Assessment methodology and case study, Renewable and Sustainable Energy Reviews, Volume 14, 2010, https://doi.org/10.1016/j.rser.2009.10.017.

[255] Brown J.P. et al (2012), Ex post analysis of economic impacts from wind power development in U.S. counties, Energy Economics, Volume 34, Issue 6, 2012, https://doi.org/10.1016/j.eneco.2012.07.010.

[256] Dvořák P. et al (2017), Renewable energy investment and job creation; a cross-sectoral assessment for the Czech Republic with reference to EU benchmarks, Renewable and Sustainable Energy Reviews, Volume 69, 2017, https://doi.org/10.1016/j.rser.2016.11.158.

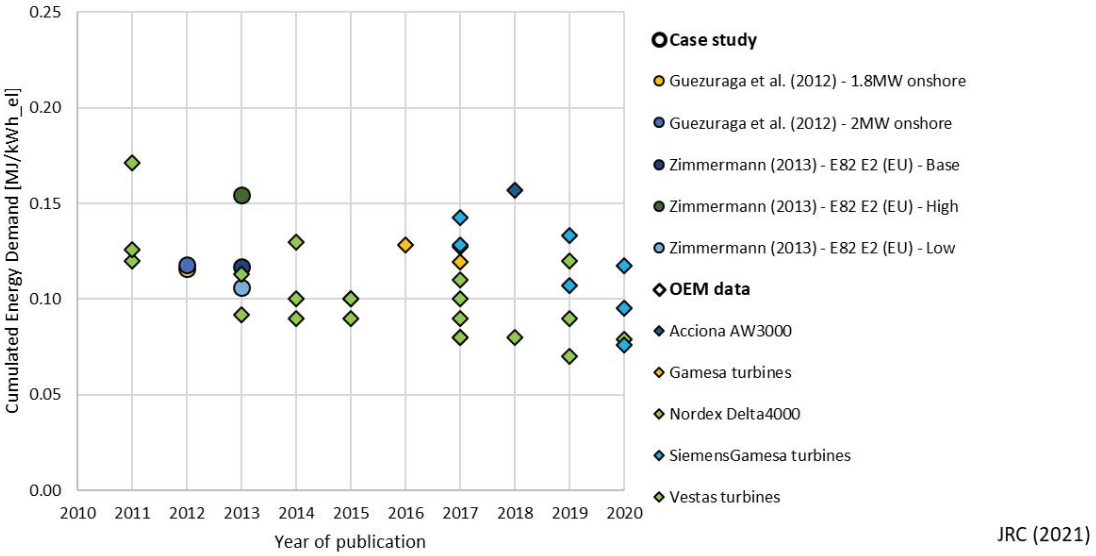
[257] WindEurope, Local Impact Global Leadership (2017, 2020 data update)

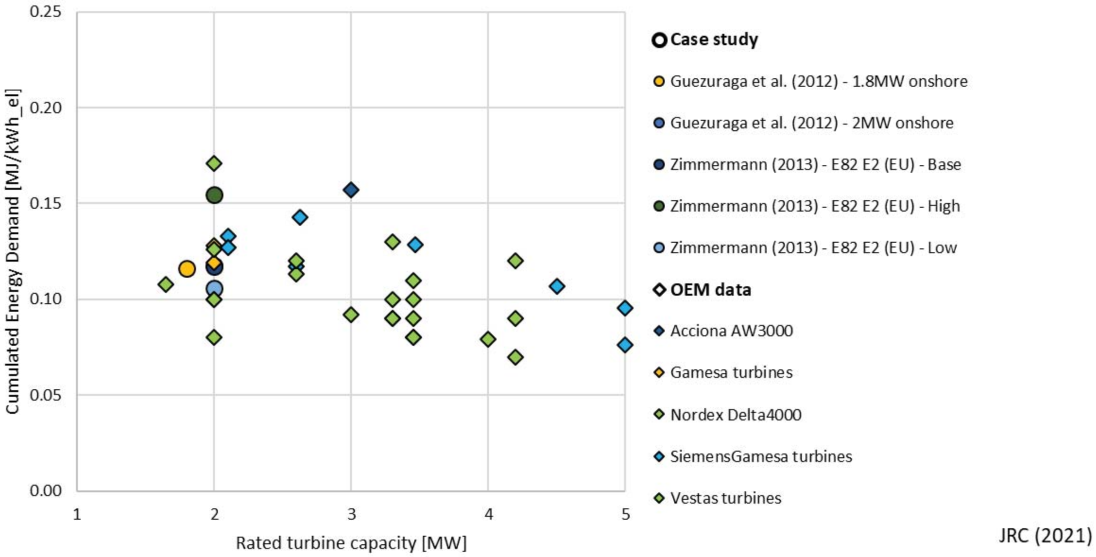
[258] Ortega et al. (2020), Analysing the influence of trade, technology learning and policy on the employment prospects of wind and solar energy deployment: The EU case. Renewable and Sustainable Energy Reviews 122 (2020) 109657, Available https://doi.org/10.1016/j.rser.2019.109657

Energy intensity considerations:

The energy intensity is analysed based on the cumulated energy demand (CED) along the lifecycle of onshore wind. Life cycle analyses from both, specific case studies and OEM data (SiemensGamesa, Vestas, NordexAcciona) indicate a decrease in the CED from 0.12 - 0.17 MJ_{input}/kWh_{el} in 2011 to current levels a range of about 0.08 - 0.12 MJ_{input}/kWh_{el}. Figure 44 shows that this decrease is driven by the continuous development of more powerful turbines up to the 5MW scale which allow to generate more electricity per input of primary energy than their predecessors.

Figure 44: Evolution (top) of Cumulated Energy Demand (MJ_primary energy/kWh_el) of onshore wind turbines and the respective rated capacity (bottom) based on different case studies and OEM data





Source JRC

8.7. Community Production (Annual production values)

The community production indicators are for the entire wind sector and are be split between onshore and offshore wind. Please see the offshore chapter.

8.8. Final Considerations

Europe is a recognized market leader in the wind energy. As onshore wind projects necessitate large investments with strong pricing competition, driving down margins, economies of scale provide a competitive advantage. It is estimated that the sector offers between 240 000 and 300 000 jobs. With the annual market size (in terms of revenues) of the EU in onshore wind expected to grow from about 25.3 BEUR in 2020 to about 35.4 BEUR in 2050 wind energy can make a substantial contribution, not only in the energy mix but can also contribute to the new challenge of the European industry in its transition towards climate neutrality and digital leadership. The trade indicators are for the entire wind sector are not split between onshore and offshore wind. Please see the offshore chapter.

9. GLOBAL MARKET ANALYSIS

9.1. Trade (imports, exports)

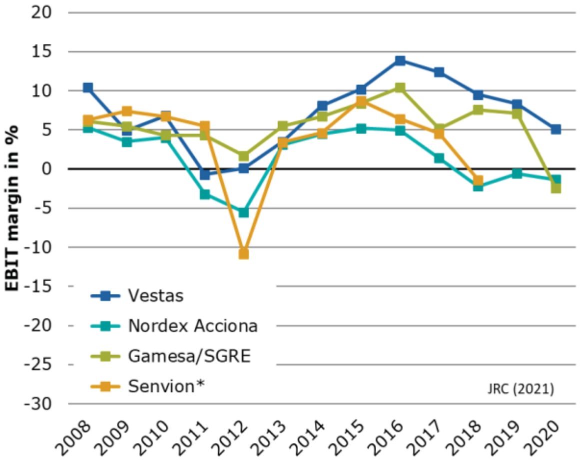
The trade indicators are for the entire wind sector are not split between onshore and offshore wind. Please see the offshore chapter.

9.2. Global market leaders vs. EU market leaders (market share)

This section is common for the entire wind sector and cannot be split between onshore and offshore wind. Please see the offshore chapter.

Since 2016 EBIT margins of EU OEMs are declining due to high competition in turbine orders particularly in the period 2017-2018 and increased material costs for main turbine components. In 2020 these factors were further intensified through the impact of Covid-19 which created logistic challenges for all manufacturers. As a result only Vestas could present a positive EBIT margin (+5.1%), whereas NordexAcciona (-1.3%) and SiemensGamesa RE (-2.5%) reported negative figures.

Figure 45: EBIT margin (Operating profit/Revenues) of the leading listed EU OEMs



Source JRC[259]

---

[259] JRC, Low Carbon Energy Observatory, Wind Energy Technology Market Report, European Commission, 2019, JRC118314 (data update April 2021).

9.3. Resource efficiency and dependence

The resource efficiency and dependence indicators are for the entire wind sector and cannot be split between onshore and offshore wind. Please see the offshore chapter.

9.4. Final Considerations

According to WindEurope, European wind turbine manufacturers have a 42% share of the global market for wind turbines. Of the 10 biggest wind turbine manufacturers in the world, 5 are EU-based. Among the top 10 Original Equipment Manufacturers (OEMs) in 2018, European OEMs led with 43 % of market share, followed by the Chinese (32 %) and North American (10 %) companies. The European OEMs in the wind energy sector held a leading position in the last few years. In 2020 they lost for the first time their first rank to the Chinese OEMs when analysing the Top10 OEMs in terms of market share (EU: 28%; China: 42%). This can mainly be explained by a surge in new installations in the Chinese wind market following China's shift from Feed-in-Tariffs towards a tender-based support scheme necessitating projects approved before 2018 to be grid-connected latest by the end of 2020 in order to receive the expiring Feed-in-Tariff.

The EU has had a positive trade balance in wind energy related eqipment in the last 20 years. Yet there is some stagnation in the growth of this indicator. This can be connected to the Chinas trade policy. Following a set of policies protecting China's domestic market (e.g. local content requirements, import tariffs and local VAT exemption), since 2007 imports of wind generating sets to China fell drastically, and did not recover until today. 21% of Chinese wind-related exports in 2018 were destined for the EU market.

Since 2016, EBIT margins of EU OEMs are declining due to high competition in turbine orders particularly in the period 2017-2018 and increased material costs for main turbine components. Despite the record year in installations in 2020[260], these factors were further intensified through the impact of Covid-19 which created logistic challenges for all manufacturers.

Supply of critical raw materials for wind generators are mainly imported from China. Material shortages and disruptions pose a potential risk to EU wind energy production industry. Circularity, recycling and substitution are therefore priority areas of innovation to abate these risks, while improving the overall sustainability of the sector and are included in the 2021-2022 Work Programme of Horizon Europe.

Within the next decade, it is expected that Europe will maintain its leadership position in annual growth of offshore wind, yet China, Asia Pacific and North America are expected to develop a significant market size (i.e. installed capacity) of more than 50% (average market shares in the period 2025 – 2030: China 21%, Asia Pacific 19%, North America 13%). With respect to onshore wind China will remain the largest market (average annual market share of about 50% in the period 2020-2025) followed by the Europe (18%), North America (14%) and Asia (excluding China) (8%).

The committed capacity of wind energy installations (268.4 GW) in the EU Member States National Energy and Climate Plans (NECP) until 2030 will form a good basis streamlining investments to the wind sector while on the same time contributing to the clean energy transition and 2050 climate targets. The committed capacity of wind energy installations (268.4 GW) in the EU Member States National Energy and Climate Plans (NECP) until 2030 will form a good basis streamlining investments to the wind sector.

---

[260] GWEC, Global Wind Report, 2021.

10. SWOT AND CONCLUSIONS

The SWOT analysis presented in the offshore wind chapter applies to the onshore wind as well. An additional threat for onshore wind turbines are in the build environment and there is more resistance to the build of new wind farms. Considering that the overall capacity is expected to be 5-6 times higher in 2050, land use and public acceptance will become potential threats. Continuous effort to reduce environmental and social impact will be needed.

EUROPEAN
COMMISSION

Brussels, 26.10.2021
SWD(2021) 307 final

PART 3/5

COMMISSION STAFF WORKING DOCUMENT

Accompanying the document

REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

Progress on competitiveness of clean energy technologies
4 & 5 - Solar PV and Heat pumps

{COM(2021) 950 final} - {COM(2021) 952 final}

SOLAR PHOTOVOLTAICS

INTRODUCTION

Renewables grow rapidly in all scenarios bringing to carbon neutrality in 2050. Solar photovoltaic is central to this emerging new configuration of electricity generation technologies. More than 3.1 TW of photovoltaic power are projected - globally - in 2030 and about 5.9 TW in 2040 (from about 0.8 TW installed worldwide in 2020)[261]. The IRENA 1.5°C Scenario projects a global solar photovoltaics power of about 14 TW in 2050[262]. The investment required in the period 2020-2050 for the new solar power capacity is estimated at about USD 4.2 trillion[263,264].

Considering that about 1 TW of solar photovoltaics (PV) is projected, in the EU, by 2050 (currently it is 0.1 TW and projected to be 0.4 TW in 2030), it is of strategic importance to establish the full PV value chain in Europe and not create a new type of energy dependency, by importing the necessary components for the installations. The European Commission in its communication "Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery" recognises that it is a key opportunity, as greater scale should bring lower energy costs for industry as well as society at large to scale up manufacturing of PV technologies in the EU, and welcomed the industry-led European Solar Initiative[265]. PV manufacturing would not only empower a fast and sustainable energy transition, including the European renovation wave, but also lead Europe's economy to generate added value in terms of economic growth, industrial jobs, and revenues, and capitalise on R&I developments in Europe. These opportunities exist in parts of the value chain and market segments where innovation/differentiation plays a relatively large role to respond to the specific needs of the final sectors of use. Furthermore, the strong knowledge position of the EU research institutions, the skilled labour force and the existing and emerging industry players are the basis to relaunch a strong European photovoltaic supply chain. Emerging approaches to solar photovoltaics promise higher performances and lower cost together with a reduced or optimised use of materials (resource efficiency) and lower environmental impact (CO_2 footprint) embedding the notion of circularity by design. European Institutes and companies are championing some of these new routes.

The description of the status of the PV technology, the analysis of the different segments of the value chain, the evidence to position the EU photovoltaic sector on the world map vis-à-vis the global competitors are analysed in the following to support a better-informed policy decision. Several emerging applications in the final energy sectors are defined in the first part of the document. Given the exceptional circumstances of the COVID-19 pandemic, a short analysis of the pandemic impact on the deployment of the PV installations is also presented.

11. TECHNOLOGY ANALYSIS – CURRENT SITUATION AND OUTLOOK

11.1. Introduction/technology maturity status (TRL)

Solar photovoltaics (PV) is a mature technology central to accomplish the energy transition and win the decarbonisation challenge. Solar photovoltaics has become the world's fastest-growing energy technology,

---

[261] A. Jäger-Waldau, Snapshot of Photovoltaics – March 2021, EPJ Photovoltaics, 2021, doi: 10.1051/epjpv/2021002

[262] International Renewable Energy Agency (IRENA), World Energy Transitions Outlook: 1.5°C Pathway, 2019.

[263] Conversion rate: 1 USD = 0.84 EUR.

[264] Bloomberg New Energy Finance (BNEF), New Energy Outlook (NEO), 2020.

[265] https://ec.europa.eu/info/sites/default/files/communication-industrial-strategy-update-2020_en.pdf.

with demand spreading and expanding as it becomes the most competitive option for electricity generation in a growing number of markets and applications. The global compound annual growth rate of PV installations was about 37% in the period 2010-2019. This growth is due to the decreasing cost of the PV modules and systems (EUR/W), and increasingly competing cost of the electricity generated (EUR/MWh). Analysing the global evolution of module price vs cumulative production, a price decrease of 25% for each doubling of cumulative production is inferred. In the period between 2011 and 2020, an 85% price decrease has been recorded[266].

Globally, silicon solar cells comprise more than 95% of PV capacity installed in 2019. The record efficiency for silicon solar cells is 26,7% and was attained by using amorphous silicon-crystalline silicon heterojunction (a Heterojunction with Intrinsic Thin-Layer - HIT - solar cell structure) and interdigitated back contacts (IBCs). Average HIT module efficiency is at 21% and it is expected to reach 24% in 2030.

The Chinese PV industry plans to phase out Aluminum Back-surface Field (Al-BSF) solar cells by 2022 so that Passivated Emitter and Rear Contact (PERC) solar cells will remain the workhorse for the industry[267]. The currently announced solar cell manufacturing expansion projects in China, which should be realised between 2020 and 2023, amount to 320 GW of new PERC and PERC+ capacity. Depending on the actual market growth and economic conditions between 70 and 90% of this capacity could be realised. The total investment needed for such an expansion would be between RMB 47 billion[268] and RMB 76 billion[269]. In addition, heterojunction and tunnel oxide passivated contact (TOPCon) solar cells are gaining market share and are responsible for additional investments of RMB 18 billion[270] in solar cell manufacturing lines and could add reach 35 GW manufacturing capacity by 2023.

PV modules based on thin film technologies are also commercially available, especially copper indium/gallium disulfide/diselenide (CIGS) and cadmium telluride (CdTe), although their market share is limited.

More recently, an efficiency higher than 29% has been reported for a perovskite solar cell combined with silicon in a double-junction configuration. In the tandem configuration, the perovskite solar cell absorber can be adjusted and optimised by modifying its composition to take better advantage of the solar spectrum. Perovskite photovoltaic solar technology has been proved in pilot manufacturing by *Oxford PV*[271]. The rapid learning of perovskite solar cells enriches the number of approaches, at different readiness and maturity levels, which are available for the direct conversion of light into electricity. Finally, multi-junction solar cells based on III-V semiconductors are the PV devices attaining the highest efficiency. Multi-junction solar cells are used in space applications and can be combined with concentrating systems to generate electricity in terrestrial configurations if significant cost reduction is achieved for such systems.

Emerging innovative PV deployment applications

Besides the classical PV installations on rooftops and free standing, the dual use of infrastructures for the installation of PV capacity offers additional potential and is often close to the place of electricity use, as

---

[266] PSE/Fraunhofer ISE 2020.

[267] Overview of the global PV industry, Arnulf Jäger-Waldau, 2nd edition of Comprehensive Renewable Energy, Elsevier, to be published.

[268] EUR 6.1 billion (1 EUR=7.7139 RMB)

[269] EUR 9.8 billion.

[270] EUR 2.3 billion.

[271] Oxford PV claims that "*long term stability/reliability of their tandem solar cells are confirmed by third party measurements*".

well as to avoid the use of open land. However, the analysis of these potentials as well their exploitation is still in its infancy.

A summary of meaningful emerging applications is provided below[272].

- Agricultural photovoltaics (Agri-PV): Agri-PV offers the possibility to optimise the use of agricultural land, increase agricultural yields and generate electricity, which can either be used locally or sold for extra revenue.
- Closed landfill sites: First, landfills are brownfields, and their use for PV plants will not alter sensitive ecosystems. Second, closed landfills are often connected to the electricity grid, and in the case of landfill gas use, the PV system can improve the load factor of the plant.
- Building envelopes: PV installed on façades and roofs on buildings can act simultaneously as a power source and as a shading device, thereby reducing the heat load in the building and demand for cooling.
- Hydro dams: In the case of earthen dams, the PV installation can protect the surface and minimise erosion caused by rain.
- Irrigation channels and floating PV: Both applications can help reduce water evaporation, which, especially in arid regions, is of substantial importance;
- Parking lots: Covering parking lots with PV canopies enables sustainable electricity generation to charge electric vehicles and provides shading for the automobiles.
- Sound barriers: Sound barriers along motorways and train lines can be used to generate electricity not only when they are south facing; thanks to bifacial PV technology, east- and west-facing barriers can also be utilised. The electricity generated along train lines could be used directly to power trains. In contrast, sound barriers on motorways could provide sustainable electricity either to the municipalities they are shielding the noise from or to electric vehicle charging stations in service areas.
- Vehicle integrated PV: In the emerging domain of vehicle integrated PV (VIPV), new products to provide on-board electricity to trucks have been developed, as a key element in sustainable mobility.

11.2. Capacity installed, generation/production

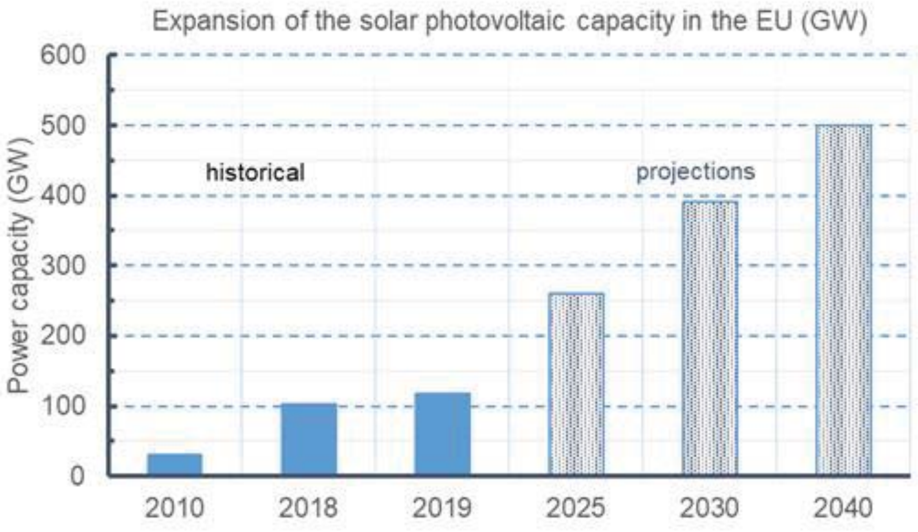
Very recently, the IEA developed a Roadmap to achieve net zero emission by 2050. The global electricity generation from solar photovoltaic is projected to grow from 821 TWh in 2020, to 6 970 TWh in 2030, 17 031 TWh in 2040, 23 460 TWh in 2050. This would require the installation of a photovoltaic power capacity of 737 GW in 2020, 4 956 GW in 2030, 10 980 GW in 2040 and 14 458 GW in 2050. According to the BNEF NEO 2020, the global investment required in the period 2020-2050 to install the new solar power capacity is about USD 4.2 trillion, with utility scale projects absorbing a share of 62% of the total amount[273].

Figure 1: Historical and projected solar photovoltaics capacity in the EU

---

[272] Arnulf Jäger-Waldau, The Untapped Area Potential for Photovoltaic Power in the European Union, Clean Technol. 2020, 2, 440–446; doi:10.3390/cleantechnol2040027.

[273] Bloomberg New Energy Finance (BNEF) New Energy Outlook (NEO), 2020.



Source IEA, World Energy Outlook, 2020 (SDS analysis)

The European Commission's Long-Term Strategy scenarios (EC LTS) are technology-oriented decarbonisation scenarios, which leads to carbon-neutrality by 2050[274]. The Climate Target Plan analysis shows wind and solar power providing over 60% of the EU electricity in 2050, up from about 13% in 2015. At that time horizon, the EU solar generation capacity values achieves approximately 1 200 GW[275]. The IEA projects instead the expansion of the photovoltaic capacity in the EU until the time horizon 2040 (Figure 1). The IEA SDS scenario projects about 500 GW of PV capacity installed in 2040[276]. Alternative scenarios project larger penetration of photovoltaics in the EU.

The photovoltaic power capacity installed worldwide from the year 2011 to the year 2021 is reported in the figure below.

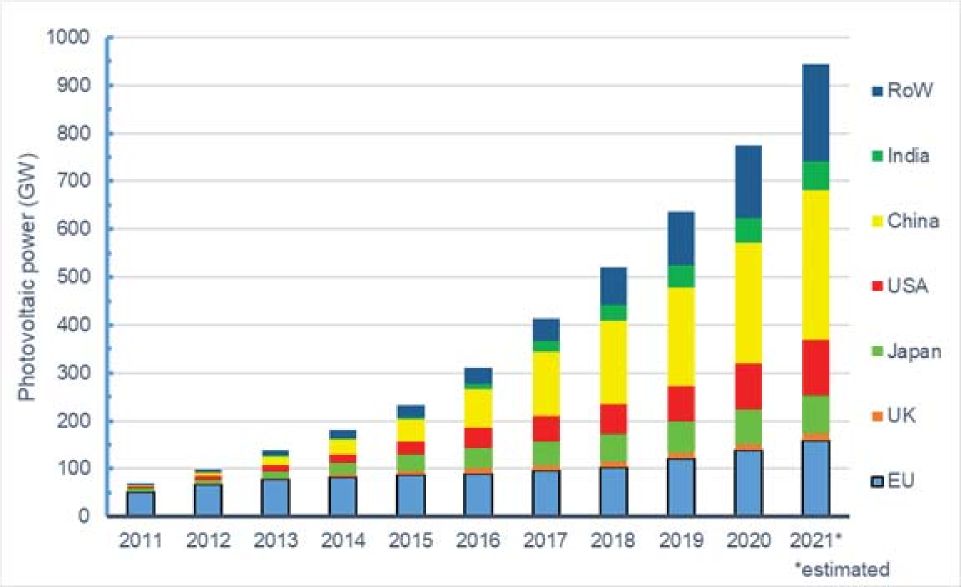
Figure 2: Cumulated photovoltaic capacity installed worldwide, years 2011-2021 (GW)

---

[274] A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy COM/2018/773 final

[275] SWD(2020) 176 final.

[276] IEA World Energy Outlook, 2020



Source: AJW PV Snapshot 2021[277]

At the beginning of the period considered, the cumulated photovoltaic capacity installed worldwide was about 71 GW. It is estimated to reach more than 940 GW by 2021. In terms of compound annual growth rate (CAGR)[278], this growth corresponds to a CAGR close to 30%, in the indicated ten-year period. A second consideration is that the bulk of installations are now outside of Europe and USA. China is the largest single PV market, with numerous other markets of significant scale.

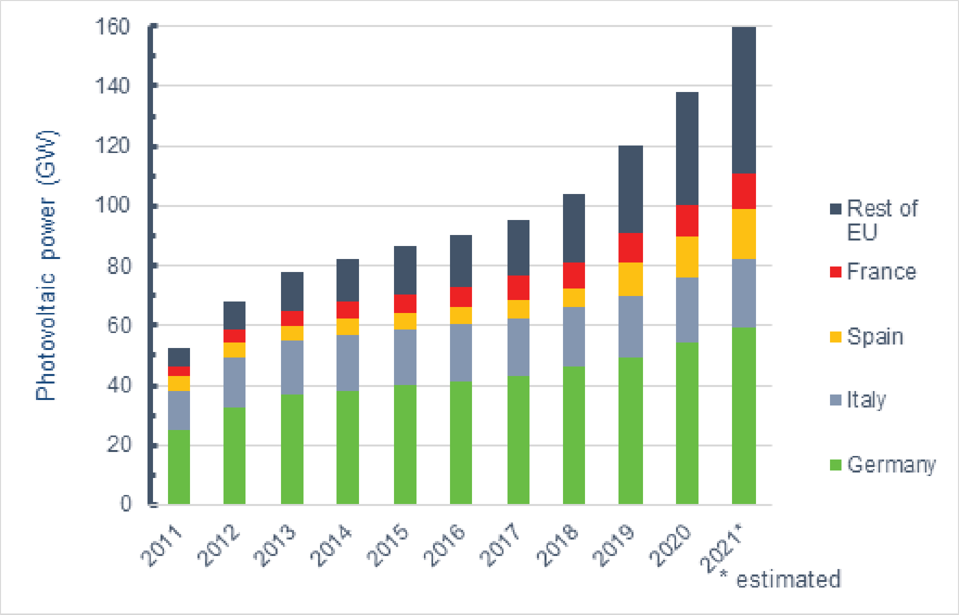
A more detailed view of the progress reported in the EU in the period 2011-2021 is presented in the figure below. From 52 GW of photovoltaic systems installed in 2011, the EU is reaching almost 160 GW by 2021. The EU CAGR in the period approaches 12%, considerably lower than the 30% recorded globally. Germany, Italy, Spain, and France account for 69% of the cumulated EU installations in 2021.

---

[277] A. Jäger-Waldau, Snapshot of Photovoltaics – March 2021, EPJ Photovoltaics, 2021, doi: 10.1051/epjpv/2021002

[278] This indicator was initially developed to compare investment alternatives

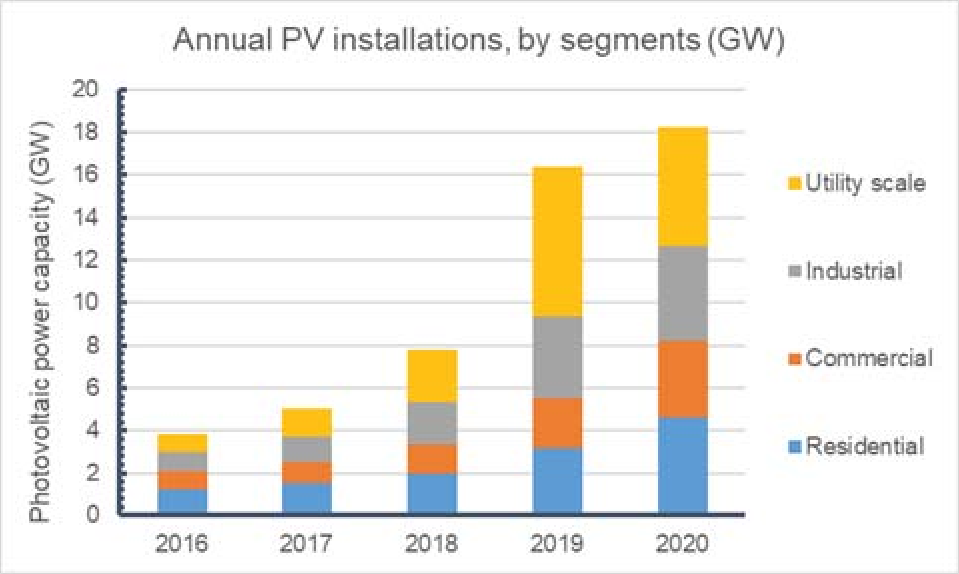
Figure 3: Photovoltaic installations in the EU, years 2011-2021 (GW)



Source: AJW PV Snapshot 2021

The annual capacity added in the EU, between 2016 and 2020, broken down by segments is given in . The cumulative capacity in the same years 2016-2020 is given in the figure below.

Figure 4: Annual photovoltaic installations in the EU, by segments, years 2016-2020 (GW)

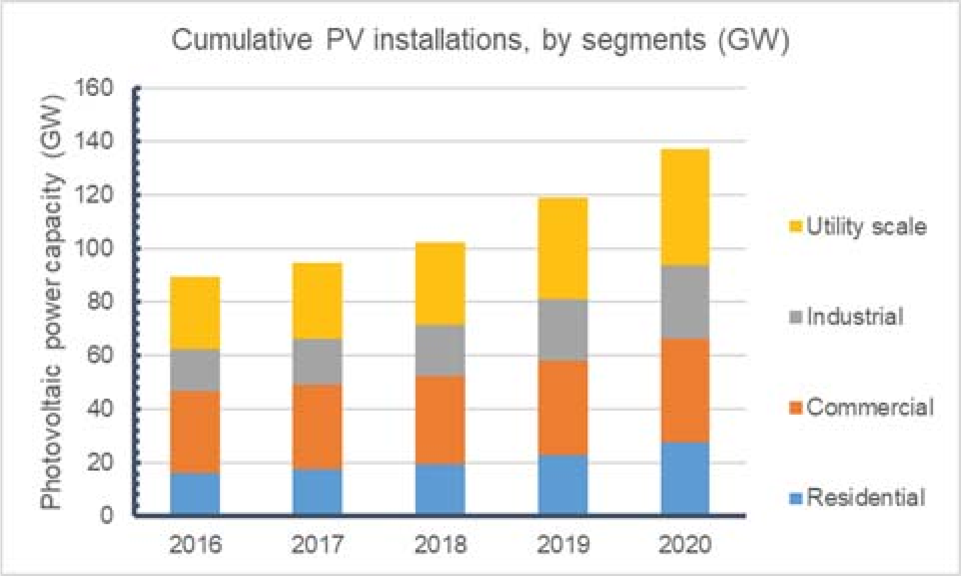


Source: SPE 2021[279]

---

[279] Residential: <10 kW; Commercial: 10 kW - 250 kW; Industrial 250 kW - 1 MW; Utility-scale >1 MW

Figure 5: Cumulative photovoltaic installations in the EU, by segments, years 2016-2020 (GW)



Source: SPE 2021[280]

In the year 2020, the utility scale segment represents a share of 32% of the cumulative installations, the commercial applications have a share of 28% and industrial and residential applications are both at 20%.

11.2.1. COVID-19 pandemic and photovoltaics

Globally, PV installations have never experienced a down year, even during the global financial crisis or during Covid-19 pandemic. Preliminary data shows that the global PV installations grew in 2020 and are expected to grow in 2021, as well (Jaeger-Waldau, PV snapshots 2021). In the EU, about 18 GW of photovoltaic capacity was added in 2020, more than in the year 2019 (Jaeger-Waldau, PV snapshots 2021). The largest European market in 2020, in terms of installations, was Germany. This evidence suggests no direct negative effect of the pandemic on PV deployment.

11.3. Cost / Levelised Cost of Electricity (LCoE)

The cost of solar PV electricity (EUR/MWh) depends on several factors. It is a function of the capital investment for the system, its location and its design and the related available solar resource. Furthermore, the solar electricity cost depends upon the permitting, installation and the operational costs, the useful operation lifetime, the end-of-life management costs and, finally, the financing costs. The following focusses mainly on the investment needed for the PV modules and the system.

PV modules are the largest single cost component of a system, currently accounting for approximately 40% of the total capital investment needed for utility systems, and somewhat less for residential systems where economies of scale for installation are lower and soft costs are higher. The cost of PV modules has decreased dramatically in recent years. Analysing the global evolution of module price vs cumulative production, a price decrease of 25% is inferred for each doubling of cumulative production. In the period from 2011 to 2020, an 85% price decrease has been recorded. This is due to both economies of scale and technological improvements. With PV modules spot market prices as low as 0.20 EUR/W,

---

[280] Residential: <10 kW; Commercial: 10 kW - 250 kW; Industrial 250 kW - 1 MW; Utility-scale >1 MW

the total installation cost of solar PV will continue to decline in the future, making solar PV highly competitive in most markets and locations with adequate solar resource. The power generation technology costs used by the IEA SDS scenario, decrease from 840 USD/kW in 2019 to 490 USD/kW in 2040[281] for the EU.

Rooftop systems for residential or small commercial buildings have traditionally been an important market segment, particularly in Europe. Prices have seen a significant decline and are now approximately 1 000 EUR/kW (approximately 200 EUR/m^2) in the well-developed and competitive German market. However, across Europe prices vary considerably and can be more than double these values. Building integrated roofing systems range from 200 to 500 EUR/m^2 for standardised products and increase to 500 to 800 EUR/m^2 for customised solutions[282]. Costs for PV facades are in the upper part of this range.

An analysis of the results of a recent bidding process for the installation of commercial-scale photovoltaic systems on the roofs of buildings gives further insight. The total power of 2 428 kW is divided, for bidding purposes, in five different batches. The average cost resulting from the process, included inverters and installation (excluding storage) is 1 064 EUR/kW. The modules are all based on monocrystalline silicon solar cells. However, they differ in power, size, efficiency, and warranty provided. Minimum and maximum cost differ in a significant way from the average.

In terms of cost per MWh, PV emerges as highly competitive for utility scale PV in favourable locations. In the first half of 2020 the global LCOE benchmarks for PV are reported with 39 to 50 USD/MWh[283]. For rooftop systems there is still a wide spread in LCOE (61.9 to 321.5 EUR/MWh) across the EU[284]. Useful also to report the LCOE values indicated for the EU by ETIP-PV for 2020, ranging from 16 EUR / MWh (Spain, 2% nominal WACC) to 50 EUR / MWh (Finland, 10% nominal WACC) [285].

LCOE

It should be said that LCOE, alone, does not provide an accurate measure of cost competitiveness and is not appropriate to use it for comparison with other generation technology. The LCOE metric does not capture the energy, capacity and flexibility value of a generation technology. The energy value of a technology represents the ability to produce electricity when it is most valuable. Furthermore, the contributions of technology to the adequacy of the system are reflected in a technology's capacity value, and the contribution of technologies to the overall functioning of the system, is reflected in technology's flexibility value. As the share of variable renewables increases, flexibility is set to become more important. High penetration rates of variable renewable technologies implies investment in storage, enforced grids and demand side management. The mix and intensity of renewables will determine the requirements of those elements and the total system costs.

The LCOE spread is due in part to the location and significantly to local regulations and market conditions. Depending on the actual retail prices, electricity generated from PV rooftop systems can be cheaper for a large part of the European population. Even in less sunny locations, the electricity cost is only bettered by onshore wind, again providing the location has a favourable wind resource. Auctions for PV power supply

---

[281] IEA WEO 2020, 706 to 412 EUR/kW (1 USD = 0,84 EUR)

[282] BIPVBoost H2020 Project, Competitiveness status of BIPV solutions in Europe, January 2020, available on project web site

[283] 33 to 42 EUR/MWh, BNEF 1H LCOE update, 28 April 2020, (1 USD = 0.84 EUR)

[284] Bódis K, Kougias I, Jäger-Waldau A, Taylor N, Szabó S. A high-resolution geospatial assessment of the rooftop solar photovoltaic potential in the European Union. Renew Sustain Energy Rev 2019;114.

[285] ETIP- PV (2020) https://etip-pv.eu/publications/fact-sheets/

provide a further indicator of cost level. Over the last few years, the number of EU Member States conducting such auctions has continuously increased. Prices have reduced to the current average range between EUR 35 and 70/MWh. A Portuguese auction in August 2020 reached EUR 11.14/MWh, although this price is considered to reflect more the value of the grid connection to the bidder than the cost of PV electricity.

A Commission study published in June 2020 shows that both solar PV and wind power can be cost-competitive in almost all EU markets by 2030[28]. It underlines the importance of flexibility in power systems, e.g., grid interconnections, storage and demand management, to mitigate negative price trends at peak production times, which could occur when variable renewables reach a high market share.

11.4. Public R&I funding

Figure 6 shows estimate of the public spending on research development and demonstration on solar energy technologies from 2010 to 2019, based on the data reported to the IEA. The broader "solar" reporting category is preferred here because it is completed by 16 Member States (Germany, France, Italy, Netherlands, Spain, Austria, Poland, Sweden, Denmark, Belgium, Finland, Slovakia, Czechia, Ireland, Portugal and Lithuania, in order of decreasing budget). Instead, the disaggregated value for the "solar PV" reporting category is filled on regular basis, by 6 Member States only (Germany, France, Austria, Belgium, Sweden and Denmark).

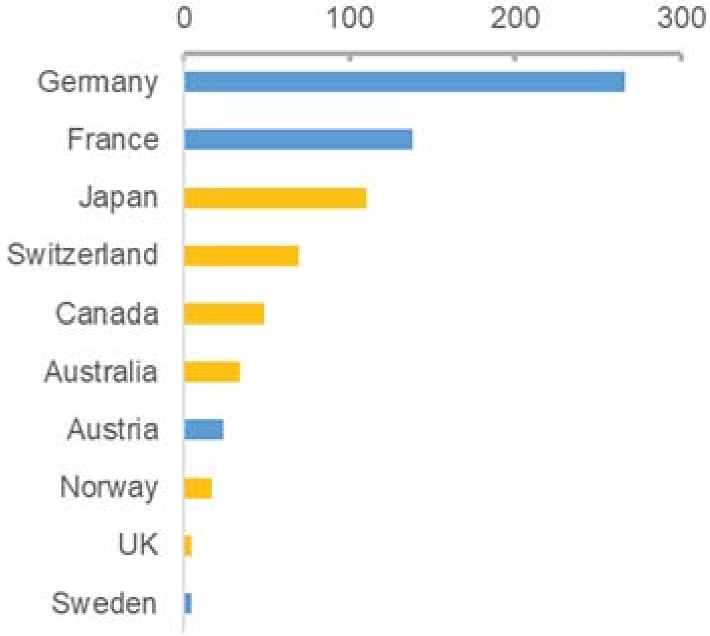
After the peak reached in 2011, a constant funding decline is observed. Since 2016 it is at an average yearly level of about EUR 230 million. A part of the decline in the 2011-2015 period may be due to a reduction in funding for solar thermal. Further factors may be a reluctance to invest in a sector without a local manufacturing base and a trend towards shifting research funds to other sectors. Nevertheless, if the EU is to keep its role as technology leader, this level will need to be increased in the future.

Figure 6: EU MSs Annual spending on solar RD&D as reported to the IEA (EUR million)

Source: JRC 2021, based on IEA data

The "Top 10" countries in terms of investments in PV RD&D, at global level, in the three years period 2017-2019 are reported in Figure 7. Germany leads by far the list with more than EUR 266 million invested in the period, followed by France, which invested, in the same period, EUR 138 million.

Figure 7: Public RD&D Investments, Top 10 (years 2017-2019, EUR million)



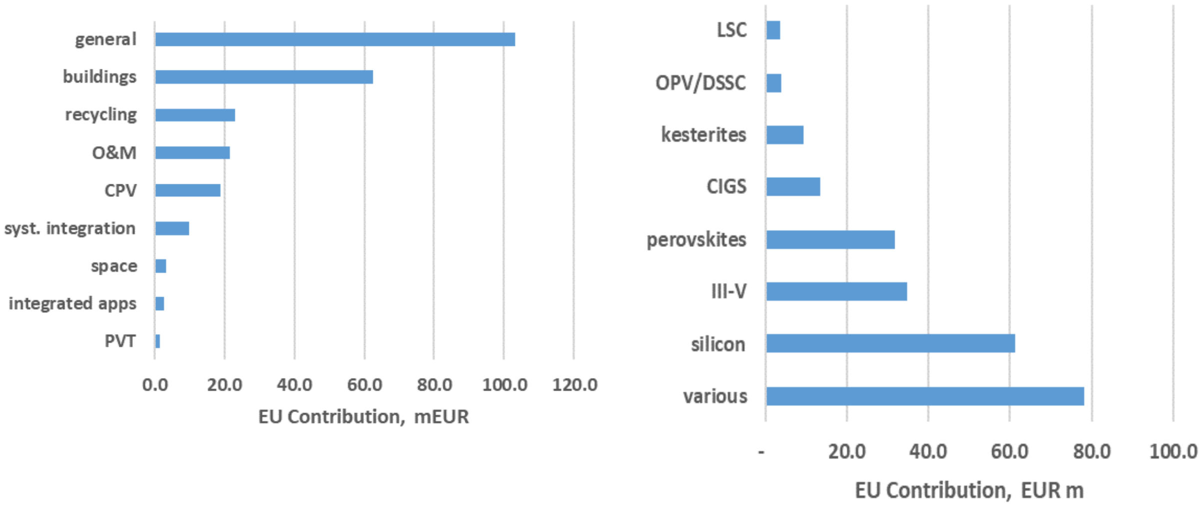
Source: JRC 2021, based on IEA data

Photovoltaic activities supported by Horizon 2020

A total EU financial contribution of about EUR 259.5 million has been invested, under Horizon 2020, on activities related to photovoltaics, in the time period 2014-2020. This contribution is mostly spent for innovation actions (43%), research and innovation actions (30%), and grants to researchers provided by the European Research Council (8%). Fellowships, awarded by the Marie Skłodowska-Curie programme, absorb 6%. The same share of 6% of the overall investment is for actions for SMEs. Coordination actions, like ERA-NETs, represent 7% of the budget.

In Figure 8a the distribution amongst applications is displayed. The category "general" accounts for the bulk of funding, followed by buildings. The EU has also made significant grants for recycling technology. Figure 8b provides the distribution between materials technologies. Here tandem concepts counted as 50% for the top and 50% for the bottom cell material. A significant development is the emergence of perovskites as a major research sector.

Figure 8: EU funding to PV R&I activities under H2020, given per application and technology (years 2014-2019)



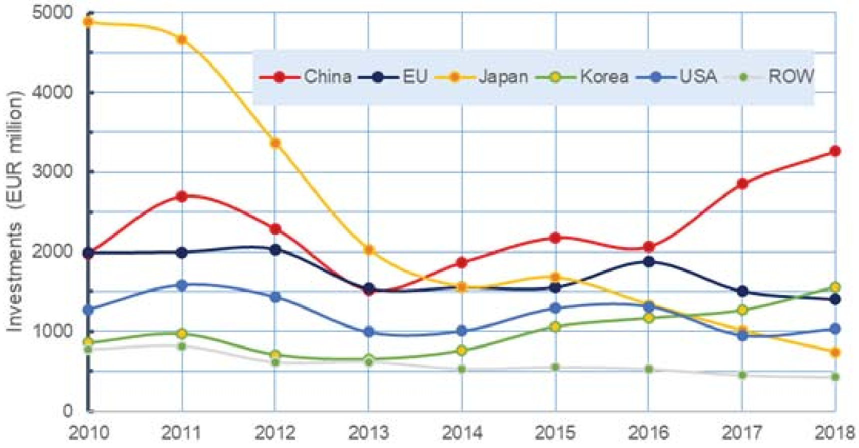
a) Application areas b) PV materials

Source: JRC 2021, analysis of COMPASS data [286]

11.5. Private R&I funding

The latest private R&I spending in solar energy has been estimated by JRC from the numbers of patents.

Figure 9: Private R&D Investments in Photovoltaics (EUR million)



Source: JRC 2021[287]

According to this analysis, the EU private R&D spending on PV, which was about EUR 2 000 million in 2010, declined to EUR 1 400 million in 2018 (Figure 9). In the same graph, the decrease of the private

---

[286] N. Taylor, A. Jäger-Waldau, Photovoltaics technology development report 2020 - Deliverable D2.3.2 for the Low Carbon Energy Observatory, European Commission, Ispra, 2020, JRC120954

[287] 2018 data still preliminary and to consolidate

spending in Japan is remarkable, which dropped from about EUR 4 900 million in 2010 to EUR 740 million in 2018. In stark contrast, China records an increase during the same 2010-2018 period from EUR 2 000 million to about EUR 3 300 million.

The rather low flows of private investments into R&D appears counterbalanced by high flows of investments in project development. Solar photovoltaics attracted more private investment in deployment in 2019 than in any year since 2012, the tail-end of the booms in Germany and Italy driven by government-set feed-in tariffs. The sector in 2019 benefitted from the spread of low-cost projects in Spain and elsewhere, relying on tariffs set in auctions or via private sector power purchase agreements. In 2019, about USD 31 billion (or about EUR 26 billion) were invested in the EU for new renewable energy capacity projects[288]. Assuming a share of 45% for the solar photovoltaic sector, it is estimated that about EUR 13 billion were invested in 2019 in the EU for new solar photovoltaic capacity. The size of these investments and their trend provide a direction of the private sector interest which should also impact R&D.

For an international comparison, it is also useful to compare the investment costs in utility-size photovoltaic power plants in terms of the average investment expenditures per MW of capacity (Table 1).

Table 1: International investments (EUR million/MW)

	2014	2015	2016	2017	2018
Canada	3.4	2.8	1.7	1.1	0.8
China	1.6	1.4	1.2	1.1	0.9
India	1.2	1	0.9	0.9	0.7
Japan	2.1	1.8	1.8	1.5	1
Russian Federation	3.1	1.7	1.1	1.4	1
Turkey	1.6	1.4	1.1	1.1	1.2
USA	2	1.7	1.2	1.1	0.8
Average EU	1.2	1.4	1.1	1.1	0.8

Source: EurObserv'ER, online-database

11.6. Patenting trends - including high value patents

The categories considered are all patent families and the so-called "high-value" patent families[289] i.e., applications made to two or more patent offices.

The number of total inventions in photovoltaics in the three years period 2015-2017 is reported in Figure 10. In the given period, China has the largest patent family applications with more than 10.000 inventions, followed by Korea and Japan.

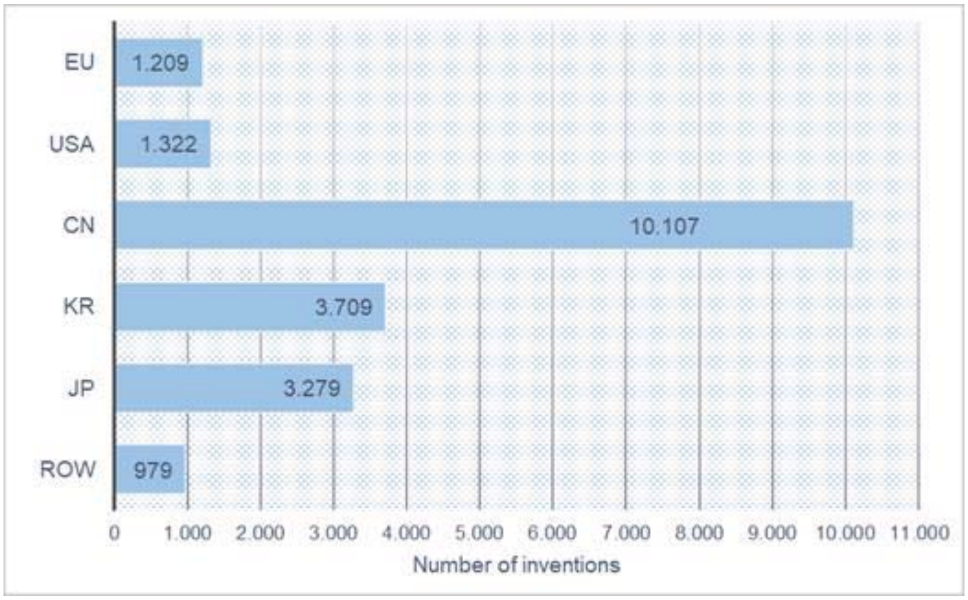
If the "high-value" patent families are considered, in the same three years period, a different picture emerges. Japan leads, followed by Korea and with the EU in the third positon (Figure 11). The “high value” inventions domain is highly dynamic. In just one year, since the CPR 2020 analysis, the EU declined from the second, after Japan, to the third position, after Japan and Korea. In the same period, an increase of the Chinese “high value” inventions can be observed, which will soon surpass the EU.

---

[288] The figure of USD 31 billion is derived from the Figure 37 of Global Trends in Renewable Energy Investment 2020, (Frankfurt School-UNEP Centre/BNEF. 2020) http://www.fs-unep-centre.org

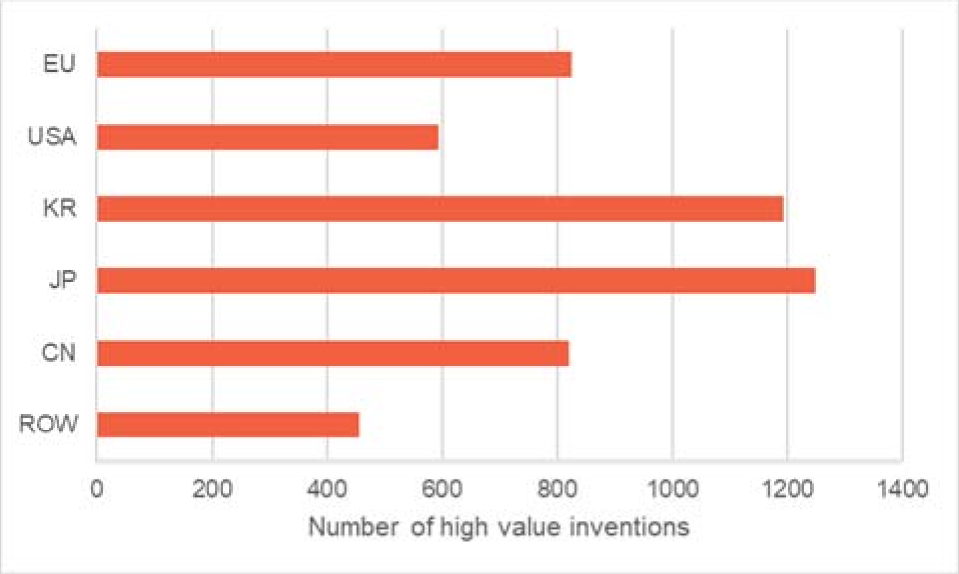
[289] Patent documents are grouped in families, with the assumption that one family equals one invention.

Figure 10: Total number of inventions in photovoltaics in the three years 2015-2017



Source: JRC 2021, based on EPO Patstat

Figure 11: Number of high value inventions in photovoltaics in the period (2015-2017)



Source: JRC 2021, based on EPO Patstat

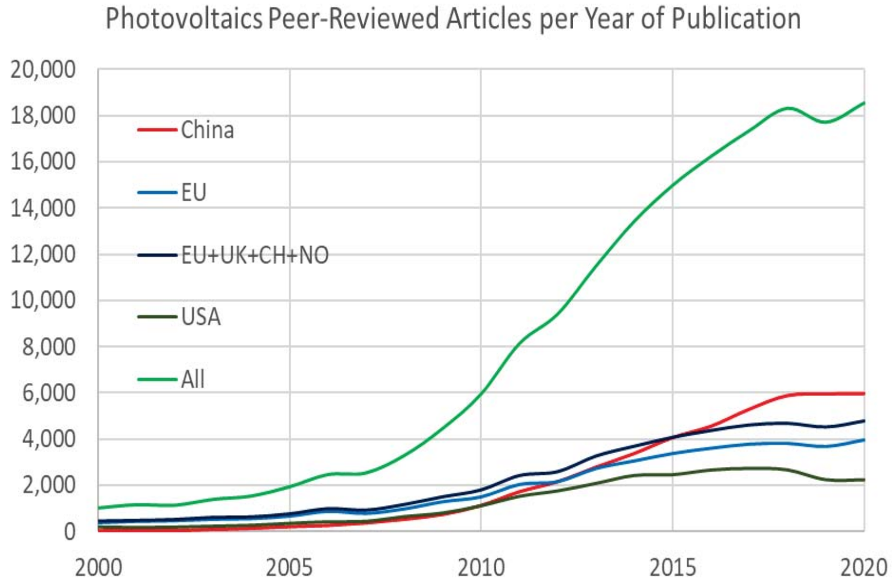
11.7. Level of scientific publications

The annual scientific output on photovoltaics is approximately 18 000 peer-reviewed articles and appears to have stabilised at this level after a decade of rapid growth. Over the last decade, China emerged as the leading single country for research output on PV in terms of number of author affiliations, but the growth has now stopped. The EU, and Europe in general, remain the 2nd largest contributors, again at stable level of output and underlining its continued high-level scientific excellence in photovoltaics.

Figure 13 shows how PV research is increasingly global, with universities and institutes from many countries now featured in addition to the traditional centres of excellence in the USA, Japan, Europe, South Korea and Australia.

The trends in highly cited[290] articles are shown in Figure 14. The European share is approximately 30%, in line with its share of the overall number of publications per year and like that of the USA. China has seen distinct rise in its share of highly cited publications.

Figure 12: Peer-reviewed articles on photovoltaics and solar cells, with a breakdown for China, EU, Europe and USA based on author affiliations (years 2000-2020).



Source: JRC 2021

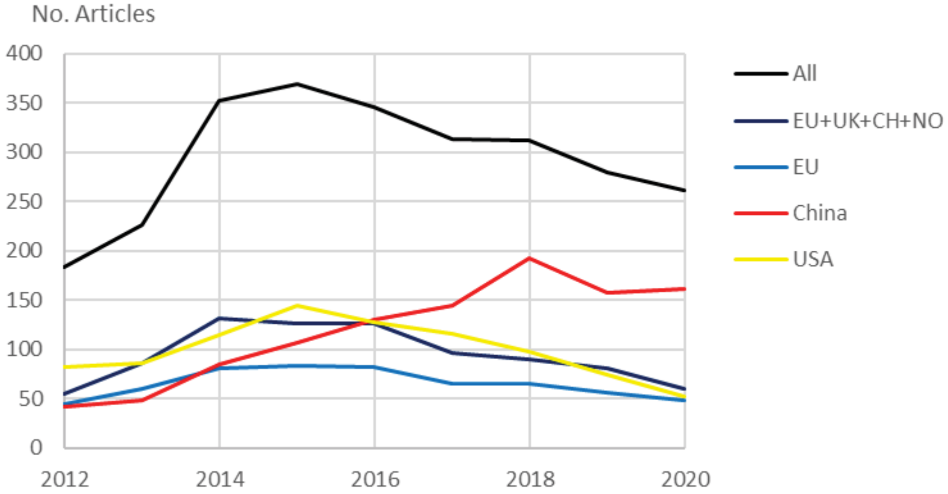
Figure 13: Top 25 countries/regions for author affiliations in PV journal articles in 2020.

---

[290] Clarivate define a “highly cited paper” a one that receives enough citations to place it in the top 1% of its academic field of based on a threshold for the field and publication year.

Source: JRC 2021

Figure 14: Trends in highly cited article on photovoltaics with a breakdown for selected countries and regions based on author affiliation (years 2012-2020).



Source: JRC 2021

11.8. Final Considerations

The photovoltaic capacity installed is growing, with a decreasing cost of the installations. The residential systems predominant five years ago, as a share of the annual installations, are now second (25.4%), after the utility scale segment (30.5%). After the peak of the year 2013, the EU total public investment on photovoltaic research development and demonstration declined and is now below the level it was at the beginning of the decade. In terms of "high value" inventions, in one year time, the EU passed from the second, after Japan, to the third position, after Japan and Korea. If the current trend continues, Chinese "high value" inventions will soon surpass the EU ones.

12. VALUE CHAIN ANALYSIS OF THE ENERGY TECHNOLOGY SECTOR

12.1. Introduction/summary

The photovoltaic industry is characterized by a long and complex value chain, which starts from raw materials, to reach the systems installation and their maintenance, and continues until the end-of-life management and post-service operations, including dismantling and recycling. In addition to the solar cell and module manufacturers, there are the upstream and downstream industrial sectors. The former includes materials, polysilicon production, ingot production, wafer production and equipment manufacturing, glass, laminate and contact material manufacturers, while the latter encompasses inverters, balance of system (BOS) components, system development, project development, financing, installations and integration into existing or future electricity infrastructure, plant operators, operation and maintenance. Soon, it will be necessary to add (super)-capacitor and battery manufacturers as well as power electronics and IT providers to manage supply and demand and meteorological forecasts.

There are different possible ways of breaking down the value chain. Considering only the value chain manufacturing components, five main segments are generally identified: polysilicon, ingots, wafers, cells and modules. The production of each of these components requires very different processes and competencies, with a variety of specialized materials and equipment used in each of them. Currently most of the manufacturing industry is concentrated in China. Some key aspects of the global solar PV manufacturing supply chain are qualitatively described in Table 2.

Table 2: Qualitative aspects of the photovoltaic manufacturing supply chain

	Largest manufacturer	**Market concentration (by country)**	**Market concentration (by company)**	**Adjacent industries**	**Barrier to entry**	**Value**
Overall	China	High	High	Power, Silicon, Glass	Medium	High
Polysilicon	Germany	High	High	Power, Silicon, Glass	High	High
Wafers	China	High	High	Crucibles, wire saws	High	High
Cells	China	High	Medium	Silver, Aluminium	Medium	High
Modules	China	High	Medium	Glass, Aluminium	Medium	Medium

Source: Adapted from: BNEF, Solar PV Trade and Manufacturing, A Deep Dive, February 2021

The top ten polysilicon and wafer firms supplied 83% and 95% of the global market in 2019, respectively. This high market concentration is because polysilicon and wafers have higher technical hurdles and factories are more expensive and require longer lead time to build. Instead, solar cells factories and, especially, module factories can be built relatively quickly and can respond faster to market trends and policy moves. This is reflected in the medium market concentration of the relevant industries. The top ten cells and modules manufacturers supplied 59% and 60% of the global market in 2019, respectively[291].

In addition to polysilicon, ingots, wafers, cells and modules production, the value chain could also include other upstream segments (e.g., basic and applied R&D, design) and downstream parts (e.g. EPC, implementation).

The added value is distributed along the segments. The highest value added is generally located in both the far upstream (basic and applied R&D, and design) and far downstream (marketing, distribution, and brand management) parts, while the lowest value-added activities occur in the middle of the value chain (manufacturing and assembly). However, an increasing number of installations are realized in harsh climates, e.g. high UV, high temperature differences between day and night, high humidity, floating configurations. Therefore, companies are interested to control the manufacturing process to reduce risks and lower financing costs. Moreover, a high concentration of the manufacturing reduces the power of negotiations of the EU downstream industry, which is also more sensitive to potential manufacturing disruptions in the dominating region. Finally, evidence suggest that the dominance of cell and module manufacturing, allows companies to move upstream in the value chain, towards more profitable segments. Therefore, looking at the added value of a single segment of the value chain might not be sufficient to have the full insight of the industry and inform policy decision.

12.2. Turnover

According to the Global Trends in Renewable Energy Investment 2020[292], global annual investments in solar PV were USD 126.5 billion in 2019 (EUR 106.3 billion), of which USD 52.1 billion (EUR 43.8 billion) were investments in small distributed solar capacity.

Solar capacity investment in Europe was USD 24.6 billion (EUR 20.7 billion). The EU (plus UK) share of new PV installations was 14% in 2019 with an estimated annual investment level at about USD 18 billion (EUR 15 billion).

Recently, an analysis published in 2020 puts the market size of the global PV industry at about EUR 132 billion[293], with the segments of value chain related to polysilicon production, ingot production, and cells and module manufacturing capturing the lion share (44%). According to this analysis, the EU market size is about EUR 17.1 billion corresponding to about 13% of the global value.

More recently, the relevant industry association provided an estimate of the turnover of the photovoltaic manufacturing value chain, in the five identified segments, for the year 2020 (Table 3).

Table 3: Estimated turnover in the photovoltaic manufacturing value chain (year 2020)

---

[291] *Solar PV Trade and Manufacturing, A Deep Dive, BNEF, February 2021*

[292] https://www.fs-unep-centre.org/wp-content/uploads/2020/06/GTR_2020.pdf

[293] Asset Study Competitiveness (2020)

Segment	EU + Norway (USD billion)	World (USD billion)	Share (EU + Norway) (%)
Polysilicon	About 0.7	About 5	1.4
Ingot/wafer	Less than 0.1	About 9	1.1
Cell	Less than 0.5	About 15	0.3
Module	between 4-6	About 30	13
Total	About 6.4	About 59	11

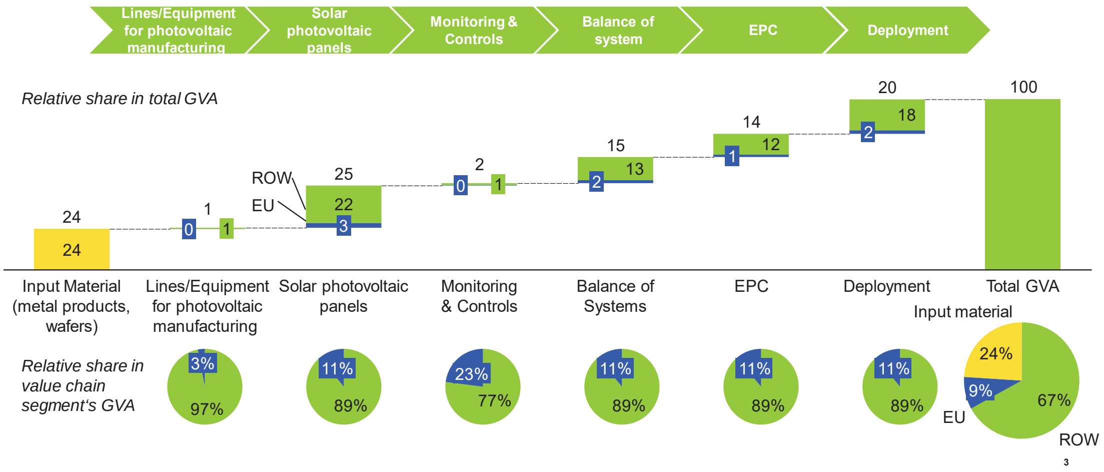
Source: BNEF

12.3. Gross value added

The gross value added (GVA) in general is like the market sizes for the respective value chain segment and region, when 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, in

Figure 15. Therein a potential source for inaccuracies in the GVA calculation may be found because 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 cells and modules manufacturing.

Figure 15: Breakdown of GVA throughout solar PV value chain

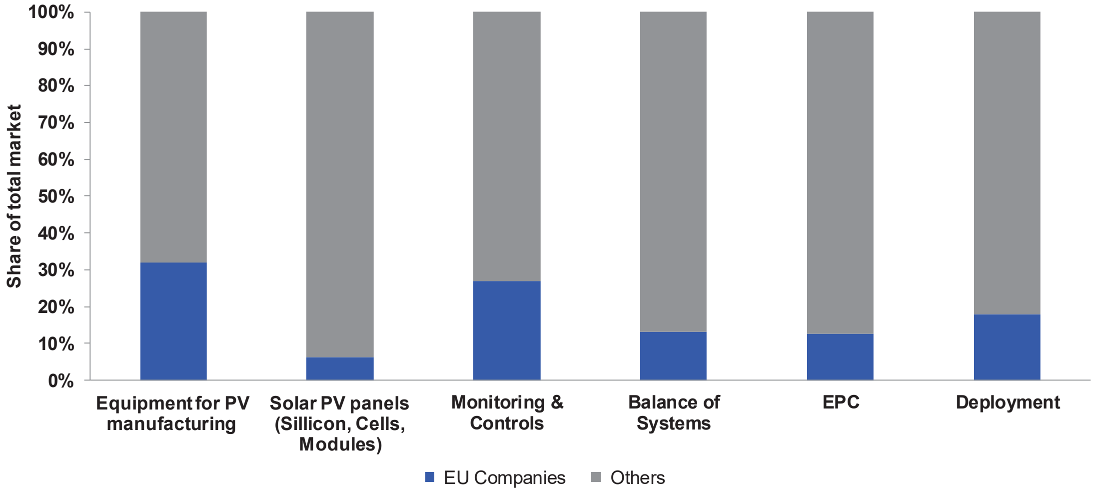


Source: Guidehouse Insights, 2020

12.4. Number of EU companies

The EU performs differently across the segments of the PV value chain (Figure 16). Europe, along with the USA 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.

Figure 16: Competitive Intensity across Each Value Chain Segment, Global, 2020



Source: Guidehouse Insights, 2020

European companies still maintain a relevant presence in the industry value chain in which the key European market players are represented (Figure 17)[294].

---

[294] Climate neutral market opportunities and EU competitiveness – Final Report, December 2020, https://data.europa.eu/doi/10.2873/458629

Figure 17: Key European market players, along the segment of the solar photovoltaic modules value chain[295].

Source: "Climate neutral market opportunities and EU competitiveness", report written by ICF and Cleantech Group December 2020

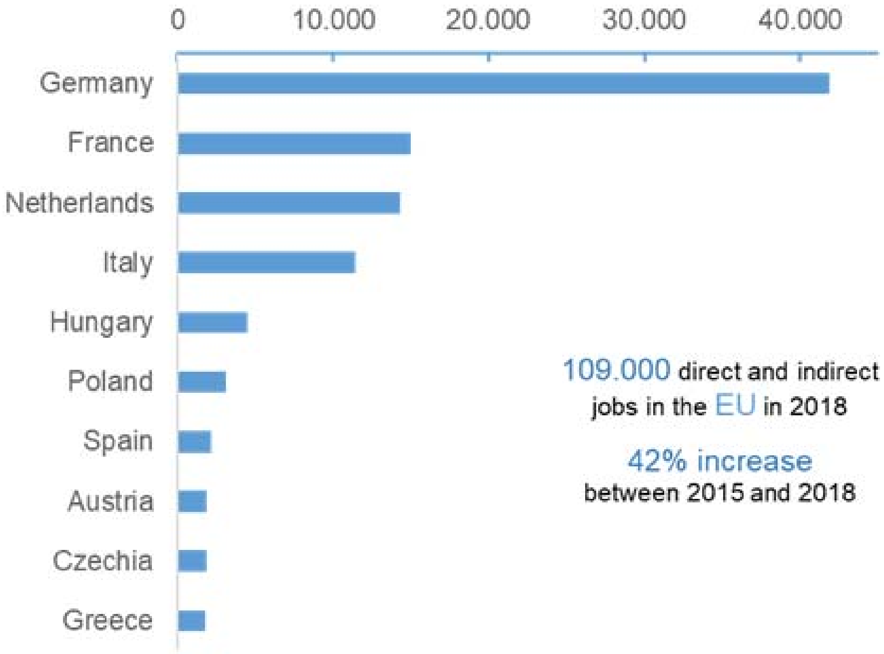
---

[295] Climate neutral market opportunities and EU competitiveness – Final Report, December 2020, https://data.europa.eu/doi/10.2873/458629

12.5. Employment in the selected value chain segment(s)

PV installations creates jobs across the value chain, from the installation phase to operation and maintenance and in the up-stream sector. The photovoltaic sector employs a highly educated and skilled work force for the areas of R&D, polysilicon and wafer production and cells and module manufacturing. System designs, EPC, O&M, decommissioning and recycling are also demanding activities in terms of skills required. Other important employment relevant factors include the ensuing need for high quality education, training and certification programmes for PV technology and products.

Figure 18: Direct and indirect jobs in Solar PV (top 10 EU countries, year 2018)



Source: JRC 2021, based on EurObserv'ER data

The preliminary results of a more recent study indicates about 123 000 direct and 164 000 indirect full-time jobs in the EU PV industry in 2020. The indirect jobs figure is calculated by using the Input/Output Tables (*Leontief Tables*) approach. The direct jobs, instead, are determined using two different methods, for jobs in deployment and O&M segments and jobs in manufacturing, decommissioning, and recycling segments[296].

12.6. Energy intensity considerations, and labour productivity considerations

The direct and indirect energy necessary for different photovoltaic solar cells technologies, during the whole lifetime, in China, EU and USA is compared in a recent study published in 2020[297]. Electricity, fossil fuels and energy used for transportation represent the direct energy input in the life cycle. Labour and material represent indirect energy inputs. Differences in energy consumption among photovoltaic technologies are related to the solar cells manufacturing. Mono-crystalline silicon solar cells requires more energy than solar

---

[296] SolarPower Europe study on employment 2021– The publication will be available in November 2021

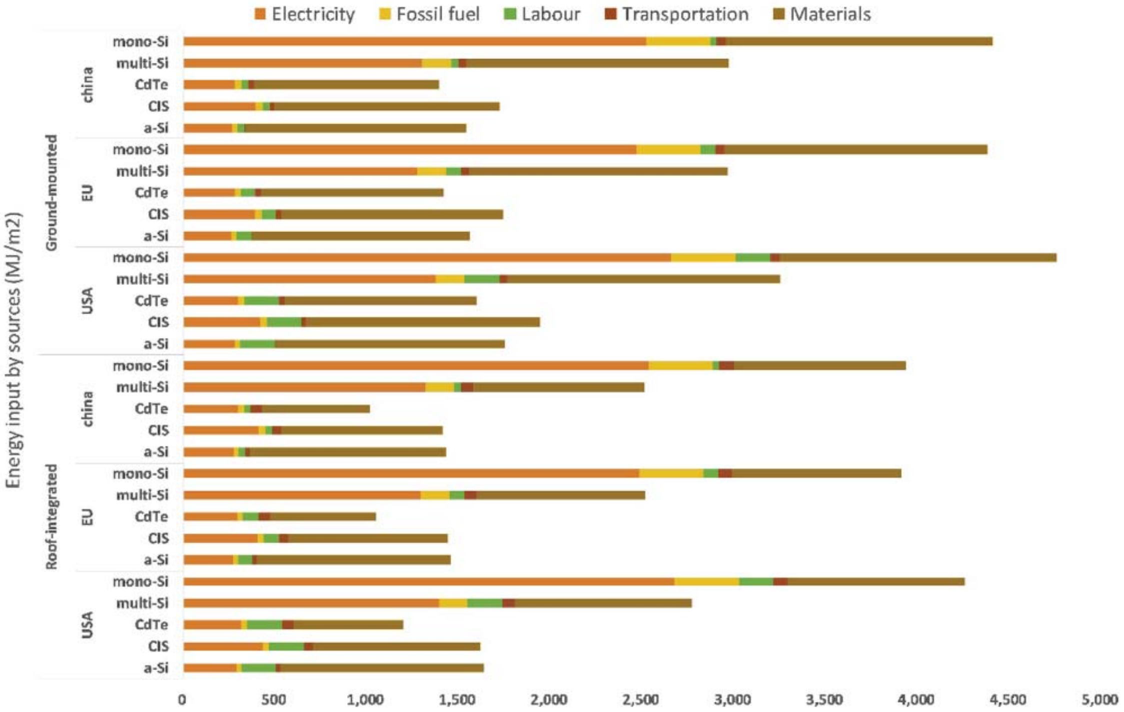
[297] F. Liu and J.C.J.M. van den Berg, Energy Policy 138 (2020) 111234

cells based on multi-crystalline silicon. Even less energy is necessary for the manufacturing of solar cells based on thin-film semiconductors. The EU shows the best performance in terms of the EROI (energy return on energy invested) indicator, followed by China. The worst EROI is recorded by the USA, caused by its high amount of energy use by labour and electricity (Figure 19).

In addition, the authors compare carbon dioxide emissions over the life cycle of the solar power installations and note how the differences of carbon dioxide emissions among technologies are mostly due to the use of electricity. As a result, for the same region more carbon dioxide emissions are embodied in mono-crystalline than multi-crystalline silicon solar cells.

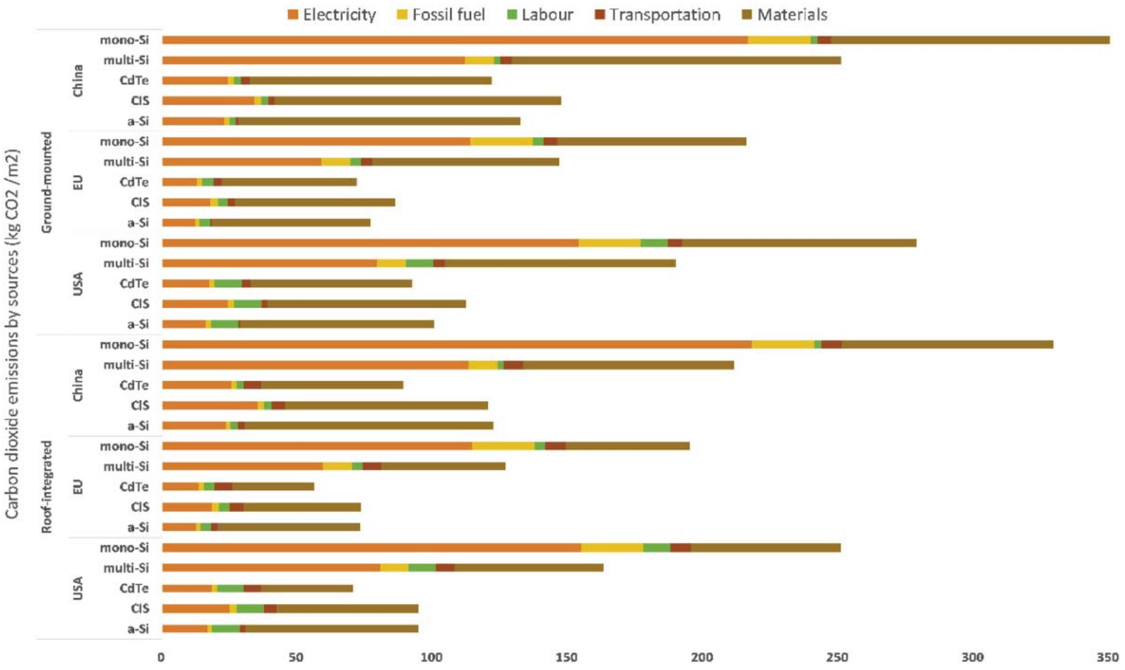
Due to significant differences in carbon intensity of the production cycle, the EROC (energy return on carbon invested) indicator among regions differs from that of EROI. The EU has the highest EROC, while China has the worst performance (Figure 20).

Figure 19: Direct and indirect energy investment of PV technologies in China, EU and USA.



Source: F. Liu and J.C.J.M. van den Berg, Energy Policy 138 (2020) 111234

Figure 20: Direct and indirect CO_2 emissions for PV technologies in China, EU and USA

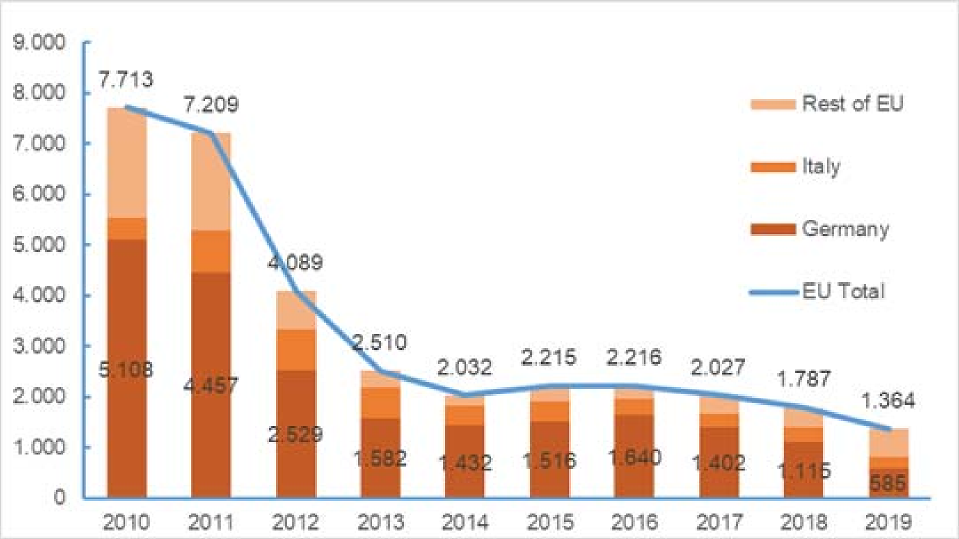


Source: F. Liu and J.C.J.M. van den Berg, Energy Policy 138 (2020) 111234

12.7. Community Production (Annual production values)

The EUROSTAT statistics on production of manufactured goods PRODCOM (PRODuction COMmunautaire) includes data on national production and EU aggregates. The EU total production value and top producer countries are reported in Figure 21. There is a remarkable decline observed in the 10 years period 2010-2019. The EU photovoltaic total production value decreased from EUR 7.713 million in 2010 to EUR 1.364 million in 2019.

Figure 21: EU Total Production Value and Top Producer Countries (EUR million)



Source: JRC2021, based on PRODCOM data

12.8. Final Considerations

The EU hosts one of the leading polysilicon manufacturers such as Wacker Polysilicon AG. Furthermore, the EU companies are more competitive in the downstream part of the value chain with key roles in the monitoring and control, and balance of system segments, especially inverter and solar trackers manufacturing. European companies have also maintained a leading position in the equipment and machinery for PV manufacturing and deployment segment.

On the other hand, EU has lost its market share in ingots and wafers production and solar cells and module manufacturing.

A recent investigation shows that the EU records the best performance in terms of the EROI (energy return on energy invested) indicator, followed by China and USA. The EU has also the highest EROC (energy return on carbon invested) indicator value, while China has the worst performance and USA is in the middle.

In 2018, 109 000 direct and indirect jobs in photovoltaics are reported in the EU, with a 42% increase between 2015 and 2018. According to preliminary figures, about 123 000 direct and 164 000 indirect full-time jobs are reported in the EU PV industry in 2020, for a total of 287 000 jobs[298].

13. GLOBAL MARKET ANALYSIS

13.1. Introduction/summary

The EU trade balance in the solar photovoltaic sector, measured as the difference among the extra-EU import and export, is negative (Figure 22). The EU solar PV imports are strongly dependent on imports from Chinese and Asian companies.[299]

---

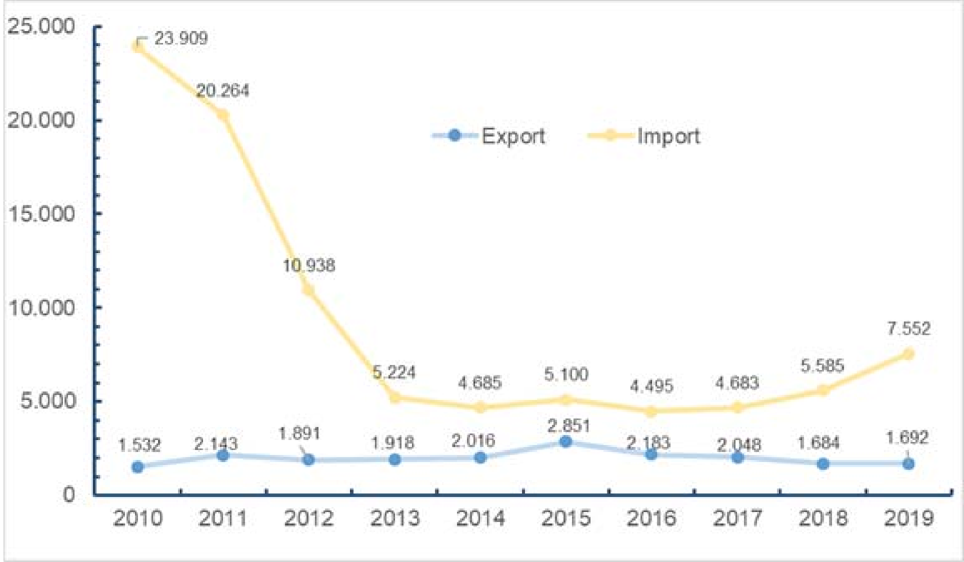
[298] SolarPower Europe study on employment 2021– The publication will be available in November 2021

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

13.2. Trade (imports, exports)

After years of fast reduction, the trade deficit started increasing again in the years 2016-2017. This imbalance reflects substantially the value of the imports, as the exports do not change dramatically over the years.

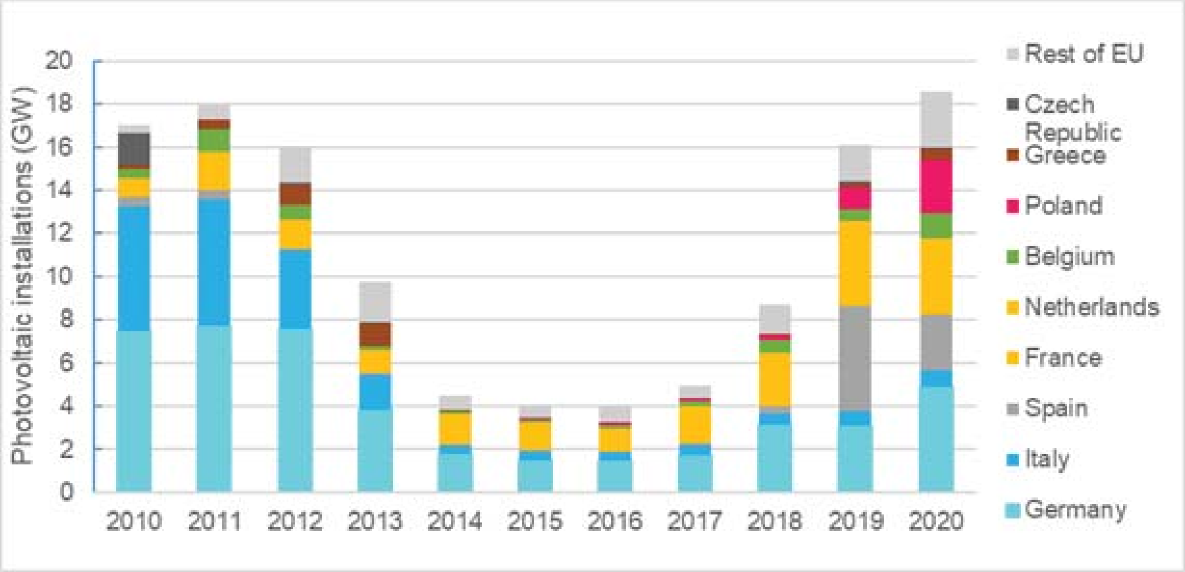
Figure 22: Extra-EU Import and Export (EUR million)



Source: JRC 2021, based on COMEXT data

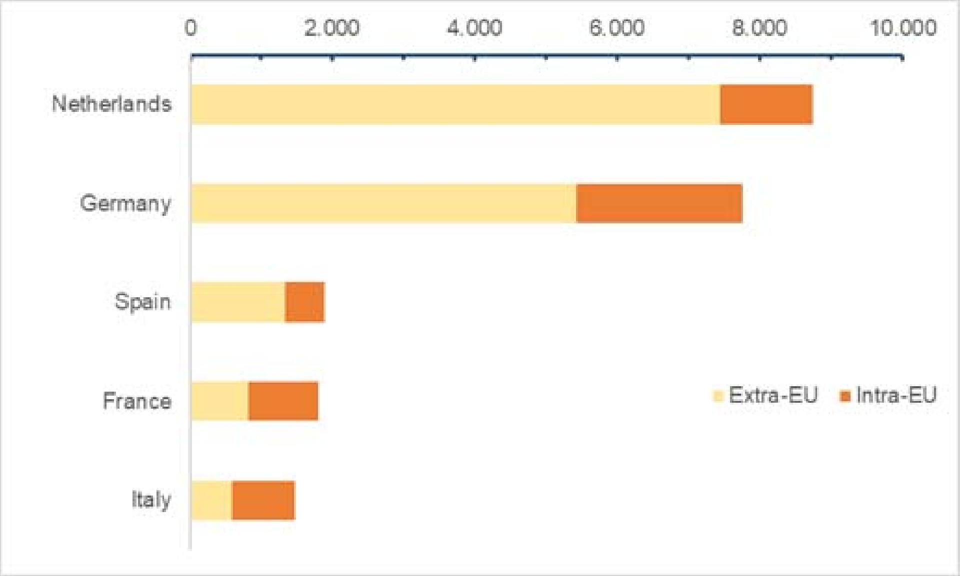
Figure 23 show a similar behavior, recording minima and maxima at about the same years. This suggests a relationship of cause (annual installations of photovoltaic systems) and effect (import of solar photovoltaics from extra EU countries).

Figure 23: Annual photovoltaic installations in the EU (GW)



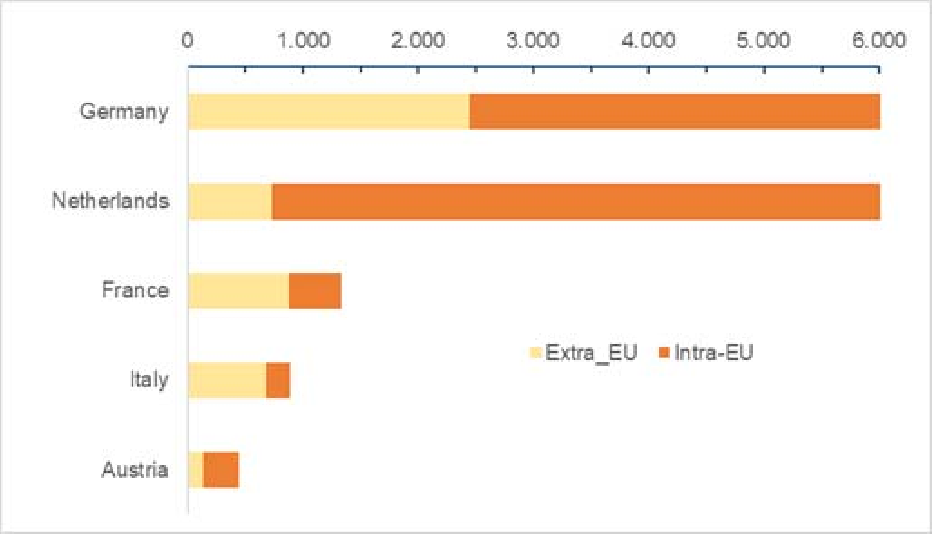
Source: AJW PV Snapshot 2021

Figure 24: Top 5 EU Importers (2017-2019) (EUR million)



Source: JRC 2021, based on COMEXT data

Figure 25: Top 5 EU Exporters (2017-2019) (EUR million)

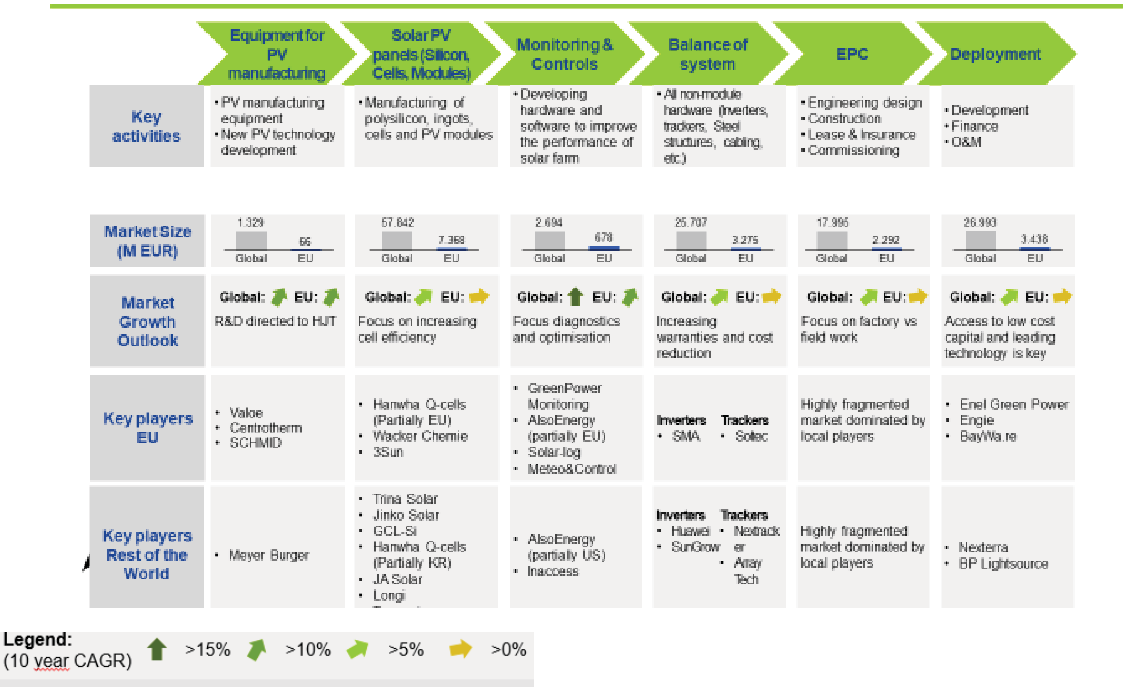


Source: JRC 2021, based on COMEXT data

13.3. Global market leaders vs. EU market leaders (market share)

A representation of the solar photovoltaic value chain, which includes the main EU and global actors for the different segments is provided in Figure 26.

Figure 26: Solar photovoltaics value chain segments, their market size, and market growth outlook. Key EU and global players per each market segment are also reported.



	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 polysilicon, 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 EUR)	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 26.993 EU 3.438
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	• AlsoEnergy (partially US) • Inaccess	**Inverters** • Huawei • SunGrow **Trackers** • Nextracker • Array Tech	Highly fragmented market dominated by local players	• Nexterra • BP Lightsource

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

Source: Guidehouse Insights (2020)

EU companies are most competitive in the downstream part of the value chain and have maintained key roles in i) the monitoring and control (with companies like GreenPower Monitoring, Meteo&Control and Solar-log), ii) balance of system (BOS) segments, hosting some of the leaders in inverter manufacturing (like SMA, FIMER, Siemens, Gamesa Electric, Ingeteam and Power Electronics), and iii) solar trackers (like Soltec). European companies have also maintained a leading position in the deployment segment, where established players like Enerparc, Engie, Enel Green Power or BayWa.re have been able to move into new solar markets and gain new market share worldwide[300].

Table 4: Polysilicon production capacity of the six largest manufacturers (year 2020)

	Manufacturer	**Capacity** (ton)
1	Tongwei	96 000
2	GCL-Poly	90 000
3	Wacker	84 000
4	Daqo New Energy	80 000
5	Xinte Energy	80 000
6	East Hope	80 000
	Total production capacity	510 000

Source: Bernreuter Research[301]

EU, instead, lost its market share in some of the upstream part of the value chain (e.g., ingots and wafers production and solar PV cell and module manufacturing. The EU hosts one of the leading polysilicon manufacturers such as Wacker Polysilicon AG, whose production alone is sufficient for manufacturing 20 GW of solar cells.

Non-Chinese polysilicon manufacturers have long prevailed with their know-how of the Siemens process. In the meantime, however, China's top producers have caught up on the learning curve. The six global largest manufacturers reached a production capacity of 510 000 tons in 2020 (Table 4). Competition in the top six manufacturers group is intense. Wacker Chemicals is a polysilicon production pioneer, having developed the Siemens process in the 1950s. This process has remained the dominant technology to produce highly pure polysilicon, despite several attempts to develop less expensive alternatives. However, low-cost plants in China have driven the production costs of the process down to unprecedented levels.

---

[300] ASSET Study on Competitiveness, 2020

[301] https://www.bernreuter.com

Polysilicon production is characterized by high operating costs, due to electricity consumption and, to a less extent, to materials consumption. While labor is not a relevant cost factor, the investment costs (for the machines and equipment for polysilicon production) are also high. China, initially produced polysilicon with equipment imported from abroad (e.g. USA and EU) but, makes now much of it domestically, at a lower cost.

Impact on competitiveness of industrial electricity prices

Comparing electricity prices in EU vs global competitors using average electricity prices could be misleading, as prices significantly differ in countries/regions. Furthermore, large consumers increasingly have customized contracts with utilities. That said, the cost of electricity remains a sensitive issue when it represents a significant fraction of operating costs.

Even limited differences in absolute prices can have a large impact on the competitiveness of power intensive export goods in global markets.

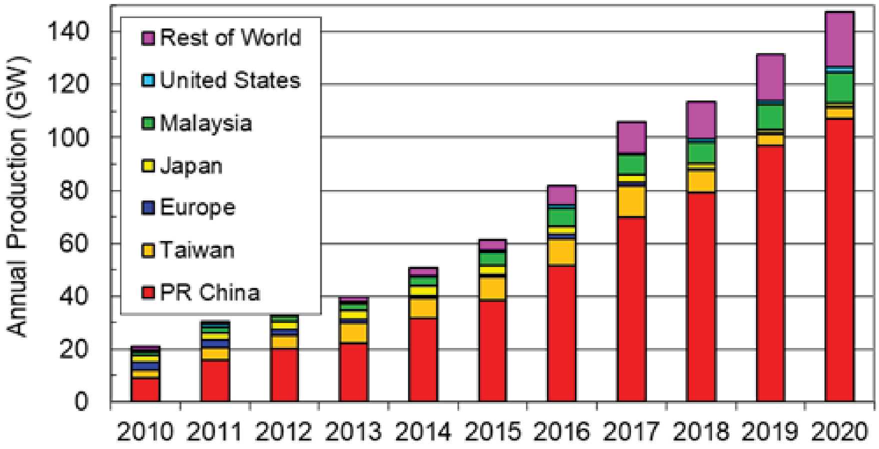
A further critical consideration is the role of carbon pricing (or lack thereof) in such costs.

Competitiveness of industrial prices should be measured not only by country but by production location or even individual company considerations, in order to better inform policy decision.

The segments of the value chain which include the polysilicon and ingots and wafers production and the solar cells and modules manufacturing have a global value which is currently of about EUR 57,8 billion, of which the EU's share (12,8%) corresponds to EUR 7,4 billion. This still relatively high share of the whole value captured by EU is mostly due to the polysilicon production.

Nine of the top ten solar cell manufactures will be headquartered in China by the end of 2021. The only exception is Canadian Solar, headquartered in Canada, but having most of the manufacturing capacity located in China as well. The remarkable predominance of Asian manufacturers of PV solar cells and the negligible EU production is well represented in Figure 27.

*Figure 27**:** World Photovoltaic solar cell/module production*



Source: AJW PV Snapshot 2021

The springboard to even higher efficiency devices is through their combination with thin films in tandem structures. Oxford PV (Germany) has already raised EUR 120 million for pilot production of its perovskite and silicon tandem at a new German factory and aims to go into commercial production in 2022.

Several other projects to scale up manufacturing of solar photovoltaics cells and modules are now taking off, showing a renewed interest of EU companies to invest in the EU.

Meyer Burger (CH/DE) has recently unveiled its first EU-made module and started production in Germany (Saxony-Anhalt and Saxony) in May 2021, initially with an annual capacity of 0.4 GW of heterojunction silicon solar cells and 0.4 GW of solar modules and plans to scale up its production capacity to the multi-gigawatt scale, which is the norm for many Asian manufacturers. ENEL Greenpower's 3SUN factory (Italy) aims to ramp up its 200 MW HJT PV cell and module production line in Catania to 400 MW by Q2 2022 and 3 GW by 2023. IconiQ (Netherlands) has unveiled in September 2020 its prototype modules based on the IBC cell technology produced by German university ISC Konstanz. A pilot line should open in Q3 2021 in the Netherlands. The wafer industry has also announced important investment rounds. NorSun (Norway) has doubled its production capacity of low-carbon monocrystalline silicon ingots and wafers from 450 MW to 1 GW in 2021. It has secured public funding for the pre-project of the ‘phase 2’ expansion project which should see the factory scale up to 4 to 5 GW, before financing starts in Q4 2021. The Si-Fab project (Germany) will manufacture high-quality mono-crystalline wafers developed by NexWafe. The current 5 MW pilot line, located in Freiburg, Germany, will be ramped up to 400 MW production capacity by 2023. The company completed a EUR 10 million capital raise in February 2021 in that purpose and is exploring global exports.

13.4. Resource efficiency and dependence

The relevant materials for solar photovoltaics contained in the EU’s list of critical raw materials are boron, germanium, silicon, gallium and indium. To note that indium and gallium are not used in the 95% of the solar photovoltaics devices currently manufactured (being only used in CIGS-based devices). Silicon metal is included in the list due to the current import dependence on Chinese PV products, although silicon oxide feedstock is abundant. Usage of silver for connections is sometimes cited as a cause for concern. The industry in any case works to decrease its use for cost reasons. R&D efforts concentrate on minimising silver use or on substitute materials, like copper. Now in the EU there is a limited manufacturing of solar cells. Consequently, concerns on the CRM issues for the industry are reduced. The launch of large-scale manufacturing facilities in the EU should face this challenge. The fact that PV offers a broad range of options for materials and their sources can mitigate concerns that may arise from projections based on current device technologies. Finally, it is also important to highlight the reliance on glass and aluminium for the production of solar modules.

1 kWh of electricity generation for self-consumption via a PV-battery system has a carbon footprint of about 80 g CO_{2eq}/kWh which is higher than the footprint of PV electricity consumed directly or fed into the grid, which is about 55 g CO_{2eq}/kWh[302].

In the EU, treatment of end-of-life PV modules must comply the WEEE Directive since 2012. Several organisations have developed recycling processes. However, waste volumes are still too low for these to be economically viable.

---

[302] IEA PVPS Task 12 Report “Environmental Life Cycle Assessment of Residential PV and Battery Storage Systems” (2020), ISBN 978-3-906042-97-8

Several of these sustainability aspects are now being addressed in the framework Ecodesign, where the Commission is performing an impact assessment on the application of mandatory Ecodesign requirements for solar panels and inverters, and Energy labelling for solar panels and for small PV systems. Ecodesign[303] and Energy Labelling[304] are indeed recognised as key contributors in product policy, supporting the transition to a Circular Economy. They drive investment and innovation in a sustainable manner and reduce CO_2 emissions.

13.5. Final Considerations

The trade deficit (extra-EU import vs export) started increasing again in the years 2016-2017 and was at more than EUR 5 700 million in 2019. This imbalance reflects substantially the increased value of the imports, as the exports do not change dramatically over the years. The EU solar PV imports are mainly originating from Chinese and Asian companies.

The polysilicon, ingots and wafers production and solar cells and modules manufacturing have, together, a global value which currently is about EUR 57.8 billion. The EU's share (12.8%) corresponds to EUR 7.4 billion. This still relatively high share of the whole value captured by EU is mostly due to the polysilicon production. The EU positioning in ingots and wafers production and solar cells and modules manufacturing has fallen behind its Asian competitors.

14. CONCLUSIONS

Solar photovoltaics emerges as a very large and innovative industry, growing with unexpected speed. The technology is central to future carbon neutral electricity generation systems. About 1 TW of solar photovoltaics installations are projected to be deployed in the EU by 2050. Globally, more than 3.1 TW of photovoltaic power are projected by 2030 and about 14 TW by 2050. This will correspond to an investment of about USD 4.2 trillion (EUR 3.5 trillion) over the period 2020-2050.

The EU is a global leader in several parts of the PV value chain: R&D, polysilicon production, trackers, inverters and power electronics, and system engineering. There are however important gaps, notably for manufacturing of the silicon wafers and cells that are at the core of the technology, representing the "*engine of the car*". With market demand accelerating in Europe and around the world, and new production technologies emerging, European manufacturers are showing a renewed interest to invest in the EU based on the latest technologies. Should this not materialise, the EU will continue to rely on global supply chains.

The Commission's recent strategy paper[305] welcomed efforts of the industry-led European Solar Initiative to scale up manufacturing of solar photovoltaics. Several projects are already taking off in the EU for manufacturing wafers, solar cells and modules.

Finally, this report has outlined scenarios for strong growth in the EU market for PV systems, driven by the new Climate Law requiring a 55% reduction of GHG emissions by 2030. In parallel, the Recovery and Resilience Facility, the Innovation Fund and the Modernisation Fund, are providing unprecedented funding opportunities for actions by the Member States to combat climate change. The PV sector needs to take maximum advantage of this opportunity to promote cost-efficient novel and integrated solutions, also for

---

[303] Directive 2009/125/EC of 21 October 2009 establishing a framework for the setting of Ecodesign requirements for energy-related products.

[304] REGULATION (EU) 2017/1369 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU.

[305] COM(2021)/350 final., 5/5/2021.

applications in combination with other renewable energy sources, with battery storage and for hydrogen production.

HEAT PUMPS FOR BUILDINGS

INTRODUCTION

The Energy Performance of Buildings Directive (EPBD)[306], directs the Member States to develop national long-term energy renovation strategies (LTRS) for their housing stocks and other buildings until 2050. These LTRS should lead to a 80% to 95% reduction in CO_2 emissions from buildings compared to 1990 levels. Member States must also set minimum energy performance requirements for all new buildings and buildings undergoing renovations. In most cases, these requirements extend to the level of individual building elements or heat generation (e.g. boilers).

Heat pump technology is identified by the EU Strategy for Energy System Integration[307] as a key technology to decarbonise space heating and domestic hot water production, as well as cooling for buildings and industry. The heat pump (HP) sector is already the biggest contributor to the increase in renewable energy production for heating and cooling across the European Union. According to Eurostat's SHARES tool, heat pumps accounted for just over half the increase in renewably-sourced heating and cooling in the EU between 2016 and 2018, or 1.4 Mtoe[308] of the 2.5 Mtoe increase.

Following the COVID-19 crisis, the European Commission reaffirmed the importance of the Green Deal on 27 May 2020 when it proposed the Next Generation EU plan to relaunch the European economy. The plan's first component is to instigate a "renovation wave" strategy to increase the building renovation rate. Apart from its impact on GHG emissions, building renovation is seen as a strong recovery and job creation lever which will benefit all Member States.

The scope of this 'Heat Pumps' section mainly covers heat pumps for building space and/or domestic water heating applications, and cooling as a possible secondary function (reversible or multifunctional heat pump). It excludes: industrial applications, household appliances (fridges, washing machines, dryers) and building air conditioners (which cannot be used for heating).

The Building heat pumps market consists of three segments:

1. Residential (up to 20 kW thermal for single-family housing, more for multiple). This includes all ambient and geothermal heat sources (air, solar, ground, water), hybrid heat pumps (natural gas backup) and heating-only or reversible heating/cooling.
2. Light commercial (several hundred kilowatts thermal), including all heat sources (air, solar, ground, water) and heating-only or heating/cooling.
3. District heating (in the order of magnitude of one or more MW thermal)

---

[306] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings

[307] COM(2020) 299 final.

[308] This number refers to all heat pumps, including industrial heat pumps, but industrial heat pumps represent only a very small share of the total.

15. TECHNOLOGY ANALYSIS – CURRENT SITUATION AND OUTLOOK

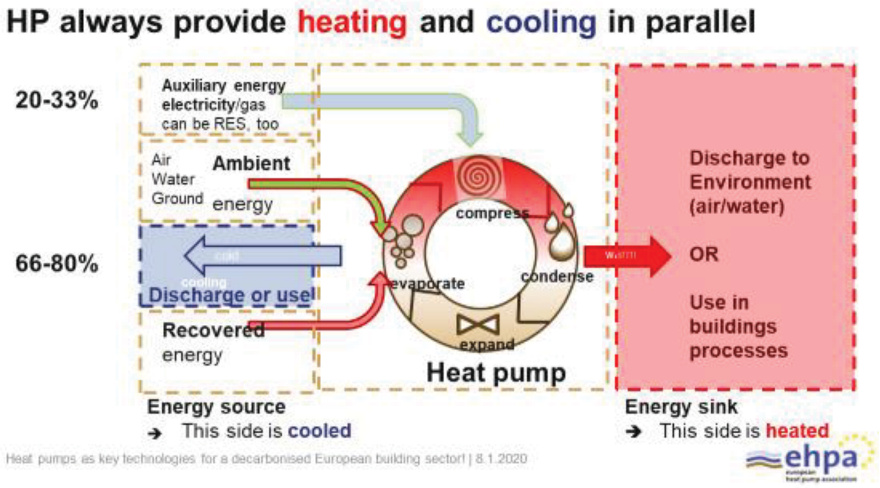
15.1. Introduction/technology maturity status (TRL)

Heat pumps transform thermal renewable energy from natural surroundings to heat at higher temperatures. The heat pump cycle can be also used to provide cooling, or both cooling and heating.

Heat pumps can be categorised according to the medium from which they extract renewable energy (air, water or ground), the heat transfer fluid they use (air or water) and their purpose (cooling, space heating, and water heating, or both heating or cooling in case of reversible heat pumps).

Heat pumps can be driven by mechanical energy, produced by an electric motor (electric compression heat pumps) or more rarely by a combustion engine (gas/motor driven heat pumps), or by thermal energy using the principle of sorption.

Figure 28: Schematic overview of a compression heat pump producing heat and cold



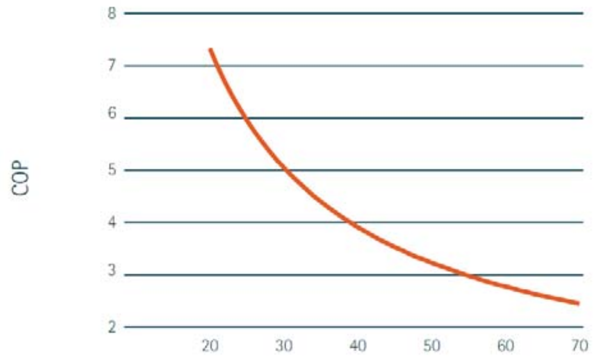
Source: EHPA

The thermal efficiency of a heat pump is described as coefficient of performance (COP). This indicator describes the ratio of thermal energy produced (in other words the useful energy available for heating) over input energy to the process (in case of the electric compression heat pump this is the electricity needed to run the compressor). Likewise in cooling mode, the efficiency is described by the energy efficiency ratio (EER), which is the ratio of cooling provided relative to the amount of electrical input required to generate it.

While the COP is usually based on lab measurements in standard conditions, the seasonal COP (sCOP) gives a realistic indication of energy efficiency over an entire year and is calculated for a given climatic zone (e.g. northern Europe, central Europe and southern Europe). In addition, the Seasonal Performance Factor (SPF) is measured for a given heat pump over one year and depends on the building in scope.

The COP of the heat pump depends on the temperature difference between the energy source and the energy sink; the lower the temperature difference, the more efficient the heat pump unit will be. The same applies for cooling.

Figure 29: Maximum theoretical COP-heating as a function of the temperature difference (in °C) between heat sink and source



Source: Copper Institute White paper 2018

The HP is a mature technology with available products in residential, light commercial and district heating/cooling segments, however R&I is still ongoing to further improve the products:

a. <u>R&I applicable to all segments</u>

As the performances of heat pumps are very sensitive to their operational environment, the integration of the heat pump in the larger energy system is key. This can include the optimisation of the use of local renewable self-generation (solar thermal, PV) and storage (thermal or electrochemical), the contribution to electricity grid flexibility and price/weather-based performance management (artificial intelligence). Better interfaces and standards will also be needed to collect and store information on heat pump operations, and communicating such information to other systems (e.g. BEMS[309] and/or BACS[310]), for autonomous or remote inspection of systems (state, performance and failures).

In order to comply with the F-gas regulation[311], heat pumps must be adapted to low global warming potential refrigerants (e.g. propane, butane) while maintaining/enhancing their performances: capacity and efficiency, including at low ambient temperature (extended operating range).

In view of the growing replacement market, the circularity of heat pumps should be improved (reparability, modular design for selective replacement and upgrade, recyclability of materials). Full life-cycle analysis (LCA) data for heat pumps (extension of Scope 3 for emissions accounting) will be required for next-generation carbon accounting in order to provide easy-to-use indicators expressing the carbon content of heating and cooling systems in gCO2/kWh of hot/cold delivered.

b. <u>R&I applicable to the residential heat pump segment</u>

In this segment, research and innovation covers very compact, highly integrated and silent units, which also lead to cost savings and open new segments such as apartment heat pumps (notably non-compressed technologies, such as thermoelectric technologies). Research is also ongoing in Building-Integrated Heat

---

[309] BEMS – Building Energy Management System

[310] BACS - Building automation and control systems

[311] The F-Gas regulation (EU) No 517/2014, Art 11 (1), specifies that: "*the placing on the market of products and equipment listed in Annex III shall be prohibited from the date specified in that Annex*", (notably: 14. Movable room air-conditioning […] that contain HFCs with GWP of 150 or more; 15. Single split air-conditioning […] that contain […] gases with GWP of 750 or more)

Pump (BIHP) exchangers using the solar heat collection capabilities of southbound roofs and facades, or the waste heat from cooling systems.

Especially for buildings that require renovation, there is a need for improved solutions for the direct replacement of boilers with higher feed-in temperatures (55 – 70°C), as well as extended operating range (maintaining capacity and efficiency at lower ambient temperature), to avoid the use of backup heater.

Finally, small water-to-water heat pumps which are to be connected to a centralised hydraulic network, for multiple unit residential buildings renovation market, is also relevant.

c. <u>R&I applicable to the light commercial heat pump segment</u>

Research and innovation in this segment covers system integration (see above) and multi-functional units (for supplying simultaneous heating and cooling needs such as: cooling/DHW[312], refrigeration/heating/DHW in commercial buildings or buildings of mixed occupation), as well as the integration with other local renewable and storage, possibly using a local DC network between photovoltaic, batteries and heat pumps to avoid DC/AC and AC/DC converters and losses.

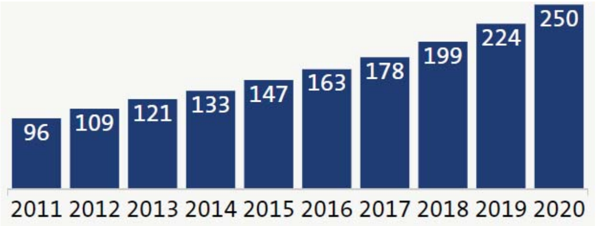
d. <u>R&I applicable to the district heating heat pump segment</u>

Research and innovation is ongoing in planning support, for example to develop software for city planning and integration of large heat pumps in heat networks which also include several other energy sources.

15.2. Capacity installed, generation/production

Considering the ‘mainly heating heat pumps’, the installed stock amounted to 14.8 million units in 2020, after a growth of 12% per year over the last 10 years in the EU21[313] considered by EHPA. The usable heat generation in EU21 has been growing at 11.2% per year over the last 5 years (see Figure 30 below, usable heat generation from 2011 to 2020) to reach 250 TWh in 2020.

Figure 30: Usable heat generation (TWh) in the 21 European Countries of EHPA



Source: EHPA[314]

By considering all heat pumps, the European Union installed heat pump stock increased to about 39.7 million units in 2019 (38.0 million ASHPs[315] and 1.7 million GSHPs[316]), from 37.5 million in 2018, including heating-only, heating-cooling and cooling-only (air-co) heat pumps. Note that cooling-only heat pumps represent approximately two thirds of the heat pump market[317].

---

[312] DHW : Domestic Hot Water

[313] EU-21 (including UK, NO, CH and 18 EU MS, not including: BG, CY, EL, HR, LV, LU, MT, RO, SL)

[314] EHPA database, http://www.stats.ehpa.org/hp_sales/cockpit/

[315] ASHP : Air-Source Heat Pump

[316] GSHP: Ground Source Heat Pump

[317] Eur’Observer Heat Pump Barometer, 2020

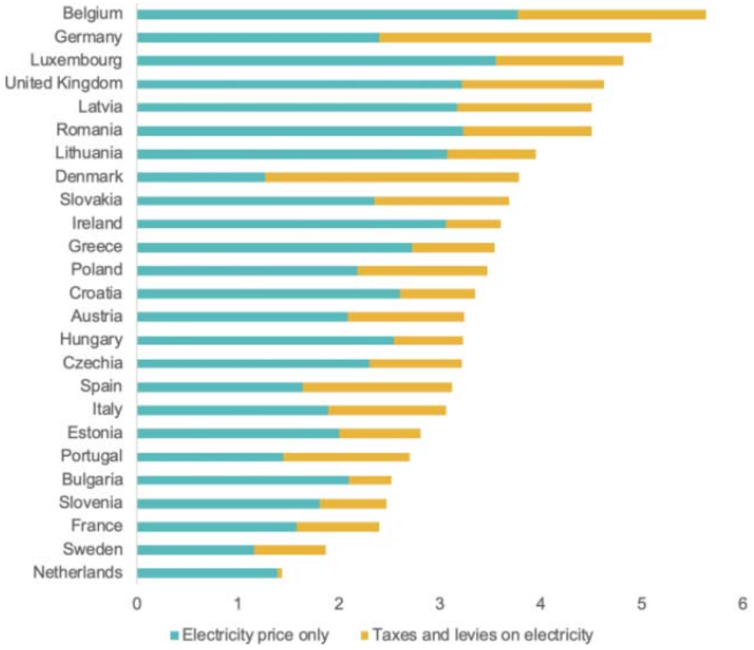
According to Eurostat[318], the total renewable energy contribution of heat pumps in the EU amounted to 12.4 Mtoe[319] in 2019 (or 12.2% of all renewable heating and cooling).

Growth projections of heat pumps for 2030 and 2050 can be found in section 17.1.

15.3. Cost / Levelised Cost of Energy (LCoE)

Even though heat pumps are the most efficient form of heat electrification and can deliver typically three times more thermal energy than the electrical energy consumed thanks to their high coefficient of performance (typical COP of 3, lower or higher depending on climate zone and heat source nature and temperature), the relatively higher electricity prices can prevent sufficient cost savings that would justify switching from fossil gas to a heat pump. Electricity is, on average, 3.3 times more expensive than gas in the EU, making gas boilers cheaper to operate in addition to a cheaper purchase price.

Figure 31: Electricity to fossil gas price ratio in 2020 (residential sector)



Source: figure EURACTIV, data from 'Energy prices and costs in Europe', COM(2020) 951 final.

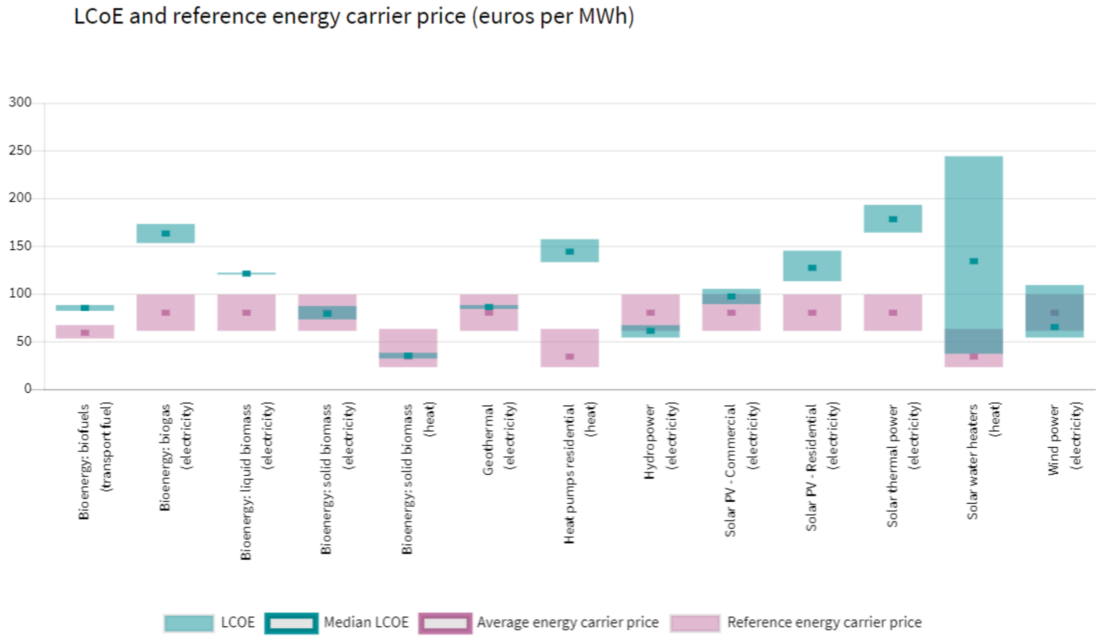
The calculated LCOE ranges from EUR 133 to 157 per MWh (median: EUR 144 per MWh) for heat generated by heat pump, versus the reference energy carrier price, ranging between EUR 23 and 63 per MWh. (See Figure 32 below)

---

[318] Eurostat SHARES

[319] *Assuming a seasonal COP of 3, the generated heat is 1.5 times the renewable heat (1 kWh-el + 2 kWh-RES = 3 kWh-th). So, 12.4 Mtoe i.e. 143 TWh-RES correspond to 215 TWh-th (EU27, 2019), to be compared with 224 TWh-th from EHPA (EU21, 2019)*

Figure 32: LCOE and reference energy carrier price (EUR per MWh)



Source: EurObserver, last update 20/02/2018

15.4. Public R&I funding

EU public R&I funding

Over the period 2014-2020, heat pump projects for building applications represented a total funding of EUR 146.8 million under the Horizon 2020 programme. The largest share was dedicated to the integration of heat pumps with other renewables (60.9%), compared to the share dedicated to the development of residential heat pumps (6.5%); the share of heat pump development for district heating amounts to 32.6%. The main beneficiary countries were Spain, Italy, Germany and Sweden.

Table 5: EU funding - top 10 beneficiaries

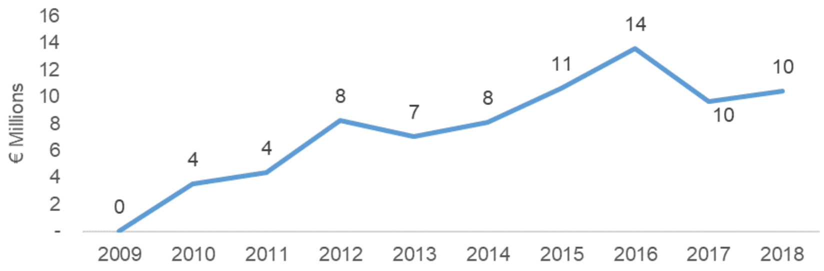
Country	**EU Contribution (EUR million)**	
Grand Total	**146.8**	**100.0%**
Spain	24.2	16.5%
Italy	21.3	14.5%
Germany	11.9	8.1%
Sweden	10.3	7.0%
Denmark	7.6	5.2%
Belgium	7.3	5.0%
Greece	6.4	4.4%
France	6.1	4.2%
Norway	5.4	3.7%
The Netherlands	5.2	3.5%

Source: Horizon 2020 data, CINEA

National public RD&D investments

The data on public investment in RD&D is available for the countries reporting the relevant statistics to the IEA. Following a peak in investments in 2016 of EUR 14 million, EU (plus UK) public investments reached EUR 10 million in 2018. Out of the countries for which the IEA has data, the largest public investors in Europe were Austria, followed by Switzerland, Denmark, France and Belgium.

Figure 33: EU (plus UK) Member States Public RD&D Investments in the Heat Pumps value chain (reporting to IEA)



Source: ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Final, 2020)

15.5. Private R&I funding

Data on private R&I funding dedicated to heat pumps are generally not available publicly. The confidential data collected revealed R&I spending ranging from 4% to 33% of the turnover, but were insufficient to derive relevant conclusions for the sector.

15.6. Patenting trends - including high value patents

Due to the variety of heat pump types, the results of this analysis depend on the choice of the Cooperative Patent Classification (CPC) code[320].

a) <u>‘Mainly-heating heat pump for building applications’</u>[321]

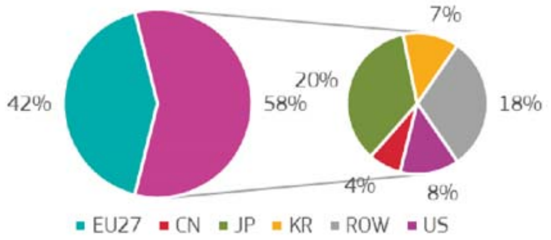
Over the period 2015-2017, 42% of global high-value inventions linked to ‘mainly-heating heat pump for building applications’ were filed in the EU, demonstrating EU leadership in this innovative value chain. The relative strength of the EU has been growing between 2014 and 2017, as can be seen in Figure 35 below.

---

[320] Information collected from industry revealed that some of their patents are reported under a large variety of CPC codes beyond Y02B, such as: F25B Refrigeration, heating, F24D domestic- or space-heating systems; F24H fluid heaters; F28D and F Heat exchange

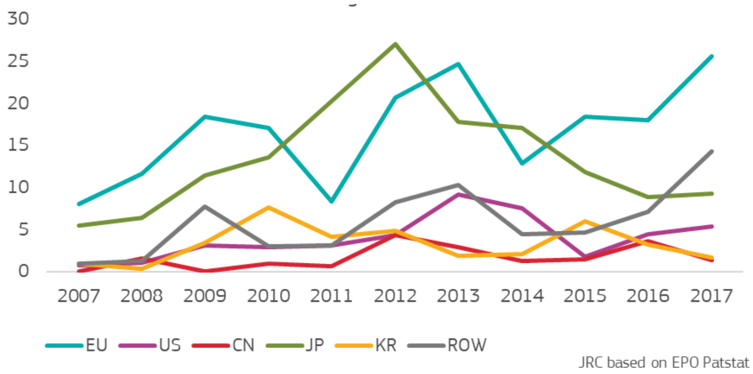
[321] CPC codes included: Y02B (climate change mitigation technologies related to buildings), Y02B 10/40 (geo-thermal HP), Y02B 30/12 (Hot water central heating systems using heat pumps), Y02B 30/13 (Hot air central heating systems using heat pumps), Y02B 30/52 (Heat recovery pumps, i.e. heat pump based systems able to transfer the thermal energy from one area of the facilities to a different one, improving the overall efficiency). But **excluding** : Y02B 30/54 Free-**cooling** systems.

Figure 34: Share of global high-value inventions (2015-2017)



Source: JRC, based on EPO Patstat

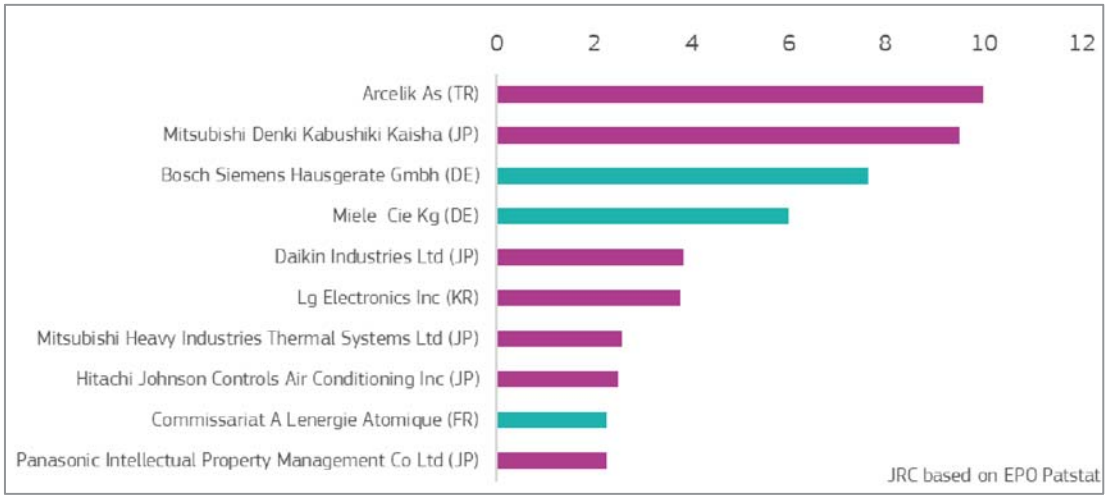
Figure 35: Number of high-value inventions



Source: JRC, based on EPO Patstat

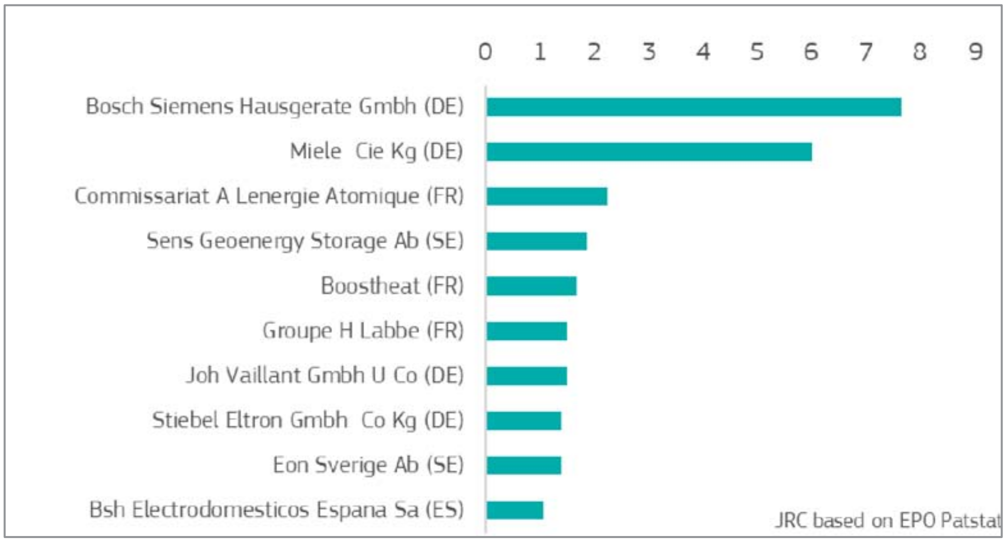
However, out of the top ten most innovative companies, six are located in Asia (5 in Japan and 1 in South Korea), while three are in the EU and one in Turkey. This seems to show a higher concentration of larger companies in Asia than in Europe. Germany, France Sweden and Spain have companies in the top 10 most innovative EU companies.

Figure 36: High-value inventions - Top 10 companies (2015-2017)



Source: JRC, based on EPO Patstat

Figure 37: High-value inventions - Top 10 EU companies (2015-2017)



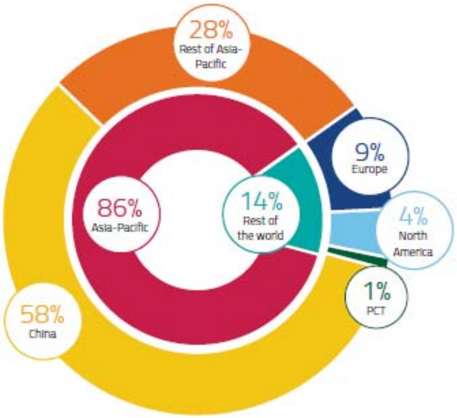
Source: JRC, based on EPO Patstat

b) <u>Heat pumps in space and water heating systems, incl. standalone / portable air-conditioning and water heating units, as well as industrial heat pumps</u>

For this wider range of heat pumps, the EIT-Top-10-innovators report from 2018[322] provides the analysis of patents in the EU and the rest of the world, covering the 2005-2015 period.

The highest number of inventions originates from Asia- Pacific, representing 86% of global inventions. China is a major contributor, with 58% of the total inventions, followed by Europe at 9% and North America at 4%. The average IP strength score for inventions from Europe is more than that of Asia-Pacific (including China), but less than North America.

Figure 38: Global shares of inventions - all types of heat pumps – 2005-2015



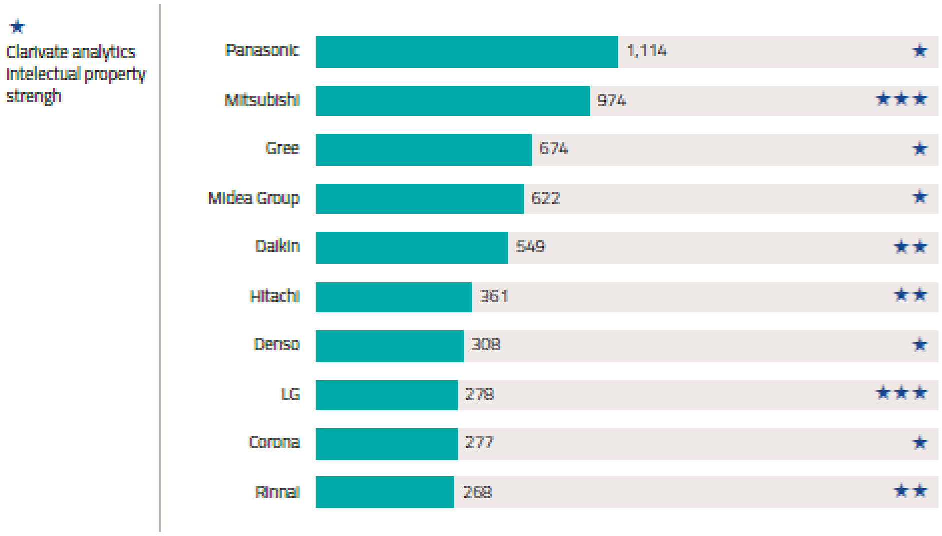
Source: EIT Top-10 innovators report, 2018

---

[322] EIT-Innoenergy-Top-10-innovators, Heat pumps report, 2018

Of the top 10 innovators worldwide, Japanese and Chinese companies dominate. Panasonic has the largest patent portfolio in this sector, followed by Mitsubishi and Gree. LG has a smaller portfolio, but its IP strength score is the highest in the top 10.

Figure 39: Patents portfolio and IP strength - all types of HP - 2005-2015



Source: EIT Top-10 innovators report, 2018

Of the top 10 players from Europe, Stiebel Eltron and Robert Bosch are the most prominent, with the highest number of inventions. Siemens, Électricité de France, Robert Bosch, Vaillant, Atlantic Climatisation & Ventilation SAS and Viessmann Group remain active since 2010, and have high quality patent portfolios.

15.7. Level of scientific publications

Regarding the scientific publications on 'heat pump' technology[323] (which includes all types of heat pump applications: heating and cooling in buildings and in industry), over the past decade, the EU accounted for a share of 23% scientific papers under Scopus[324] and 27% under Web of Science (WoS)[325]. The leading country in the number of publications is China with 34% and 32% indexed in Scopus and WoS, respectively. At EU level, Italy has produced most of the publications followed by Germany, Spain, Denmark and Sweden.

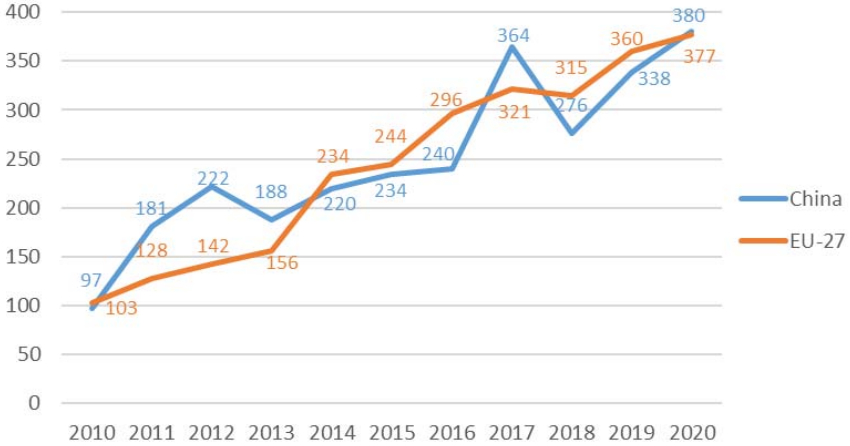
---

[323] based on the number of publications resulted by **searching 'heat pump' in title and keywords**

[324] https://www.scopus.com/

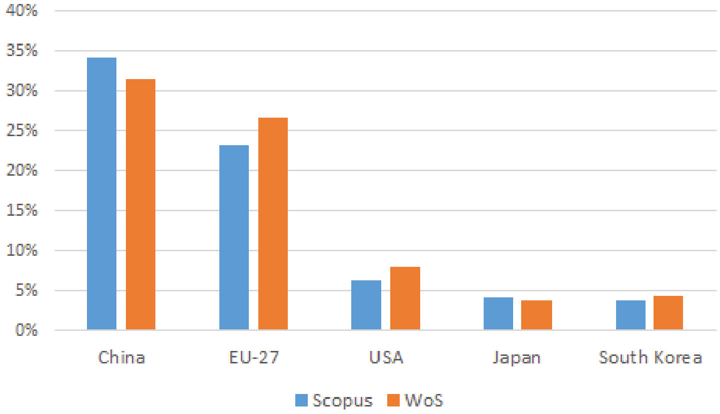
[325] https://www.webofscience.com/wos/woscc/basic-search

Figure 40: Scientific publications trends over the last 10 years



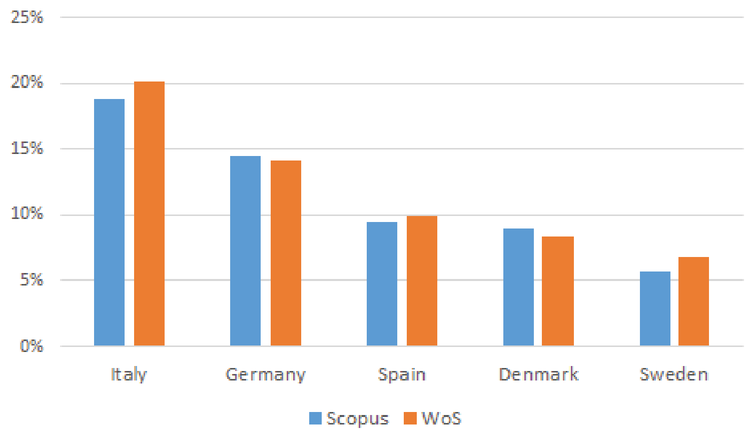
Source: WoS

Figure 41: Top 5 worldwide regions with scientific publications on heat pumps indexed in Scopus and WoS (2010-2020, based on year of publication)



Source: Scopus, WoS

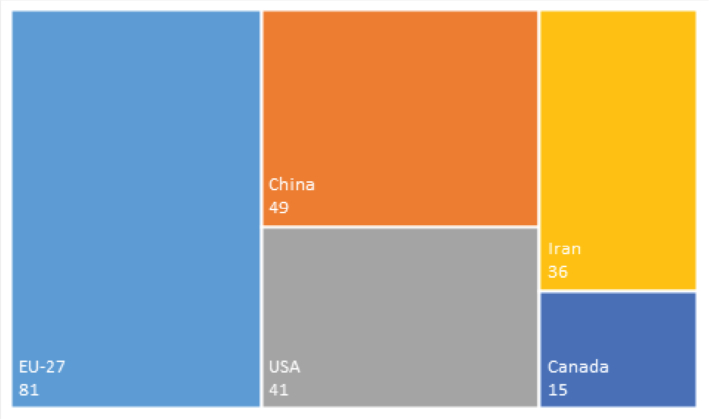
Figure 42: Top 5 EU-27 countries with scientific publications on heat pumps indexed in Scopus and WoS (2010-2020, based on year of publication)



Source: Scopus, WoS

However, as per the number of most cited scientific papers, according to Web Of Science, over the past decade, out of the highly cited[326] scientific publications on heat pump technology, more than 37% belong to the EU, followed by China with a share of 23% and the USA with almost 20%. Within the EU, the leading countries in the number of highly cited publication on heat pumps are Germany (15), Denmark (13) and Italy (12).

Figure 43: Top 5 worldwide regions in highly cited scientific publications on heat pumps (2011-2021, based on year of publication)

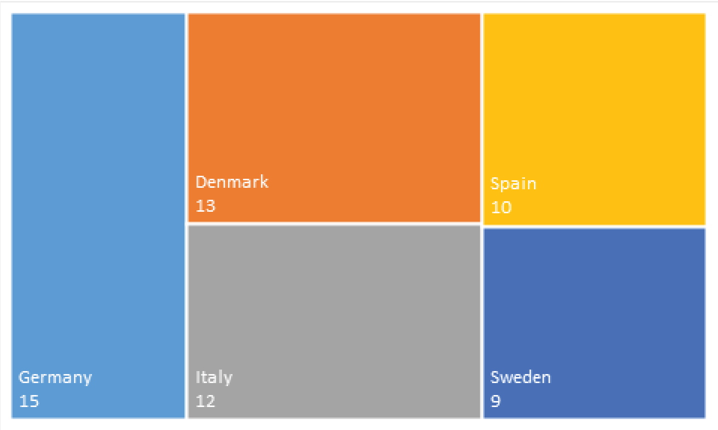


Source: WoS

---

[326] 215 publications on heat pumps in top 1% of their academic field based on a highly cited threshold for the field and publication year

Figure 44: Top 5 EU countries in highly cited scientific publications on heat pumps (2011-2021, based on year of publication)

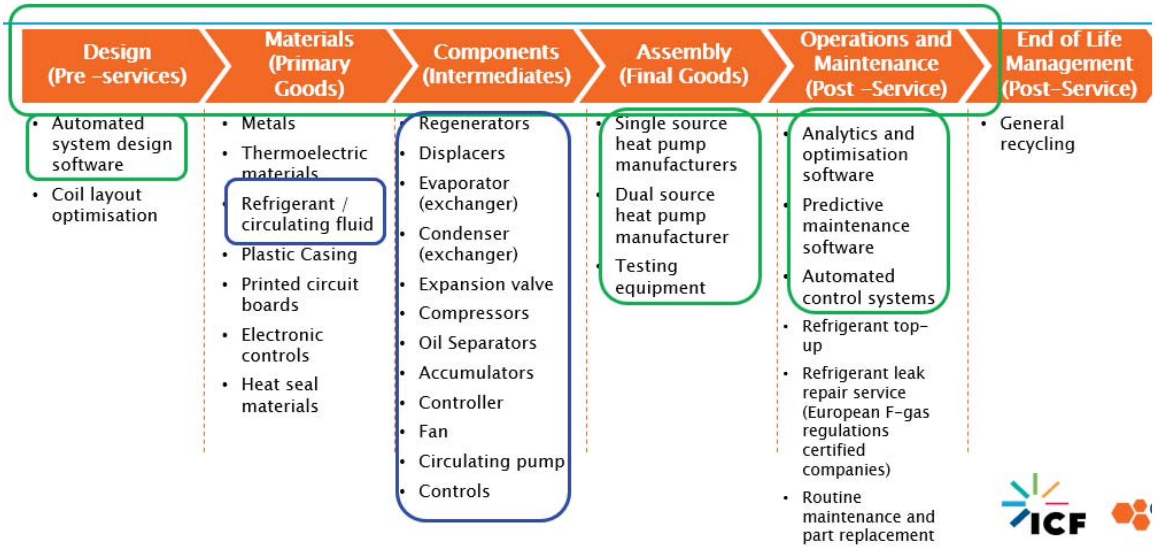


Source: WoS

16. VALUE CHAIN ANALYSIS OF THE ENERGY TECHNOLOGY SECTOR

16.1. Introduction/summary

Figure 45: Overview of value chain segments



Source: ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Final, 2020)

Based on the above value chain segments, it is in practice very complex to gather data specific to each segment. The competitiveness analysis below can therefore not differentiate the relevance of specific segments.

A. Design: the heat pump design itself will be a main contributor to improve performances, and to lower the climate/environment footprint and costs over all steps of the heat pump life-cycle.

B. Materials: mainly the working fluid (for compliance with regulations and GWP reduction), but also the reduction of use of other materials, such as metals (see section 17.4)

C. Components manufacturing: the industry will need continuous access to relevant components.

D. Assembly (final goods) and marketing/sales: efficient assembly lines are critical for reducing the units cost of heat pumps, as well as marketing and sales to ensure that consumers are aware of product performances and can purchase them via local distribution networks.

E. Operations and maintenance: the control software and engineering services, as well as the installation and after sales monitoring, performance optimisation and repair services are key for the deployment and the efficient operation of heat pumps.

F. End of life management: the adequate decommissioning and disposal or recycling of HP and their components, materials and fluids are key for their environmental footprint.

16.2. Turnover

According to EurObserver[327], the turnover of all types of heat pumps in the EU amounted to EUR 26.6 billion in 2018, growing by 18% vs. 2017, however following a decline of 25% between 2016 and 2017. The top three countries are Spain, France and Italy, mostly active in air-to-air cooling (sometimes reversible) heat pumps. This turnover data includes all types of heat pumps, including also air-to-air heat pumps used for cooling-only or for heating and cooling, which represented 86% of the number of units sold in 2019. More information can be found in section 17.1.

Table 6: Turnover - all types of heat pumps

EUR billion	2015	2016	2017	2018
Total EU	29.4	30.0	22.6	26.6
Annual growth		2%	-25%	18%
Spain	4.6	5.8	5.3	6.5
France	4.7	4.6	5.3	6.0
Italy	13.1	12.3	5.4	5.0
Germany	1.9	1.9	1.4	2.2
Sweden	2.0	2.1	1.0	1.6

Source: EurObserver

According to EHPA, the turnover from the sales of heat pumps used mainly for heating in EU21[328] amounted to EUR 8.22 bn, i.e. approximately 1/3 of the total market value (EUR 26.6 bn), which includes also the air/air cooling heat pumps.

16.3. Gross value added (GVA) growth

Data on GVA dedicated to heat pumps are generally not accessible to the public and the confidential data collected were insufficient to derive relevant conclusions.

---

[327] EurObserver- https://www.eurobserv-er.org/online-database/

[328] EHPA considers EU21: incl. CH, NO, UK and EU27 except BG, CY, EL, HR, LV, LU, MT, RO, SL.

16.4. Number of EU companies

The industrial landscape of heat pump manufacturing is very diverse and depends on the market segment. The number of companies does not reflect the relative strength of the EU vs. the rest of the world, because the sizes of the companies are very different.

Table 7: Number of Companies in Europe

Country (Top-10 EU)	Number of companies
EU (18 countries in EHPA)	**82**
Germany	20
France	13
Italy	12
Belgium	6
Netherlands	6
Spain	5
Sweden	5
Austria	3
Denmark	3
Finland	2

Source: EHPA[329]

More information on the relative strength of the EU vs. other continents can be found in section 17.2, while more information on European and global market players can be found in section 17.3.

16.5. Employment in the selected value chain segment(s)

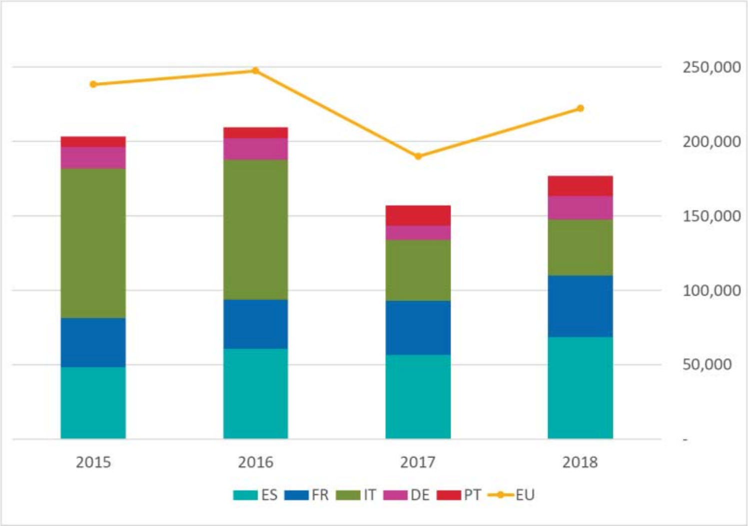
According to EurObserver[330], and mirroring turnover trends (see section 16.2), the direct and indirect jobs of all types of heat pumps amounted to 222 400 in 2018 in the EU, growing by 17% vs. 2017, rebounding after a decline of 23% between 2016 and 2017. The top three countries are Spain, France and Italy, mostly due to their activity in air-to-air cooling (sometimes reversible) heat pumps.

---

[329] https://www.ehpa.org/about/members/ Excl.: Associations and Research/Academia. CIAT (FR) added.

[330] https://www.eurobserv-er.org/online-database/ and ‘État des énergies renouvelables en Europe 2018’

Table 8: Direct and indirect jobs in Heat Pumps - EU and Top-5



Source: EurObserver

From the skills perspective, the heat pump sector employs a well-educated work force in the areas of R&D, components and heat pump manufacturing, thermo-technical engineers and geologists, installers (including drillers) and service & maintenance.

EHPA estimates approximately 88 000 full-time equivalents are necessary to maintain the current stock of heat pumps in the EU21 market.

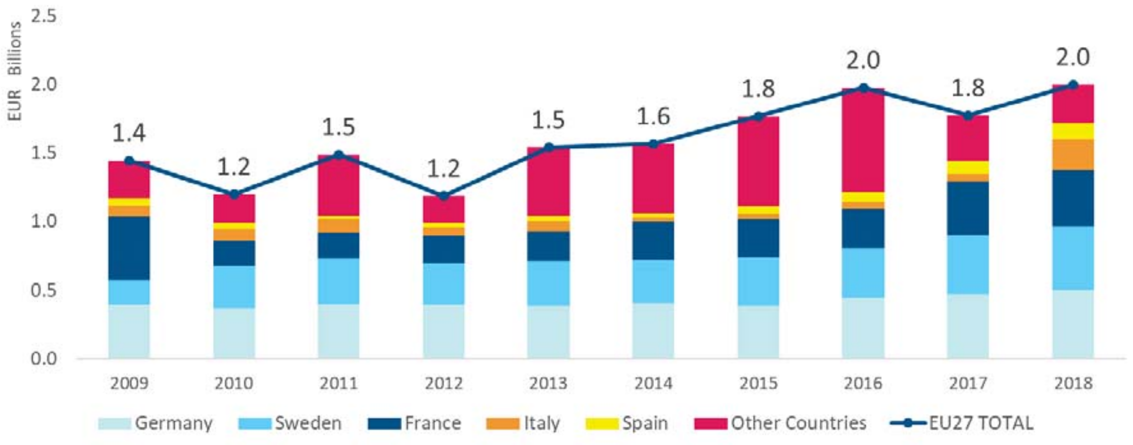
16.6. Energy intensity considerations, and labour productivity considerations

Data on energy intensity considerations, and labour productivity, dedicated to heat pumps, are not sufficiently accessible to the public to derive relevant conclusions.

16.7. Community Production (Annual production values)

The community production grew 6% per year on average over the 2013-2018 period.

Figure 46: Total production value in the EU and Top-5



Source: ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Final, 2020)

17. GLOBAL MARKET ANALYSIS

17.1. Market size in the EU and Rest of the World (RoW)

According to EurObserver, about 3.8 million heat pumps were sold during 2019 in the EU, a 12.6% growth compared to 2018.

Table 9: Heat pumps sales in the EU in 2019

Heat pumps sales in the EU	**(1000 units)**	
Air/air Air-source heat pumps	3273	86%
Air/water Air-source heat pumps	458	12%
Ground-source heat pumps	91	2%
TOTAL	**3821**	**100%**

Source 1, EurObserver Heat pumps barometer, 2020

These figures are representative of the residential and service sector markets mainly, as the medium- and high-capacity heat pump markets are much smaller (fewer than one thousand industrial and heating network heat pumps are sold annually in the EU).

Air-to-air air source heat pumps (ASHPs, for cooling only or more usually reversible) still account for most of the sales in the European market, with almost 3.3 million systems sold in 2019, a 10.4% rise vs. 2018. The three biggest markets (Italy, Spain, and France) together account for 81.2% of Europe's newly-installed reversible air-to-air systems. Air-to-air heat pumps are among the most popular technologies in the new build market because they are ideally suited to well-insulated dwellings, particularly those whose only exchanges with the outside are those permitted by their ventilation system[331].

The air-to-water ASHP market mainly caters for heating. Its sales have increased steadily since 2013 and tended to pick up since 2017. They increased by 33.0% between 2018 and 2019, with 485 831 units sold (identified in 23 EU countries), having already increased by 19.2% between 2017 and 2018. Growth in this

---

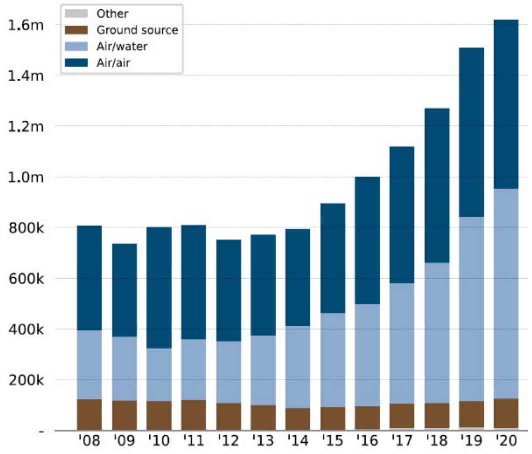
[331] EurObserver

segment during 2019 was particularly high in France (80.1%), driven by very strong incentives, Italy (37.2%), Poland (90.8%), Czechia (27.0%), and Finland (26.3%). Water-borne heat pumps are also ideal for recently- built, well-insulated houses that have underfloor heating systems or low-temperature water-filled radiators that require the water to be heated to 40-50°C. However, today's challenge for heat pump manufacturers is to increase their renovation market segment shares (by replacing oil- and gas-fired boilers) that account for the majority of heating system sales, with heat pumps that can supply the heating circuit with water at about 65°C. Houses built to older insulation standards, requiring higher temperature water heating are less suitable for heat pump technologies. In that case, it might make more economic sense to install a supplementary heating appliance or a hybrid heat pump comprising an air-to-water HP and a condensing gas boiler[332].

Likewise, the ground source heat pump (GSHP) market growth has surged, with 90 647 units sold in 2019 in the EU, an increase by 7.3% from 2018, compared to 4.5% between 2017 and 2018[333].

Considering only the heat pumps used as main heating system, the sales in EU21 (EHPA countries) reached 1.61 million units in 2020, and have been growing an average 12% annually of the last five years (see Figure 47 below).

Figure 47: Mainly-heating heat pump sales in EHPA EU21 countries



Source: EHPA report 2021

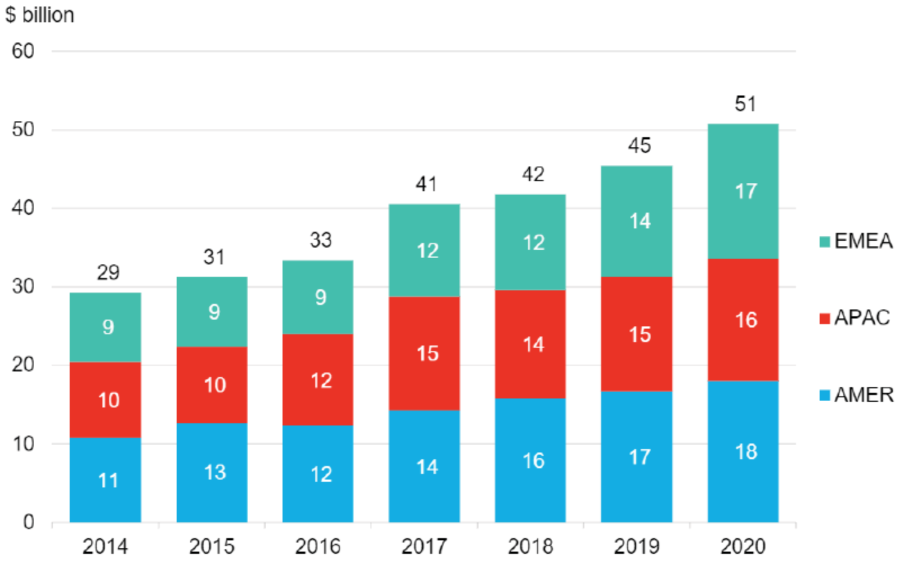
At global level, referring to Figure 48 below, the world market has been growing at an average rate of 10% per year between 2014 and 2020, while the EMEA market has been growing at 11% per year over the same period, with 14% growth in 2020, supported by subsidies and strong energy standards in Europe. The Americas still represent the biggest market, both for new buildings and oil/gas furnace replacement (+8.5%/y, 2014-2020). Growth is slower (8%) in Asia-Pacific, mainly driven by Japan and the north of China.

---

[332] EurObserver

[333] EurObserver

Figure 48: Global investment in residential heat pumps by region, calculated as sales multiplied by average cost for equipment and installation for a typical single-family home.



Source: BloombergNEF, Energy Transition Investment Trends, 2021, p19 (EMEA: Europe and Middle East, APAC: Asia Pacific, AMER: Americas)

<u>Market prospects</u>, considering only the heat pumps used as main heating system:

In the 1.5TECH scenario of the EU Long Term Strategy (LTS)[334], the electricity share in heating grows from 5% in 2015, to 14% in 2030 and 34% by 2050, in the residential sector in the EU; this means an average annual stock growth rate of +7.5% from 2015 to 2030, and +4.5% from 2030 to 2050. The trend is stronger in services buildings, as electricity share for space heating grows from 13% in 2015, to 29% in 2030 and 51% in 2050 in the EU.

According to the EU Energy System Integration strategy (ESI)[335], in the residential sector, the share of electricity in heating demand should grow to 40% by 2030 and to 50-70% by 2050 (middle scenario: 50% by 2050); this means an average annual stock growth rate of +14.9% from 2015 to 2030, and between +1.1 and +2.8 % from 2030 to 2050 (middle scenario: +2%). In the services sector, these shares are expected to be around 65% by 2030 and 80% by 2050.

According to the Sustainable Development Scenario (SDS) of the IEA[336], by 2050, two-thirds of residential buildings in advanced economies and around 40% of residential buildings in emerging market and developing economies would be fitted with a heat pump. Globally, the number of installed heat pumps would rise from 180 million in 2020 to 600 million in 2030 and 1 800 million in 2050; this represents an average annual growth rate of +12.8% between 2020 and 2030, and +5.6% between 2030 and 2050.

Based on these projections of heat pump penetration in the building heating sector, an economic model of the future heat pump market has been built to assess what the associated heat pumps production volume

---

[334] In-depth analysis in support of Long Term Strategy COM(2018) 773, fig 43, p104

[335] An EU Strategy for Energy System Integration, COM(2020) 299, p8

[336] IEA - Net zero by 2050 – May 2021, p24 and p72

could be, as well as the turnover and employment in the EU. Note that the accuracy of the model is limited by the simplifying assumptions[337]:

The model results for heat pumps production and turnover are as follows.

Based on EU-LTS scenario, the model results in a slow but sustained penetration and regular sales/turnover growth. The stock growth rate (+7.1%/y) is however below the reality of the past 5 years (+12%/y).

Based on the EU-ESI middle scenario, the model results in a very fast penetration and sales/turnover growth till 2030, followed by market saturation and sales collapse by 2040, and a slight recovery by 2050. The stock growth rate (+14.9%/y) is however above the reality of the past 5 years (+12%/y).

The future in the EU should be somewhere between these LTS and ESI scenarios, therefore a combined scenario was created in which the share of electricity in heating demand would grow from 5% in 2015, to 20% by 2030 and to 35% by 2050; this means an average annual stock growth rate of +9.7% from 2015 to 2030, and +2.8 % from 2030 to 2050 (with the conservative assumption that the HP share does not grow faster than the resistor heating share). Based on this combined scenario, the model results in a relatively fast penetration and sales/turnover growth till 2030, followed by a slower penetration progression and market maturity afterwards.

When considering the IEA-SDS scenario (at global level), the model results in fast penetration and sales growth until 2030. Afterwards, the sales continue to slightly increase until 2050.

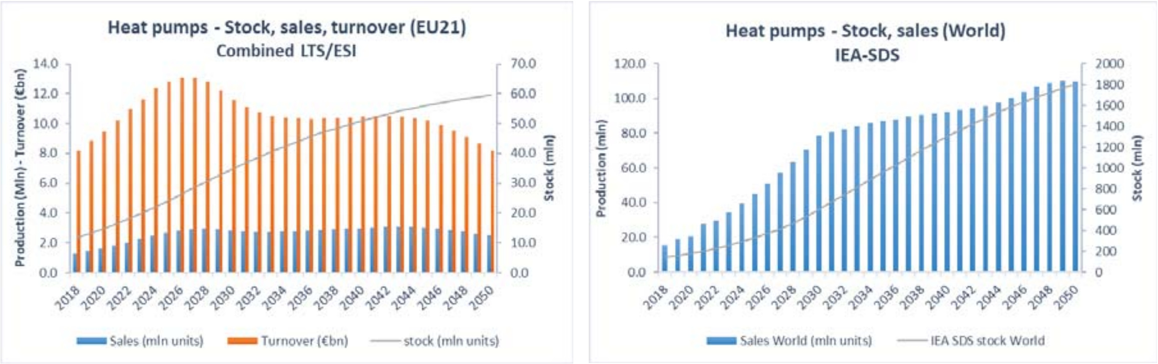
The faster penetration in the EU front-runner market is an opportunity for EU industry to grow and develop competitive production until 2030, and to capture the sustained growth at global level afterwards.

---

[337] Assumptions:

- o The baseline is the HP stock (8.5m units in 2015, 11.6m in 2018) and turnover (EUR 8.2bn, 2018) of EHPA EU21 countries, i.e. the ‘mainly-heating’ HP. For the employment, the EurObserver 2018 data (224k employees, turnover: EUR 26.8 bn) are used and the employment share (30%) for ‘mainly heating HP’ is calculated proportionally to the turnover: 224k * €8.2bn / €26.8bn = 68.7k employees
- o The HP stock grows at the same rate as the electrification share in building heating (with the conservative assumption that the resistor heating share does not grow faster than the HP share)
- o The HP stock projections in 2015 (or 2020), 2030 and 2050, have been first converted in average stock growth rates for the periods 2015(or 2020)-2030 and 2030-2050, then stock growth rate curves have been fitted to match with the real rate (in 2015 or 2020) and to avoid rate discontinuities around 2030 (because stock growth discontinuity would result in unrealistically large production discontinuity)
- o The EU industry maintains a neutral trade balance, i.e. it grows at the same rhythm as the EU market.
- o The production accounts for new installations and replacements of units after 16 to 20 years
- o The learning curve is 25%, meaning the production cost is reduced by 25% each time the cumulated capacity (=stock) is doubled. The same curve is applied to the turnover in constant EUR (no inflation).
- o The employment evolves proportionally to the industry turnover.

Figure 49: Model results for (a) EU-Combined LTS/ESI, (b) IEA-SDS scenarios



Source: own elaboration

17.2. Trade (imports, exports)

The following COMTRADE[338] table shows that the Asian countries (China, Thailand, then Malaysia, Japan, South-Korea) are world leading exporters in air conditioners, followed by America (Mexico, USA) and Europe (Germany, Italy, the Netherlands).

Table 10: Air-conditioners: imports, exports, vs world – Top-10 exporters

Trade (1000 EUR)		**Export**	**Import**	**Balance**
Reporting country	Region	2019	2019	2019
China	Asia	14,509,344	624,523	13,884,822
Thailand	Asia	4,586,779	448,419	4,138,360
Mexico	America	3,614,013	1,101,113	2,512,900
USA	America	2,368,240	8,185,454	-5,817,214
Germany	Europe	1,832,446	1,941,724	-109,278
Italy	Europe	1,656,146	1,447,898	208,248
Malaysia	Asia	1,182,538	271,391	911,147
Japan	Asia	1,102,406	2,397,769	-1,295,362
Netherlands	Europe	1,101,603	898,538	203,065
South Korea	Asia	1,099,269	727,282	371,987

Legend: Asia – orange, America – red, Europe – blue
Source: UN-COMTRADE, code 8415, ISDB Extraction date: 2021-06-23

The unbalance is already less pronounced when considering reversible air conditioners[339], where Asian countries (Thailand and China) are still leading, followed by European (Spain, UK, Italy), as can be seen in Table 11 below.

---

[338] ISDB Report: COMTRADE Trade - MS dataset. Several COMTRADE codes cover heat pumps activities. 8415 covers the air conditioning machines, of which 841581 cover the reversible air conditioners; these are mainly air-to-air heat pumps whose main function is cooling. 841861 'heat pumps, excl. air conditioning machines of heading 8415', covers the heat pumps whose main function is heating. Note that some products are reported under 841869 'Refrigerating or freezing equipment; heat pumps, other than compression type units whose condensers are heat exchangers'.

[339] COMTRADE code 841581

Table 11: Reversible air-conditioners: imports, exports vs. world – Top-10 exporters

Trade (1000 EUR)		**Export**	**Import**	**Balance**
Reporting country	Region	2019	2019	2019
Thailand	Asia	616,732	3,767	612,966
China	Asia	409,981	6,506	403,475
Spain	Europe	135,194	210,274	-75,080
United Kingdom	Europe	120,564	58,330	62,234
Italy	Europe	110,834	96,949	13,886
USA	America	88,412	215,857	-127,445
Austria	Europe	77,733	45,231	32,502
Malaysia	Asia	41,382	5,276	36,105
Japan	Asia	28,558	5,429	23,129
Germany	Europe	27,469	76,300	-48,832

Legend: Asia – orange, America – red, Europe – blue
Source: UN-COMTRADE, code 841581, ISDB Extraction date: 2021-06-23

When considering mainly-heating heat pumps[340], European countries (France, Germany, then Italy, Austria, Belgium and Spain) are leading world exports, followed by Asia (China, Japan), as can be seen in Table 12 below.

Table 12: Mainly-heating heat pumps: imports, exports vs. world – Top-10 exporters

Trade (1000 EUR)		**Export**	**Import**	**Balance**
Reporting country	Region	2019	2019	2019
France	Europe	574,197	199,020	375,176
Germany	Europe	311,563	227,540	84,023
China	Asia	246,316	10,063	236,253
Sweden	Europe	212,678	37,643	175,035
Italy	Europe	163,291	117,316	45,975
Japan	Asia	120,799	9,927	110,872
USA	America	77,299	36,575	40,724
Austria	Europe	72,841	80,229	-7,388
Belgium	Europe	72,160	91,734	-19,574
Spain	Europe	47,641	77,410	-29,769

Legend: Asia – orange, America – red, Europe – blue
Source: UN-COMTRADE, code 841861, ISDB Extraction date: 2021-06-23

The tables below present the imports and exports to and from the EU for code 841861 - *heat pumps, excluding air conditioning machines of heading 8415*.

In 2020, approximately three quarters of EU Member States' imports and exports (resp. EUR 1.5 billion and EUR 1.8 billion) were traded inside the EU (resp. EUR 1.1 billion and 1.4 billion). The extra EU imports have been growing steadily and significantly, at an average annual rate of 14% between 2010 and

---

[340] COMTRADE code 841861

2015, and 21% from 2015 to 2020, while the exports have remained stable (+2%/y from 2010 to 2015, -0.5% from 2015 to 2020) and are mainly directed to the rest of Europe (EU excluded).

Table 13: 'Heat pumps, excluding air conditioning machines' EU global imports and exports

Trade value (1000 EUR)	Import	Import	Import	Import	Import	Import	Export	Export	Export
Partner	2010	2016	2017	2018	2019	2020	2010	2016	2020
World	583,314	841,575	944,026	1,136,641	1,349,263	1,520,282	1,209,754	1,298,034	1,810,416
EU27	489,869	649,986	716,295	873,415	979,362	1,064,947	822,874	904,533	1,395,102
Extra EU27	93,445	**191,589**	**227,731**	**263,226**	**369,901**	**455,335**	386,880	**393,501**	**415,314**
Extra EU27 annual growth		**8%**	**19%**	**16%**	**41%**	**23%**			
Extra EU27 5y-aver growth						**21%**			**-1%**
Asia (all countries)	64,949	149,859	182,201	210,111	289,344	354,606	58,038	80,911	37,831
America (all countries)	6,560	2,711	2,413	2,885	2,837	1,360	25,181	31,847	27,157
Africa (all countries)	1,214	214	5	10	54	3	38,515	29,064	23,360
Oceania And Polar Regions	14	28	17	24	44	71	10,155	15,952	20,770
Rest of Europe (EU27 excl.)	20,710	36,585	41,459	48,378	77,604	101,218	253,981	239,139	298,758

Source: Eurostat, COMEXT, HS841861, ISDB Extraction date: 2021-06-14

The imports into the EU come mainly from Asia: China, then Japan, Malaysia and South-Korea, as can be seen in Table 14 below.

Table 14: 'Heat pumps, excluding air conditioning machines' EU imports / exports vs. Asia

Trade value (1000 EUR)	Import	Import	Import	Import	Import	Import	Export	Export	Export
Partner	2010	2016	2017	2018	2019	2020	2010	2016	2020
Extra EU27	93,445	**191,589**	**227,731**	**263,226**	**369,901**	**455,335**	386,880	**393,501**	**415,314**
Asia (all countries)	64,949	149,859	182,201	210,111	289,344	**354,606**	58,038	80,911	37,831
China	45,346	93,614	107,823	133,909	185,929	**243,545**	10,946	8,461	8,940
Thailand	1,459	14,144	20,619	29,454	46,441	**45,460**	878	1,556	329
Japan	9,502	16,123	20,683	20,700	29,175	**33,917**	3,169	7,192	544
South Korea	784	3,884	8,591	82	959	**3,244**	966	3,121	307

Source: Eurostat, COMEXT, HS841861, ISDB Extraction date: 2021-06-14

Extra-EU exports mainly go to the rest of Europe (and Israel)[341], as shown in Table 15 below.

Table 15: 'Heat pumps, excl. air conditioning machines' EU imports / exports vs. rest of Europe

Trade value (1000 EUR)	Import	Import	Import	Import	Import	Import	Export	Export	Export
Partner	2010	2016	2017	2018	2019	2020	2010	2016	2020
World	583,314	841,575	944,026	1,136,641	1,349,263	1,520,282	1,209,754	1,298,034	1,810,416
Extra EU27	93,445	**191,589**	**227,731**	**263,226**	**369,901**	**455,335**	386,880	**393,501**	**415,314**
Rest of Europe (EU27 excl.)	20,710	36,585	41,459	48,378	77,604	101,218	253,981	239,139	**298,758**
Switzerland	12,079	7,418	7,510	8,204	10,262	28,816	80,221	84,900	**129,555**

---

[341] Liechtenstein, Norway, Russia, Switzerland, Turkey, Ukraine, United Kingdom, and also Israel

United Kingdom	5,175	26,292	31,283	38,298	64,689	67,491	98,870	87,879	**96,142**
Norway	236	767	1,744	529	245	595	26,245	26,506	**27,085**
Russia	5	10	34		28	8	17,136	13,067	**15,234**
Liechtenstein	253	246	96	101	78	271	4,512	6,231	**11,255**
Turkey	773	1,805	488	322	311	326	18,292	5,969	**9,851**
Israel	38	45	304	736	1,972	3,683	5,859	11,375	**5,592**
Ukraine	2,152	2		187	18	30	2,846	3,211	**4,044**

Source: Eurostat, COMEXT, HS841861, ISDB Extraction date: 2021-06-14

The trade balance has been degrading from a surplus of EUR 293 million in 2010, to 249 million in 2015,to a deficit of EUR 40 million in 2020. The source of the deficit is mainly towards Asia, in particular China, Japan and Thailand.

Table 16: 'Heat pumps, excl. air conditioning machines' EU trade balance vs. Asia

Trade value (1000 EUR)	Balance	Balance	Balance	Balance	Balance	Balance	Balance
Partner	2010	2015	2016	2017	2018	2019	2020
World	626,440	497,167	456,459	508,751	406,553	389,512	290,134
Extra EU27	293,435	**248,855**	**201,911**	**186,234**	**139,772**	**47,083**	**-40,021**
Rest of Europe (EU27 excl.)	233,271	220,342	202,554	199,132	208,957	203,445	197,539
Asia (all countries)	-6,911	-46,866	-68,948	-106,273	-146,190	-242,389	**-316,775**
China	-34,399	-78,247	-85,154	-92,403	-126,615	-179,991	**-234,605**
Thailand	-582	-13,293	-12,589	-19,492	-28,432	-45,882	**-45,131**
Japan	-6,332	-5,838	-8,931	-15,013	-20,044	-28,409	**-33,373**
South Korea	182	-403	-763	-5,677	951	-586	-2,937

Source: Eurostat, COMEXT, HS841861, ISDB Extraction date: 2021-06-14

The table below shows the exchanges on the '*air-conditioning, reversible heat pumps*' code 841581, mostly intra-EU, with decreasing extra-EU imports and exports, but a significant and recurrent extra-EU trade deficit.

Table 17: 'Air conditioning, reversible heat pumps' EU global imports and exports

Trade value (1000 EUR)	Import	Import	Import	Import	Export	Export	Export	Export
Partner	2010	2016	2019	2020	2010	2016	2019	2020
World	1,012,020	1,091,591	1,186,661	1,027,375	596,771	582,067	629,194	590,057
EU27	417,590	468,279	597,698	529,676	401,654	418,354	505,600	476,198
Extra EU27	594,430	**623,312**	**588,963**	**497,699**	195,117	**163,713**	**123,594**	**113,859**
Rest of Europe (EU27 excl.)	45,228	77,992	138,080	151,995	96,657	86,363	61,903	63,760
Asia (all countries)	542,577	531,405	439,840	337,558	43,863	28,415	22,529	13,772
America (all countries)	7,202	13,251	9,813	6,632	15,219	14,685	10,947	6,400
Africa (all countries)	63	124	182	260	27,733	24,048	14,171	13,900
Oceania And Polar Regions		25	19	0	1,295	3,930	3,284	3,243

Source: Eurostat, COMEXT, HS841581, ISDB Extraction date: 2021-06-14

17.3. Global market leaders vs. EU market leaders (market share)

The industrial landscape of heat pump manufacturing is very diverse and depends on the market segment.

As demonstrated by the trade exchanges in section 17.2, the air-to-air air conditioning heat pumps are dominated by global leaders, mainly in Asia (China, Thailand) and North America (Mexico, USA), with some smaller European manufacturers. The market for reversible air conditioners is slightly more balanced, with global leaders in Asia exporting worldwide, and European manufacturers supplying mainly the European market. The market of air-to-water and ground source heat pumps is led by EU countries.

Still, when only considering ‘mainly-heating’ heat pumps (air conditioners excluded), the industrial landscape in EU consists of a large number of SMEs – supplying mainly national markets - and a few larger companies (but smaller than Asian competitors active also in air conditioners), supplying mainly European countries (EU and non-EU).

In recent years, a few major consolidations have taken place between the main heat pump players. In 2016, Midea (CHN) acquired majority in the Italian Clivet group. In 2018, the German group Stiebel Eltron took over Danfoss Värmepumpar AB. In 2019, Hisense acquired Slovenian Gorenje[342]. In 2020, the Swedish company NIBE Industrier AB acquired the German manufacturer Waterkotte[343].

Figure 50: Global players in the EU and in the World

Region	Company (Country)
EU	IDM (AT)
	Daikin Europe (BE)
	Bosch Thermotechnology, (DE) Emerson (DE) Grundfos (components) (DE) Panasonic (DE) Stiebel Eltron (DE+SE) Valliant (DE+FR) Viessmann, (DE)
	Hitachi (ES)
	CIAT (FR) EDF-Electricité de France (FR)
	Oilon (FI)
	AERMEC (IT), Clivet (> Midea) Galetti Group (IT)
	BDR Thermea (NL+FR, DE),
	Nibe Industrier (SE+FR, DE, AT),
Europe non-EU	CTA AG (CH), Mitsubishi Electric (UK)
Asia	Gree, Haier, Hisense, Midea, Phnix (CHN)
	Corona, Daikin, Hitachi, Mitsubishi Electric, Panasonic, Rinnai, Sanden (JAP)
	LG (S-KOR)

---

[342] ITP.net, Hisense acquires Slovenian home appliances firm Gorenje, 7 April 2019

[343] EurObserver-HP-baro-2020 and EHPA

Region	Company (Country)
	Ecotec Systems Ltd, Energy Master, J-7 Engineering Company Limited, Taitronics Industries Co. Ltd. (Thailand)
America (USA)	Carrier (part of UTC), Honeywell, Johnson Controls (subsidiaries in DK, FR), Ingersoll Rand/Trane (subsidiary in BE)

Source: Own elaboration

17.4. Resource efficiency and dependence

Heat pumps are made of different types of metal. Copper or aluminium tubing, critical ingredients in many heat pump components, provide superior thermal properties and a positive influence on system efficiency. Various components in a heat pump are usually comprised of stainless steel and other corrosion-resistant metals.

The working fluid is typically a refrigerant with specific thermodynamic properties like HFC, CFC, HCFC, ammonia, methane, propane or water. Note that the use of fluorinated gasses is limited by the F-Gas regulation, based on their global warming potential.

Apart for common materials such as steel, copper, aluminium and zinc, heat pumps have no specific vulnerabilities[344].

Table 18: Vulnerability in the heat pump technology supply chain

	Supply chain stage	Vulnerable element	Import dependency	Know-how/specialisation	Market concentration	Easy of substitutability	Price stability	Criteria score
			Import reliance	Patents share / other	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation	
Heat Pumps	raw materials	Stainless steel	42% (tubular) Net importer in 2018		44% (Extra-EU) (RU, TR, CN, UK)		21%	Vulnerable
		Copper	42%	NA	58% (PL, CL, PE, ES	Medium by aluminium		Vulnerable
		Aluminim	64%	NA	79% (AU, CN, GN, BR)	Medium by cooper	22%	Vulnerable
		Gold						
		Zinc	61%	NA				Vulnerable
	Components / Equipment / Assembly	Printed Circuit Boards						Not vulnerable

Legend: green – raw materials relevant/used in a technology (does not necessarily indicate problems);
light orange – raw material required, but no technology-specific vulnerability identified;
dark orange – raw materials relevant/used in a technology and identified as vulnerable

Source: Trinomics, 2021

18. SWOT AND CONCLUSIONS

18.1. Strengths

Europe is a recognised market leader in the ‘mainly-heating‘ heat pumps segment, especially in the bigger size heat pumps for the ‘light commercial’ and ‘heat networks’ segments. In the smaller units for residential

---

[344] Trinomics, Study on resilience of the critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis, 2021

segment, the global market leaders are however in Asia when looking at air-air heat pumps, while European manufacturers are still technology leaders for air-water, ground-water and brine/water-water heat pumps.

Over the period 2015-2017, 42% of global high-value inventions linked to ‘mainly-heating heat pump for building applications’ were filed in the EU, followed by Japan (20%), US (8%), S-Korea (7%), China (4%).

18.2. Weaknesses

In the EU, the heat pump sector turnover decreased by 23% between 2015 and 2017, but recovered partly (+17%) in 2018. Employment was shrinking until 2017 (-23% versus 2016), but similarly partly recovered (+17%) in 2018.

In several Member States, the heat pump systems are not yet sufficiently cost-effective compared to other technologies, because of high upfront investment costs (heat pump costs, installation costs, e.g. drilling cost for geothermal), the unfavourable price ratio between electricity and gas, partly due to the higher taxes and charges on electricity and the lack of internalisation of the external cost of GHG emissions in the gas/oil prices.

The high costs are partly attributable to a high level of fragmentation and nationally focused markets at least in some segments; despite EU manufacturers *collectively* offering a wide range of performant products, these are rarely easily available in all Member States. Moreover, national laws differ, notably on product approval requirements (e.g. noise, efficiency), as well as application and permitting rules (e.g. land and water environmental laws for geothermal). The EU market fragmentation increases transaction and distribution costs, reduces competition in both the manufacturing and installation parts of the value chain.

Due to the European industrial structure consisting of many SMEs and fewer big players, the R&D capacities are limited to address simultaneously the adaptation to new regulations and the improvement of performances/cost of the products.

The deployment of heat pumps is hampered by the lack of building experts and qualified heating/cooling installers (including drillers for geothermal) to provide customer information and integrated solutions, and ensure optimal operation of heat pumps.

18.3. Opportunities

The European heat pump market has been growing steadily. Current deployment is far below potential, as the decarbonisation of the heating sector requires a much faster uptake of heat pumps in the EU, in order to contribute effectively to 2030 and 2050 European climate goals.

Economies of scale in manufacturing and installation are to a very large extent still underexploited.

Smart grids create opportunities for heat pumps as an intraday grid balancing mechanism, to compensate for the renewables variability. There are opportunities for new business models to share the value of this flexibility with heat pump owners.

Developments in digitalisation and building management systems can maximise the self-consumption of other renewables and optimise heat pumps drive usage together with local thermal or electrochemical energy storage.

18.4. Threats

The EU imports of ‘mainly heating’ heat pumps have been growing, at an average annual rate of 21% from 2015 to 2020. As a consequence, the trade balance between the EU and the rest of the world has been degrading from a surplus to a deficit.

If EU manufacturers maintain focus on high-end, costly products and do not develop more performant sales and installation business models, the potential for growth might be met with imported products of increasing quality by players establishing effective distribution channels and models.

18.5. Conclusions

Heat generation by HP has been growing at +11.5%/y over the last 5 years in the EU. This trend is to increase, as a consequence of EU Green Deal policy, where the electrification of heating (based on decarbonised electricity) is to contribute to the building sector path to climate neutrality.

Asia and - to a lesser extent - America are dominating the residential air conditioning market[345]. The unbalance is already less pronounced when considering reversible air conditioners[346] which can operate also in heating mode. When considering ‘mainly-heating heat pumps’[347], European countries are leading world exports.

However, over the last 5 years, the EU market growth of ‘mainly-heating heat pumps’ has been captured by imports from Asia, growing at an average annual rate of 21% from 2015 to 2020. As a consequence, the trade balance has been degrading from a surplus of EUR 249 million in 2015 to a deficit of EUR 40 million in 2020.

Based on a combination of projections from the EU long-term strategy and the energy system integration strategy for electrification in the building heating sector, sales of heat pumps are expected to increase rapidly through 2030 in the EU, in line with higher ambition contained in the policy package presented on July 2021 to accelerate the transition through in 2030, followed by a slower penetration progression thereafter. The faster penetration in the EU front runner market is an opportunity for EU industry to grow and develop competitive production till 2030, then to seize the sustained growth globally, projected by the IEA sustainable development scenario.

In several Member States of the EU, the Heat-pump systems are not yet sufficiently cost-effective compared to other technologies, because of high upfront investment costs and the unfavourable price ratio between electricity and gas, partly due to the higher taxes and charges on electricity and the lack of internalisation of the external cost of GHG emissions in the gas/oil prices.

The high costs are partly attributable to a high level of fragmentation and nationally focused markets; especially in the residential market, the EU companies are in many cases proposing good products, but serving mostly their local/national market. In some cases, national laws differ, notably on product approval requirements and permitting rules. Better marketing and the development of more performant distribution networks in the EU and outside, and potentially more cooperation and alliances with partners with relevant competences and capabilities, would contribute to increase the sales, size and competitiveness of EU companies.

---

[345] UN-COMTRADE 8415 ‘air conditioning machines’, refer to section 3.2 for more details

[346] UN-COMTRADE 841581 ‘air conditioning machines incl. a valve for reversal "reversible heat pumps’

[347] UN-COMTRADE 841861 ‘heat pumps, excluding air conditioning machines of heading 8415’

In parallel with the development of distribution networks, the growing sales must be supported by more building experts and skilled installers, who will provide the right support to customers in the heating system design phase; install and maintain the heat pump for optimal performances; and dispose the systems at end of life.

The adaptations to evolving EU climate and environmental regulations and strategies are competing with the improvement of performances/cost of the products, in the small, medium or large enterprises of the EU, where R&D capacities are limited; they nevertheless offer opportunities for industry to propose innovative products, such as for example using heat pumps as an intraday grid balancing mechanism to compensate for the renewable energies variability.

The EU is a leader in scientific publications on heat pumps of all types; the EU is also leading in high value inventions in the 'mainly-heating heat pumps for building applications'. Building on this knowledge and innovation base, the EU industry has the capacity to propose innovative products in the following areas.

- The integration of the heat pumps in the larger system is necessary for optimizing the use of local renewable generation and storage, for contributing to electricity grid flexibility, for managing the heat pump performance based on electricity price and weather forecasts, and for remote or self-inspection of systems. Better interfaces and standards will be needed, as well as more digitalisation and artificial intelligence.
- The development of very compact, highly integrated and silent units, leading also to cost savings, would open new segments such as apartment heat pumps
- Improved solutions with higher supply temperatures (55 – 70°C) would allow direct replacement of boilers in buildings that are not fully renovated.
- The further development of multi-functional units including heat and cold recovery would improve the efficiency of systems in commercial buildings or buildings of mixed occupation.
- The circularity of heat pumps can be enhanced by design for improving their lifetime, repairability, upgradability and recyclability. Full life cycle analysis data for heat pumps will be required for next-generation carbon accounting in order to provide easy-to-use indicators expressing the carbon content of heating and cooling systems in gCO2/kWh of hot/cold delivered.

EUROPEAN
COMMISSION

Brussels, 26.10.2021
SWD(2021) 307 final

PART 4/5

COMMISSION STAFF WORKING DOCUMENT

Accompanying the document

REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

Progress on competitiveness of clean energy technologies
6 & 7 - Batteries and Hydrogen Electrolysers

{COM(2021) 950 final} - {COM(2021) 952 final}

BATTERIES

INTRODUCTION

Batteries are a key enabling technology to reap the benefits of electrification, in a cost effective manner. At utilisation stage, batteries are the most energy efficient storage technology: most advanced batteries have a round trip efficiency of just around 95%[348,349]. This contributes to the overall high energy efficiency of battery electric transport modes of 77%[350] or higher: EVs convert over 77% of the electrical energy from the grid to power at the wheels. Conventional gasoline vehicles only convert about 12%–30% of the energy stored in gasoline to power at the wheels[351].

Because the transport sector is the primary market for batteries, this report generally puts focus on lithium-ion batteries for electric vehicles (EV). However, other end uses, such as stationary energy storage are of increasing importance and have potential to develop beyond lithium based technologies, with the possibility of increasing sustainability and value chain security. Therefore, where possible, indicators in this report will also assess other battery technologies and storage end uses.

19. TECHNOLOGY ANALYSIS – CURRENT SITUATION AND OUTLOOK (EU-27)

19.1. Technology maturity status

Even in 2020, most batteries brought on the market (in terms of electricity storage capacity) were still lead-acid batteries[352] and their production continues to benefit from moderate growth of around 4% per year[353]. These are mainly used in conventional cars or to provide a backup for uninterrupted electricity supply in case of unforeseen outages. The EU has a strong position in this market, with a turnover of over EUR 7 billion[354], and a net-export[355]. Europe accounts for ~20% of world-wide supply (around 75 GWh in Europe).

EU production of lithium-ion batteries is still far from the level of the lead-acid battery market. Still, it is a dynamic sector and the e-mobility boom is now leading to significant growth of lithium-ion production thanks to their superior energy density.

---

[348] US National Renewable Energy Laboratory, Energy Storage, Days of Service Sensitivity Analysis, 2019.

[349] Lithium ion battery test centre, 2021. https://batterytestcentre.com.au/project/lithium-ion/

[350] Transport & Environment, How to decarbonise European transport by 2050, 2018.

[351] US DoE: All-Electric Vehicles (fueleconomy.gov)

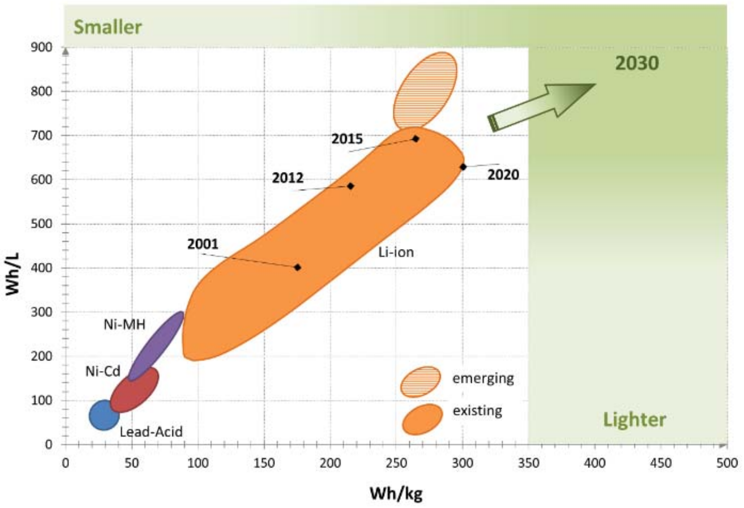
[352] EUROBAT, Lead based battery technologies, 2021.

[353] Avicenne energy, EU battery demand and supply (2019-2030) in a global context, 2021.

[354] Ibid.

[355] SWD(2019) 1300 final.

Figure 1 Energy density of lithium-ion batteries at cell level over recent years



Source: JRC, 2020[356]

Various battery chemistries exist today and are being further developed. These battery chemistries may differ depending on whether the application focus is mobility or stationary usage. In 2020, Batteries Europe technology platform[357] published a strategic research agenda for the entire batteries value chain. In 2021 it provided detailed technology road-maps for all segments of the value chain as well as guidance on cross-cutting issues such as safety, sustainability, digitalisation, and skills.

19.1.1. Battery technology and e-mobility

In e-mobility space, technology development mostly focusses on lithium-ion chemistries. Today, lithium-ion batteries with lower energy density such as lithium iron-phosphate batteries are typically used e.g. in city busses while “generation 3a” lithium-ion[358] batteries are used in the most performant electric vehicles. Iron-phosphate batteries are increasingly used in entry-level and cheaper passenger cars, including by leading producers such as Tesla and BYD, and soon also Volkswagen[359]. Such batteries are not dependent on scarce and price-volatile raw materials like cobalt and nickel. They also have some other advantages in their intrinsic characteristics, like, e.g. higher safety or cycle-life durability.

At the same time long-haul truck sector and even more so - the aviation sector (air taxis, commuter planes, hybrid planes) require batteries with much higher energy density than today’s state of the art. In this respect, lithium-ion technology still offers considerable untapped potential: energy density can roughly be doubled and exceed 450 Wh/kg when Generation 4 batteries get commercialized[360].

---

[356] Updated from Strategic Energy Technology (SET) Plan: At the heart of Energy Research and Innovation in Europe. SET PLAN 10th anniversary 2007-2017; doi:10.2777/476339 (2017)

[357] https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe_en

[358] E.g. batteries with cathode ranging from NMC622 to NMC 811 and carbon graphite anode + silicon content (5-10%).

[359] Techcrunch (Aria Alamalhodaei), What *Tesla's bet on iron*-based batteries means for manufacturers, July 28, 2021

[360] European Technology and Innovation Platform, Batteries Europe, Strategic Research Agenda for batteries 2020.

According to the BNEF 2021 EV outlook[361], average battery energy density of EVs is currently rising at 7% per year.

Lithium-ion cells can usually be quite small cells (e.g. diameter 21 mm x length 70 mm) and are packed in thousands in an EV. Mass-produced prismatic and pouch cells for EVs are generally bigger (e.g. 168 mm x 255 mm x 42 mm). Such batteries are packed in hundreds in an EV. A trend towards larger and prismatic cells could be identified[362] for example, Tesla/Panasonic has introduced the next generation of cylindrical cells that measures 46MM x 80mm.

Ongoing innovation focusses on advanced materials for lithium-ion technology. Innovation areas include use of graphene, silicon anodes, solid state electrolytes, room-temperature polymer electrolytes, and big-data-driven component recycling/repurposing techniques. In solid-state batteries (Generation 4), both the electrodes and the electrolytes are solid state. They can potentially be made thinner, more flexible, contain more energy per unit weight than conventional lithium-ion batteries while being safer at the same time. Their commercialisation would represent the next major mile-stone in development of EV batteries. The currently open Horizon Europe call[363] targets TRL6 for solid-state lithium batteries. In parallel, development of the current lithium-ion technology and post- li-ion technologies take place. Another technology that should be observed is lithium-sulfur, however recently the companies focusing on this technology has dropped it (Sion) or entered bankruptcy (OXIS Energy).

19.1.2. Battery technology and stationary storage

Given the economies of scale related to the rise of e-mobility, lithium-ion batteries are also increasingly used for stationary electricity storage and have reached a market share of around 90% (if UPS batteries are not counted)[364]. There are projects focused on tailoring lithium-ion batteries to the needs of stationary storage sector in terms of cost, number of cycles, etc. In stationary storage sector the trend towards increasing use of iron phosphate type of lithium-ion batteries (i.e. cobalt and nickel- free batteries) is even more pronounced as energy density has less importance and price sensitivity is higher[365].

Lithium-ion batteries are viable in short-duration applications where services can be stacked and adapted to market pricing (e.g. hourly balancing, peak shaving and ancillary services), but are less cost effective for longer duration storage (above 4-6 hours). There are cases of 2nd life EV batteries being used for stationary storage. Most of these installations relate to research and innovation projects.

There are a variety of other technologies on the market, including well-established lead-acid[366] and nickel metal hybrid technologies[367].

Redox flow batteries are one of the main lithium-ion battery competitors currently approaching the market[368]. Flow batteries offer a unique advantage compared to traditional batteries, because the power

---

[361] BloombergNEF, Electrical Vehicle Outlook 2021, 2021.

[362] World Electricle Vehicle Journal, 10 December, 2020.

[363] HORIZON-CL5-2021-D2-01-03

[364] Energy Storage News (Andy Colthorpe), China's energy storage deployments for first nine months of 2020 up 157% year-on-year, 2020.

[365] Greentechmedia (Mitalee Gupta), A New Battery Chemistry Will Lead the Stationary Energy Storage Market by 2030, August 20, 2020

[366] Research and Markets, Global Lead Acid Battery Markets, 2016-2020 & 2021-2026 - Growing Digitalization has Created an Enormous Demand for UPS in the Workforce, 2021.

[367] See e.g. https://www.nilar.com/

[368] Daniele Gati, IDTechEx Overview of the Redox Flow Battery Market, 2021.

(kW) rating of the system is based on the power stack size selected, and the energy (kWh) capacity is independently selected based on the storage tank size and volume of electrolytes in the tanks. In principle, this means that any combination of energy and power can be configured.

The gradually maturing sodium-ion battery technology is gradually entering the market[369], yet has a good chance to become the next generation of small-scale storage technology. Unlike lithium batteries, they don't require increasingly scarce cobalt[370] nickel nor lithium, and copper might be replaced with less costly aluminum. They are safer and easier in transportation. Sodium-ion batteries could ultimately compete with lithium-ion batteries also in the grid scale applications, home energy storage or backup power for data centres, where cost is more important than size and energy density. Energy density improvements would increase these batteries' relevance for the transport sector[371]. In mid-2021 one of the leading Chinese producers of lithium-ion batteries, CATL, unveiled its intention to set up by 2023 a supply chain for newly-developed sodium-ion battery, together with its battery pack solution. The latter enables the integration of sodium-ion cells and lithium-ion cells into one pack targeting the segment of low cost electric vehicles market[372]. A trend to be monitored.

Such alternative technologies to lithium-ion can offer cost-efficient and sustainable solutions not depending on critical raw materials. The extraction of lithium is largely limited to a few places in the world and linked to geopolitical risks, while sodium is an abundant resource.

19.2. Capacity installed

Over 90% of clean energy transition-related additions to battery capacity in EU were related to e-mobility in 2020[373]. At the same time, stationary batteries are normally used much more intensively, for many more cycles, thus providing much higher energy throughput per installed capacity. The extreme case is batteries used in frequency regulation which can be in continuous charge/discharge cycles. Stationary batteries will play an important role in supporting fast-charging of EVs.

19.2.1. Capacity installed: batteries for clean energy transition in transport

19.2.1.1. Car sales

Only about 17 thousands electric cars were on the world's roads in 2010[374] and just few of them in the EU. Just 10 years later, EVs hit historic highs with 1 045 000 cars sold in the EU in 2020 representing 10.5% of the market share (an increase from 3% market share in 2019)[375]. This was driven in part by enhanced support to acquisition of EVs. Public opinion and consumer choice are also driven by some Member States announcing bans on conventional car sales as early as 2030[376]. The European Commission, in turn, proposed that only zero-emission cars could be sold in the EU as of 2035. The number of EVs on the road doubled to more than two million in the EU from end-2019 to end-2020, an

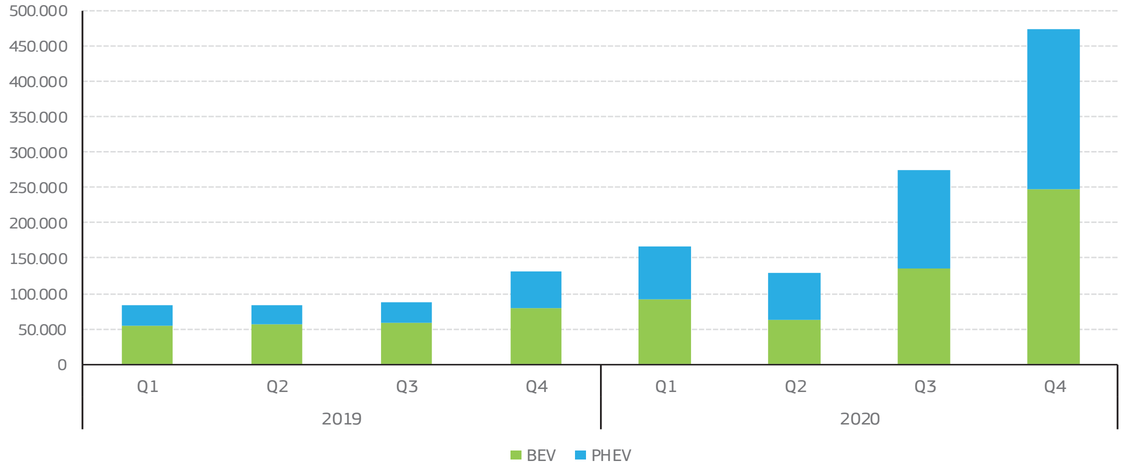
---

[369] Brand Essence Research, Sodium Ion Battery Market by Product Type, By End Use, Forecast to 2027 and Analysis 2019-2025, 2021.
[370] Paul Hockenos, In Germany consumers embrace a shift to home batteries, Yale Environment 360, 18 March 2019.
[371] Bridie Schmidt, Researchers say the salty sodium battery as good as lithium-ion, The Driven, 3 June 2020.
[372] Reuters, China's CATL unveils sodium-ion battery - a first for a major car battery maker, 29 July 2021
[373] Derived from ACEA data on EV sales and EMMES data on stationary storage deployments (excluding pumped hydro)
[374] IEA, Global EV outlook 2020, 2020.
[375] Transport and Environment, CO2 targets propel Europe to 1st place in e-mobility race, 2021.
[376] DK, IRL, NL, SE, SI and a number of non-EU countries: see page 47 of IEA Global EV outlook 2021.

equivalent of more than 60 GWh storage capacity given an average battery capacity of 55 kilowatt-hours (kWh) for BEVs and 14 kWh for PHEVs[377].

While somewhat fewer EVs were sold in the EU than in China (1.2 million EVs[378]), the share of EV sales in the EU was significantly larger (twice higher EV share in the last two quarters of 2020)[379].

Figure 2 Quarterly EV sales in EU



Source: ACEA, 2020

Policy support was strong as 2020 was an important target year in the EU for emissions standards: 95 g CO_2/km for cars and 147 g CO_2/km for vans[380]. Purchase incentives increased, notably in Germany[381]. Germany had higher EV sales (395 000) than the entire US (295 000), where only about 2% of sold vehicles were electric. This will likely change with a new US administration and its different stance on decarbonisation and e-mobility[382].

The plug-in shares in the largest markets were 13.5% in Germany and 11.3% in France in 2020[383]. Both included electric vehicle subsidies in their economic recovery packages.

In relative terms, Sweden (32%), and the Netherlands (25%) ranked highest in plug-in market shares in 2020, having announced bans on combustion engine car sales as of 2030 along with a number of other countries[384]. In this respect, Norway, which will be the first country to ban the sales of conventional cars (2025), had 74% share of EVs in car sales in 2020.

---

[377] IEA Global EV outlook 2021, 2021.

[378] EIT InnoEnergy, The European Battery Alliance A European Success Story, 2021.

[379] European Commission, 2021 (https://ec.europa.eu/energy/data-analysis/market-analysis_en)

[380] Regulations (EC) No 443/2009 and (EU) No 510/2011

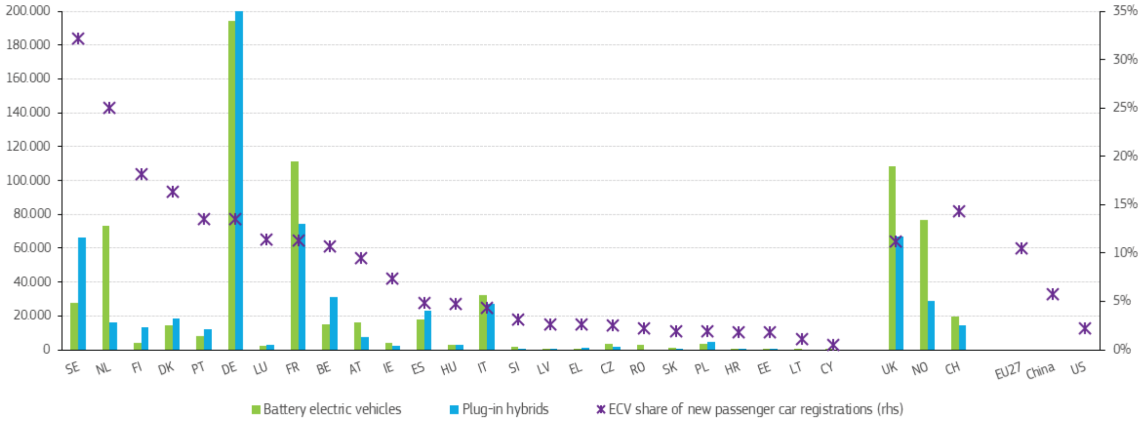
[381] IEA, How global electric car sales defied Covid-19 in 2020, 2021.

[382] Time (Joey Lautrup), The Biden administration is trying to kickstart the great American electric vehicle race, 19 April 2021.

[383] Transport&Environment, CO2 targets propel Europe to 1st place in e-mobility race, February 2021.

[384] ICCT (Sandra Wappelhorst and Hongyang Cui), Growing momentum: global overview of government targets for phasing out sales of new internal combustion engine vehicles 2020

Figure 3 Number and share of new electric vehicles in 2020



Source: European Commission Electricity market reports, based on data of ACEA CPCA, BNEF, 2021

The data for the first months of 2021 indicate a new record in number of EVs sold and EV share in car sales will be reached in 2021. E.g. Sweden saw the plugin electric vehicle market share reach new record 39.1% in May 2021, likely as a result of a generous bonus-malus scheme[385].

More than 50 million EVs are expected on EU roads by 2030[386] and the European Commission has proposed that only zero-emission cars could be sold in EU as of 2035[387].

19.2.1.2. Capacity installed: e-busses and heavy-duty vehicles

In Europe, electric bus sales grew 170% in 2019 and a further 7% in 2020, however totaling only 1714 busses and accounting for only 6.1% of new bus registrations in Europe[388]. Nearly twice as many new busses run on natural gas. Also striking is that the share of privately purchased electric vehicles in EU is higher than public purchases of busses.

In 2020, the Netherlands was the leading market for electric busses with 446 electric buses sold last year, followed by Germany (388 units) and Poland (200 units)[389]. Performance in terms of electric busses acquisition varies strongly across the EU: from a negligible share in some eastern and southern Member States to over three quarters of new vehicles in Denmark, where all the six largest municipalities buy only zero emission buses from 2021. EIB ELENA facility played an important role in facilitating procurement of electric vehicles in a number of Member States[390].

The US lags even more in electric bus sales[391], while China leads with more than 61 000 annual electric bus sales[392] and 60%[393] of its bus fleet already electrified.

---

[385] CleanTechnica (Maximilian Holland), Sweden Continues Electric Vehicle Progress In May With 39.1% Plugin Vehicle Share, 2021.

[386] central MIX scenario of the Fit for 55 proposals (COM(2021) 550 final)

[387] COM(2021) 556 final.

[388] ACEA, Medium and heavy busses (over 3.5t) new registrations by fuel type in the EU, 2020.

[389] Ibid.

[390] e.g. TEBB and HELLO projects.

[391] CALSTART, Zeroing in on ZEBS: 2020 Edition, 2020.

[392] Sustainable-bus.com “Over 61,000 e-buses sold by Chinese bus makers in 2020”, 15 January 2020.

The situation is similar for electric heavy duty trucks. Global electric heavy duty vehicle registrations were 7 400 in 2020, up 10% since 2019, while global stock reached 31 000 vehicles. China continues to lead, with 6 700 new registrations in 2020, up 10% after a fourfold increase in 2019. Electric heavy duty vehicle registrations in Europe rose 23% to about 450 vehicles and in the United States increased to 240 vehicles, while electric trucks are still below 1% of sales in both[394].

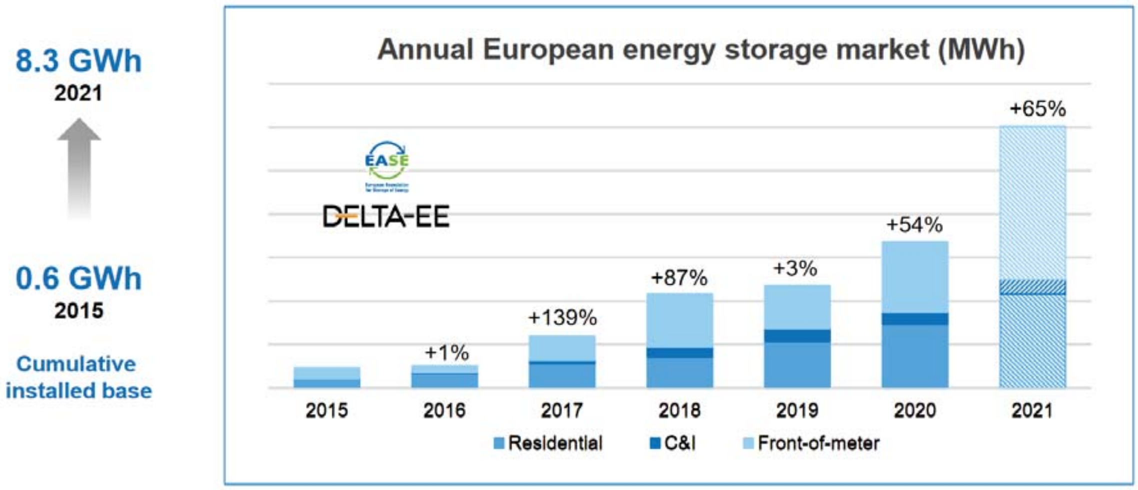
The EU's leading truck manufacturers and climate researchers agreed in December 2020 that by 2040 all new trucks sold must be fossil free[395].

19.2.2. Capacity installed: stationary batteries for clean energy transition

As recently as in 2015 the worldwide capacity of battery stationary storage was just 1.5 GW[396]. In EU installed capacity in 2015 was 0.6 GWh[397] (which should be less than 0.6 GW).

According to EASE[398], the European annual energy storage market (other than pumped hydro, i.e. mostly batteries) grew to 1.7 GWh in 2020, with a cumulative installed base of 5.4 GWh across all segments. The EU roughly accounts for 4/5th of the installed capacity (4.3GWh). Despite the quick growth, this may not be enough even to store the volume of electricity generated during one hour by the new wind generation capacity installed in the EU in 2020[399].

Figure 4 Annual European energy storage market (MWh)



Source: EASE, EMMES 5.0 market data and forecasts - electrical energy storage, 2021. Vertical gradient/horizontal division of the graph on the right is of 0.5 GWh of annual storage deployment

---

[393] News of China, 60% of China's buses go electric amid clean energy push, 26 October, 2020.

[394] IEA Global EV Outlook 2021, 2021.

[395] ACEA, All new trucks sold must be fossil free by 2040, 15 December 2020.

[396] Global Data, Grid connected battery storage system- market size, competitive landscape, key country analysis and forecasts to 2020, 2016.

[397] Ecofys, commissioned by DG ENER- Support to R&D strategy for battery based energy storage costs and benefits for deployment scenarios of battery systems (D7) (Final 2017).

[398] EASE, EMMES 5.0 market data and forecasts electrical energy storage, 2021.

[399] 10.5 GW of wind power installations (WindPower, 2021).

The total annual energy storage market in Europe is expected to reach 3 000 MWh in 2021 (4/5th in the EU). Global storage market is expected to reach 10 GW/28 GWh[400] at the same time.

World-wide battery energy storage systems (BESS) market is anticipated to grow at least at 33% a year (compound annual growth rate) from 2019 to 2030[401].

While Europe outpaces both China and the US for renewable energy capacity growth, it is not (yet) the case for stationary battery deployments[402]. On the one hand, the EU has much more robust and dense electricity grid, limiting current dependence on storage. However, a patchwork of legislation within the EU often reflects the past flexibility offered by conventional power plants[403]. With fundamental common enabling provisions on energy storage brought about by the Clean Energy Package[404] the situation is swiftly changing.

Looking at the largest stationary battery projects recently started in the EU, new capacities were entering into operation or planned in the context of renewable energy auctions (co-location of renewable electricity generation and storage)[405] or frequency response[406] or balancing services[407] for transmission systems operators (TSOs).

In addition, TSOs started to prepare for congestion management with 98 MWh storage capacities deployed in 2021 in France[408] and 450 MWh grid booster capacity planned in Germany for 2022[409].

While the largest grid-scale battery installations occur in the US and Australia (e.g. US biggest battery system at 300 MW/1 200 MWh[410] and 1.2 GW mega battery system in the pipeline in Australia[411]), Germany stands out with the largest number of home battery systems installed every year[412], with cumulative capacity reaching about 2.3 GWh across more than 300 000 households by the end of 2020[413]. In Germany, battery attachment rates in today's residential solar market are over 90%. Most German federal states support storage through direct upfront subsidies, typically with energy content-based incentives ranging between EUR 200–300 per kWh. More importantly, and as opposed to other Member States, Germany does not employ full net metering support schemes for residential PV installations[414]

---

[400] PV Magazine (Michael Longson), Strong growth ahead for battery storage, 2021.

[401] Markets and Markets, Battery energy storage system market, 2020.

[402] Energy Storage News (Andy Colthorpe), Europe predicted to deploy nearly twice as much electrical storage in 2021 than last year, 2021.

[403] Ecofys, commissioned by DG ENER- Support to R&D strategy for battery based energy storage, Battery Promoting Strategies in Selected Member States (Final 2018).

[404] Communication from the European Commission "Clean Energy For All Europeans" COM(2016) 860 final.

[405] E.g. in Germany see: Energy Storage News (Andy Colthorpe), Solar-plus-storage projects win 258 MW of capacity in Germany's latest renewable energy auction, 5 May 2021.

[406] E.g. in Italy, see: Energy Storage News (Andy Colthorpe), Italy's battery storage market, 2021.

[407] E.g. in Ireland, see: Energy Storage News (Molley Lempriere and Alice Grundy), UK listed fund Gore Street issues new shares, completes 100MW of Northern Ireland battery projects, 2021.

[408] Energy Storage News (Andy Colthorpe), France's grid battery 'experiments' take aim at creating market fit for carbon neutrality, 2020.

[409] TenneT, Der Netzbooster, die wichtigste Fragen und Antworten, 2019.

[410] Energy Storage News (Andy Colthorpe), At 300MW / 1,200MWh, the world's largest battery storage system so far is up and running, 2021.

[411] EBA250, World's biggest battery project to date to be implemented in Australia, 2021

[412] Solar Power Europe, European market outlook for residential battery storage 2020-2024, 2020.

[413] Energy Storage News (Andy Colthorpe), Europe predicted to deploy nearly twice as much electrical storage in 2021 than last year, 2021.

[414] With the retail electricity rate for households being about 0.30 EUR/kWh for many years now, and the feed-in tariff offered by the EEG continuing to go down steadily on a monthly basis, the value for increasing self-consumption is high.

which dis-incentivise self-consumption and the installation of battery energy storage systems. Promoting self-consumption has gained Germany two-thirds of the EU residential battery storage market[415].

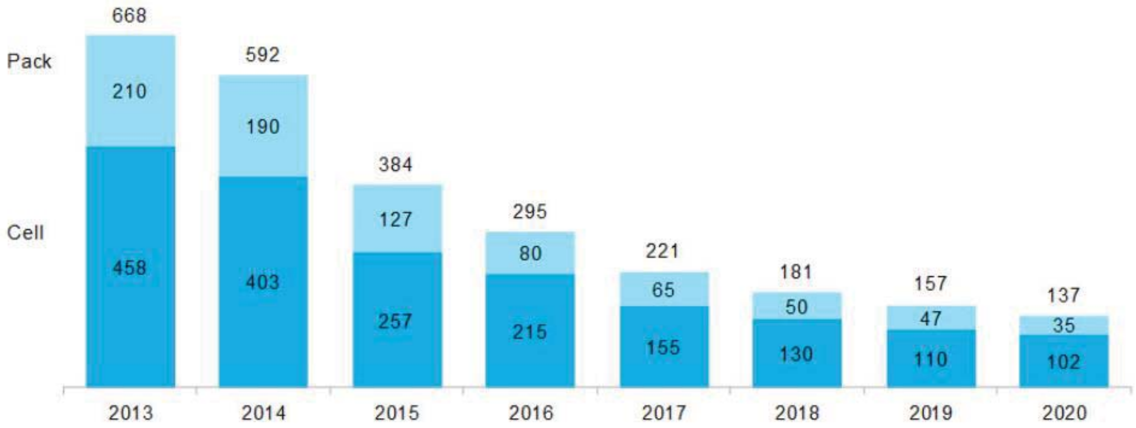
By 2030 grid scale applications of batteries will be approaching the importance of pumped hydropower (PHS) in EU stationary storage in terms of energy throughput. By 2050 batteries will cover close to half of the total need for storage within the EU energy system (more than 100 TWh annually[416]), bypassing the currently dominant pumped hydro storage technology. Stationary batteries will likely reach an installed capacity of close to 40 GW in 2030[417] and over 100 GW in 2050[418] (for comparison: PHS is expected to reach 64 GW in 2030, with limited further increase up to 2050) .

19.3. Cost

19.3.1. Cost of EV battery cells and cell packs and approach of cost parity for ICE vehicles and EVs

Electric vehicle (EV) demand is the main driver of cost reduction in Lithium-ion batteries. According to BNEF, Lithium-ion battery prices, which were above USD 1 100/kWh in 2010, have fallen 89% in real terms to USD 137/kWh in 2020. BloombergNEF's annual battery price survey finds prices fell 13% from 2019.

Figure 5 Volume weighted average pack and cell price split



Source: Bloomberg BNEF, 2021

By 2023, average prices will be close to USD 100 per kWh, according to the latest forecast from research company BloombergNEF. This is an important precondition for addressing bigger up-front costs that electric cars and buses incur compared to fossil combustion vehicles.

Furthermore, PV systems may export only up to 60% of their electricity production on the EEG feed-in tariff, incentivising homeowners willing to install higher capacity PV systems to invest in a coupled BESS.

[415] Solar Power Europe, European market outlook for residential battery storage 2020-2024, 2020.

[416] COM (2018) 773 final, page 79.

[417] SWD(2020) 176 final PART 2/2, page 60, see central MIX scenario of the Fit for 55 proposals.

[418] Ibid.

For the first time, battery pack prices of less than USD 100 per kWh have been reported in 2020. These were for batteries in e-buses in China[419]. BNEF expects EV battery pack prices to fall to USD 58 per kWh by 2030.

Indeed, already today the overall cost for owning an electric car is comparable to conventional cars. Therefore the share of government incentives in the total world-wide spending on electric cars has drastically decreased over the last five years, down to 10%[420]. While the purchase price of electric cars can be relatively high, they are cheaper to run, as electricity costs less and is taxed less than petrol. Electric vehicles are also cheaper to maintain[421]. The difference in the purchase price of a new electric car and a new conventional car is expected to disappear well within the current decade[422, 423].

19.3.2. Cost of stationary lithium-ion systems

Worldwide lithium-ion batteries make up about 90% of stationary battery storage capacity[424]. The prices for stationary lithium-ion systems are also dropping. However, the cost reduction, like in waterborne transport, has been slower than in road transport sector. There are a number of additional cost components (e.g. inverters, balance of system hardware, soft costs such as engineering, procurement and construction) that come into play, and there are many use cases with different requirements. In addition, early stage of the market development also plays a role, notably in terms of lack of competition compared to automotive market. Thus today, the whole system costs between EUR 300 and 400 per kWh (for grid-scale applications), depending on configuration of the storage system[425].

Reducing battery energy system cost to half current prices is key for mass deployment throughout Europe[426], which may take an entire decade. There are economic driving forces to substitute large conventional thermal power plants by combination of renewables electricity generation and batteries. As the total cost of solar and wind electricity continually declines, the capacity to pay for supplementary batteries will increase, helping batteries (in combination with renewable energy generation) to out-compete thermal power plants[427]. In the near future until 2025 the expected reduction in lithium-ion cell costs will be the main driver for stationary energy storage system cost reduction. In the medium to long-term the cost share of the electronic and hardware components will become more significant and further cost reduction strategies need to be identified[428].

As batteries are expected to represent shrinking portion of all-in system costs, there will be heightened focus on balance of system cost reductions moving forward.

Home batteries of +/- 10 kWh are at least twice as expensive per kWh. Nevertheless, they often already pay off, especially in the southern EU regions. With sufficiently high irradiation factors and difference in electricity price and feed-in tariff of +/- EUR 0.15 per kWh, it usually makes economic sense to buy a home battery.

---

[419] BloombergNEF, Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh, 2020.

[420] IEA 2021 Global EV Outlook, 2021

[421] Benjamin Preston, Pay Less for Vehicle Maintenance With an EVCR research shows that EVs cost less to maintain than gasoline-powered vehicles, Consumer Reports, 2020.

[422] Jasper Jolly, Electric cars 'as cheap to manufacture' as regular models by 2024, The Guardian, 21 October 2020.

[423] Transport &Environment (Eoin Bannon), EVs will be cheaper than petrol cars in all segments by 2027, May 10, 2021.

[424] Energy Storage News (Anthony Colthorpe), China’s energy storage deployments for first nine months of 2020 up 157% year-on-year, 2 December 2020.

[425] Batteries Europe, WG on stationary integration, 2021

[426] Ibid.

[427] EBA250, Fast-growing grid scale stationary battery storage, 2021.

[428] BloombergNEF (James Frith), Lithium-Ion Batteries: The Incumbent Technology, 2019.

Even higher difference between electricity and feed-in prices in Germany, coupled with public support for deployment of storage, make Germany the largest European market for home batteries.

19.4. Public R&I funding and Private R&I funding

Public R&I funding is rising considerably. At the EU level, EUR 925 million have been earmarked for collaborative research on batteries under Horizon Europe programme covering the period 2021-2027 (to be implemented through the Batteries Partnership[429]). The continuation of Battery 2030+ initiative (focused on ICT based research) will also be funded under the Batteries Partnership within Horizon Europe.

This is almost twice the funding under the previous Horizon 2020 programme. In addition, the battery integration is funded under the 2 Zero partnership - a partnership to achieve carbon-neutrality in road transport, European Partnership for Zero Emission Waterborne Transport, Clean Sky partnership and other headings of Climate, energy and mobility work programme of Horizon Europe. For example, many calls related to renewable energy and smart energy systems will support innovative deployments of stationary batteries and EV integration aspects not covered by specific partnerships. Horizon Europe funding will also allow greater support to Batteries Europe to foster a common R&I agenda throughout EU and facilitate its implementation in a coordinated way.

At national level, a number of Member States are strengthening their R&I capacity. One prominent example includes the Fraunhofer Gesellschaft (Germany) with its own "battery alliance", consisting of a number of institutes and the biggest research production facility[430]. Other important R&I players include CEA (France), ENEA (Italy), CIC energiGUNE (Spain) and many others as can be seen in Batteries Europe publications[431].

In addition, a number of major research and innovation needs are addressed by two multi-billion euro Important Projects of Common European Interest (IPCEIs), the first coordinated by France[432] and the second by Germany[433]. 2020 was the first year of implementation of the first IPCEI and 2021 is the first year of implementation of the 2nd IPCEI. They involve 12 EU countries and tens of companies and research organisations across the EU, along the whole value chain. This involves both public and private funding: EUR 6.1 billion of public funding by participating member states, which is expected to unlock an additional EUR 14 billion funding in private investments.

Mostly funded by industry, innovation also continues on established battery technologies, such as lead-acid nickel-cadmium and nickel-metal hydride[434].

Beyond R&I funding, the EU industry has invested significantly in batteries and end use integration. In total, the European Battery Alliance has generated investments of EUR 100 billion[435]. The EU is closing the investment gap with its competitors, with investment to produce electric vehicles and batteries reaching EUR 60 billion in 2019 compared to EUR 17 billion in China the same year[436]. In a survey conducted on the

---

[429] BATT4EU (bepassociation.eu).

[430] Fraunhofer Institute 2021: https://www.fraunhofer.de/en/research/key-strategic-initiatives/battery-cell-production.html.

[431] https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en

[432] IP/19/6705.

[433] IP/21/226.

[434] EUROBAT, Battery Innovation Roadmap 2030, 2020.

[435] https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en.

[436] Transport & Environment, Can electric cars beat the COVID crunch? The EU electric car market and the impact of the COVID-19 crisis, 2020.

industrial manufacturing projects disclosing financial details, Western Europe figured a 43.5% share of the total global investment into battery manufacturing projects in 2020, followed closely by Asia with 37%[437].

19.5. Patents

Historically, most patent applications have been filed outside the EU[438].

According to a 2020 EPO-IEA study[439], firms from Asia have a clear lead as of 2018, in the global race for battery technology, with Japanese and South Korean companies at the forefront. Asian companies account for nine of the top ten global applicants for patents related to batteries, and for two-thirds of the top 25, which also includes six firms/organisations from Europe (mostly Germany)[440] and two from the US.

At the same time it is recognised that Europe and the US can count on a rich innovation ecosystem, including a large number of SMEs and research institutions, to help them stay in the race for the next generation of batteries. Recent investments in production facilities and R&I in the EU should soon have a positive impact also on patent indicators.

19.6. Level of scientific publications

According to Batteries Europe, EU publications stagnated in 2020, most probably because researchers are needed by the booming battery industry in EU. Recent publications of Batteries Europe members in the Journal of Power sources are summarised on Batteries Europe web-site[441].

19.7. Final Considerations

In the past few years batteries have led in the sales of zero emission vehicles and stationary storage deployment in the EU. This is the start of a boom since only recently did development in battery technology enable a major break-through in EV driving range and EV price.

A number of tipping points reached in 2020 fuelled EU demand for EVs, notably in terms of total cost of ownership, charging speed, availability of models. Further decrease in price of lithium-ion battery packs is necessary to ensure purchase price parity with conventional cars. The latter is expected to gradually happen in the coming years, starting with 2023. Sunset policies for conventional vehicles in some EU and third party countries, as well as [442] the Commission proposal envisaging that only zero-emission cars could be sold in the EU as of 2035, accelerate the development and deployment of EVs.

When it comes to lithium-ion battery stationary storage, the cost reduction has been slower due to the contribution of non-battery-related major cost components (e.g. inverters, balance of system hardware, soft costs such as engineering, procurement and construction). Still, in some markets battery storage is competitive and much depends on national conditions or level of feed in tariffs for residential PV installations.

---

[437] "Batteries Investment Round Up: Diversification Trend Sees Europe Claim Biggest Share" Fitch Solutions / Autos / Global / 13 April, 2021

[438] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study, 2020.

[439] EPO & IEA, Innovation in batteries and electricity storage- a global analysis based on patent data, 2020.

[440] Bosch, Daimler, CEA, Johnson Control, BASF, Volkswagen.

[441] https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en

[442] DK, IRL, NL, SE, SI and a number of non-EU countries: see page 47 of IEA Global EV outlook 2021.

In 2020 and 2021, there were promising developments also in alternative chemistries for stationary storage, especially flow batteries sodium-ion batteries which may reduce demand for critical raw materials.

Plenty of R&I is still needed to improve performance of EV and stationary batteries. In addition, research should help to improve sustainability and decrease dependence on critical raw materials. “Batteries Europe” technology platform is the leading European forum for identifying what would be the most meaningful R&I spending in each segment of the value chain, in view of already ongoing research activities, the issues identified and the needs of the economy of a specific Member State.

20. VALUE CHAIN ANALYSIS OF THE ENERGY TECHNOLOGY SECTOR

20.1. Introduction/Summary

As recently as 2016[443], the EU was severely lagging in key segments of the lithium-ion battery value chain. It was largely absent in key raw materials markets (e.g. lithium, cobalt, graphite) and lithium-ion cells market. Particularly in processed materials, the EU activity in cathode and electrolyte markets was limited, and the EU was absent from anode market.

2017 marked the start of EU’s industrial policy on batteries when the Commission launched the European Battery Alliance with EU countries and industrial actors. A strategic action plan for batteries, covering the whole process from producer to end-user, was adopted in May 2018[444]. Since autumn 2019, the Business Investment Platform of the European Battery Alliance also gathers stakeholders along the entire battery value chain to accelerate transactions between investee and investor[445].

The European Battery Alliance has proved to be a catalyst into turning the EU into a region with well-developed battery eco-system across the entire value chain. Major EU initiatives are being implemented by the EU based on the Action Plan on Batteries. They are complemented by a buoyant industry network facilitated by EIT InnoEnergy – EBA250[446].

---

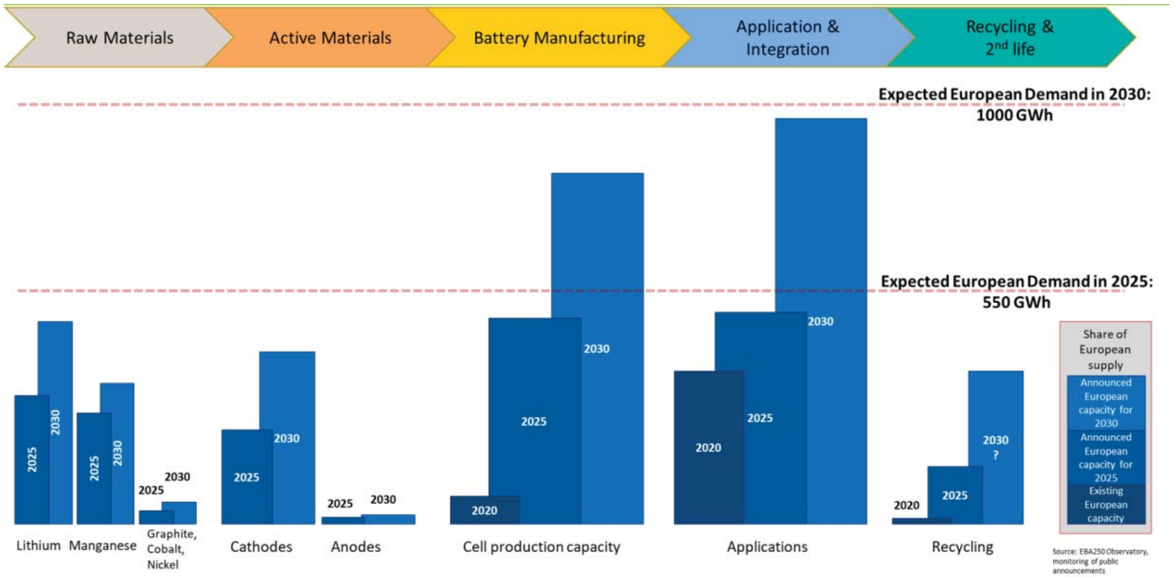
[443] JRC Lithium ion battery value chain and related opportunities for Europe, 2016.

[444] https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en

[445] https://eit.europa.eu/news-events/news/european-battery-alliance-eit-innoenergy-launch-business-investment-platform

[446] https://www.eba250.com/

Figure 6: Expected supply and demand balance in Europe from present day to 2030 for the batteries value chain



Source: EBA250, 2021.

Currently, the weakest point in the value chain for the EU are critical raw materials, in particular graphite, cobalt and lithium. Anode production is also a weak point, but recently there have been some positive developments, mostly in Finland and Sweden[447].

20.2. Turnover – Batteries

Currently separate statistics on lithium-ion battery turnover have only been collected for 2019 and these are incomplete, not even covering Member States of main producers, as reporting is voluntary.

To give at least a general idea, according to Avicenne, the overall demand for Lithium-ion batteries in 2020 was estimated at roughly EUR 9 billion in Europe[448] and local production satisfied much less than half of this demand. For comparison turnover from lead acid-battery production is still higher in Europe (with over EUR 7 billion)[449].

20.3. Gross value added growth

Due to incompleteness of turnover data, statistical data for gross value added is also not available.

20.4. Number of EU companies

At least 10 EU headquartered companies or company groups will start battery cell production in the coming years:

---

[447] https://www.eba250.com/supply-of-graphite-from-europe/

[448] Avicenne energy, EU battery demand and supply (2019-2030) in a global context, 2021: https://www.eurobat.org/images/Avicenne_EU_Market_-_summary_110321.pdf

[449] EUROBAT, 2021

- ACC (France and Germany – JV of TOTAL/Stellantis[450]), building on technological strength of SAFT
- CELLFORCE (Germany – JV of Porsche/Fraunhofer)
- Eneris/Leclanché (tbc)
- FAAM/LITHOPS (Italy)
- INOBAT (Slovakia)
- MES (Czechia)
- NORTHVOLT (Sweden and beyond)
- VARTA (Germany)
- VERKOR (France)
- VOLKSWAGEN (Germany and beyond)

Northvolt Ett in Sweden and MES HE3DA factory in Czechia are at advanced stage of the construction.

In 2021, 16 European flow battery stakeholders came together to confirm the formation of Flow Batteries Europe (FBE): 5 industrial companies, including the EU's largest producer of flow batteries CellCube[451], 5 start-ups, 5 research centres and a global vanadium organisation[452]. While flow batteries are usually associated with large-scale storage, German company Voltstorage, claims to be the only developer and maker of home solar energy storage systems using vanadium flow batteries.

Major EU companies in battery integration in vehicles include:[453]

- Volkswagen, targeting 1 million electric vehicle sales in 2021; by 2030 70% of its vehicles sold in Europe will be fully electric which represents 5 million cars. It has also announced plans to build 240 GWh of lithium-ion manufacturing capacity in Europe by 2030;
- Daimler - electrifying entire fleet by 2025;
- BMW – aiming to build "a quarter of a million more electric cars than originally planned between 2021 and 2023 and double the share of electrified vehicles from 8% in 2021 to 20 % by 2023;
- Stellantis group - aiming for 70% electric cars sales in Europe by 2030 (Peugeot will electrify its entire line-up by 2023);
- Renault -increasing EV sales to 65% by 2025. By 2030, the goal is a share of at least 90 per cent[454].
- Volvo will only sell full electric cars by 2030.

There are numerous European players entering the electric bus market: Solaris (PL), Volvo, Daimler, VDL (NL), Ebusco (NL), Bluebus - Bolloré (FR), Alstom (FR), Iveco Heulliez (FR), Irizar (ES) Linkker (DE), Sileo (DE), Caetano (PT), etc.

At the end of 2020 leading EU truck producers Daimler, Scania, Man, Volvo, Daf, Iveco, and Ford – have signed a pledge to phase out traditional combustion engines by 2040[455].

Siemens[456] and Alstom[457] hold the first contracts in the EU in the field of battery driven trains.

---

[450] Formed after merger of PSA and Fiat Chrysler

[451] DMG MORI AG (Gildemeister)

[452] https://www.flowbatterieseurope.eu/

[453] EBA2050, New EV targets for the European car industry fuel the battery industry, 15 March 2021.

[454] Electrive.com (Chris Randall), Renault plans to gear up EV sales to 65% by 2025, 26 April 2021.

[455] ACEA, All new trucks sold must be fossil free by 2040.

Leading companies in the region for equipping ships with battery storage and electric propulsion include: Siemens in Germany and beyond, Echandia Marine AB and ABB in Sweden, Wärtsilä in Finland and Danfoss in Denmark.

Many electric ships are integrated at Damen shipyards[458], also Holland shipyards, even if storage solutions are provided by other companies, like Echandia or ABB. Other EU shipyards are also involved as there seem to be no shipyards specifically specialised in electric ships.

Major EU actors in stationary storage sector include Fluence, co-owned by Siemens and American AES (grid storage) and Sonnen (now owned by SHELL for home storage). Among others, TOTAL/SAFT, Engie, ENEL X, ABB also play an important role.

20.5. Employment in the selected value chain segment(s) and skills

If Europe becomes the second largest lithium-ion battery cell manufacturer in the world[459], this will alone require reskilling and upskilling 800 000 people by 2025, as a direct effect. Each Member State will need professionals being able to maintain EVs and install stationary batteries as well as to take proper care of batteries when they reach their end of life[460]. In total 3 to 4 million jobs could be created by 2025[461].

EIT InnoEnergy facilitates the ‘EBA250 Academy’ helping to bridge the emerging battery value chain skills gap by upskilling and reskilling citizens. In addition, under the EU’s Erasmus + programme, the Alliance for Batteries Technology, Training and Skills (ALBATTS) has been established to design a blueprint for competences and training schemes of the future, in the battery and electromobility sector. It is due to report by the end of 2023[462].

The current situation and educational offer as well as gaps and projects under way are e.g. described in Batteries Europe position paper on skills[463].

The European Commission encouraged Member States to use funding available in the Recovery and Resilience Facility and the Just Transition Fund to bridge the skills gap.

While it is up to each Member State and company to actively enter production of raw materials, or advanced batteries, production of battery cells and systems and their repurposing or recycling, the trend is clear: battery-based technologies are taking over transportation market and energy storage market. This means that each and every Member State will need plenty of qualified staff and innovators capable of installing, maintaining and optimising batteries.

---

[456] Green Car Reports (Bengt Halvorson), Battery-powered electric trains will soon bring cleaner air- especially in Europe, 29 March 2020.

[457] EBA250, Bombardier (now Alstom) to replace diesel engines by Li-ion batteries on AGC trains, 4 February, 2021.

[458] https://www.damen.com/en/innovation/electrification

[459] Fraunhofer ISI, Li-ion Battery cell production capacity to be built up, April 2021; Benchmark Minerals, Li-ion battery cell capacity by region, 2021.

[460] https://www.eba250.com/eba250-academy/about-eba250-academy/

[461] SPEECH/21/1142

[462] Project ALBATTS (project-albatts.eu)

[463] https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications/education-skills-position-paper_en

20.6. Energy intensity considerations, and labour productivity considerations

All factories in the pipe-line should be new, energy efficient and highly automated. Labour costs account for a relatively small share of the overall battery production cost.

A trend towards ever bigger EVs (the sports utility vehicle (SUV) market is quickest growing EV market[464]) implies high energy consumption at production and utilisation stages and risks increasing dependence on critical raw materials. According to IEA, currently SUV models account for half of the available electric car models in all markets around the world. In Europe, the share of electric SUVs is even higher than for the overall market. This may be a temporary trend related to the wealthier part of population opting quicker for e-mobility, leading to most polluting cars being replaced first.

In this respect, China, unlike EU, has an official policy of reducing average power consumption of new pure electric passenger cars to 12.0 kWh/100 km by 2025[465]. SUVs consume up to twice this amount. Today, the bestselling model on the Chinese market, a small EV, consumes 8.1 kWh per 100 km.

20.7. Community Production (Annual production values)

Subsidiaries of mostly Korean companies make up the community production of lithium-ion battery cells for e-mobility and storage in the EU which has reached 44 GWh as of the end-2020. Annual production volumes are increasing. This constitutes roughly 6% of the of global EV lithium-ion cell manufacturing capacity in 2020 (747 GWh)[466] and this represents already a large increase since the start of the European Battery Alliance (3% in 2018).

The meta-study "Batteries for electric cars: Fact check and need for action," commissioned by VDMA and carried out by the Fraunhofer Institute for Systems and Innovation Research ISI suggests that production capacities of up to 400 GWh could be achieved by 2025. This is consistent with the EBA250 forecast.

EU head-quartered companies (such as Saft and Varta), currently occupying high-end lithium-ion niche applications, are preparing for mass production for e-mobility and energy storage.

The giga-factory projects announced by EU and foreign companies should largely satisfy the expected EU demand in 2025 (400 GWh)[467]. In the most optimistic estimations, Europe could supply almost 90% of its batteries from production facilities within Europe. Even with more conservative estimates, about 80% of supply from European facilities[468].

Figure 7 Ongoing and Planned Li-ion Battery Cell Factories in Europe

---

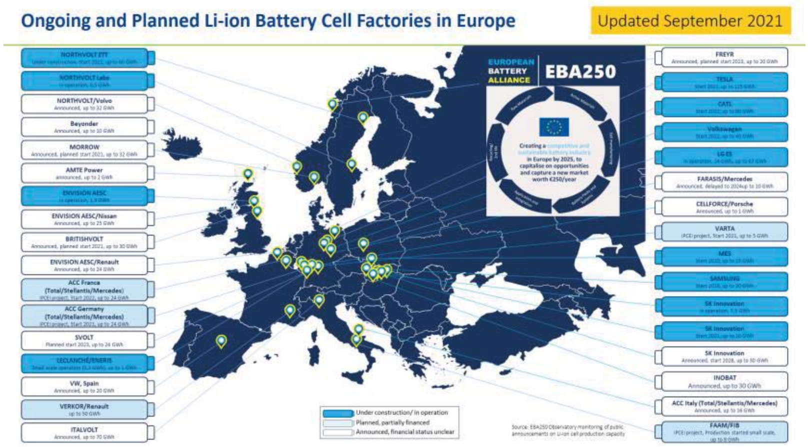
[464] IEA, Global EV outlook 2021, 2021.

[465] State Council Information Office of the People's Republic of China, New energy vehicle industrial development plan (2021-2035), 2020.

[466] US Department of Energy, National blueprint for lithium batteries 2021-2030, 2021.

[467] SPEECH/21/1142

[468] EBA250, Internal document "A Battery Market Outlook for 2025 and 2030", 2021



Source: EBA 250, 2021

The world's biggest automotive manufacturer VW will go for a new business model for the production of batteries for electric vehicles based on a single, massive-scale "unified cell" platform. The unified cell is expected to enter production in 2023 in cooperation with Northvolt. In total, VW plans to bring 240 GWh of battery production capacity to Europe by 2030 (and a third of it by 2025). This would be enough battery-making capability to supply 4 to 4.5 million EVs per year[469].

20.8. Final Considerations

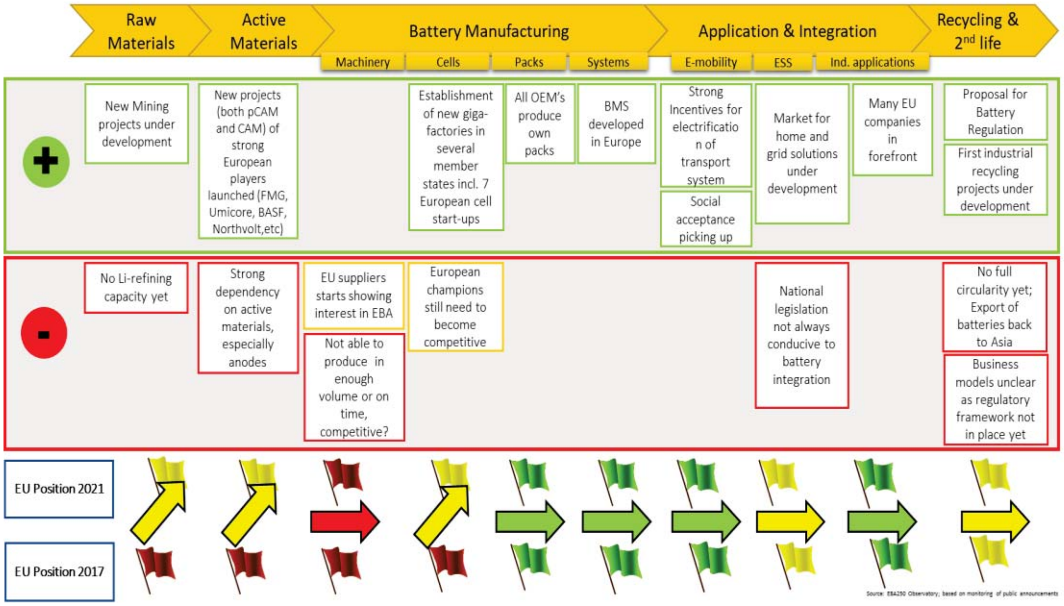
Progress along value chain of batteries within the EU between 2017 and 2021 can be summarised in the following figure compiled by EBA 250[470].

---

[469] Volkswagen, Power Day: roadmap for batteries and charging up to 2030, 15 March 2021

[470] N.B. legislative obstacles for grid-scale applications should come to an end with transposition of the Clean energy package.

Figure 8 Progress along the batteries value chain in the EU



Source: EBA 250, 2021

21. GLOBAL MARKET ANALYSIS

21.1. Introduction/summary

According to EBA250, in 2020 the EU reached a tipping point when the parity of the total cost of ownership (TCO) with combustion fuelled vehicles was achieved. This is important since about 60 % of the automotive market consists of leasing cars, where monthly costs are the most important purchasing consideration, not on the cost for purchasing the vehicle. Here a tipping point was reached in 2020 when EV became cost competitive in more than 50 % of the total European automotive market[471]. Falling battery costs are of course adding to this picture, also reducing the cost of EV's. In addition, with maximum charging speed exceeding 10 km driving range per charging minute for most models, and average range above 350 km, major obstacles for uptake of e-mobility were addressed[472].

According to Avicenne[473], in 2020, global market of Lithium-ion batteries exceeded that for lead-acid batteries in value USD 47 billion vs USD 37.5 billion with e-mobility booming. In terms of storage capacity, lead-acid batteries were still ahead with 410 GWh vs 230 GWh for Lithium-ion.

Other consultancies also estimate Lithium-ion battery market over USD 40 billion in 2020:

- Statista Research department - USD 40.5 billion in 2020[474].
- Markets and markets USD 44.2 billion in 2020[475]

Consultancies forecast market to grow at CAGR of up to 17.1% and will reach up to USD 100.43 billion by 2025[476]. This figure is likely to be revised upwards given the unprecedented boom in the EV market.

As regards lithium-ion stationary battery energy storage systems' market size, according to ReportLinker, it is expected to grow at a CAGR of 32.8% from 2020 to 2025, reaching USD 12.1 billion by 2025, up from USD 2.9 billion in 2020[477].

21.2. Trade (imports, exports)

EU imports nearly all raw materials needed for battery production. It imports most of advanced materials. It also imports most of cell manufacturing equipment.

When it comes to battery cells, trade deficit continued to increase in 2019: it widened from EUR 3.6 billion to EUR 4.2 billion[478]. While 2020 data are not yet available, it is clear that most of battery cells used for clean energy transition were still imported, given limited local production capacity and booming EV industry. Normally this trend should significantly reduce given the increasing production volumes in the EU. Similarly as in automotive industry, the recent trend is towards local production, as demonstrated by numerous third country battery cell producers setting up/planning production capacities in EU.

---

[471] Leasplan, Annual Car Cost Index, 30 September 2020.

[472] EBA250, internal document "A Battery Market Outlook for 2025 and 2030".

[473] Avicenne energy, EU battery demand and supply (2019-2030) in a global context, 2021: https://www.eurobat.org/images/Avicenne_EU_Market_-_summary_110321.pdf

[474] Statista, Lithium-ion batteries: statistcs and facts, 15 July 2021.

[475] Markets and Markets, Battery energy storage system market, 2020.

[476] GlobalNewsWire (Allied Market Research), Global Li-ion battery market, 19 February 2020.

[477] GlobalNewsWire (Reportlinker) The global battery energy storage system market, 13 October 2020.

[478] Eurostat, COMEXT, 2020.

According to Trade data monitor, in the first 10 months of 2020, China exported USD 12.5 billion of lithium-ion batteries, followed by South Korea (USD 4 billion), Poland (USD 3.2 billion), and Germany (USD 2.7 billion), according to Trade Data Monitor[479]. Even if Germany was also exporting lithium-ion batteries (normally, battery modules and system), globally it is still a net importer, unlike other listed countries.

During the month of December 2020, Poland recorded a record value of the lithium-ion battery export, amounting to EUR 609 million. In relative terms, Poland is the fastest-growing exporter of lithium-ion batteries since 2015[480]. More generally, Central Europe is gradually becoming an important EU EV battery supplier[481].

While being net exporter of cars, the EU is importing slightly more electric cars than exporting as at end 2020[482]. This is explained by the fact that the EU automotive industry took some time to embrace e-mobility. All major announcements by the EU automotive industry regarding electrification date mostly from 2020 or 2021. The positive fact is that exports of EVs are growing faster than imports. The automotive sector as such is a net exporter[483] and it is expected that, in 2021 or 2022, the EU will become net exporter also of EVs. As regards cars, it has to be noted that they are mostly produced in the region of consumers. For example, EU automotive companies are scaling up their subsidiaries in China, rather than exporting cars. US car manufacturers do the same. EU companies have subsidiaries also in other regions, notably the US. The EU itself also hosts a number of subsidiaries of foreign automotive companies.

21.3. Global market leaders vs. EU market leaders (market share)

In cathode materials field, the EU has two strong players Umicore and BASF, while the EU is still a net importer from Asia[484]. Asian players include Fujitsu Limited, Hitachi Chemical Co., Ltd., LG Chem Ltd., Mitsubishi Chemical Holdings Corp, NICHIA Corporation, Sumitomo Chemicals[485]. Chinese GEM is an important player in lithium-ion cathode precursors[486] and collaborates with Korean EcoPro.

In other advanced materials for batteries, except polymers for lithium-ion batteries (cf Solvay), EU is weak. According to BNEF, overall, China holds 60% of battery component manufacturing capacity[487].

In battery cells sector, all leading manufacturers are Asian manufacturers: BYD, CATL, LG Chem, Samsung, SK Innovation, etc. According to BNEF, 77% of cell production capacity is controlled by China. This should change with a number of EU head-quartered companies setting up lithium-ion battery cell production facilities. For example, Northvolt is expanding rapidly and aims to produce 25% of Europe’s batteries by 2030. With the EU’s Green Deal agenda, demand and production capacities for lithium-ion batteries are growing faster in Europe than in any other region of the world. According to

---

[479] Trade data monitoring, 2021: https://www.tradedatamonitor.com/index.php/data-news-articles/120-china-leads-global-trade-in-lithium-ion-batteries

[480] Daniel Workman, Lithium-ion batteries exports by country, World’s top exports, 2021: https://www.worldstopexports.com/lithium-ion-batteries-exports-by-country/

[481] Politico (Wojciech Kosc), Central Europe becomes the EU's e-car battery supplier, 10 February 2021.

[482] Eurostat, 2021. Data retrieved: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210524-1

[483] Eurostat, 2021. Data retrieved: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=International_trade_in_cars

[484] Green Car Congress, 2021: https://www.greencarcongress.com/2021/01/20210108-roskill.html

[485] Polaris Market Research, Lithium-ion battery cathode market size global industry report, 2020.

[486] Roskill (Ying Liu), Nickel sulphate: GEM and ECOPRO to build high-nickel Li-ion precursor capacity in Fujian, 17 April 2020.

[487] PV Magazine (Marian Willuhn), National lithium-ion battery supply chains ranked, 16 September 2020.

Fraunhofer, Europe's share in this global battery manufacturing business will increase from around 6 % today up to 24% in 2025 and 29% in 2030 (most optimistic of currently available estimates).

However, it is important to note that the global battery production capacity is continuously being upgraded in volume. For example, Benchmark Minerals predicted a global production volume of about 3 000 GWh by 2030 two years ago and today this volume is expected already to be achieved by 2025.

Notwithstanding the general dominance of Asian manufacturers, the European SAFT and VARTA companies play an important role in high-end niche applications for lithium-ion cells. Leclanché seems to be the main European lithium-ion cell producer for waterborne applications.

Although Asia is currently the global hub of EV battery making, in principle, European manufacturers should be able with a bit of effort to compete on price, because the biggest costs in battery making are (raw) materials, the capital-intensive manufacturing process and the cost of energy. In these three areas, there is hardly any competitive disadvantage compared to Asian manufacturers. The share of labour in the overall cost of a battery is limited, and the difference between the labour cost in Europe and Asia is offset by the cost of shipping batteries to Europe[488].

In manufacturing of lithium-ion cell production equipment, Asian companies are leading and most of equipment is being imported from Asia. Manz is the only EU company playing an important role in this segment[489, 490].

As regards other promising battery technologies, over the last 10 years, only 7% of the world's flow battery projects were installed in Europe, with much more R&D and commercial support taking place in North America and Asia[491]. At the same time, Austrian CellCube[492], belongs to top-three flow battery producers in the world, together with Sumitomo Electric Industries Ltd. (Japan) and UniEnergy Technologies (US)[493]. Recent establishment of Flow batteries Europe association can help to improve the EU's competitiveness in this segment.

As regards nascent market of sodium-ion batteries, "Sodium Ion Battery Market - Growth, Trends, and Forecasts (2020 - 2025)" shows that Europe/EU have good potential in this market, with French start-up Tiamat and Swedish start-up Altris being most active[494] and important long-standing EU battery producer SAFT also involved in development of this technology. At the same time, Chinese CATL is the first of the world major EV battery producers to go to large-scale commercialisation of sodium-ion technology[495]. CATL plans to include sodium-ion batteries into the EVs in combination with lithium-ion batteries. While lithium-ion batteries have advantage of higher energy density, sodium-ion batteries have superior low-temperature power and cycle performances. Several other countries (e.g. UK, India, US) follow China establishing production facilities for sodium-ion cells. This trend is to be observed, and eventually followed in the EU.

---

[488] SAFT, ACC's European EV battery venture on track for production, 2020:

[489] Decisive Market Insights, Lithium battery manufacturing equipment market report, 2021.

[490] Manz AG: Https://www.manz.com/en/industries/battery-production/

[491] Robin Whitlock, Flow Batteries Europe (FBE) established to represent flow battery stakeholders, Renewable Energy Magazine 03 May 2021.

[492] DMG MORI AG (Gildemeister)

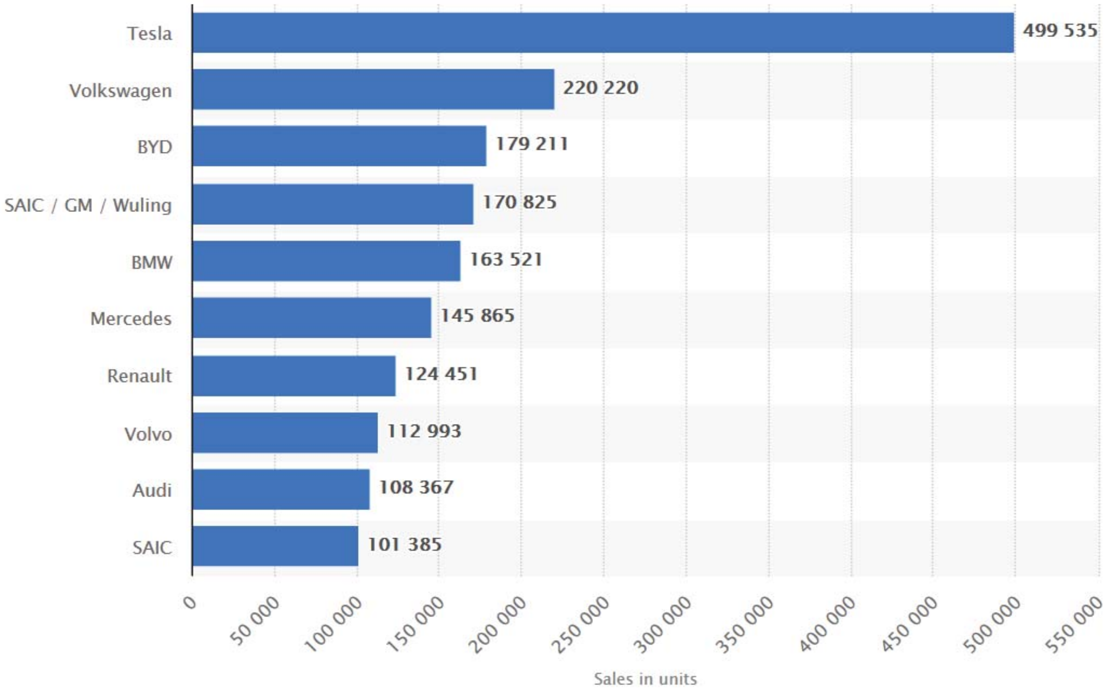
[493] JRC Batteries - Technology Development Report 2020

[494] Mordor Intelligence LLP, Sodium Ion Battery Market - Growth, Trends, and Forecasts (2020 - 2025), 2020. Verified Market research, Top 7 Sodium-Ion Battery Manufacturers, , August 2021.

[495] PV magazine (Marian Willuhn), CATL claims to have made sodium-ion batteries a commercial reality, 29 July 2021

The EU plays very strong role when it comes to battery systems and final products: electric vehicles and stationary storage systems. It has a potential to become a net exporter, even if the general tendency is that final products are manufactured in the end-use jurisdictions – China, EU, US (i.e. not much inter-continental trade is expected). Main EU manufacturers have production facilities in major global markets, China and US, as do key US producers. Chinese automotive companies are just entering the EU market for electric cars[496] and stationary storage. US based Tesla remains leading EV manufacturer[497], while total sales of EVs under EU brands (including cars produced in consumer countries) were higher.

Figure 9 Estimated plug-in electric vehicle sales worldwide in 2020, by automaker



Source: Statista, 2021 (Data retrieved: Worldwide PEV sales - by brand 2020 | Statista)

All EU car manufacturers embraced electrification race and compete with American Tesla and Chinese BYD, SAIC, NIO, Xpeng and others. VW aims to sell 1 million electric cars in 2021 and become the global EV market leader by 2025 at the latest[498].

In an optimistic scenario, the EU may achieve an annual production of 6 million electric cars by 2025[499]. The global data firm, LMC Automotive, estimates China will produce over 8 million electric cars a year

---

[496] See e.g. https://www.autoexpress.co.uk/nio/354921/chinese-ev-brand-nio-enters-european-market

[497] Statista, 2021. Data retrieved: https://www.statista.com/statistics/977407/global-sales-of-plugin-electric-vehicles-by-brand/

[498] Automotive News Europe, VW targets electric-car lead by 2025 in platform push, 16 March 2021.

[499] https://ec.europa.eu/commission/presscorner/detail/en/speech_20_2378

by 2028, compared with 1 million in 2020[500]. The US also set a clear course towards electrification under the new administration [501].

China is the world's largest producing region of electric busses (61 000 in 2020)[502]. This has been initially facilitated by considerable support to acquisition of electric busses, while recently strict public procurement rules play an important role[503]. Largest producers include: Yutong, BYD, CRRC, Zhongtong and Suzhou King Long. In comparison, the EU market for electric busses accounted for less than two thousand units in 2020. Yutong and BYD played an important role also in the EU market, while majority of the market was held by EU companies, primarily Solaris, Volvo, and VDL among others[504].

The heavy duty vehicles market is nascent, with China by far leading the sales[505]. All EU truck manufacturers are finally on board. There will be some catching up to be done as new players like American Tesla and Nikola entered the market since a while and Chinese BYD and Japanese Toyota have been making gains so far[506].

According to the International Transport Forum (ITF), Nordic EU countries as well as Norway are world leaders in electrification of short sea shipping and provision of onshore power supply and related R&I For example, Siemens in collaboration with Echandia won the contract to equip the largest electric-ferry fleet in India (78 ferries)[507]. Danfoss Editron is part of the team delivering Thailand's first fleet of fully-electric passenger ferries[508]. In 2021 ABB won a major deal for equipping 10 all-electric ferries in Lisbon[509]. Echandia, ABB, Siemens, Wärtsilä, Danfoss and many more are among leading EU companies equipping electric/hybrid ships.

When it comes to the nascent market of battery electric locomotives, Alstom[510] and Siemens are key players in Europe, while facing certain competition from the largest railway rolling stock manufacturer - Chinese CRRC[511].

In the nascent market of urban air taxi's there are plenty of opportunities for EU companies including CityAirbus and many other EU start-ups[512]. At the same time there is already considerable competition. E.g. American Airlines, Virgin Atlantic and aircraft leasing group Avolon have made preliminary commitments to buy up to 1 000 electric air taxis from a British start-up "Vertical Aerospace", a big sign of a radical shift to urban air mobility[513]

While an EU stationary storage market is only gradually developing, the EU is not lacking strong players as regards stationary battery storage systems and hybrid storage systems. Fluence (co-owned by German

---

[500] New York Times (Keith Bradsher), As cars go electric, China builds a big lead in factories, 6 May 2021.

[501] Time (Joey Lautrup), The Biden administration is trying to kickstart the great American electric vehicle race, 19 April 2021.

[502] Inside EVs (Mark Kane), There is one company that sells more EV buses than BYD: Yutong, 27 January 2021.

[503] from 2021 "new energy vehicles" (plug-ins or FCEVs) should account for not less than 80% of the vehicles newly added and replaced to public transport areas of key regions for prevention of atmospheric pollution

[504] Sustainable Bus, The pandemic doesn't stop the European e-bus market: +22% in 2020, 19 February 2021.

[505] IEA Global EV outlook 2021, 2021, pp. 28-29

[506] Electrive.com (Nora Manthey), Major truck makers pledge to go zero-emission by 2040, 15 December 2020.

[507] Echandia, 2020: https://echandia.se/echandia-marine-division-wins-battery-contract-for-the-worlds-largest-fleet-of-electric-passenger-ferries/

[508] Danfoss, Thailand's first fleet of fully-electric passenger ferries to hit the water in 2020, 01 October 2020.

[509] ShipInsight, ABB wins major deal for 10 all-electric ferries in Lisbon, 13 April 2021.

[510] Rail division of Canadian Bombardier is part of Alstom, following merger clearance in July 2020.

[511] Rail Journal, CRRC rolls out first battery-equipped locomotive for Rail Cargo Hungary, 12 September 2020

[512] Silicon Canals, The future of urban mobility in Europe, 8 July 2020

[513] Financial Times (Sylvia Pfifer), UK air taxi start-up finds early buyers for 1,000 vehicles, 11 June 11, 2021.

Siemens and American AEG) remains the top utility-scale energy storage system integrator in the world.[514]

Sonnen/SHELL is the leading EU company in home storage, with main competitors being US Tesla and Korean LG Chem[515,516]. Sonnen (now owned by SHELL) has put Germany's and the EU's largest virtual battery into operation.

21.4. Resource efficiency and dependence

Most raw and refined materials are imported. China holds 80% of the world's battery raw material refining capacity.

The 2020 critical raw materials assessment indicated a high economic importance and a high supply risk for lithium. This resulted in including lithium on the Critical Raw Materials list for the EU[517]. It is clear that the EU needs to diversify its raw materials supply chains to achieve open strategic autonomy. A secure and sustainable supply of raw materials for battery applications is one of the key challenges. Therefore, the EU and its Member States should ensure a proper framework for a sustainable, environmentally neutral and responsible sourcing.

According to EBA250, Europe should be able to cover more than a half of the battery ecosystem's needs for lithium by 2025 thanks to projects under way. An encouraging development is the trend to investigate also larger occurrences of geothermal brines as possible lithium resources, such as the Rheingraben on both sides of the German-French border where Vulcan Energy Resources just has completed a pre-feasibility study. Other areas of great geological potential for extraction of lithium from brines are found in the Pannonian Basin, Hungary. A lithium refining project is under way in Finland.

The Democratic Republic of Congo alone produces 64 per cent of the world's cobalt supply[518]. This being said, Europe, is a relatively important producer of refined cobalt with Finland (12%) having the largest share of the world's production after China[519]. The cobalt refinery in Kokkola, Finland, (now owned by Umicore) is the largest cobalt refinery outside of China. Terrafame is further developing the mining and refining capacity of cobalt in Finland.

Although the supply of nickel is more diversified, the EU relies on imports of the high-purity material necessary for battery production with a share of around 56%[520].

EU subsidiaries of Asian companies might face fewer raw materials bottlenecks as many raw materials are mined in Asia and most are processed in Asia. At the same time EU headquartered battery companies should unlock the potential of local raw material deposits and local recycling facilities.

---

[514] Energy Storage News (Andy Colthorpe), Guidehouse: Fluence ahead of Tesla in global utility-scale energy storage leaderboard, 29 January 2021.

[515] Reuters (Vera Eckert), Christoph Steitz, Shell-owned German solar battery firm sonnen sets sights on growth, 15 January 2021.

[516] YSG Solar, Top 50 Energy Storage Companies in 2021, 12 January 2021: https://www.ysgsolar.com/blog/top-50-energy-storage-companies-2021-ysg-solar

[517] COM(2020) 474 final.

[518] European Commission, Report on Raw Materials for Battery Applications, 22 November 2018, SWD(2018) 245/2 final.

[519] European Commission, Study on the EU's list of Critical Raw Materials (2020), Factsheets on Critical Raw Materials.

[520] European Commission, DG ENER "Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis", 8 October 2021.

As regards secondary raw materials, currently most of the batteries at the end of life are sent to Asia. The recycling industry is concentrated in China and South Korea, where the vast majority of the batteries are also made, but there are several dozen recycling start-ups in North America and Europe. Chinese GEM and Brunp (CATL subsidiary) and a number of other Chinese and Korean companies account for up to 88% of the market[521]. Competition is so intense in China that recyclers are willing to pay to for used batteries, which is not yet the case in EU. For the time being, Umicore, with its world-wide capacities, is the only company headquartered outside Asia belonging to leading global recyclers[522].

Overall, recycling capacities in the EU are still low. Together with significant export to Asia of end-of-life li-ion batteries this means lost opportunity for EU to retain raw materials, including critical lithium and cobalt. Umicore's existing facility in Belgium has an installed capacity of 7 000 tons per year and Northvolt's recycling plant will have the capability to recycle approximately 25 000 tons of battery cells per year from 2022. Limited recycling capacity will be added in 2021 through VW pilot recycling plant in Salziger (1 200 t/year) andFortum's plant in Ikaalinen (3 000 t/year). There are also other companies active on local markets, e.g. Nickelhütte Aue (DE) or Elemental Holding (PL).

Other projects have been announced and are under development which will enable Europe to recover important raw materials, such as lithium, cobalt and nickel. In addition, Akkuser OY, Duesenfeld, Recupyl, SNAM and a number of other EU companies have technological expertise relevant to recycling of lithium-ion batteries. Yet, capacities will need to ramp up much more quickly to meet the increasing amount of batteries that reach their end-of-life in some years from now.

EBA250 is planning to launch a Sustainable Battery Material Fund in 2021 to accelerate scoping pre-feasibility studies and definite feasibility studies. Private capital will be involved in this fund. In addition, the batteries value chain will benefit from the European Raw Materials Alliance (ERMA)[523] launched in September 2020, as part of an Action Plan on Critical Raw Materials[524].

21.5. Final Considerations

The EU is strong in the segment of integration/final products (EVs and stationary storage).

It is rather weak when it comes to raw materials, advanced materials (except cathodes) and equipment for manufacturing of lithium-ion cells. Recycling capacities are also insufficient, even if there is considerable know-how. This leads to imports from third countries and in case of recycling – export to third countries.

In the central part of the value chain – lithium-ion cell manufacturing, EU is gradually increasing its weight. It will still take a number of years before EU is largely self-sufficient in lithium-ion cell production for EVs and stationary storage.

22. SWOT AND CONCLUSIONS

STRENGTHS	**WEAKNESS**
• Large ecosystem around batteries in a growing economic sector. EBA250	• Battery industry is highly dependent on third countries for sourcing of raw

---

[521] Greentechmedia, (Jason Deign), How China Is Cornering the Lithium-Ion Cell Recycling Market, 11 September 2019.

[522] In4Research, Lithium ion Battery Recycling Market - Strategic recommendations, Trends, Segmentation, Use case Analysis, Competitive Intelligence, Global and Regional Forecast (to 2026), 2020.

[523] https://erma.eu/

[524] Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability, COM(2020) 474 final.

Business investment platform facilitating match making between investees and investors • All key world producers of batteries are establishing their subsidiaries in the EU or have plans to do so. Annual total production capacities of batteries in the EU are steadily growing. Dependence on imported battery cells is set to decrease. • EU has decades long expertise in high-end lithium-ion battery cells (Saft, Varta, Leclanché) • A number of EU headquartered companies are advancing with giga-factory plans for lithium-ion cells. • Very strong companies in end-products sector (EVs and storage systems); their active involvement in lithium-ion battery cells giga-factory projects • The EU finally has strategic research agenda for the entire batteries value chain (Batteries Europe, 2020). • Europe is increasing R&I spending, notably through multi-billion Member States-led IPCEIs and increased EU funding (Horizon 2020 and Horizon Europe). • EU CO_2 norms for cars and renewable energy targets push local demand. Some Member States have offered a number of incentives to encourage the move to electric vehicles and have envisaged sun-set clauses for sale of conventional cars. Some cities (e.g. in Denmark) stopped buying conventional busses as of 2021.	materials. • The EU has no lithium refining capacity. • Battery cell production equipment is largely imported from Asia. • EU head-quartered companies don't yet have experience in mass production of lithium-ion batteries. For the time being, EU mass production for e-mobility and storage needs is entirely dependent on subsidiaries of South Korean companies in Poland and Hungary. • Batteries are largely exported to Asia for recycling at the end of life. Even EU headquartered Umicore has most of recycling capabilities in Asia. • Trade deficit in lithium-ion batteries kept growing (at least as at end 2019), due to higher imports than exports. This trend is likely to change soon. • Firms from Asia have a clear lead as at end 2018 in the global race for battery technology, with Japanese and South Korean companies at the forefront. It is to be seen how the situation changes with recent initiatives to support R&I and giga-factory projects. • In some MS support to residential PV (notably, feed-in conditions) is organised in a way that there are no incentives for self-consumption and storage. • Lack of skills across most of the value chain, albeit a series of facilitating measures in the pipe-line. • Relatively low activity of the EU in sodium-ion battery race may mean lost opportunity to reduce dependence on critical lithium and cobalt. • Relatively low activity of EU countries on stationary BESS markets cause the price of the solutions is disproportionally high, comparing with automotive batteries, hindering wide entry on the markets.

OPPORTUNITIES	**THREATS**
• Coordination of different battery R&I activities can be strengthened using Batteries Europe technology platform. • Increased attention to the issue of raw materials through creation of the European Raw Materials Alliance. Possibility to attract investments in mining in the EU; possibility to facilitate social acceptance by sharing benefits from mining; If EBA250 sustainable battery material fund, to be established in 2021, manages to attract enough resources from private investors, it can play an important role. • Expand EU industry for lithium-ion cell production machinery based on strength of EU players such as Manz. • Expand EU competence in active materials beyond cathode materials. • Build strong lithium-ion battery recycling industry based on strength of companies such as Umicore. • Build on the strength of Nordic countries in electrification of short-sea shipping and provision of shore side electricity. • MS using possibilities under regional aid, environmental and R&I aid rules to intervene in cases of market failure. More active use of national allocations of EU funds for the benefit of weaker segments of the value chain. • Future EU Regulation on Batteries and Waste batteries can help Europe becoming a world leader in clean batteries and limit market access of batteries with high CO_2 footprint. • EBA250 Academy established in 2021 provides good opportunities to close skills gap, but support from each MS is needed to deploy the new training platform across the EU. • Through the ALBATTS project, the EU is	• Europe is increasingly dependent for both raw materials and also some active materials on third countries. EU headquartered battery cell producers may even be more concerned than EU subsidiaries of Asian companies. • Current trend towards ever bigger EVs may compromise energy efficiency and exacerbate the issue of raw materials, unless it is a temporary trend and contributes to most polluting cars being replaced first. Consumer awareness is necessary. • EU head-quartered companies face a big challenge of being able to mass-produce battery cells at competitive prices. • Ability of EU cell manufacturers to embrace cell standardization challenge launched by VW (currently, EV battery cells are produced in different shapes and sizes). • Charging infrastructure deployment may not be advancing at a needed pace (albeit a number of measures to address the issue are in the pipeline).

establishing a long-term strategy to identify and meet skills needs in the EU battery sector. • Demand strengthening measures: strengthened EU CO_2 norms for transport for 2030 at EU level; more countries setting/advancing sun-set clauses for sale of conventional vehicles; more cities moving towards zero emission zones; countries/cities being more ambitious in their public procurement of busses/bus services than required by the Clean Vehicle Directive. • Strengthened renewable energy targets for 2030 at EU level should further boost demand for stationary storage. • With the end of transposition deadlines for the Clean energy package norms, there should soon be no major legal barriers for deployment of stationary batteries It should also help deployment of batteries if MS were more ambitious with rolling out smart meters, than legally required.	

HYDROGEN ELECTROLYSERS

INTRODUCTION

With the policy impetus initiated by the European Commission's Green Deal to cut greenhouse gas (GHG) emissions by 55% by 2030 and restrict global warming to 1.5 degrees Celsius for the Long Term Scenario in 2050, there has been renewed policy and industrial interest to support renewable and low carbon hydrogen production and use, as a key contributor to European decarbonisation.

The Hydrogen Strategy for a Climate Neutral Europe Communication[525] - thereafter referred to as the Hydrogen Strategy – has outlined the policy context and necessary actions for the development and deployment of Renewable and Low Carbon Hydrogen[526].

The current EU's demand for hydrogen of about 7.7 million tonnes per year[527] is still largely met by fossil fuels. In this context, renewable hydrogen obtained through water electrolysis[528] (today's estimates for water electrolysis-produced hydrogen is less than 1% of the overall production[529]) has the potential to decarbonize hard-to-electrify and hard-to-abate sectors such as industry and heavy-duty transport, and contribute to energy services such as the grid balancing and seasonal storage.

This analysis will focus on the four main technologies used to produce renewable hydrogen through the use of water electrolysis by using (renewable) electricity, in order to contribute to the EU objectives of decarbonisation. Therefore the scope of this section will focus on Alkaline electrolysis, Polymer Electrolyte Membrane (PEM) electrolysis, Solid Oxide (SOE) electrolysis and Anion Exchange Membrane (AEM) electrolysis.

The Hydrogen Strategy aims at kick-starting and enabling the penetration of hydrogen technologies inside Europe, thus making it possible to achieve the sustainable scenarios as outlined in the LTS.

The 2030 goals of the Hydrogen Strategy are supplemented by an array of policies and funding measures, including.

1. Launching of the Clean Hydrogen Joint Undertaking - as a Public Private Partnership EU body continuing the mandate from the Fuel Cells and Hydrogen Joint Undertaking (FCHJU) during the period of the Horizon Europe Programme - to manage the R&I funding (EC proposal of EUR 1 billion) for renewable / low carbon hydrogen production, applications and storage.
2. Setting up a dedicated call for proposals from the Green Deal call in Horizon 2020 (launched in 2020) to support projects with 100 MW electrolyser capacity in real life operations, which

---

[525] A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final.

[526] Renewable hydrogen, as defined in the Hydrogen Strategy, is hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources.

[527] Fuel Cell Observatory: https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-demand data for EU MS that exclude UK, Norway, Switzerland and Iceland.

[528] For the purpose of the analysis, Renewable Hydrogen refers only to hydrogen produced through water electrolysis powered by renewable electricity.

[529] To note that in addition to Water Electrolysis, about 2%-4% are estimated to come from Chlor-Alkali Electrolysis.

resulted in selection of 3 projects and ought to lead to an increased production capacity in the EU[530].

3. Establishing the European Clean Hydrogen Alliance, which puts together industry, investors, civil society and public authorities to facilitate the large-scale deployment of clean hydrogen in Europe. The European Clean Hydrogen Alliance aims to promote projects that deliver a robust foundation for the hydrogen value chain, starting from investments in clean hydrogen production and hydrogen infrastructure and covering several hydrogen use sectors (i.e. industrial use, buildings, mobility and energy). The Alliance is also assessing bottlenecks and framework conditions that would contribute to a favourable investment climate that supports EU policies. Alliance members submitted about 1050 projects for the preparation of a pipeline of investment projects for the large-scale deployment of clean hydrogen, some of which were presented during the first Hydrogen Forum in June 2021. To date[531], the European Clean Hydrogen Alliance collected projects amounting to 60 GW electrolyser capacity by 2030, out of which, the large majority may be powered by renewable electricity.
4. Member States have notified to the EC of first hydrogen Important Projects of Common European Interest (IPCEIs), which will allow them to offer state aid to such projects under the relevant EU rules. Member States may award state aid to hydrogen also under other State aid rules, notably the Environmental protection and Energy Aid Guidelines, which are currently being reviewed. Other activities in the international arena such as, for example, Mission Innovation (cooperation launched in the context of the Conference of the Parties of the United Nations COP) and the Clean Hydrogen Mission with the European Commission co-leading, the group of the Clean Energy Ministerial on Hydrogen and the Global Ports Coalition, all supplement EU and national efforts.
5. The Commission presented an interactive online hydrogen public funding compass allowing stakeholders to navigate EU and Member States public funding opportunities for their clean hydrogen projects[532].

The Resilience and Recovery plans will include policy support mechanisms, including new schemes such as pilots for Contracts for Difference auctions for RES based hydrogen for difficult to decarbonize sectors, or it is linked with other measures in RES production such as offshore installations, or onshore wind, PV installations.

Some of the commercial and trade data for Water Electrolysis are not available mostly due to the fact that many of the reports provide only global overviews and do not cover specifically hydrogen produced through Water Electrolysis technology.

23. TECHNOLOGY ANALYSIS – CURRENT SITUATION AND OUTLOOK

23.1. Introduction

Hydrogen offers the opportunity to be used as both an energy vector and a feedstock molecule, therefore having several potential uses across sectors (industry, transport, power and buildings sectors). Hydrogen does not emit CO_2 when consumed, and offers the option to decarbonise several hydrogen-based

---

[530] European Commission Green Deal Call, 2020: https://ec.europa.eu/info/sites/default/files/research_and_innovation/green_deal/200506_gdc_brief_slides_2-2_electrolyser.pdf

[531] The assessment is based on the preliminary findings of the EC at the time of the publication of this report, and contain data on the projects submitted through the European Clean Hydrogen Alliance.

[532] Hydrogen Public Funding Compass | Internal Market, Industry, Entrepreneurship and SMEs (europa.eu).

applications, provided its production is sustainable and hydrogen does not carry a considerable carbon footprint.

Currently, the most mature and promising hydrogen production technology, which can be coupled with renewable electricity, is water electrolysis.

In short, water electrolysis, involves the dissociation of water molecules into hydrogen and oxygen and requires large amounts of electrical energy: for low temperature electrolysis, around 55 kWh[533] (about 200 MJ) of electricity are needed to produce 1 kg of hydrogen from a stoichiometric minimum of 9 kg of water. The thermodynamic limit for dissociating water at room temperature through electrolysis is around 40 kWh/kgH_2.

Solid Oxide Electrolysis (SOE) exploits the more favourable thermodynamics of water splitting at higher temperatures (usually above 800ºC) and can have efficiencies around 41 kWh/kgH_2, provided a suitable heat source is available; otherwise the heat requirements for maintaining the high temperature should also be factored in the efficiency[534].

The main electrolysis technologies[535], as well as their added values and drawbacks, are summarised below, and will be further analysed in the next sections:

Alkaline electrolysis is a well-established low temperature water electrolysis technology for hydrogen production, with relatively cost-effective stacks already available in the megawatt range. Alkaline electrolysers do not use noble metal catalysts and are stable, with a very long lifetime. Their main drawbacks are that alkaline electrolysers can only operate at relatively low current densities and their lack of flexibility. Historically, alkaline electrolysers systems have shown poor dynamic behaviour, with limited load flexibility as low loads may present a safety issue. However, progress is being made on adapting this technology for flexible operation.

Polymer Exchange Membrane (PEM) electrolysers can reach high current and power density and can operate well under dynamic operations and partial load. Therefore, they are highly responsive, which makes coupling with RES easier. Their main drawbacks are associated with durability, related to catalyst loss and membrane lifetime, and cost, partly due to their catalysts consisting of expensive and rare platinum group metals.

Solid Oxide electrolysers (SOE) must use materials capable of withstanding the higher temperatures involved with the use of this technology. They have slow ramp rates from cold-start due to the necessity to reach high temperatures and the necessity to avoid thermal shocks for the ceramic materials constituting the electrochemical cell. Therefore, they also have limited flexibility. They also contain critical raw materials such as rare-earth metals. Despite having reached a technological level able to support large demos, R&I actions are still necessary and materials related challenges have to be tackled in order to guarantee the possibility of deploying the technology at large scale.

In addition to the two main low temperature electrolyser technologies (alkaline and PEM electrolysis), recent years have also seen the development of Anion Exchange Membrane electrolysers (AEM). This

---

[533] The system efficiency value of 55kWh.kgH2 is an overall estimate. MAWP (Multi Annual Work Plan) targets of the Fuel Cell Hydrogen Joint Undertaking for 2020 are 55kwh/kgH2 for PEM and 50kWh/kgH2 for Alkaline.

[534] It is estimated that, in practice around 12- 13 kg kg of water are used for the production of 1 kg of H2. The reason for this assessment is linked to losses in purifying/deionising water down to 1-10 µS before feeding it to the electrolyser.

[535] Historical Analysis of FCH 2 JU Electrolyser Projects, JRC (European Commission) Technical Report, 2021.

technology operates in alkaline media but using a solid electrolyte. In principle, this means they can combine the use of non-platinum group metal catalysts with the production of high-purity hydrogen due to the presence of the solid electrolyte. This technology is currently at a relatively low Technology Readiness Level (TRL 3-5) and cannot presently achieve the performance and durability of other water electrolysis technologies.

Electrolysers Capacity installed, generation/production

Whilst renewable hydrogen production is still at a very low capacity, a large number of demonstration projects have been announced and production is expected to grow significantly in the coming decade.

The Hydrogen Strategy envisioned a step by step path towards a European hydrogen ecosystem:

- in a first phase, from 2020 to 2024, the strategic objective is to install at least 6 GW of electrolysers in the EU, and the production of up to 1 Mt of renewable hydrogen per year;
- in a second phase, from 2025 to 2030, the strategic objective is to install 40 GW of electrolysers and the production of up to 10 Mt of renewable hydrogen per year[536].

The European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy Communication[537] - thereafter referred to as the Long Term Strategy (LTS) - foresees that the share of hydrogen in Europe's energy mix will grow from the current level of less than 2% to 13-14% by 2050, thus amounting from 60 up to 80 million tonnes of oil equivalent (Mtoe) in 2050. This forecast increases to 16-19% if hydrogen is used for the production of synthetic fuels (i.e. fuels synthetized using hydrogen produced from electrolysis)[538].

In terms of installed electrolyser capacity, the LTS foresees up to 511 GW (scenario referring to containment of global warming at 1.5 Degrees Celsius TECH scenario[539]), whilst other studies suggest a 1 000 GW European market by 2050[540].

In 2019, the EU had around 80 MW of dedicated water electrolysis capacity installed (all technologies), of which around 30 MW were located in Germany in 2018[541].An analysis performed by a private organisation[542] in May 2021, collecting information on planned and installed capacity in the EU, and taking into account the announcements of governments in their National Strategies on Hydrogen, concluded that electrolysers pledges would sum up to 34 GW by 2030[543], making it close to the EC target of 40 GW by 2030. The estimate includes 7 EU MSs (DE, FR, NL, PT, ES, IT) and the UK.

---

[536] A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final.

[537] A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy, COM(2018) 773 final.

[538] European Commission, Hydrogen use in EU decarbonisation scenarios, JRC EU Science Hub.

[539] A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy, COM(2018) 773 final.

[540] Kanellopoulos, K., Blanco Reano, H., The potential role of H2 production in a sustainable future power system - An analysis with METIS of a decarbonised system powered by renewables in 2050, EUR 29695 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-00820-0, doi:10.2760/540707, JRC115958.

[541] DVGW, Wasserstoff Schlüssel für das Gelingen der Energiewende in allen Sektoren, 2019.
Fuel Cells and Hydrogen Observatory, Hydrogen Supply Capacity, 2021.

[542] Aurora Energy Research, Hydrogen Market Attractiveness Report, 11 May 2021.

[543] The estimate includes about 4-5 GW in UK in that presentation and include low carbon hydrogen.

Members of the European Clean Hydrogen Alliance are working on projects aiming at installing electrolysers with the capacity to produce over 6m tons of hydrogen by 2030[544.]

Calculations published by the Fuel Cell and Hydrogen Joint Undertaking (FCHJU) in their assessment of the National Energy and Climate Plans (NECPs) estimate a potential installed electrolyser capacity between 13 (less favourable scenario) and 56 GW (more favourable scenario) in EU and UK by 2030[545].

<u>Additional information on the main production pathways</u>

Today, the EU demand for hydrogen is about 7.7 million tonnes per year[546], out of about a global demand of 70 Mt/y of hydrogen in pure form, producing around 830 Mt of CO_2 globally[547]. Nowadays, the hydrogen production is almost completely based on the use of fossil fuels and associated with large industrial processes.

The dedicated worldwide production of hydrogen (hydrogen as primary product) can be classified according to the following feedstocks[548]:

- ca. 71% from natural gas (steam methane reforming), accounting for 6% of global natural gas use, and emitting around 10 tonnes of carbon dioxide per tonne of hydrogen (tCO2/tH2);
- ca. 27% from coal (coal gasification), accounting for 2% of global coal use, emitting around 19 tCO2/tH2;
- about 0.7% from Oil (reforming and partial oxidation),emitting around 6.12 tCO2/tH2);
- less than 0.7% potentially from renewable sources (water electrolysis).

<u>Additional information on the end use of hydrogen:</u>

The total worldwide hydrogen use is mainly[549]:

- ca. 33% as chemical feedstock in oil refining;
- ca. 27% is ammonia production;
- ca. 10% in methanol synthesis[550].

The remaining fractions are linked with other forms of pure hydrogen demand (e.g. chemicals, metals, electronics and glass-making industries) and use of mixtures of hydrogen with other gases (e.g. carbon monoxide) such as for heat or combined heat-and-power generation.

The current use of hydrogen as feedstock in the chemical and petrochemical industry has to be added to the future uses as i) use as feedstock in new industrial processes (e.g.: steelmaking, or carbon capture and use applications) ii) fuel for the transport sector (various modes), iii) cogeneration of electricity and heat, or electricity alone, iv) a storage option for electricity, v) for heat generation in industrial environments.

---

[544] European Clean Hydrogen Hydrogen Alliance – Overview of projects collected, Hydrogen Forum, 17-18 June 2021.

[545] Fuel Cell Joint Undertaking, Opportunities for Hydrogen Energy Technologies Report, August 2020

[546] Fuel Cell Observatory website. 8.3 MtH2/y including EU, UK, Norway, Switzerland and Iceland.

[547] As a reference total European industrial emissions were estimated at 877 $MtCO_2$/y (around 10% of these can be associated with hydrogen production) in 2017, European Environment Agency.

[548] IEA, The Future of Hydrogen- Seizing today's opportunities, p.32 – 2018 estimates, June 2019

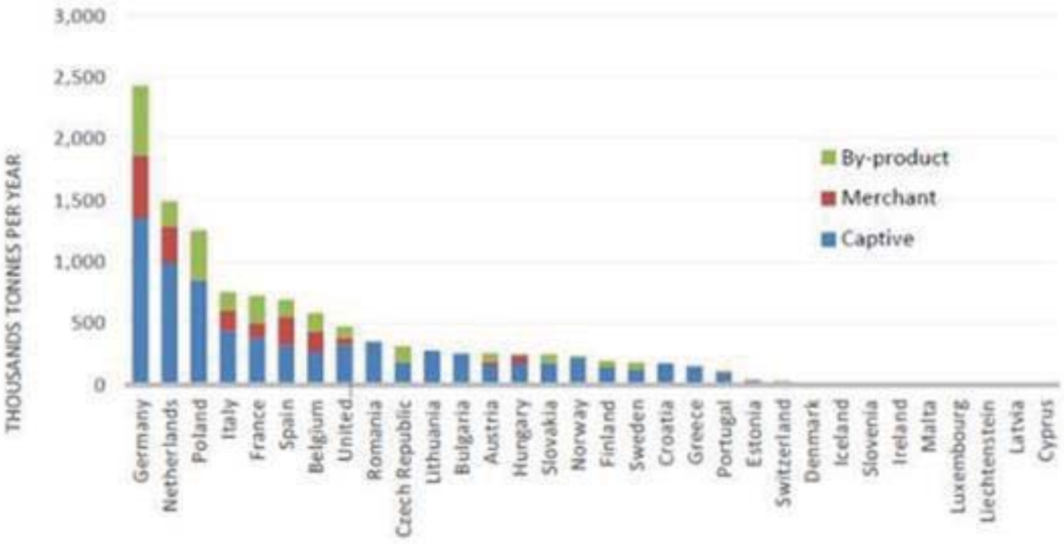
[549] IEA, The Future of Hydrogen- Seizing today's opportunities, 2019.

[550] In this case hydrogen is present as a component of syngas.

Transport of hydrogen, its storage and its conversion in end-use applications (e.g. industry, mobility, or buildings) are not part of the focus of the analysis performed in this report.

Figure 10 and Figure 11 below show the production and consumption capacity per Member State (and UK), where largely the production matches the domestic demand.

Figure 10 Hydrogen production capacity (expressed in thousands of tonnes per annum)



Source: Fuel Cell Hydrogen Joint Undertaking,2019 data

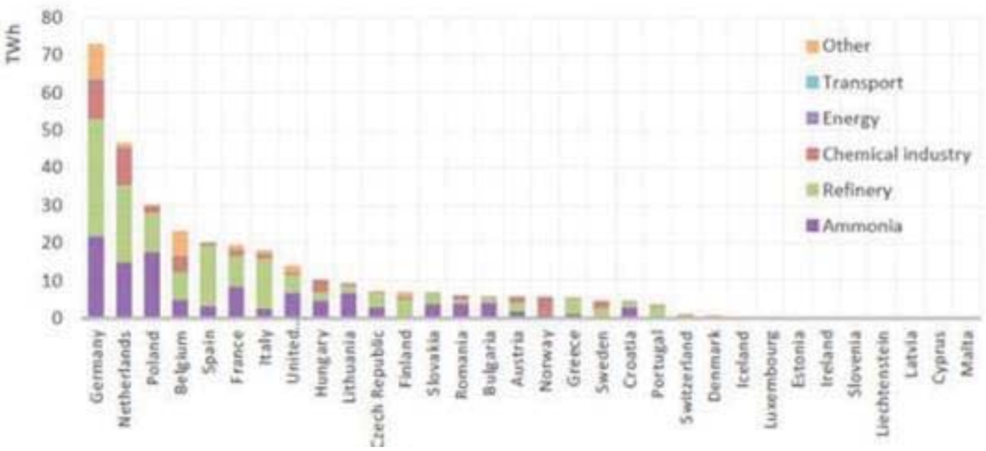
European hydrogen use in its pure form (both merchant and captive)[551]:

- ca. 47% used in oil refining;
- ca. 40% in ammonia production;
- ca.8% in methanol production and the remaining used mainly in other chemical productions and industrial processes.

Figure 11 Hydrogen Consumption (expressed in TWh)

---

[551] Fuel Cells and Hydrogen Joint Undertaking, Hydrogen Roadmap Europe, 2019.



Source: Fuel Cell Hydrogen Joint Undertaking (2019 data)

23.2. Cost of production of renewable and low carbon hydrogen; cost of electrolysers (CAPEX costs) and / other Operational (OPEX) costs including Cost of Electricity (CoE)

The cost of producing renewable and low carbon hydrogen through electrolysis depends on several factors.

1. Capital investment for electrolysers depends on the technology.
2. Operating costs, linked with the costs of electricity input (which can be a significant part of overall costs for both renewable and low-carbon hydrogen, and increasing as CAPEX costs are coming down).
3. Other electricity-related, or grid-related taxes and tariffs.
4. Load factor[552].

Other factors depends on the regulatory environment such as the price of carbon emission (e.g. in the Emission Trading System), as it impacts the competitiveness of hydrolysis (i.e. renewable hydrogen produced through water electrolysis using renewable electricity), versus other production pathways which emit CO2.

Other infrastructure or transportation cost elements such as availability and cost of storage should also be considered.

These factors may have a considerable impact on the final price of hydrogen, however the analysis of these factors is out of scope in this assessment.

Cost of Electrolysers:

Table 1 summarizes the main Key Performance Indicators for 4 main categories of Electrolysers i) Alkaline; ii) PEM Polymer Electrolyte Membrane; iii) AEM and iv) Solid Oxide Electrolysers (SOE).

---

[552] Amount of hours a production facility is able to run per year.

Alkaline and Polymer Electrolyte Membrane are technologies that have achieved commercial maturity and have been, or will be, deployed in demonstrations reaching a power of tens of MW[553].

Solid Oxide Electrolysers have been already tested in real life environment and planned demonstrations should deploy several hundreds of kW up to MW scale soon[554].

Anion Exchange Membrane Electrolysers are at a much lower technical maturity level (TRL 3-5), with only one European supplier[555] and a product offer in the range of few kWs.

Table 1 Key Performance Indicators for the four main Water Electrolysis technologies in 2020 and projected in 2030

	2020				**2030**			
	Alkaline	PEM	AEM	SO	Alkaline	PEM	AEM	SO
Chracteristic Temperature [°C]	70-90*	50-80*	40-60*	700-850*	-	-	-	-
Cell Pressure [bar]	<30*	<70*	<35*	<10*	-	-	-	-
Efficiency (system) [kWh/kgH2]	50	55	57*	40	48	50	<50*	37
Degradation [%/1,000h]	0.12	0.19	-	1.9	0.1	0.12	-	0.5
Capital Cost Range [€/kW - based on 100 MW production]	600	900	-	2700	400	500	-	972

Source: Addendum to the Multi - Annual Work Plan 2014 – 2020, FCH JU, 2018 and for parameters labelled with '', DG ENERGY (European Commission) elaboration based on IRENA data from the "Green Hydrogen Cost Reduction" report", 2020*[556].

CAPEX (in particular for PEM) have already been significantly reduced in the last ten years, and are expected to roughly halve in 2030 compared to today thanks to economies of scale and acquired expertise. Figure 12 gives an example of expected evolution of learning curves based on available historic data (until 2017).

Figure 12 Cost trajectory for PEM and AEL electrolysers based on manufacturers estimates

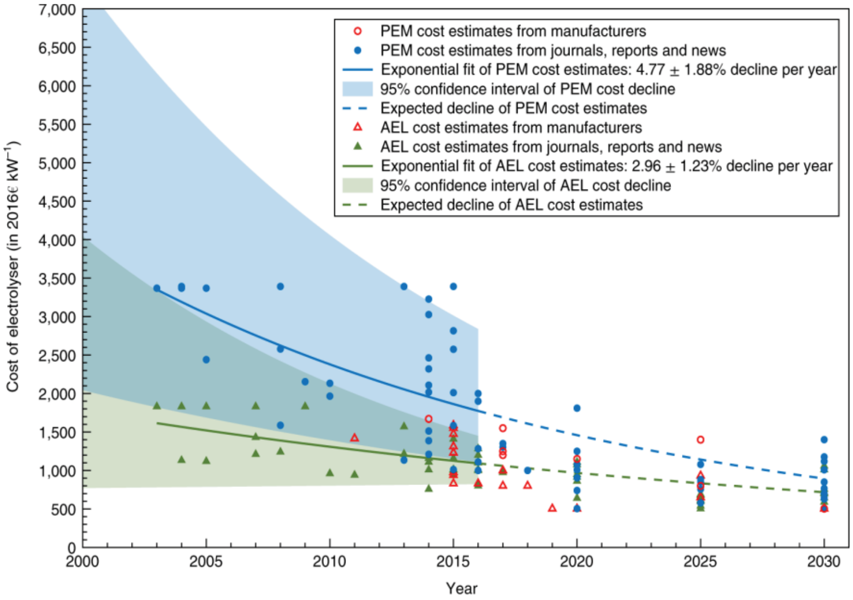
---

[553] Examples of projects: DJEWELS (Akaline) and REFHYNE (PEM).

[554] MULTIPLHY project will demonstrate at MW scale (2.4 MW) https://www.green-industrial-hydrogen.com/

[555] Enapter.

[556] FCHJU Addendum to 2014-2020 Work Plan, and IRENA, Green hydrogen cost reduction, p12.



Source: Economics of converting renewable power to hydrogen, G. Glenk, S. Reichselstein, [*https://www.nature.com/articles/s41560-019-0326-1*](https://www.nature.com/articles/s41560-019-0326-1)

Impact of the Cost of Electricity on the viability of Electrolyser investment

All analyses highlight that the price of hydrogen produced via electrolysis is reduced by increasing the number of operational hours and decreasing electricity prices; IRENA estimates that these factors have the capacity to decrease cost of hydrogen by 80% in the longer term[557]. These are the main factors that will influence the economic viability of the investment and are further strengthened by measures decreasing CAPEX impact on levelised cost of hydrogen, such as increasing system lifetime, or OPEX impact, such as increasing operational efficiency of the system. They will be key drivers for the progressive development of hydrogen across the EU economy.

The European Clean Hydrogen Alliance is identifying the availability of required amounts of competitively priced renewable and low-carbon electricity as one of the main factors determining the actual deployment of large-scale electrolysers.

In regions with suitable costs of renewable electricity, electrolysers are expected to produce hydrogen that will compete with fossil-based hydrogen already in 2030[558].

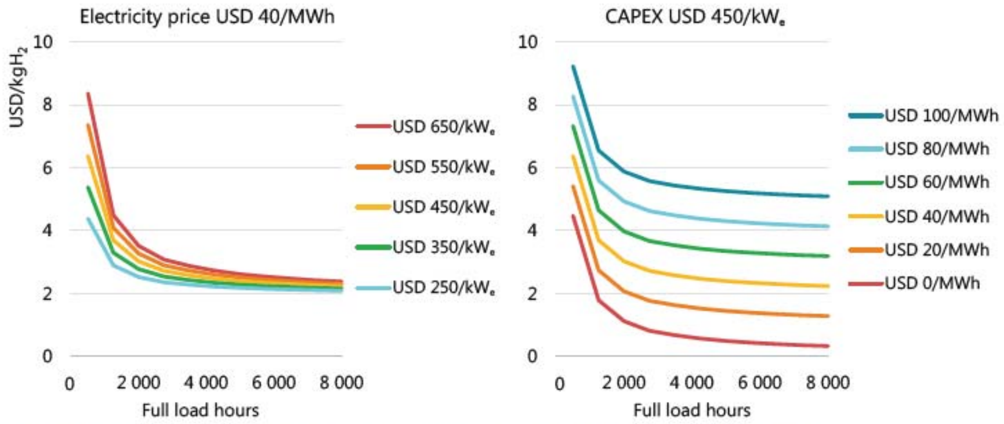
Locating electrolysers in areas with high access to cheap renewable electricity is likely to decrease overall costs and contribute to viable investments.

---

[557] IRENA, Green Hydrogen Cost Reduction, IRENA, 2020.

[558] Assuming current electricity and gas prices, low-carbon fossil-based hydrogen is projected to cost in 2030 between 2-2.5 EUR/kg in the EU, and renewable hydrogen are projected to cost between 1.1-2.4 EUR/kg (IEA, IRENA, BNEF). Costs linked with transport over long distances should be added on top of production costs.

Figure 13 Impact of electricity Costs (right) (USD/kg H2) and Electrolyser investment costs by operating hour (left)



Notes: MWh = megawatt hour. Based on an electrolyser efficiency of 69% (LHV) and a discount rate of 8%.

Source: IEA 2019. All rights reserved.

Source: The Future of Hydrogen- Seizing today's opportunities, IEA, 2019

The Renewable Energy Directive (REDII) allows hydrogen produced from installations connected to the grid (even if the electricity mix has low shares of renewable electricity) to be statistically accounted for as 100% renewable, provided that certain conditions are met, including the additionality of the renewable electricity used.

With increasing full load hours, the impact of CAPEX on hydrogen production costs declines and the relative contribution of electricity costs to the levelised cost of hydrogen production via electrolysis becomes larger.

Projected costs of renewable based hydrogen production:

According to IRENA[559], '"in the best-case scenario," using low-cost renewable electricity at USD 20/MWh in "large, cost-competitive electrolyser facilities" could produce green hydrogen at a competitive cost with hydrogen already today'. However, this depends on the availability of required volumes of competitively priced renewable electricity.

Based on these assumptions for i.a. prices for electricity and carbon prices, the associated cost estimates for production range (based on IEA, IRENA, BNEF and the EC communication[560]) are:

- International prices of low-carbon fossil-based hydrogen: EUR 1.5-2.2/kg; renewable hydrogen: EUR 2.5-5.5/kg, depending on electricity price and load hours (see Figure 14).However, calculated costs depend on a number of assumptions used as input factors including electricity price and load hours. In countries relying on gas imports and characterised by good renewable resources, clean hydrogen production from renewable electricity can compete effectively with production that relies on natural gas[561].

---

[559] IRENA, Green Hydrogen Cost Reduction report, 2020.

[560] Communication C(2020) 301 of 8 July 2020 Hydrogen Strategy.

[561] IEA - The Future of Hydrogen, 2019, IRENA, Bloomberg BNEF, March 2020.

Reducing the price of renewable hydrogen allows an increasing penetration of hydrogen into different sectors and applications. Usually, system boundaries for hydrogen production calculations are defined by the production side, but actual competitiveness for hydrogen uses comes from the opportunity offered by business cases outside the production boundaries, which likely include steps such as transport and storage. Industrial competitiveness could allow certain industrial processes to become affordable earlier than others which have to face more challenging economic competition against conventional fossil-based hydrogen (e.g. ammonia). As an additional advantage, renewable hydrogen may have a lower price volatility against hydrogen produced from fossil fuels, which follow natural gas prices. Its price will depend on the volatility of the (renewable) electricity used for electrolysis.

23.3. Public R&I funding

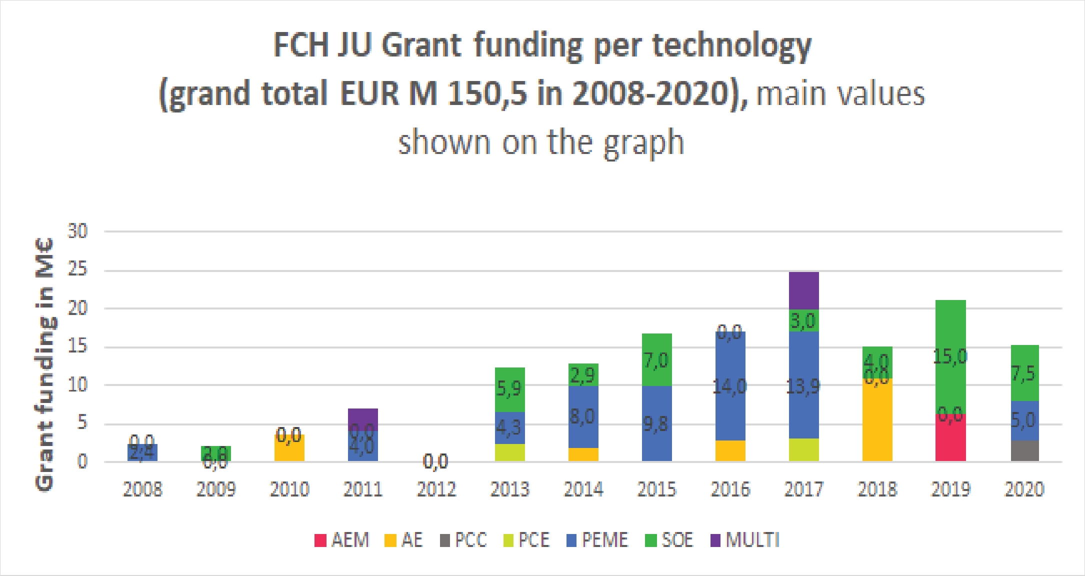
This section summarises the main sources of public funding at EU level.

- The Fuel Cell Joint Undertaking (established in 2008) as the Public Private Partnership (PPP);

To date, the Fuel Cell Joint Undertaking established in 2008, as an EU body to manage funding in relation to Hydrogen and Fuel Cell technologies, has dedicated about EUR 150.5 million since 2008 to electrolyser technologies (EUR 74.7 million are for research actions and EUR 75.9 million for Innovation Actions (IA).

The main beneficiary countries are Germany, France and the UK with about EUR 31.4, 25.4 and 18.4 million respectively.

Figure 14 Fuel Cell and Hydrogen JU grant funding per technology in period 2008-2020

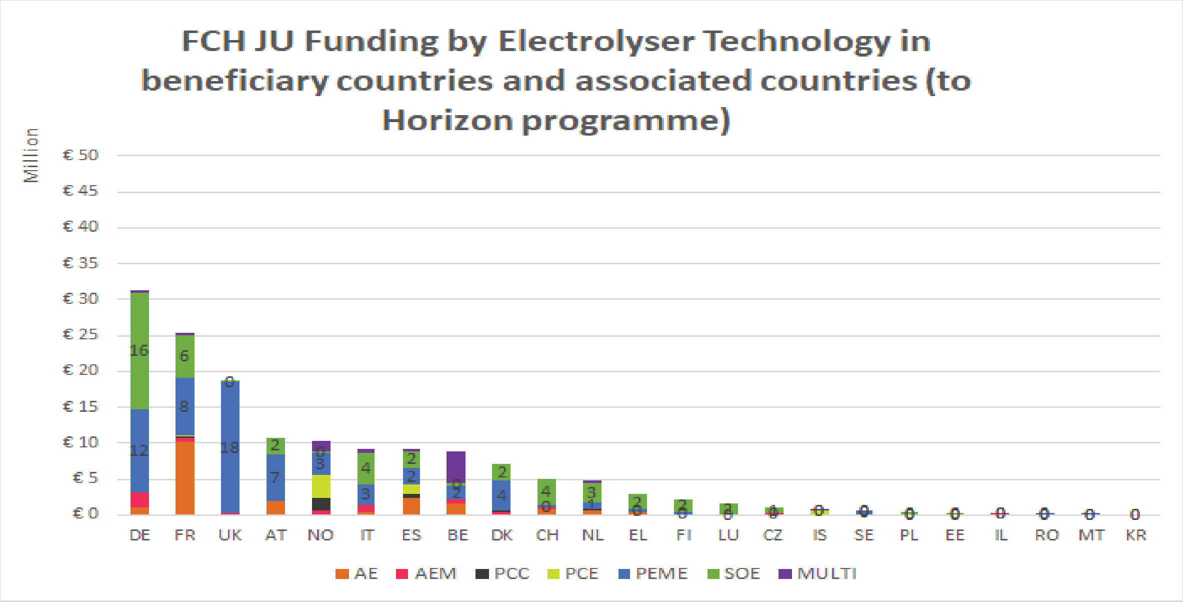


Source: Fuel Cell and Hydrogen JU, 2021

Notes:
PCE is proton conducting electrolyser (a low technology readiness level version of the Solid Oxide) which conducts protons through the solid oxide membrane

Multi- refers to multiple types of electrolyser technologies

Figure 15 Fuel Cell and Hydrogen JU funding by country and associated country, and per technology



Source: Fuel Cell Joint Undertaking, data 2021

Notes:
PCE is proton conducting electrolyser (a low technology readiness level version of the Solid Oxide) which conducts protons through the solid oxide membrane
Multi- refers to multiple types of electrolyser technologies

1) Dedicated call for proposals: 100 MW Electrolyser from the Green Deal Call (Horizon 2020 programme)

The European Commission has made circa EUR 90 million funding available in the Green Deal Call for proposals to install and operate electrolysers in real life environments.

After the competitive call for proposals and budget optimisation, 3 projects have been selected in 2021: one in the Netherlands to support electrolyser in the TSO and port environment, one in Germany in refining industry and one in Portugal combined with solar investments for multi end use applications.

Public national spending and European initiatives such as IPCEI and the ETS innovation Fund relevant for Renewable/ Low Carbon Hydrogen are today not easily measurable due to different reporting methodology and/or classifications and cannot be provided in an accurate and comprehensive way.

23.4. Private R&I funding

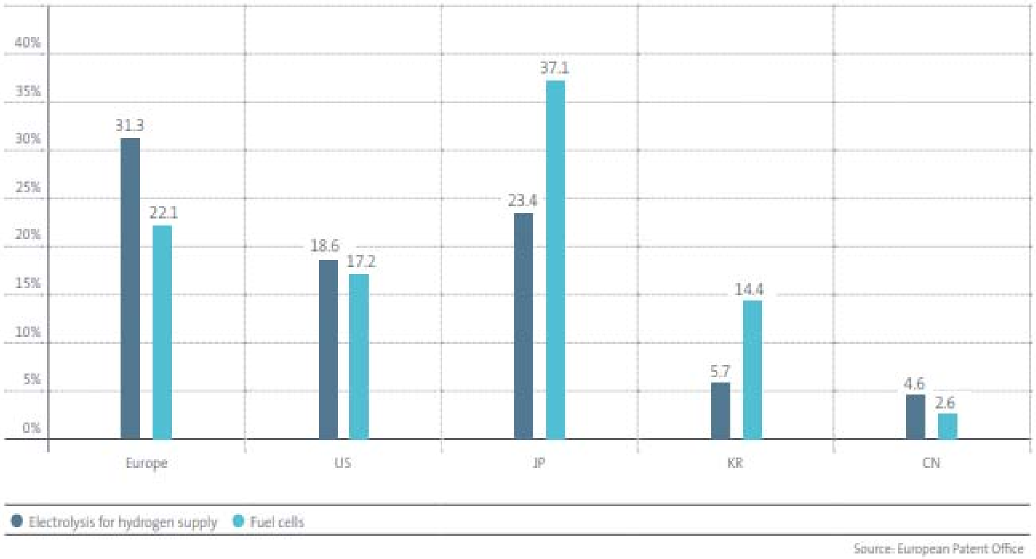
Due to the sensitivity of the information involved and the lack of fully developed electrolyser value chains outside of niche applications, it is very difficult to obtain accurate information on private R&I

funding. It is expected that with the growth of electrolyser deployment this information will become more readily available in the following years. Venture capital has already announced dedicated interventions targeted at hydrogen technologies[562].

23.5. Patenting trends - including high value patents

Whilst Japan has been patenting consistently in this technical area for many years, in other regions (in particular China) a steady increase in the number of inventions related to electrolysers has occurred in recent years. For electrolysers, Europe (including UK) files proportionally higher numbers of International Patent Families (patent applications filed and published at several international patent offices) than other leading economies.

Figure 16 Share of International Patent Families (IPF) in major economies for hydrogen and fuel cell technologies (historic data 2010-2019). Each IPF covers a single invention and includes patent applications filed and published at several patent offices.



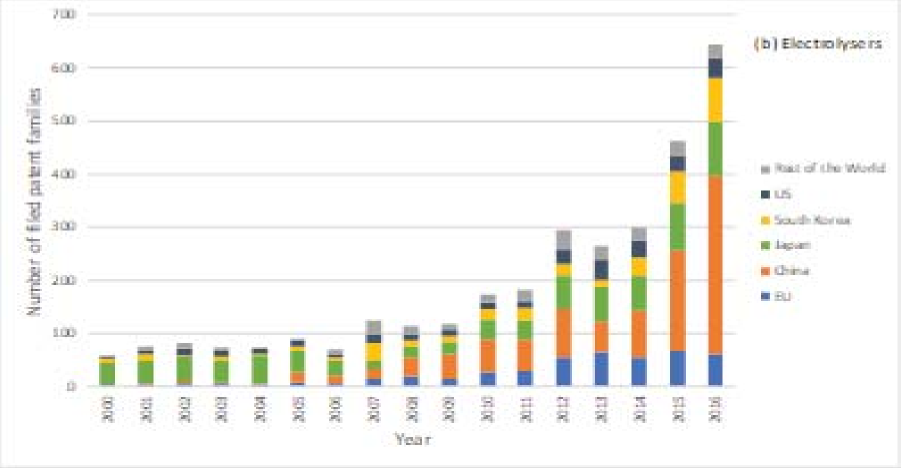
Source: European Patent Office/IEA[563]

---

[562] E.g.: Breaktrhrough energy ventures / FiveT Hydrogen https://fivet.com/experience /AP Ventures https://apventures.com/hydrogen / Planet Power Finance AG/ White Summit Capital https://whitesummitcap.com/press/.

[563] IEA, Patents and the energy transition, April 2021.

Figure 17 Number of patent families for electrolysers and geographical area



Source: JRC based on EPO Patstat data, 2020.

The majority of patent filings in Asia and in particular in China contain domestic patents.

23.6. Level of scientific publications

The Fuel Cell Observatory published some data[564] with regard to fuel cell and hydrogen production. The Fuel Cell Observatory lists the following countries ranking highest: Germany, France, Italy,

23.7. Final Considerations

To conclude on technology aspects for Water Electrolysis, four main technologies at different stages of maturity exist: Alkaline, Polymer Exchange Membrane, Solid Oxide and Anion Exchange Membrane electrolysis. Technology improvements are one of the factors that will contribute to lower the costs and availability of electrolysers on the market.

Most of the studies conclude that availability and cost of electricity will be the determining factor for the production of cost-competitive hydrogen.

As regards RI aspects[565], the technical report of the EC Joint Research Centre has provided recommendations based on the technology maturity and challenges to be addressed. These recommendations are summarised below.

For Alkaline electrolysers: The main challenge seems to be flexibility of use with renewable energy, however improvements are being made. Alkaline electrolysers seem to be more suited for the industrial use of hydrogen, rather than looking at flexibility for which PEM is more suited.

PEM electrolysers: future projects should consider the aspect of recyclability. This is of particular relevance because of the platinum group metals used. In particular, recycling of iridium is known to be

---

[564] FCHO, Publications: https://www.fchobservatory.eu/observatory/publications-eu28

[565] European Commission, Joint Research Center, 2021, Historical Analysis of FCH 2 JU Electrolyser Projects, Evaluation of contributions towards advancing the State of the Art. Davies, J. Dolci, F. Weidner, E.

challenging. An increase in operating hours (in order to reduce the share of CAPEX in the overall cost) will be important to the success of the technology.

AEM electrolysers are a promising technology, which could combine the positive aspects of AEL and PEMEL: the use of non-platinum group metal catalysts, with the production of high-purity hydrogen due to the presence of the solid electrolyte. They are however at a much earlier stage of technical development and there are still significant performance and durability challenges. AEM electrolysers have yet to be proven to be able to perform in real world conditions at the scale reached by PEM and alkaline electrolysers.

For SO Electrolyser longer term durability testing is required at system level and under real world operating conditions.

24. VALUE CHAIN ANALYSIS OF THE ENERGY TECHNOLOGY SECTOR

24.1. Introduction

There is a lack of fully developed electrolyser value chains outside of niche applications. The current market does not allow for a full value chain analysis. Ambitious future plans, such as those outlined in the Hydrogen Strategy point out to an exponential growth expected in future years. It is therefore not yet possible to provide relevant information on ‘Turnover’, ‘Gross value added growth’, ‘Energy intensity and labour productivity’ and ‘Community Production’.

As of today Water Electrolysis for hydrogen production does not go beyond 1% of the overall hydrogen production.

Europe is highly competitive in clean hydrogen technologies manufacturing and is well positioned to benefit from a global development of clean hydrogen as an energy carrier.

As highlighted in the Hydrogen Strategy investments in electrolysers could range between EUR 24 and EUR 42 billion between 2020 and 2030. Over the same period, EUR 220-340 billion would be required to scale up and directly connect 80-120 GW of solar and wind energy production capacity to the electrolysers and provide the necessary electricity. In addition, investments of EUR 65 billion will be needed for hydrogen transport, distribution and storage, and hydrogen refuelling stations[566, 567]. Finally, adapting end-use sectors to hydrogen consumption and hydrogen-based fuels will also require significant investments.

24.2. Number of EU companies

Main companies

The electrolysis market is very dynamic with several mergers and acquisitions registered in recent years. An overview of the manufacturers of medium to large scale electrolysis systems, considering only

---

[566] FCH JU, Hydrogen Roadmap Europe, based on an ambitious scenario of electricity production of 665 TWh by 2030, 2019.

[567] EC study Asset study (2020). Hydrogen generation in Europe: Overview of costs and key benefits. Investment projections assume 40 GW of renewable hydrogen as well as 5 MT of low-carbon hydrogen by 2030, and 500 GW of renewable electrolysers by 2050.

manufacturers of commercial systems and not manufacturers of laboratory-scale electrolysers[568], shows that:

Electrolysers based on alkaline electrolysis (AEL), are provided by:

- 9 EU producers (four in Germany, two in France, two in Italy and one in Denmark)
- 2 in Switzerland and 1 in Norway
- 2 in US
- 3 in China
- 3 in other countries (Canada, Russia and Japan).

Electrolysers based on proton exchange membrane (PEM) electrolysis, are provided by:

- 7 EU suppliers (four in Germany, one in France, one in Denmark and one in Spain)
- 1 supplier from UK and one from Norway
- 2 suppliers from US
- and 2 suppliers from other countries.

Electrolysers based on solid oxide electrolysis, are manufactured by 3 suppliers from EU (2 in Germany and 1France), 1 from the UK and 1 from the US.

Table 2 Location of the manufacturers of large electrolysers, by technology

Electrolyser technology	EU	CH, NO, UK	US	China	Others
Alkaline AEL	**9**	**3**	**2**	**3**	**3**
Proton Exchange Membrane PEM	**7**	2	3		2
Solid Oxide Electrolysis SOEL	**3**	1	1		
Anion Exchange Membrane	**1**				

Source: A. Buttler, H. Spliethoff, Renewable and Sustainable Energy Reviews 82 (2018) 2440–2454 updated with IRENA Green Hydrogen Cost Reduction, 2020

24.3. Employment in the selected value chain segment(s)

As regards to employment in the value chain, various studies show different results, due to the different methodology and assumptions adopted (for example direct versus indirect jobs, sectors of employment including manufacturing of fuel cell vehicles).

A study commissioned by the EC DG Energy[569]does not single out clear figures for electrolysers, but evidences a significantly larger fraction of jobs located in sectors linked with the production of renewable electricity. The electricity sector is expected to be the largest sector of employment linked with large scale renewable hydrogen deployment in Europe (Electricity production would account for 5.9 million jobs

---

[568] A. Buttler, H. Spliethoff Renewable and Sustainable Energy Reviews 82 (2018) 2440–2454 updated with data from IRENA Green Hydrogen Reduction Costs 2020.

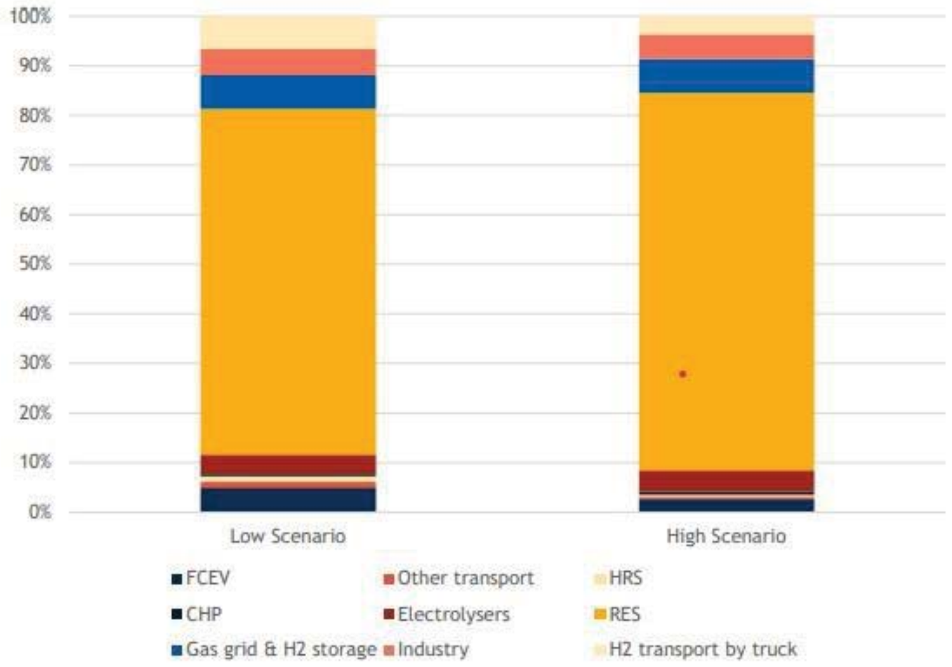
[569] Hydrogen generation in Europe: Overview of costs and key benefits, ASSET study, 2020 Investment projections assume 40 GW of renewable hydrogen as well as 5 MT of low-carbon hydrogen by 2030, and 500 GW of renewable electrolysers by 2050.

created for each billion euros of investment and an estimated 7 million jobs in the electricity sector for each billion euros of investment).

According to a study published by the Fuel Cell Joint Undertaking[570], *"Hydrogen-related investments and operations are estimated to generate in 2020-2030 employment of 29 270 – 106 980 direct jobs (in production and operations & maintenance) and contribute to further 74 790 – 250 650 indirect jobs, depending on the scenario (these numbers are calculated as annual full time equivalent jobs). In summary, the hydrogen economy could by 2030 generate 104 060 – 357 630 jobs".*

Their forecast for employment according to the sectors are highlighted in Figure 18 below.

Figure 18 Value Added Share per Value Chain Segment – EU + UK



Source: Fuel Cell Joint Undertaking, Opportunities for Hydrogen Energy Technologies and NECPs, 2020

Investments in electrolysers would represent a minor part of the overall value of the employment, with the main sector being the job creation in RES production.

24.4. Final Considerations

Despite the small size of the current value chains for electrolysers, the market for this applications is set to grow exponentially in the future, supported by the momentum of several announced hydrogen strategies. It is difficult to have accurate predictions, but overall it is expected that the magnitude of electrolyser value chains will be surpassed by that of renewable energy production value chains, which will be needed for achieving full electrolyser value chain maturity.

---

[570] FCH JU, Opportunities for Hydrogen Energy Technologies Considering the NECPs, August 2020.

25. GLOBAL MARKET ANALYSIS

25.1. Introduction/summary

The Hydrogen Strategy[571] highlighted the potential of renewable and low carbon hydrogen to contribute to the EU goals of decarbonisation. From now until 2050, investments in production capacities would amount to EUR 180-470 billion in the EU[572].

With regard to hydrogen production technologies, these announcements refer to low carbon hydrogen most likely using available technologies or technologies under development such as Carbon Capture and Storage (CCS).

While the global market capacity for hydrogen expands, competitiveness of the EU industries and producers needs to be contextualised taking into account the internal EU constraints such as the CO_2 pricing in the Emission Trading Scheme (ETS) prices.

As a general consideration, a level playing field between outside EU and internal EU companies producing hydrogen domestically, needs to be safeguarded.

25.2. Trade (imports, exports)

The current EU hydrogen demand matches its production with 7.7 million tonnes per year[573]. Imports to the EU may grow significantly for hydrogen imported as fuel. Data on the imports of electrolysers as a specific technology is unavailable.

25.3. Global market leaders vs. EU market leaders (market share)

Due to the lack of developed markets for electrolysis it is difficult to have a clear vision on global market leaders. As outlined in section 20.4 it seems that Europe has a higher concentration of producers for certain technologies with respects to other parts of the world (e.g. for Solid Oxide Electrolysis), it is however not possible to draw solid conclusions since the market is underdeveloped and is expected to significantly change in the coming years.

25.4. Resource efficiency and dependence

Around 30 raw materials are needed for producing fuel cells, electrolysers and hydrogen storage technologies. Of these materials, 13 materials are deemed critical for the EU economy according to the 2020 Critical Raw Materials (CRM) list[574]. The corrosive acidic regime employed by the PEM electrolyser, for instance, requires the use of noble metal catalysts like iridium for the anode and platinum for the cathode, both of which are mainly sourced from South Africa (84%), followed by Russia and Zimbabwe.

---

[571] A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final.

[572] Asset study (2020). Hydrogen generation in Europe: Overview of costs and key benefits. Investment projections assume 40 GW of renewable hydrogen as well as 5 MT of low-carbon hydrogen by 2030, and 500 GW of renewable electrolysers by 2050.

[573] Fuel Cell Observatory: https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-demand data exclude UK, Norway, Switzerland and Iceland.

[574] Joint Research Center report https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

While the EU still has a relatively small production of fuel cells and electrolysers, risks related to the use of specific raw materials will become more apparent if large-scale manufacturing is to be developed in the EU.

For green hydrogen production, electrolysers will need to use electricity from renewable energy sources such as wind, solar power, hydropower and other renewable sources. This introduces additional pressure on the availability of materials required for these technologies, as well as other limitations, such as high land usage requirements. If 40 GW electrolysers are to be installed in the EU by 2030 and fed by renewable electricity, coming predominantly from wind and solar energy sources, the strong dependency on materials required for these two technologies should be carefully analysed. The critical materials for wind turbines and solar panels, both crystalline and thin film panels, are supplied predominantly from China.

25.5. Final Considerations

Due to the lack of maturity of renewable and low-carbon hydrogen value chains it is impossible to have an accurate market overview since there is no remarkable global market dimension yet. It is likely that in the near future, international trading of large amounts of renewable or low-carbon hydrogen will become a viable option. Significant growth in electrolyser production and deployment on European territory will also bring to the forefront possible bottlenecks in the supply of electricity and critical raw materials, in particular for PEM and SO technology.

26. CONCLUSIONS

Even though renewable hydrogen is commercially available, its current high costs provide limits to its large-scale deployment. To ensure a full hydrogen supply chain to serve the EU economy, further research and innovation efforts are required[575]. It is also key to put into place a supportive regulatory and policy framework and to support the creation of a European hydrogen industry and market, including with public financial support during the ramp-up phase.

As outlined in the Hydrogen Strategy, upscaling the generation side will entail developing to larger size, more efficient and cost-effective electrolysers in the range of gigawatts that, together with mass manufacturing capabilities and new materials, will be able to supply hydrogen to large consumers. The Green Deal call (under Horizon 2020) for a 100 MW electrolyser has led to the selection of 3 projects that, when operational, will increase EU capacity by 300 MW. These projects will also offer the opportunity to test expansion options for electrolysers manufacturing capacity.

The availability and cost of electricity will be a main factor deciding upon the actual deployment of large-scale electrolysers. Research can also play a role in increasing electrolyser performance and reducing its costs for instance by increasing the durability of membranes, while reducing their critical raw materials dependence and recyclability.

Related to hydrogen production, subsequent new hydrogen technological chains should be developed. Infrastructure needs further development to distribute, store and dispense hydrogen in large volumes. Points of production of large quantities of hydrogen and points of use (especially of large quantities) are

---

[575] A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final.

likely not to be close to each other. Hydrogen will have therefore to be transported over long distances and stored.

Large-scale end-use applications using renewable hydrogen need to be further developed, notably in industry (e.g. using hydrogen to replace coking coal in steel-making[576] or upscaling renewable hydrogen use in the chemical and petrochemical industries), and in transport (e.g. heavy duty[577], rail, waterborne transport and possibly aviation).

Finally, further research is also needed to enable improved and harmonised (safety) standards and monitoring, and assess social and labour market impacts. Reliable methodologies have to be developed for assessing the environmental impacts of hydrogen technologies and their associated value chains, including their full life-cycle greenhouse gas emissions and sustainability. Importantly, securing the supply of electricity and critical raw materials in parallel to their reduction, substitution, reuse, and recycling needs a thorough assessment in the light of the future expected increasing hydrogen technologies deployment, with due account being paid to ensure the security of supply and suitable levels of sustainability in Europe.

---

[576] Already today, the H2FUTURE project in Austria operates a 6 MW electrolyser powered with renewable electricity that supplies hydrogen to a steel plant, while providing grid services at the same time. The HYBRIT project in Sweden is taking concrete action to become completely fossil-free steel plant by 2045, converting their production to use renewable hydrogen and electricity.

[577] European bus companies have also acquired expertise in production of fuel cell busses, due to several JIVE projects funded from the Fuel Cell Joint Undertaking and from the Connecting Europe Facility (transport).

EUROPEAN
COMMISSION

Brussels, 26.10.2021
SWD(2021) 307 final

PART 5/5

COMMISSION STAFF WORKING DOCUMENT

Accompanying the document

REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

Progress on competitiveness of clean energy technologies
8 & 9 - Smart Grids and Renewable Fuels

{COM(2021) 950 final} - {COM(2021) 952 final}

SMART GRIDS (DISTRIBUTION AUTOMATION, SMART METERING, HOME ENERGY MANAGEMENT SYSTEMS AND SMART EV CHARGING)

INTRODUCTION

Smart grids can be described as upgraded electricity networks to which two-way digital communication between supplier and consumer, intelligent metering and monitoring systems have been added[578]. Smart grids co-ordinate the needs and capabilities of electricity generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability[579].

Fundamental in the smart grids, digital technologies (like smart meters and sensors, the Internet of Things, big data and artificial intelligence) support the transformation of the power sector in several ways, including better monitoring of assets and their performance, more refined operations and control closer to real time; the integration of distributed implementation of new market designs; and the emergence of new business models.

Digitalisation goes hand in hand with decentralisation and decarbonisation that involve local generation, storage and new loads integrated locally. In this context, aside from offering a range of useful energy services, distributed generation and enabling technologies have become sources of valuable data. Detailed, and sometimes real-time information on local generation/consumption patterns, load profiles, the performance of components in electricity systems and failures can enable better planning and system operation by grid operators. This also allows for a better forecasting of electricity production and consumption of distributed sources and, consequently, the electricity system can be operated with a higher share of variable renewable energy (VRE). By reducing supply and demand uncertainty, the related risks are reduced as well, without increasing the operation costs[580].

The digitalisation that started in the power transmission much earlier, due to the criticality of the latter, it is by now gaining strength in the power generation, distribution and end-use domains, too. In the recent years, while the size of global annual investment in power infrastructure declined (from USD 304 billion to USD 271 billion between 2016 and 2019[581]), the share of smart grid investments kept on growing (from 13% to 17% in the same period)[582] (Figure 1).

---

[578] Smart Grids: from innovation to deployment, COM(2011) 202 final.

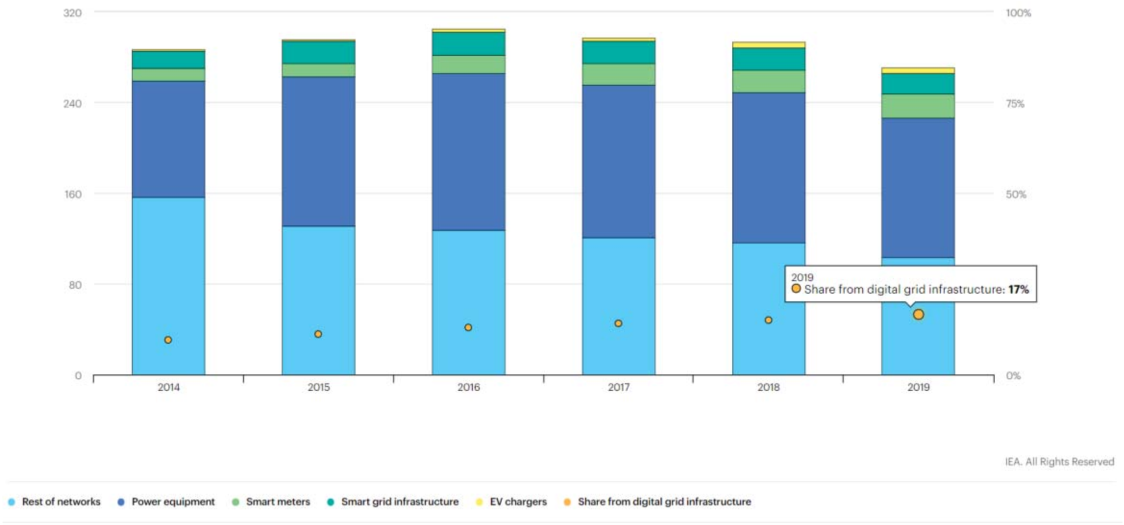
[579] International Energy Agency (IEA), 'Technology Roadmap- Smart grids'April 2011, pp. 50.

[580] International Renewable Energy Agency (IRENA), Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables, Abu Dhabi, 2019, pp. 32.

[581] Conversion rate: 1 USD = 0.84 EUR

[582] International Energy Agency (IEA), Tracking Energy integration 2020- Smart Grids: Investment in smart grids by technology area (2014-2019), Paris, June 2020.

Figure 1 Investment in smart grids by technology area, 2014-2019 (USD billlion)



Source: IEA, Tracking Energy integration 2020- Smart Grids, Paris, June 2020

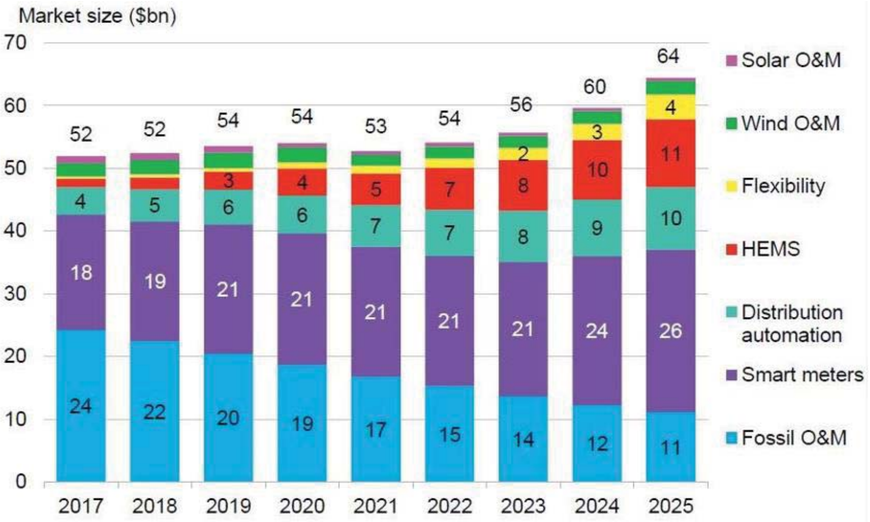
Similar growth is observed in patenting in enabling technology areas such as electricity storage and smart grids, which now have clear market value for the resilient operation of electricity networks with higher levels of variable renewable power", namely for enabling demand-side flexibility[583].

The take-up of smart grid technologies is expected to remain a robust trend during this decade and beyond, in close correlation with electrification and decentralisation: they will create market value by supporting higher levels of variable renewable power without compromising electricity network resilience. Consequently, it is widely anticipated that the market size for digital technologies will continue growing in all related segments, such as digital operation & maintenance (O&M) systems, Home Energy Management Systems (HEMS), distribution automation and smart meters (Figure 2).

---

[583] European Patent Office (EPO) and OECD/IEA, Statistics report: Patents and the energy transition - Global trends in clean energy technology innovation, April 2021, pp. 72

Figure 2 Market size for digital technologies in the energy sector (USD billion)



Source: Bloomberg New Energy Finance (BNEF), Market for Digitalisation in Energy Sector to Grow to USD 64 Billion by 2025, November 2017

Innovation, however, will remain key all along the smart grids value chain. While individual smart grid technologies (from information and communication technologies to smart energy appliances and devices) are relatively mature, their deployment at system level is both financially costly and technologically challenging. Demonstrating the benefits and security of a decentralised power system running on variable renewables is in the centre of innovation efforts[584]. The non-technological part of the challenge is also considerable: with access to (near) real-time end-users data, energy service providers (e.g. aggregators) will seek to increase their market share by offering innovative energy services for consumers (e.g. quality heating, cooling and vehicle charging) as well as for energy suppliers (flexibility services). As the digitalisation of energy progresses, so does its exposure to cyberattacks, and consequently cyber security will also top innovation and policy agendas[585].

In last year's Competitiveness report[586], the smart grid chapter provided an insight into technology (software) and market developments with regard to distributed energy resource management systems, virtual power plant and distributed energy resource analytics. This year, the report explores technology areas around the smart meters that allow a more efficient management of the grid and tapping potential flexibility sources. Namely, the take-up of distribution grid and substation automation, the rollout of smart meters, HEMS and smart charging of electric vehicles (EVs).

---

[584] See for instance the objectives of the 'Green Powered Future Mission', *Mission Innovation*, June 2021: http://mission-innovation.net/missions/power/

[585] "Between 2018 and 2023 the EU cybersecurity market is expected to grow at a compound annual growth rate (CAGR) of 11.3% and its value is expected to exceed EUR 40 billion." Kochanski, M., Korczak, K., Skoczkowski, T., 'Technology innovation system analysis of electricity smart metering in the European Union', *Energies*, 18 February 2020

[586] Progress Report on Competitiveness, COM(2020) 953 final and Accompanying document, SWD(2020) 953 final

27. DISTRIBUTION AUTOMATION

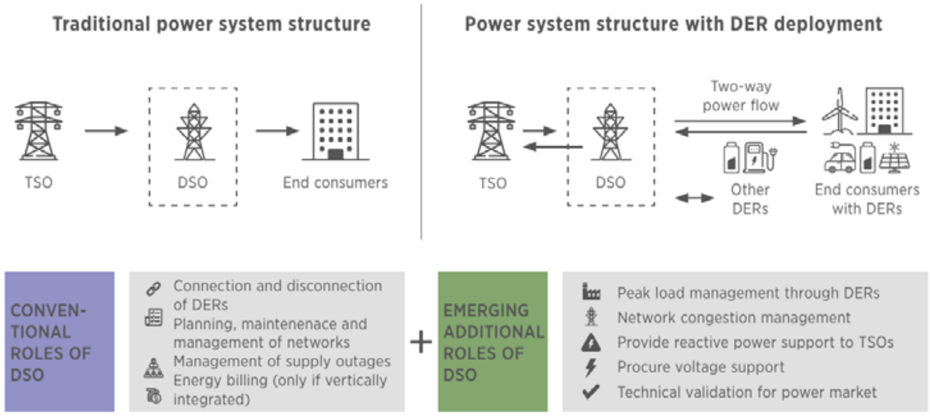
27.1. Technology Analysis

27.1.1. Introduction and technology maturity

Automation is a family of technologies, including sensors, processors, information and communication networks, and switches, through which a network operator can collect, automate, analyse, and optimise data to improve its operational efficiency. Automation can improve the speed, cost, and accuracy of several key distribution system processes, including fault detection, feeder switching, and outage management; voltage monitoring and control; reactive power management; preventative equipment maintenance for critical substation and feeder line equipment; and grid integration of DER[587]. As an example, by means of distribution automation, after a fault occurs, sections of the network can be restored remotely within a few minutes, instead of several hours as is the case with manual restoration. Early identification of changes in the operation of equipment through digital sensors also improves the operational efficiency and productivity of assets, allowing maintenance to take place before the problem worsens, becomes more expensive to resolve and results in unplanned outages.

With access to the flexibility coming from MV and LV grids, DSOs could better optimise the use of the whole distribution network and minimise the need for future grid reinforcements procuring flexibility services like peak load management through distributed energy resources (DERs), network congestion management and voltage support from the assets already connected to their distribution network (Figure 3).

Figure 3 DSOs role changes in the emerging decarbonising scenarios



Source: International Renewable Energy Agency (IRENA), Innovation landscape brief: Future role of distribution system operators, Abu Dhabi, 2019

In a study of 2019[588], 68% of the almost 2 000 energy industry professionals recognised that automation and digital workflow are among those technologies which are most impacting the transmission and distribution industry. Despite this clear drive towards digitalisation, research reveals that only some half

---

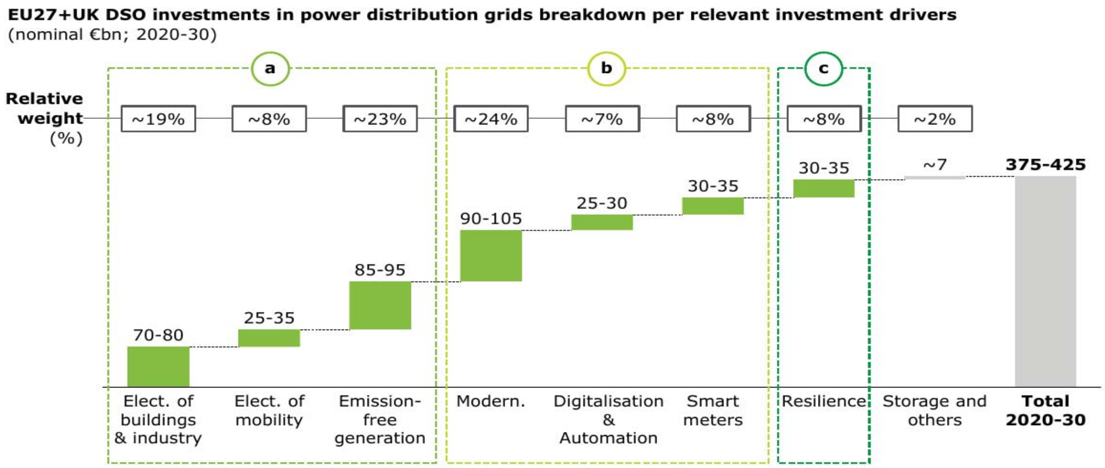
[587] National Electrical Manufacturers Association (NEMA), 'Distribution Automation', https://www.nema.org/directory/products/view/distribution-automation

[588] DNV GL, Digitalization and the future of energy : beyond the hype - how to create value by combining digital technology, people and business strategy, Arnhem, January 2019, pp.28

(52%) of Distribution Network Operators (DNOs) have digitalisation as a core part of their publicly stated strategy.

It has been estimated that for the EU and UK between EUR 25 billion and EUR 30 billion are needed in digitalisation and automation (Figure 4) until 2030, which corresponds to 7% of the total needed investment for this period[589].

Figure 4 Estimated investments in distribution grids until 2030



Source: Eurelectric, 'Connecting the dots: Distribution grid investment to power the energy transition'. January, 2021

Many technologies are already available today and allow for immediate large-scale deployment. However, data point to the fact that while this type of asset control is well-spread at the HV - MV substations, it is not common at MV level: over three-quarters of the DSOs taking part to the DSO Observatory[590] exercise had less than 7.5% of their MV substations remotely controllable.

27.1.2. Public Research and Innovation (R&I) funding

To better implement and connect among them different technologies in different locational scenarios, several projects, for a total of around EUR 200-400 million, each including more than one demonstrator, have been carried out at the EU level in the framework of the Horizon 2020 funding programme[591] (due to the fact that often, investment figures are aggregated into larger families of technologies, for instance, Transmission and Distribution, Power Grids … the provided figure is to be considered as order of magnitude)

A non-exhaustive list of projects includes UPGRID, Flex4GRID, FLEXICIECY, GOFLEX, INTEGRID or InterFLEX[592].

---

[589] Connecting the dots: Distribution grid investment to power the energy transition - Eurelectric – Powering People

[590] Prettico, G., Marinopoulos, A., Vitiello, S., 'Distribution System Operator Observatory 2020: An in-depth look on distribution grids in Europe', EUR 30561 EN, P*ublications Office of the European Union*, Luxembourg, 2021, ISBN 978-92-76-28430-7, doi:10.2760/311966, JRC123249

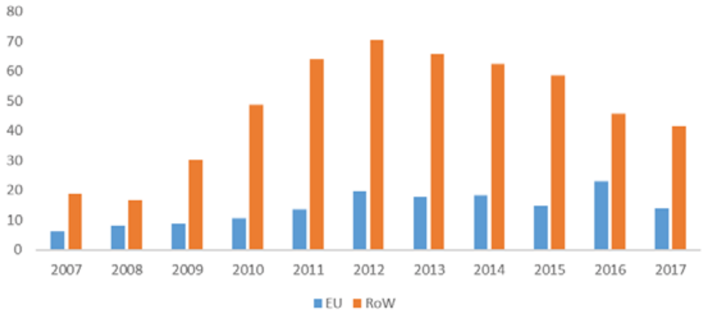
[591] European Commission, 'Cordis: EU research results', https://cordis.europa.eu

[592] Projects - Bridge (h2020-bridge.eu)

27.1.3. Patenting trends

For the 2007-2017 30% of the high-value inventions were submitted by applicants headquarters in the EU (Figure 5. Japan and the US lead the rank of host countries, with Germany in third and France and Italy also in the top 10).

Figure 5 High-value inventions in Grid Energy Management systems

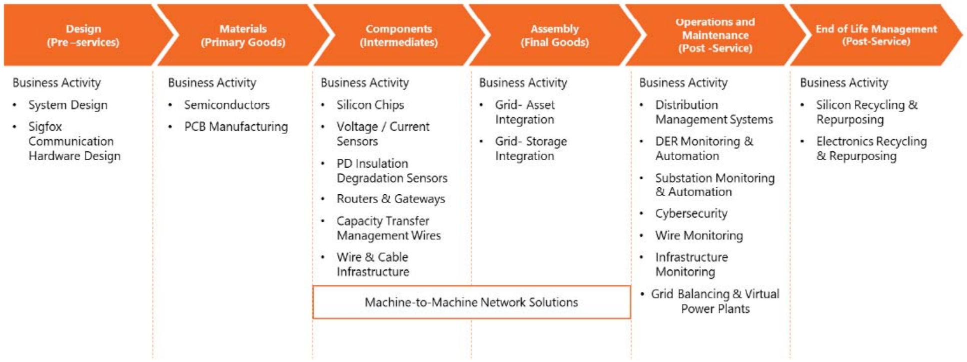


Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2021)

27.2. Value chain analysis

Due to the technology aggregation reason stated above, value chain data cover the full transmission and distribution level considering the automation as a combined item (with Substation Monitoring) under the Operation and Maintenance segment (Figure 6).

Figure 6 Grid Energy Management System value chain structure



Source: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 'Climate neutral market opportunities and EU competitiveness Final Report', Written by ICF and Cleantech Group, December 2020

The scope of the Grid Energy Management System value chain[593] covers digital-integrated systems to manage, coordinate, monitor and control utility-connected grids for the efficient transmission and distribution of electricity. The analysis includes hardware and software operating on transmission and distribution networks, communication hardware, distributed energy resource management devices as well

---

[593] Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 'Climate neutral market opportunities and EU competitiveness Final Report', Written by ICF and Cleantech Group, December 2020

as power and Volt/VAR control systems. However, this value chain does not include smart meters, inverters, other on-building energy systems (e.g. plug loads), demand response or grid edge technologies.

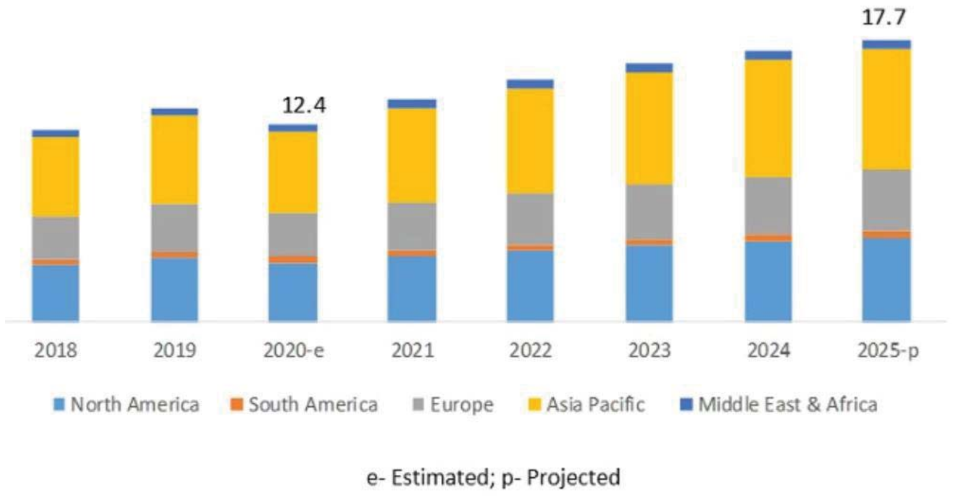
Over the 2015-2019 period, 27% of the total value of global private venture capital investments in early-stage companies active in the Grid Energy Management Systems value chain was in EU companies. When assessing the number of investments, this percentage grows to 43%, suggesting that the average size of investments was higher outside of the EU. The value chain saw over 150 investments during that period for a total of EUR 477 million, showing a very active market in terms of innovation and appetite from venture capital investors. In the EU, Germany (EUR 19 million) stands out in terms of total size of investments in early stage companies over the studied period but remains behind the US that benefited from close to 50% of these early stage investments (i.e. EUR 235 million during 2015-2019). China and Israel also performed very well in terms of early stage investments attracting respectively EUR 66 million and EUR 27 million.

In terms of late-stage investments in innovative companies, the EU attracted 23% of the total value of global late stage investment tracked by the Cleantech Group. The volume (EUR 3.5 billion) and number of deal (167) of late-stage investments confirm the dynamism of this Venture Capital (VC) at global level. At the EU level, France (EUR 368 million), Germany (EUR 218 million) were the leaders, but were largely outperformed by the US (EUR 2 billion) and to a lesser extent China (EUR 398 million). Additionally, Israel attracted EUR 233 million in terms of late stage investments.

27.3. Global market analysis

The distribution automation market size is projected to reach USD 17.7 billion by 2025 from an estimated value of USD 12.4 billion in 2020, at a CAGR of 7.4 % during the forecast period[594]. The need for improved grid reliability and operating efficiency and increasing investments to upgrade aging grid infrastructure are the key growth drivers for this market (Figure 7).

Figure 7 Distribution automation market by region (USD billion)



Source: Distribution Automation Market - Global Forecast to 2025, Markets and Markets, 2020

---

[594] Markets and Markets, Distribution Automation Market by Component (Field Devices, Software, Services), Communication Technology (Wired (Fiber Optic, Ethernet, Powerline Carrier, IP), Wireless (RF Mesh, Cellular, Wimax)), Utility, Region - Global Forecast to 2025, 2020 https://www.marketsandmarkets.com/Market-Reports/distribution-automation-market-65029172.html.

The major players in the distribution automation market include ABB (Switzerland), Eaton (Ireland), GE (US), Schneider Electric (France), and Siemens (Germany).

27.4. Conclusions (Distribution)

In the EU, and in some other parts of the world (most notably in the US), substation automation has been a trend in recent years, coupled with utilities' efforts to expand the use of software platforms to monitor and control their assets, notably through digital twins. Correspondingly, some utilities and grid companies in EU (Iberdrola, Enel, Rte and e.On) and in the US (Exelon, Duke and Edison International) have started spending a greater part of their budget on software.[595]

Enel (IT) offers a prime example of how digitalisation can increase operational efficiency and improve quality of service for a grid owner or operator. The IEA reports that in just ten years, Enel reduced the System Average Interruption Duration Index (SAIDI, an indicator of grid quality) by 65%, and it is currently spending nearly one-third of its investment budget on digital technology. On the other side of the Atlantics, National Grid (US) partnered with Utilitidata and Sense to create a "digital twin" of the grid, mapping power flow, voltage and infrastructure from the substation to the home. American Electric Power also announced the digital twinning of their transmission infrastructure, developed in collaboration with Siemens.

Quantifying benefits remains difficult, however. Many regulatory regimes reward cost savings, whereas smartening the grid often produces other qualitative or softer benefits (e.g. enabling other technology or business models; reducing emissions; creating jobs) that cannot be easily rate-based. While some utilities have begun reporting direct financial savings, improvements in traditional reliability metrics remain the mainstays to evaluate costs and benefits of smartening the grid.

There are, however, big differences among EU Member States when grid modernisation levels are considered. Despite requirements in the Clean Energy Package to fully deploy smart grids, distribution system operators need stronger incentives to move from conventional grid expansion options to more alternative and sophisticated solutions based on ICT, artificial intelligence and automation.

Among the main barriers hindering the full deployments of smart grids, the uncertainty related to the missing universal standards, the lacking of mature markets and the return on investments not guaranteed are the most burning ones. The missing consumer awareness represents another barrier: the benefits of a smart grid can be achieved only if customers are fully aware of the smart grid concepts and they use all of its features. At present, privacy concerns and the risk of cyber-attacks does not help deploy smart grid solutions as paved. At the same time the scaling of solutions is often impeded by proprietary standards that lack of interoperability. Last but not least, the shortage of training and technical staff required for deploying and operating especially intragrid control applications is another important obstacle.

28. SMART METERS

28.1. Technology Analysis

28.1.1. Introduction and Technology maturity

Smart electricity metering system means an electronic system that is capable of measuring electricity fed into the grid or electricity consumed from the grid, providing more information than a conventional meter,

---

[595] IEA, Smart Grids, IEA, Paris, 2020 https://www.iea.org/reports/smart-grids

and that is capable of transmitting and receiving data for information, monitoring and control purposes, using a form of electronic communication[596].

Smart meters are well developed technologies. In 2012, the European Commission recommendations[597] defined ten minimum functionalities for smart meters (Table 1), which became guidelines for Member States, technology providers and utility companies during the first wave of deployment (the 2010s). Leading countries that mostly completed their rollout strategies by 2020 (e.g. Finland, Italy, Spain and Sweden) have been preparing, or are already undertaking, a second wave of smart meter deployment, with enhanced or new features.

A significant majority of smart meters installed in the EU use Power Line Communication (PLC) technology[598] that makes Europe one of the world leaders. PLC enables the use of existing power lines for telecommunications between smart meters and DSO interfaces. PLC comes especially "handy” where power lines and installations are below the ground and hence not well covered by wireless services (like most European cities).

Table 1 Minimum functionalities for smart meters in EC recommendations

Consumer	1. Provide readings directly to consumer and/or any 3rd party 2. Upgrade readings frequently enough to use energy saving schemes
Metering operator	3. Allow remote reading by the operator 4. Provide 2-way communication for maintenance and control 5. Allow frequent enough readings for network planning
Commercial aspects of supply	6. Support advanced tariff systems 7. Remote on/off control of the supply and/or flow or power limitation
Security & Data Protection	8. Provide secure data communications 9. Fraud prevention and detection
Distributed generation	10. Provide import/export and reactive metering

Source: ESMIG

Landys+Gyr observes increasing focus on grid edge intelligence and direct consumer benefits for second wave use cases, including “hyper-critical focus” on (consumer) data security, increasing value of prepayment (Pay-As-You-Go solutions) and common approach to single management solution for home-plus-EV metering and management (Figure 8)[599].

---

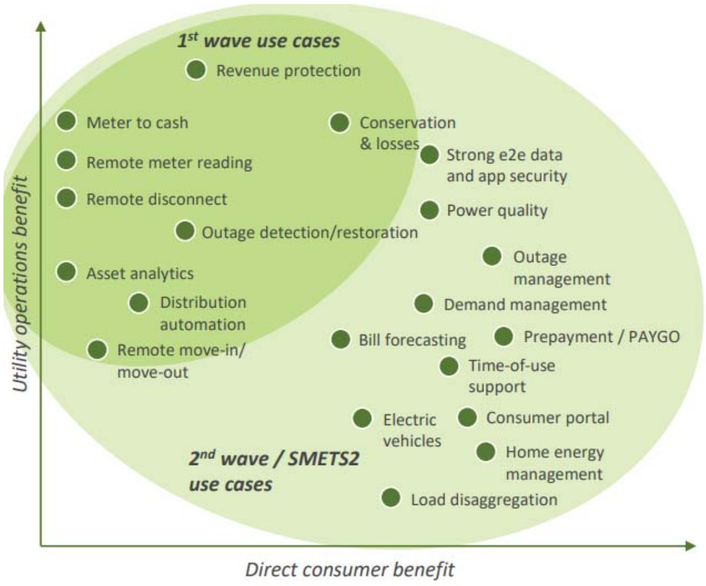
[596] DIRECTIVE (EU) 2019/944 on common rules for the internal market for electricity.

[597] COMMISSION RECOMMENDATION of 9 March 2012 on preparations for the roll-out of smart metering systems (2012/148/EU)

[598] Horizon 2020 Project INTEGRIDY, D2.5: Smart Grid Deployment, Infrastructures & Industrial Policy applicable to the inteGRIDy pilot cases, inteGRIDy hyperlink

[599] Landis+Gyr, Capital Markets Day: EMEA, January 2019: https://www.landisgyr.com/webfoo/wp-content/uploads/2019/01/4.-CMD-EMEA.pdf

Figure 8 Grid edge use cases driven by retail market innovation



Source Landis+Gyr, Capital Markets Day: EMEA, January 2019

28.1.2. Capacity installed

The 2009 Electricity Directive envisaged an 80% rollout rate of smart meters in Member States by 2020, in which the cost-benefit assessment provided a positive outcome. However, this goal was not achieved. While by the end of the last decade three quarters of EU Member States adopted specific legal provisions for the rollout of smart metering systems[600], in 2018 44% of all electricity meters were "smart" in the EU+UK (the global – worldwide – penetration rate was 14% (2019), 70% in China and also 70% in the US, with 98 million smart meters installed).[601] There were, however, big disparities between individual Member States as shown in Table 2.

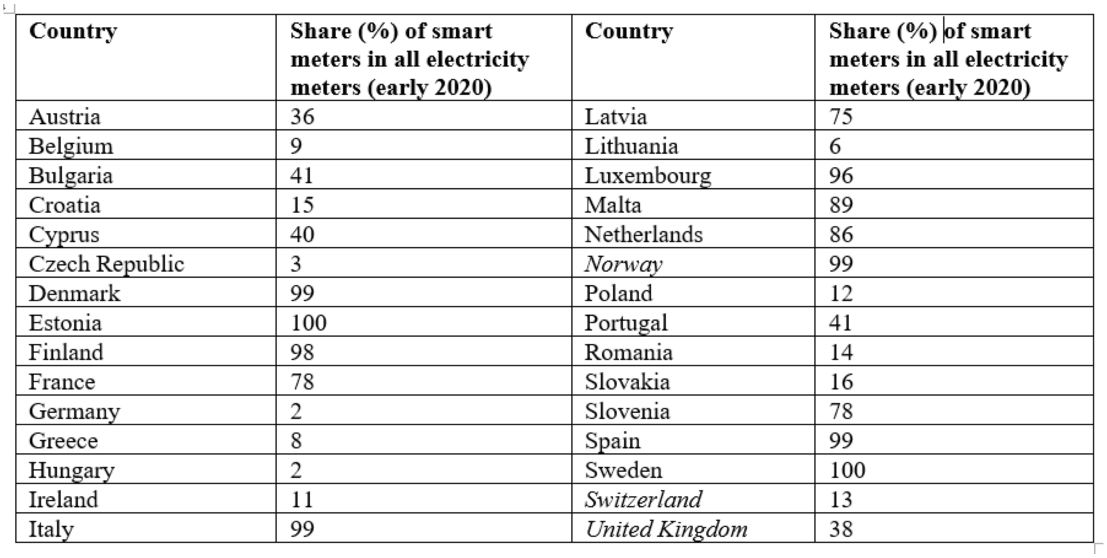
The rollout of smart meters will continue during the next decade, pulled by the favourable policy environment and the digitalisation trend in the energy sector. ESMIG, the association of European smart energy solution providers, estimates that the penetration rate in EU + Norway, Switzerland and UK will grow from 45% in 2019 to 69% by 2025 based on available figures and expected shipments (Table 3).

---

[600] Benchmarking smart metering deployment in the EU-28, Study produced by Tractebel Impact for the European Commission, DG Energy (2019)

[601] IRENA, Innovation landscape brief: Energy as a Service, International Renewable Energy Agency, Abu Dhabi, 2020

Table 2 Rollout of smart meters in EU, Norway, Switzerland and UK



Country	**Share (%) of smart meters in all electricity meters (early 2020)**	**Country**	**Share (%) of smart meters in all electricity meters (early 2020)**
Austria	36	Latvia	75
Belgium	9	Lithuania	6
Bulgaria	41	Luxembourg	96
Croatia	15	Malta	89
Cyprus	40	Netherlands	86
Czech Republic	3	*Norway*	99
Denmark	99	Poland	12
Estonia	100	Portugal	41
Finland	98	Romania	14
France	78	Slovakia	16
Germany	2	Slovenia	78
Greece	8	Spain	99
Hungary	2	Sweden	100
Ireland	11	*Switzerland*	13
Italy	99	*United Kingdom*	38

Source: Berg Insight Report, June 2020, www.berginsight.com

Table 3 Electricity smart meter penetration rate, 2019–2025 (EU+CH, NO, UK)

Million units	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Smart meters, installed base	135.5	149.6	167.8	182.9	194.4	205.0	214.4
Penetration rate	45 %	49 %	55 %	60 %	63 %	66 %	69 %

Source: Berg Insight Report, June 2020, www.berginsight.com

28.1.3. Public R&I funding

Between 2012 and 2017, a total of 416 public procurements for energy meters were announced at the EU level, mainly by utilities. In this sense government procurement can be regarded as a direct investment that is actively used at the EU level for smart meter development and deployment[602].

28.1.4. Patenting trends (smart grids)

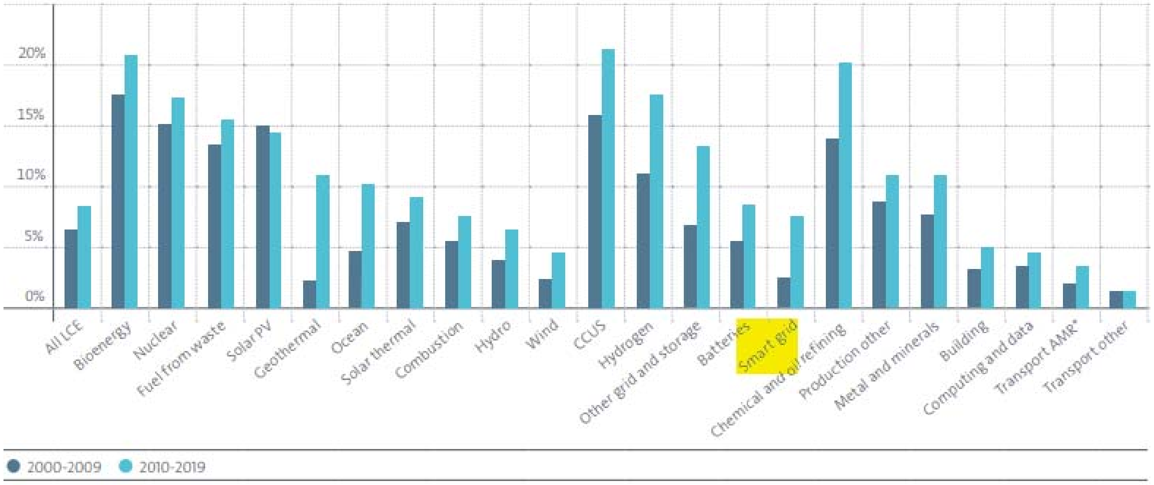
The recent joint EPO-IEA report[603] demonstrates an increasing patenting activity for technologies enabling the integration of clean energy resources, including smart grids. For example, the share of smart grids international patent families (IPFs) in all low-carbon energy technology IPFs almost tripled between the beginning of the 2000s and the end 2010s (Figure 9).

---

[602] Kochanski, M., Korczak, K., Skoczkowski, T., 'Technology innovation system analysis of electricity smart metering in the European Union', *Energies*, 18 February 2020

[603] European Patent Office (EPO) and OECD/IEA, Statistics report: Patents and the energy transition - Global trends in clean energy technology innovation', April 2021, pp. 72

Figure 9 Share of IPFs in low-carbon energy technology fields, 2000-2019



Source: European Patent Office (EPO) and OECD/IEA, Statistics report: Patents and the energy transition - Global trends in clean energy technology innovation, April 2021

For smart grid technologies, the EPO-IEA report identified three top clusters. They are largely dominated by the region of Tokyo, Japan, which alone generated nearly twice the total of smart grid IPFs than in the other two top clusters (Seoul, R. of Korea, and Beijing, P.R. of China) between 2010 and 2018.

Patenting trends also unveil different specialisation strategies. Some companies show strong specialisation in technologies related to EV in their respective IPF portfolios. Toyota, for instance, has a strong patenting contribution in EV, hydrogen, batteries and smart grids, although it also generated a significant share of IPFs in other low-carbon emission technologies (LCE) for road transportation. Other high-ranking automotive companies show similar profiles. Companies such as Samsung, LG and Panasonic specialise in batteries and are likewise active in EV and smart grid technologies, as well as solar and other end-use technologies (building, industrial production, ICT), with possible spill-over effects.

General Electric and Siemens show a different profile, specialising in all LCE energy supply technologies, especially efficient combustion and wind power, as well as in smart grids and other grid and storage technologies. Japanese companies Hitachi and Toshiba have a comparable profile, with patenting activities in these fields, as well as in EV and batteries. Nearly all top applicants are significantly active in the full spectrum of enabling technologies, with a stronger focus on batteries, hydrogen and smart grids.

28.2. Value chain analysis

28.2.1. Turnover

The penetration of smart meters has been steadily growing in the EU for a decade now. In 2019 (hence before the global breakout of the COVID19 pandemic), a forecast by Landis+Gyr saw the number of installed smart meters reaching 211 million unit in 2023 in the EU, corresponding to an 11% Compound Annual Growth Rate (CAGR) between 2018 and 2023. This sharp growth in units installed would have led the EMEA market value (including Europe, as well as the smaller markets of Africa and the Middle East) to grow in the 2017-2021 period from USD 1.4 billion USD to USD 2.2 billion.[604]

The impacts of the pandemic were such that, in 2020, some shipments and installations have been delayed or postponed. However, this should be a temporal impact. ESMIG expects that the lost volumes will be recuperated during 2021–2022, underpinned by the post-COVID-19 acceleration of ongoing projects as well as the completion of major first-wave rollouts in countries such as France and the Netherlands along with second-wave deployments in Italy and Sweden. This should lead to a peak in annual smart meter shipments in 2021-2022 (with approximately 26 million units shipped in 2022) (Table 4 Electricity smart meter shipments, 2019–2025 (EU+CH, NO, UK)).

Table 4 Electricity smart meter shipments, 2019–2025 (EU+CH, NO, UK)

Million units	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	
Electricity meter shipments	25.5	23.0	30.5	25.5	20.2	17.3	12.7	
Of which smart meters		20.9	19.5	26.5	22.3	17.3	14.9	10.4

Source: Berg Insight Report, June 2020, www.berginsight.com

28.2.2. EU market leaders

Smart electricity meters are typically produced by electronic and/or software companies, or by manufacturers covering several segments of the metering market (electricity, gas and water). The major regional European players according to ESMIG are: ADD Group (Moldova), AEM (Romania), Apator (Poland), Energomera (Russia), Iskraemeco (Slovenia), Landis+Gyr (Switzerland), Sagemcom (France) and ZIV (Spain) in electricity metering and Kamstrup (Denmark) in electricity and heat metering. Significant international players active on the European smart electricity metering market include Aclara (Hubbell, US), EDMI (Osaki Electric, Japan), Itron (US), NES (US) and Sensus (US).

According to the above-sited Landis+Gyr report, in 2017, Sagemcom (France) and Landis+Gyr (Switzerland) had each a quarter of the smart meter market in the Europe, Middle East and Africa (EMEA) grand region, while Itron (US), ENEL/Endesa (Italy/Spain) and Iskraemeco (Slovenia) roughly shared another quarter, with the last quarter left to "others". In the same (EMEA) region, the services & metering software market was dominated by Landis+Gyr, Kamstrup (Denmark) and Sagemcom (France), while Capgemini (France), ELTEL (Sweden), Eriksson (Sweden), Honeywell (US), IBM (US), ZIV (Spain) and were the contenders.

28.3. Global market analysis

28.3.1. The global market for smart meters

The global market for smart meters is growing, and will continue doing so in the near future. One market analysis estimates that global smart meter penetration (electricity, water and gas) has surpassed 14% in 2019, i.e., 14% of all meters are now smart meters[605]. The estimated installed base of smart meters (electricity, gas and water) is expected to surpass the 1 billion mark within the next 2 years. Just under 132

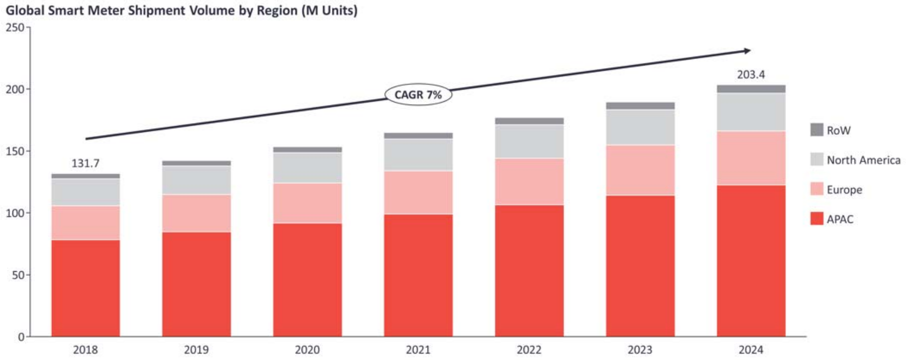
---

[604] Landis+Gyr, Capital Markets Day: EMEA, January 2019: https://www.landisgyr.com/webfoo/wp-content/uploads/2019/01/4.-CMD-EMEA.pdf

[605] Knud Lasse Lueth, "Smart meter market 2019: Global penetration reached 14% – North America, Europe ahead", *IOT Analytics*, 13 November, 2019; https://iot-analytics.com/smart-meter-market-2019-global-penetration-reached-14-percent/

million smart meters (electricity, gas and water) were shipped worldwide in 2018. This number is expected to grow 7% per year to exceed 200 million by 2024.

Figure 10 Global smart meter shipment volume by region (million units)



Source: IoT Analytics research blog, Smart Meter Market Report 2019-2024, 13 November 2019

ESMIG reports that the global market size, in 2019, was estimated at USD 21.3 billion and projected to grow to USD 38-39 billion in 2027; this sharp increase being due to projected market growth mainly in Asia.

There is a high level of fragmentation in the global smart meter market, due to a combination of different regional or country-level institutional support and regulatory frameworks and the varying needs of utilities in different areas of the world. The three main regions (North America, Europe, Asia Pacific) have vastly different characteristics and market dynamics.

The smart meter market in North America is fairly mature, with a penetration rate estimated at about 30-40% of total utility consumers of electricity, gas and water. Both the US and Canada were early adopters of smart meters. Today many of the tier 1 utility operators in the region have deployed a large-scale smart meter solution or are currently in the process of doing so.

Asia Pacific (APAC) currently represents the largest region in the global smart meter market (with focus on smart electricity meters), with an estimated 78.1 million smart meters shipped in the region in 2018. That number corresponds to almost 60% of the global shipments volume. The overall penetration of smart meters in the region remains lower than North America and Europe however, with less than 20% of utility customers equipped with smart meters. As in Europe, there are large differences among countries. **China** is the leading country in the APAC smart meter market. In 2011, the State Grid Corporation of China began the deployment of smart electricity meters in various areas of the country, installing a total of 476 million meters that represent more than half the worldwide installed base today. Japan and South Korea are two other hotspots in the region, with large scale deployments of smart energy meters currently ongoing. India is expected to roll out 250 million smart meters by 2025 according to latest figures[606]. Indonesia, Malaysia, Philippines, Singapore and Thailand are expected to become key markets after 2020.

In the rest of the world, the smart meter market is largely still at an early stage with some countries such as Mexico, Brasil, Egypt, Nigeria, or South Africa planning for large deployments.

---

[606] https://www.smart-energy.com/industry-sectors/smart-meters/indias-smart-meter-rollout-250-million-meters-by-2025/"

28.3.2. Global market leaders

One market analysis mentions the following significant non-European market players: Azbil Kimmon Co. Ltd (Japan), Honeywell International Inc. (US), General Electric Company (US), Hexing Electric Company Ltd (China), Holley Technology Ltd (Zhejiang Huamei Holding Co. Ltd, (China), Itron Inc. (US), Jiangsu Linyang Energy Co. Ltd (China), Nanjing Xinlian Electronics Co. Ltd (China), Ningbo Sanxing Medical & Electric Co. Ltd (China), Sensus USA Inc. (US), Shenzhen Hemei Group Co. Ltd (China), Wasion Group Holdings (China)[607].

28.4. Conclusions (Smart meters)

The clear, early vision of EU-level actors for smart meters deployment, founded on the grounds of energy conservation and empowerment of customers, and supported with regulatory measures, has been the major driver for the development and rollout of these technologies. Even though the penetration rates of smart meters have not reached the established ambitious objectives by 2020, they have contributed directly not only to the introduction of top-down obligation schemes in various Member States, but also to bottom-up, voluntary initiatives of local stakeholders, for example with DSOs in Poland which started deploying smart meters ahead of any nationally binding regulations. Despite the recent introduction of more ambitious policies in the field (Clean Energy Package), according to some experts[608], the regulatory framework may need further strengthening to ensure full interoperability, data protection and security standards, as well as a competition for the best solutions at the national level.

The early regulatory push created a growing EU market for smart meters, supplied by mostly EU producers, at least when it comes to hardware; the software market for smart meters, even in the EU, seems to be more balanced, with the presence of some strong US actors. On the other hand, the Asian (and especially Chinese) markets are huge in terms of shipped units compared to the European one.

29. HOME ENERGY MANAGEMENT SYSTEMS (HEMS)

29.1. Technology Analysis (HEMS)

29.1.1. Introduction and technology maturity

Home Energy Management Systems (HEMS) development has been undergoing significant change in the past 5 years. While home area networks (HANs) and smart appliances have not spread at the speed expected earlier, other technologies (new data streams from smart thermostats for electric heating, heat pumps, as well as DERS like solar PV and EVs) have grown in importance, requiring new HEM information channels and setting new directions for HEMs development and projects (Figure 11). Connection to smart meters also remained important as they should ensure bi-directional dataflow to and from utilities (see also Figure 8).

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

---

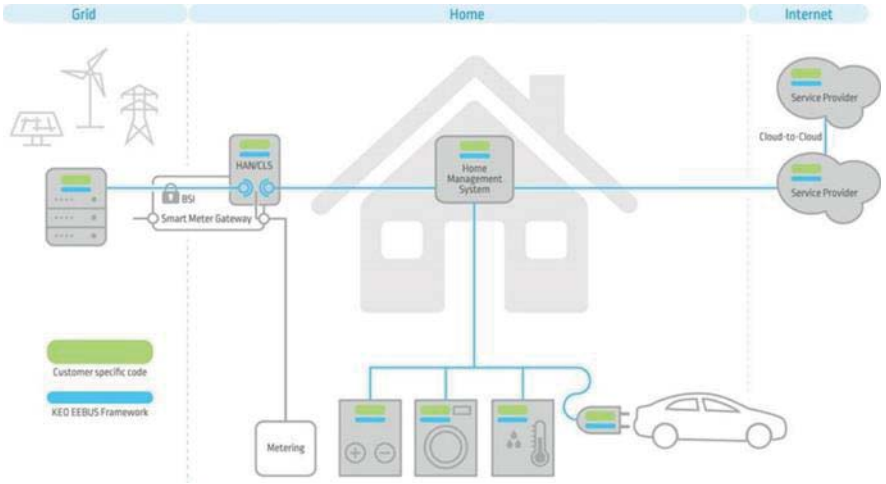
[607] Mordor Intelligence, Global smart meter market (2021-2026), 2020 (free sample).

[608] Kochanski, M., Korczak, K., Skoczkowski, T. (2020), "Technology innovation system analysis of electricity smart metering in the European Union", *Energies*, 18 February 2020

occupants. Additionally, residential customers now also have options to efficiently manage their energy consumption without a smart meter.

As a result, utilities have had to change their thinking about how they play in the HEMS space in order to engage consumers. Utilities now emphasise advanced analytics, personalisation, 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. All solutions support basic energy monitoring functionality, alerts, and report features. More advanced platforms support personalisation and disaggregation and help identify faulty equipment or similar appliance-level data[609].

Figure 11 HEMS as a central point in the smart house



Source: 'Technology', EEBus Initiative e.V, 2021[610].

HEMS technologies nowadays are based on microcontrollers and work with distributed protocols. The latter means that devices do not have to interact in a centralised system and this provides more resilience to the whole ecosystem. HEMS also use cloud technologies for data storage and processing[611]. The usage of several techniques improve the response time of the HEMS and the avoidance of data privacy issues since operations are executed locally. The components of a HEMS include sensors, measuring devices, smart controllers/actuators, infrastructure for communication, and a management controller for supervision and control of data. These components address primary functions: management, control, logging, and monitoring and fault detection for energy systems. The target application is to enable end-users to control and schedule appliances, including EV chargers, to consume more efficiently, following utility-sponsored demand-response programs based on incentives or price schemes. At the same time, HEMS might provide in the future detailed information about home energy use for demand side flexibility services.

---

[609] Guidehouse Insights, Asset Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020.

[610] EEBUS,

[611] Zafar, S. Bayhan and A. Sanfilippo, "Home Energy Management System Concepts, Configurations, and Technologies for the Smart Grid," in *IEEE Access*, vol. 8, pp. 119271-119286, 2020, doi: 10.1109/ACCESS.2020.3005244.

29.1.2. Capacities installed

While in 2019, over 20 million homes were equipped with large electrical loads (e.g. electric heating, battery, EV, PV etc.) in the EU, only some 300 000 of these were connected to a HEMS; however, this number is expected to reach more than 2 million by the end of 2023[612].

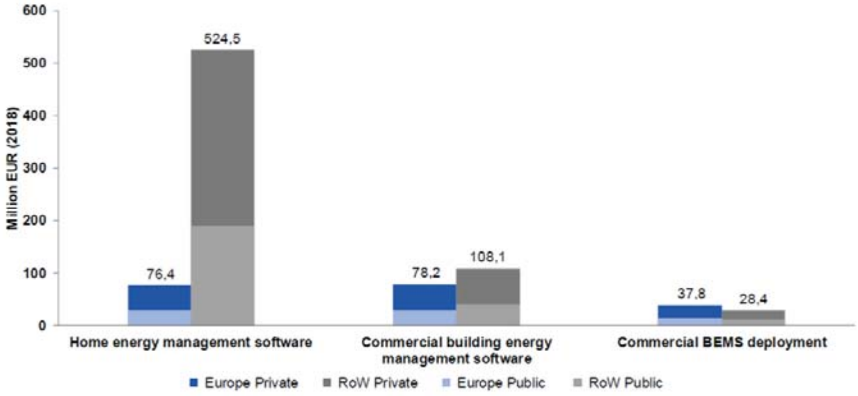
Similarly, electrified heating solutions already equip around 20 million households in the EU – reaching more than 50% penetration in some countries. The potential for HEM in these cases is therefore already large, and will grow higher as governments are pushing for more electrified or decarbonised heating. The Nordics and France, leaders in electrified heat, will have their HEM potential grow significantly on the back of that.

Lastly, with new trends in connectivity, white goods, batteries and PV can become part of a wider HEM ecosystem. By 2023, the percentage of batteries interoperable – and consequently accessible to HEM – is expected to have reached more than 70%. Countries with significant PV and battery markets today will therefore represent a large uptake in HEM. This is the case of Germany with 6% of households equipped with PV, and Belgium since the net metering has been removed from smart meter owners[613].

29.1.3. Public R&I funding

In the EU, the public investments are part of the Horizon 2020 programme and are estimated at 35% according to ETIP SNET in 2018. Overall, the research investments in both EU and the rest of the world are very similar, where EU leads commercial Building Energy Management Systems (BEMS) deployment research while the rest of the world leads HEMS and BEMS software research[614] (Figure 12).

Figure 12 R&D investments in Energy Management



Source: Guidehouse Insights, Asset Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

---

[612] Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020.

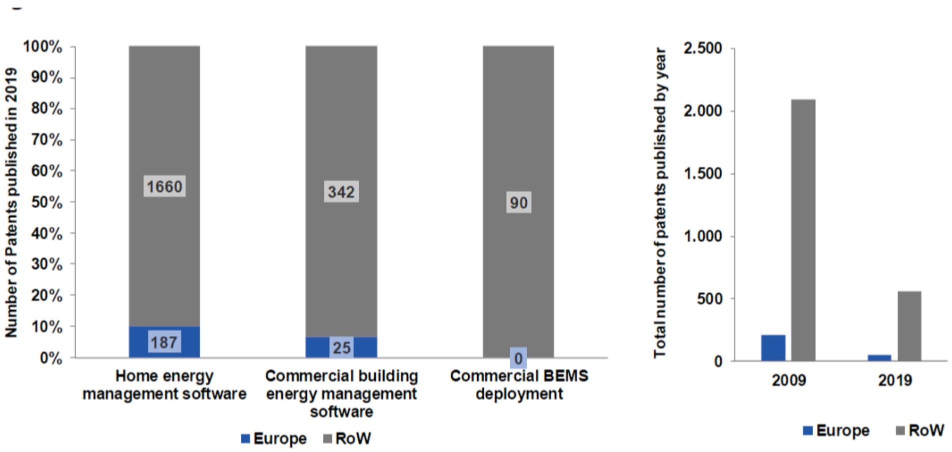
[613] Delta-EE, Accelerating the energy transition with Home Energy Management, *New Energy Whitepaper*, February 2020, https://www.delta-ee.com/downloads/2458-delta-ee-whitepaper-accelerating-the-energy-transition-with-home-energy-management.html#form-content

[614] Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

29.1.4. Patenting trends

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

Figure 13 Patents for Home and Building Energy Management Systems



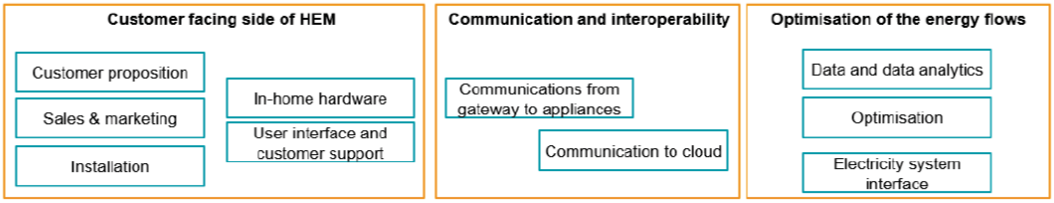
Source: Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

29.2. Value chain analysis (HEMS)

29.2.1. The HEMS value chain

The long and complex HEMS value chain can be divided into three segments: i) customer facing side, ii) communication and interoperability and iii) energy flows optimisation (Figure 14), with specialised technology and service providers in each segments[615].

Figure 14 The HEM value chain



Source: Accelerating the energy transition with Home Energy Management, Delta-EE New Energy Whitepaper, February 2020

Some companies have their focus set on the customer facing side of HEM, with the objective of developing innovative marketing and business models. Often these are the companies which already have a relationship

---

[615] Delta-EE, Accelerating the energy transition with Home Energy Management, *New Energy Whitepaper*, February 2020, https://www.delta-ee.com/downloads/2458-delta-ee-whitepaper-accelerating-the-energy-transition-with-home-energy-management.html#form-content

with the customer, either by selling products (e.g. PV, EV charging point, etc.) or by offering services (e.g. energy supply, installation etc.). Energy suppliers such as Fortum (FI) or EDP (PT), and product manufacturers such as NIBE (SE) and Vaillant (UK) are good examples of this (Table 5).

Other companies may specialise on communication and interoperability solutions. Their role is to ensure data flows between the HEM, the gateway, the appliances and the cloud. They will also often look up appliance manufacturer APIs (Application Programming Interface) and integrate the functionalities available to their platform. Connected home companies such as GEO (UK) and Passiv Systems (UK) are typically those specialising in this segment; or others would develop products in this segment while also working on more parts of the value chain (e.g. Greencom Networks (DE)).

Finally, the 'actual' optimisation of the energy flows is done in the background by companies specialising in this, who often aim at providing a white label platform on a B2B model for other companies involved in HEM. Tiko (CH) or Kaluza (UK) are good examples of such companies.

Table 5 Non-exhaustive list of companies active in HEM, by type of company

Home Energy Management				
Energy suppliers	**HVAC companies**	**Electricity OEM**	**Tech Companies**	**PV/ Storage Specialists**
Fortum (FI) Shine (AU) Octopus (UK) Tibber (NO) Verbund (AT) LichtBlik (DE) Centrica (UK) E.ON (DE) EDF ENR (FR) EDP (PT) Enel X (IT))	NIBE (SE) Stiebel Eltron (BE) IVT (UK) Vaillant (UK) Viessmann (DE) Bosch (DE)	DeltaDore (DE) Hager (DE) Legrand (FR) Schneider Electric (FR)	Smappee (BE) Kiwigrid (DE) Resilience Energy (UK) Beegy (DE) Tribe (BP) (UK) Wondrwall (UK) BeNext (BE) Enervalis (NL)	Senec (DE) Tesla energy (US) Fenecon (DE) Coneva (DE) E3/DC (Hager) (DE) EO charging (UK) Myenergi (UK) Solaredge (IL) Solarwatt (DE)
Home energy Management Offerings + Electricity Systems value				
Energy Supplier	**HVAC companies**	**Electricity OEM**	**Tech Companies**	**PV/ Storage Specialists**
EDF Energy (UK) Solo Energy (UK) True Energy (UK) aWATTar (AT) SocialEnergy (UK) Fortum (FI) LichtBlick (DE) Ishavskraft (NO) EON-GridX (DE)	tepeo (UK)	TIKO (CH)	GreenCom Networks (DE) Kaluza (UK) Beegy (DE) There Corp. (FI) Climote (IE) Peeeks (NL) PassivSystems (UK) TW-TG (NL) GEO (UK) Kiwigrid (DE) Resilience Energy (UK) Tiko (Engie) (CH) Rockethome (DE) GridX (DE)	Moixa (UK) Sonnen (Shell) (DE) Coneva (DE) Fenecon (DE)

Source: Delta-EE, Accelerating the energy transition with Home Energy Management, New Energy Whitepaper, February 2020

Overall, over 50 companies are somehow active in the HEM market, some of which have a strong legacy in energy. This is the case of many energy suppliers, heating ventilation and air conditioning (HVAC) manufacturers or electricity original equipment manufacturer (OEMs), which are now diversifying their offer to include HEM products. Most aggregators or tech companies, have appeared more recently in this market, focusing their business models solely around HEM and sometimes positioning themselves as enablers. Enablers offer products or services to major companies, avoiding these ones to cover the whole HEM production chain.

29.2.2. Market size

The HEMS value chain is closely related, and to some extent embedded, to the BEMS value chain, with some overlaps across market leaders and a potential for integrating functionalities on the longer run. However, today, the two are still fairly distinct markets, with BEMS having longer history and larger size (Table 6).

Table 6 HEMS and BEMS market size, CAGR and leading vendors

Technology	**EU *(vs global)* market size in 2020 (EUR million)**	**EU (*vs global*) market size in 2030 (EUR million)**	**CAGR *(both EU and global)***	**Leading EU companies**	**Leading non-EU companies**
HEMS	300 *(869)*	800	10%	Schneider Electric (FR)	Oracle, Uplight, Bidgely, Itron (all US)
BEMS	1.160 *(4.095)*	3.450	12%	Schneider Electric (FR), Siemens (DE), Johnson Controls (IE), Trane Tech (IE)	Honeywell (US)

Source: Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

29.2.3. Employment

The HEMS (and BEMS) value chain employment consists of software development on the one hand, and deployment in downstream operation and management on the other. It is estimated that in 2020, some 5 000 jobs were found in software development in the EU (17 000 in RoW); by 2030, this figure would grow to 7 200 in the EU (and 25 000 in RoW).[616]

29.3. Global market analysis (HEMS)

Global HEM revenue is projected[617] to grow from nearly USD 4.4 billion in 2019 to more USD 12 billion in 2028, at a CAGR of 12.3%. In North America where HEM technologies have an established foothold, revenue from HEM solutions is expected to increase from USD 2.3 billion in 2019 to USD 4.6 billion in the final year of the forecast, at a CAGR of 8%. The EU is forecast to have the next-highest annual totals,

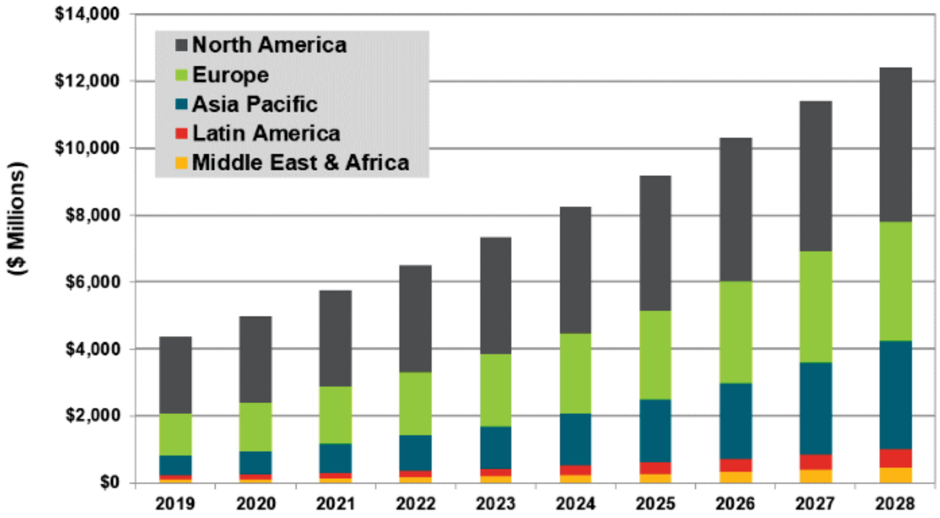
---

[616] Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

[617] Navigant Research: Home Energy Management Overview HERs, HEM Software, HEM Hardware, and Services: Global Market Analysis and Forecasts

with revenue growing from nearly USD 1.3 billion in 2019 to almost USD 3.6 billion in 2028 at a CAGR of 12.1%.

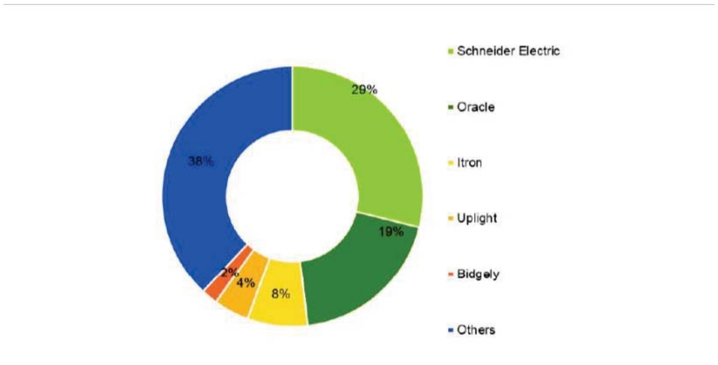
Figure 15 HEM revenue by region (World Markets: 2019-2028)



Source: Navigant Research

The smart home market has had its beginning in the US, and North America currently leads the world in smart home IoT device adoption. Consequently, most innovative HEMS solutions that emphasise data aggregation and personalisation have evolved in the US to capitalise on data-driven opportunities for efficiency. Schneider Electric is the only HEMS market leader that is headquartered in EU. However, it holds significant market share, estimated at 29% (Figure 16).

Figure 16 Top 5 HEMS Market Players Global 2020



Source: Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

29.4. Conclusions (HEMS)

The direction of travel of the European HEMS market is clear: strong growth, in line with the trends of digitalisation and decentralisation of the energy system. However, there are many uncertainties, affecting exactly how the market will grow. While there is a rather large choice of HEMS platforms (applications, software) available on the market for managing smart home devices, the high cost of advanced HEM devices remains an important barrier. Another major barrier is the lack of standardisation and a common framework for interoperability testing[618], which is an enabler for smart home technologies to interoperate thus expanding their usefulness and offering to consumers more choices.

It is estimated that the number of households with HEMS will grow from hundreds of thousands by end 2019 to millions of homes equipped with HEM systems by 2023[619]. A big part is due to the electrification of heat in EU: high penetration of electric-based heating or cooling for space and hot water and the possibility of controls being retrofitted onto these systems. The increasing need for self-consuming PV is driving the battery market in countries like Germany and Italy, meaning HEM will have a role to play to help customers maximise their installation. Finally, the booming EV market could create enormous opportunities for the HEMS market, as this will become one of the most important electric loads in the home.

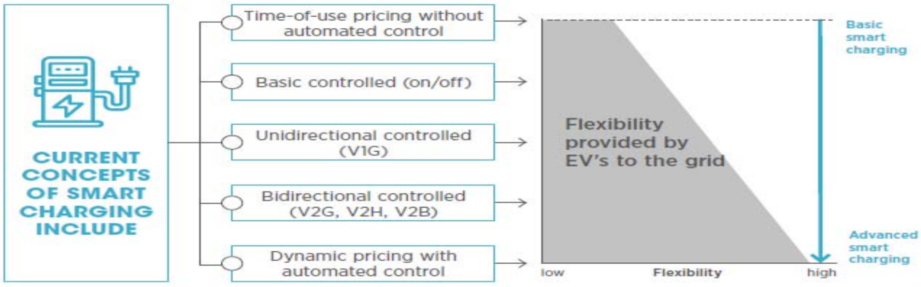
30. SMART CHARGING

30.1. Technology analysis (Smart Charging)

30.1.1. Technology maturity

Smart charging allows a certain level of control over the charging process. Smart charging has evolved from simple controls to sophisticated intelligent applications over the years and it comprises several pricing and technical charging options. The simplest form of incentive – time-of-use pricing – encourages consumers to transfer their charging from peak to off-peak periods. More advanced smart charging approaches, such as direct control mechanisms, will be necessary as a long-term solution at higher penetration levels and for the delivery of close-to-real-time balancing and ancillary services[620], as illustrated in Figure 17.

Figure 17 Smart charging enables EVs to provide flexibility



Source: IRENA, 2019c

---

[618] Papaioannou, I., Tarantola, S., Rocha Pinto Lucas, A., Kotsakis, E., Marinopoulos, A., Ginocchi, M., Masera, M. and Olariaga-Guardiola, M., Smart grid interoperability testing methodology, EUR 29416 EN, *Publications Office of the European Union*, Luxembourg, 2018, ISBN 978-92-79-96855-6, doi:10.2760/08049, JRC110455.

[619] Delta-EE, Accelerating the energy transition with Home Energy Management, *New Energy Whitepaper*, February 2020, https://www.delta-ee.com/downloads/2458-delta-ee-whitepaper-accelerating-the-energy-transition-with-home-energy-management.html#form-content

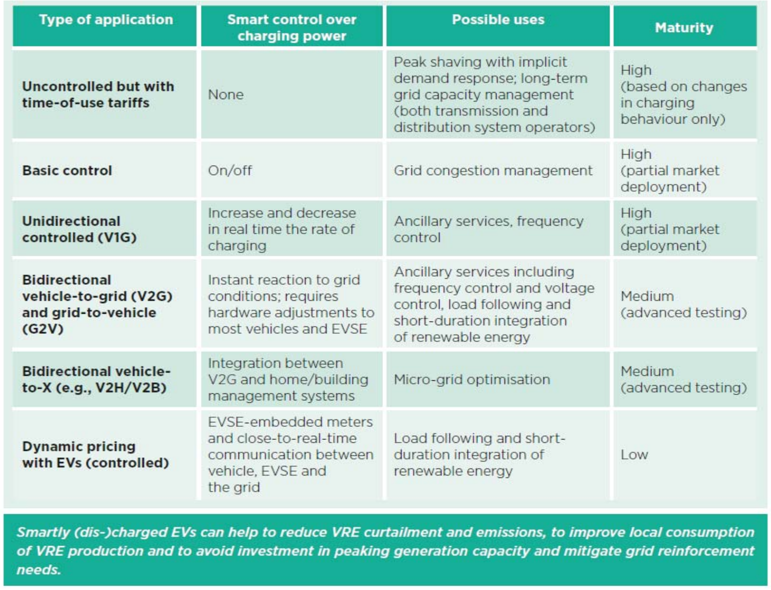
[620] International Renewable Energy Agency (IRENA), Electric- Vehicle Smart Charging, Innovation Landscape Brief, 2019

Source: Electric-Vehicle Smart Charging, Innovation Landscape Brief, International Renewable Energy Agency (IRENA), 2019

Smart charging technology deployment will be mainly driven by Charging Point Operators (CPOs) and Mobility Service Providers (MSPs). CPOs own and operate a pool of charging points, collect data on diagnostics and service maintenance. MSPs help clients find available charging points, activate charging, handle payments, billing, and e-roaming. Smart digital platforms enable the communication between the CPOs, MSPs and EVs, as well as energy providers[621].

Table 7 Types of smart charging and maturity shows the most common types of smart charging and their maturity stage. Applications around bidirectional charging are medium technology-mature but they are in advanced testing stage with many pilot projects running in the EU.

Table 7 Types of smart charging and maturity



Type of application	Smart control over charging power	Possible uses	Maturity
Uncontrolled but with time-of-use tariffs	None	Peak shaving with implicit demand response; long-term grid capacity management (both transmission and distribution system operators)	High (based on changes in charging behaviour only)
Basic control	On/off	Grid congestion management	High (partial market deployment)
Unidirectional controlled (V1G)	Increase and decrease in real time the rate of charging	Ancillary services, frequency control	High (partial market deployment)
Bidirectional vehicle-to-grid (V2G) and grid-to-vehicle (G2V)	Instant reaction to grid conditions; requires hardware adjustments to most vehicles and EVSE	Ancillary services including frequency control and voltage control, load following and short-duration integration of renewable energy	Medium (advanced testing)
Bidirectional vehicle-to-X (e.g., V2H/V2B)	Integration between V2G and home/building management systems	Micro-grid optimisation	Medium (advanced testing)
Dynamic pricing with EVs (controlled)	EVSE-embedded meters and close-to-real-time communication between vehicle, EVSE and the grid	Load following and short-duration integration of renewable energy	Low

Smartly (dis-)charged EVs can help to reduce VRE curtailment and emissions, to improve local consumption of VRE production and to avoid investment in peaking generation capacity and mitigate grid reinforcement needs.

Source: International Renewable Energy Agency (IRENA), Innovation Outlook, Smart Charging for Electric Vehicles, 2019

Private chargers have different applications and requirements than public charge points as they are typically with lower power and are used for longer charging periods (when the vehicle is left parked during the day or night). Because there are less constraints on when and how the energy should be delivered, a higher level of flexibility or “smartness” can be included for these chargers. According to a study[622], in the short to mid-term, about 20% of kWh will be charged at public sites in and between cities, while 80% of kWh will be charged at private sites (at home or at work), mostly in buildings where normal-power smart charging points (between 3.7 and 22 kW) will be enough.

30.1.2. Public R&I funding

The summary results for EV charging infrastructure, after a peak in 2018 show a decrease in EU Public Research Development and Deployment (RD&D) investments (Figure 18). The leading country in EU for

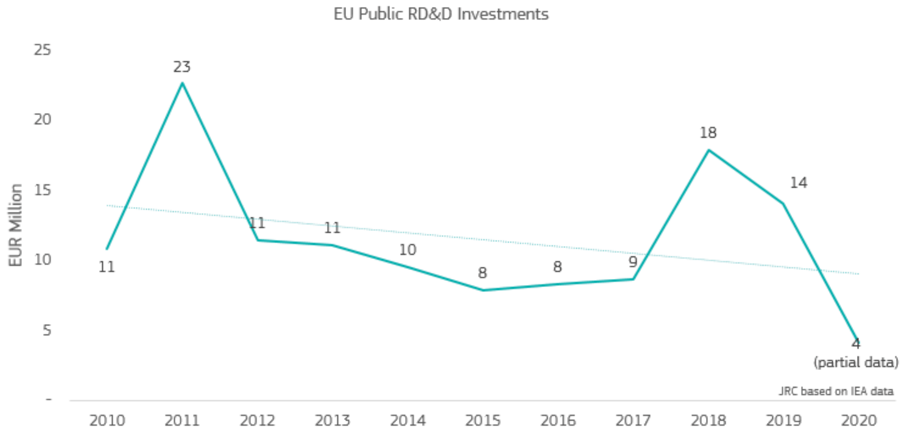
---

[621] Guidehouse Insights, Asset Study on Digital Technologies and Use Cases in the Energy Sector, 2020

[622] SmartEn, White Paper, Making electric vehicles integral parts of the power system, July 2019

the period 2017-2019 is France with total public investments of approximately EUR 27 million. The total amount for EU Member States for the same period is approximately EUR 4 127 million[623].

Figure 18 EU Public R&D Investments



Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS)

This trend will change in the coming two years, where the main source of support for R&I investments in smart EV charging at EU level, the Horizon Europe Framework Programme, will invest around EUR 150 Mio in various smart changing call (i.e. calls[624] [625] [626]).

30.1.3. Private R&I funding

The total capital invested by EU from 2015 to 2020 for early stage investments reached almost EUR 40 million compared to the EUR 480 million invested by RoW with a big jump in both for 2020. As far as the later stage investments are concerned, EU spent around EUR 77 million from 2015 to 2020, compared to EUR 1 600 million of the RoW.

Figure 19 Early stage investment by region [EUR Million]

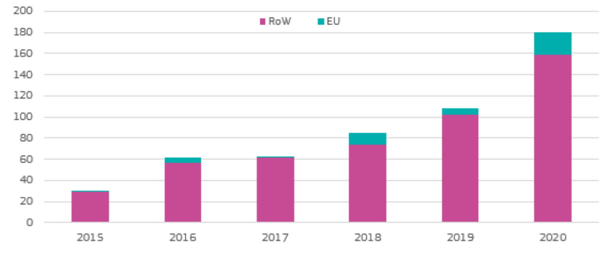
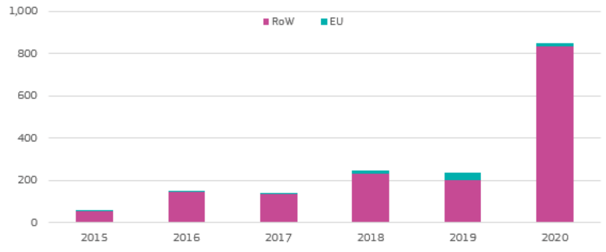


Figure 20 Late stage investment by region [EUR Million]



Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard(CIndECS)

---

[623] Some countries keep their data confidential or do not report to this level of detail.

[624] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2021-d5-01-03

[625] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2021-d5-01-01

[626] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2022-d5-01-08

30.1.4. Patenting trends

On the patenting side, the EU has a share of 15% (678 out of the 4309) of the patents published from 2015 to 2017 regarding electric vehicle charging infrastructure (Figure 21Figure 21) is leading the patent applications in total, but its high value and international share remains relatively small.

Figure 21 Number of inventions and share of high-value and international activity (2015-2017)

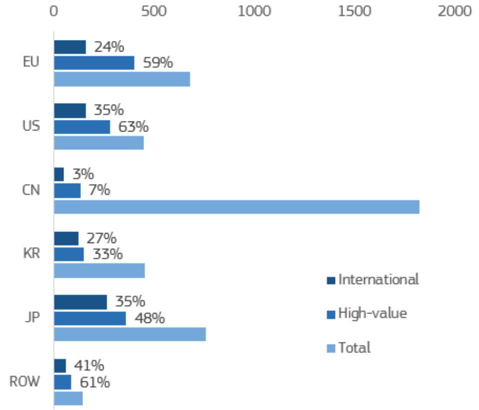
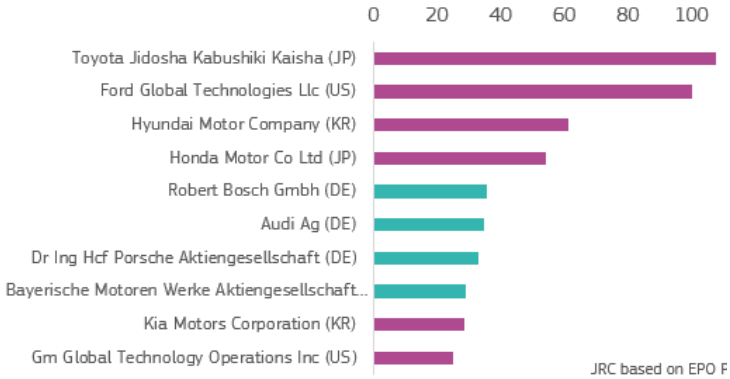


Figure 22 Top 10 high-value inventions companies in the world (Fig. 28b)



Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard(CIndECS)

30.2. Value chain

The value chain of smart EV charging can be grouped in the following three main streams:

Energy suppliers: The first stream includes everything from producing and transmitting energy from source to vehicle, to monitoring energy provider and recipient information and offering an easy-to-understand, easy-to-integrate payment system.

Charging infrastructure providers: The second stream comprises everything from building and operating charging stations to sales and maintenance and from creating home, public, and workplace charging infrastructure programs and managing the power supply and grid effects.

E-mobility service providers: The third stream contains everything from battery management and roaming environments to charging infrastructure and vehicle services to ensure flawless product performance, compliance with global standards, customer safety and satisfaction.

The three key insights gained with regards to the supply chain of EV charging infrastructure[627] are: (i) supply chain of manufacturers is mainly local and/or regional, in particular for EU based vendors, (ii) the basic electronic parts are purchased in Asia, and (iii) the value chain is not fully mature yet as vendors develop, design, and manufacture mainly in-house, with some contract manufacturing.

30.2.1. Turnover

The increased penetration of EVs to the market will lead revenues from EV charging to surge and likely hit EUR 36 billion in 2030 (Figure 23). This is a seven times increase from 2021 and implies a massive growth rate of about 25% per year. EV charging opens up enormous opportunities for business models. The EV charging market can be divided into the following revenue pools: (*i*) hardware, (*ii*) asset ownership, (*iii*) technical operation, (*iv*) electric mobility service provider (e-MSP), (*v*) energy management, and (*vi*) electricity and grid[628].

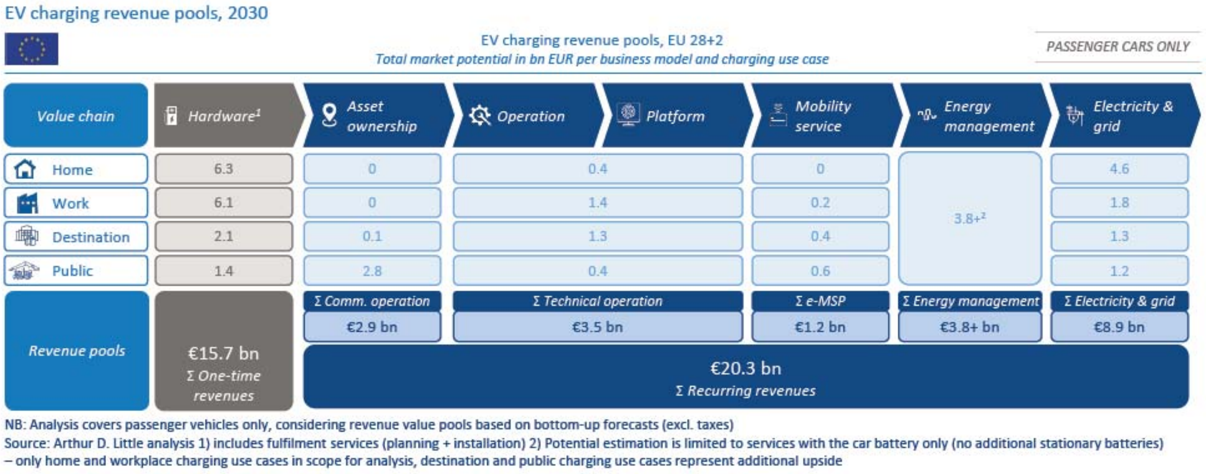
Recurring revenues will increase from a 20% share today to more than 50% in 2030. In the long run recurring revenues will outgrow one-time revenues, but even by 2030, hardware and related fulfilment services will still account for almost 50% of the market potential. It is also projected that electricity and grid only accounts for 25% of total revenues.

---

[627] Guidehouse Insights, Asset Study on Digital Technologies and Use Cases in the Energy Sector, 2020

[628] Alexander Krug, Thomas Knoblinger, Florian Saeftel: Electric vehicle charging in Europe, *Arthur D. Little Global*, website publication, January 2021, www.adlittle.com/en/insights/viewpoints/electric-vehicle-charging-europe

Figure 23 EV charging revenue pools, 2030



EV charging revenue pools, 2030

EV charging revenue pools, EU 28+2

Total market potential in bn EUR per business model and charging use case

PASSENGER CARS ONLY

Value chain	*Hardware*[1]	*Asset ownership*	*Operation*	*Platform*	*Mobility service*	*Energy management*	*Electricity & grid*
Home	6.3	0	0.4		0	3.8+[2]	4.6
Work	6.1	0	1.4		0.2		1.8
Destination	2.1	0.1	1.3		0.4		1.3
Public	1.4	2.8	0.4		0.6		1.2
Revenue pools	€15.7 bn *Σ One-time revenues*	*Σ Comm. operation* €2.9 bn	*Σ Technical operation* €3.5 bn		*Σ e-MSP* €1.2 bn	*Σ Energy management* €3.8+ bn	*Σ Electricity & grid* €8.9 bn
		€20.3 bn *Σ Recurring revenues*					

NB: Analysis covers passenger vehicles only, considering revenue value pools based on bottom-up forecasts (excl. taxes)

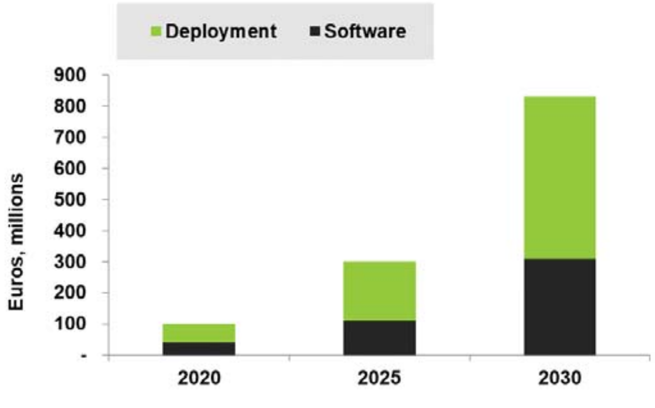
Source: Arthur D. Little analysis 1) includes fulfilment services (planning + installation) 2) Potential estimation is limited to services with the car battery only (no additional stationary batteries) – only home and workplace charging use cases in scope for analysis, destination and public charging use cases represent additional upside

Source: Alexander Krug, Thomas Knoblinger, Florian Saeftel: Electric vehicle charging in Europe, Arthur D. Little Global, website post, January 2021

Energy management refers to smart charging services (i.e., optimizing charging behaviour of consumers on power connection level – peak load shaving, PV integration, time-based tariffs) and the provision of balancing power to the electricity grid by pooling EVs connected to the grid. The latter, is increasingly happening as an aggregator business model under a Virtual Power Plant (VPP)[629] logic.

Europe has been and continues to be the global VPP leader in terms of capacity (GW); largely reflecting the supply-side VPP capacity [630].Germany is the largest and most mature VPP market, and is anticipated to capture about one-third of VPP market's annual capacity by 2028.

Figure 24 EU-27 Market Size



Source: Guidehouse, Digital Technologies and use cases in the energy sector, 2021

---

[629] VPP is system that relies on software and a smart grid to remotely and automatically dispatch DER flexibility services to a distribution or wholesale market via an aggregation and optimization platform.

[630] Digital technologies and use cases in the energy sector - Publications Office of the EU (europa.eu) 2021. The VPP related information in this chapter is coming from this study by the EC.

Comparatively the VPP market, in 2028, in Japan is expected to be USD 45 million and in Australia USD 250 million[631].

The VPP aggregation software supply chain is highly integrated and the leading vendors in Europe are EU companies such as Schneider Electric, Next Kraftwerke, Enel X or ABB. These leader companies are in a strong position for long-term success in the VPP arena.

Europe has also been the driving force behind VPP spending, accounting for nearly 45% of global investment in 2020. This is a function of several factors, including Distributed Energy Resources, DER, growth, market opening, valuation of non-traditional assets, and carbon reduction and efficiency goals. At the same time, Europe is opening doors to new value streams linked to creative ancillary service markets and real-time energy trading.

As advanced grid management technologies continue to evolve and DER penetration on the grid increases, grid operators may require both the economic optimization provided by VPP platforms and the physics-based management provided by a DER management system (DERMS). Thus, a hybrid VPP-DERMS solution may become more prominent moving towards 2050.

30.2.2. Compound annual growth rate

EV smart charging can be segmented in two wide technology categories: (i) EV charging infrastructure, which is broadly defined as charging hardware technology that supplies electric energy from the grid for recharging plug-in EVs, and (ii) EV charging platforms, broadly defined as a software tool for managing charge point business activities and energy demands.

Table 8 EV smart charging overview

Use case	Technology	EU Market Size 2020 (EUR Million)	EU Market Size 2030 (EUR Million)	CAGR	Leading EU companies	Leading non-EU companies
EV Smart Charging	EV charging infrastructure	500	5,200	26%	ABB, EVBox, Efacec, Alfen, New Motion	Tritium
	EV charging platforms	130	1,500	28%	Virta, Fortum Charge & Drive, has.to.be, Green Flux, Last Mile Solutions	

Source: Asset Study on Digital Technologies and Use Cases in the Energy Sector, Guidehouse Insights, 2020

30.2.3. EU market leaders

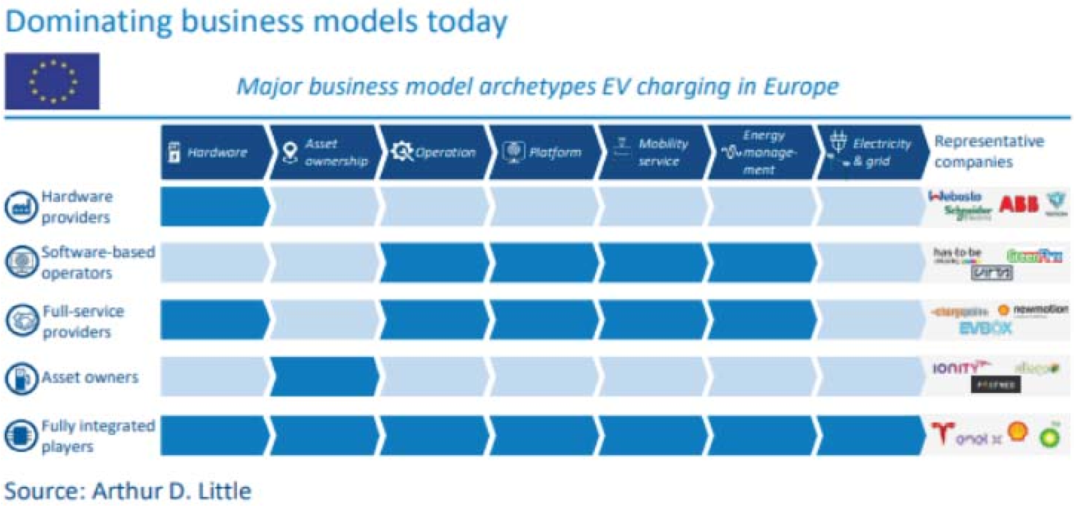
Leading charging hardware suppliers are producing solutions across the major use cases and technology segmentations. The EU is highly competitive with a dense network of suppliers. The market has seen significant investment from established power and automation suppliers, oil and gas companies, and

---

[631] Navigant Research, 2019

electricity suppliers. Among the vendors of EV charging infrastructure in the EU today, the leading companies are ABB, EV Box, Enel X, New Motion, etc. with an important role for Tesla (US). In terms of EV charging platforms, the leading companies in EU are Virta, Fortum Charge & Drive, GreenFlux, has.to.be, etc.

Figure 25 Dominating business models in the market and major players

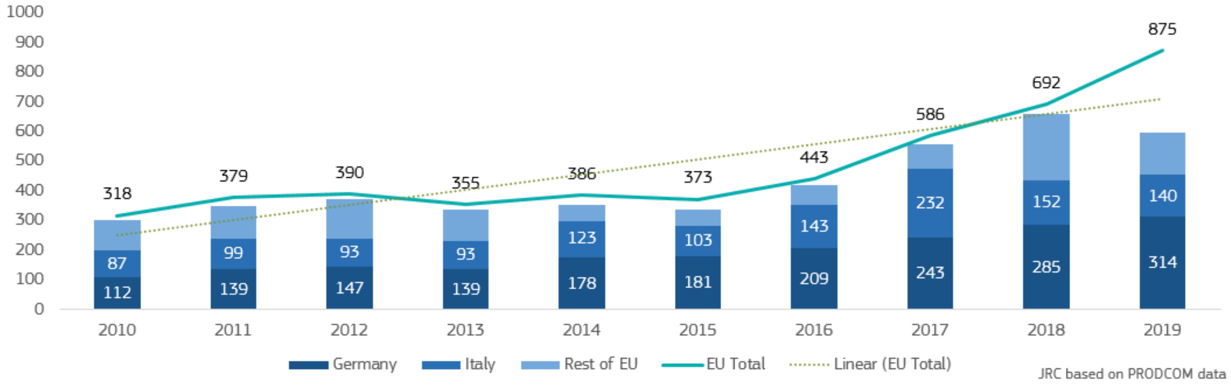


Source: Alexander Krug, Thomas Knoblinger, Florian Saeftel: Electric vehicle charging in Europe, Arthur D. Little Global, website post, January 2021

30.2.4. Community Production

The total production value on the electric vehicle charging infrastructure value chain in the EU reached EUR 875 million in 2019, showing a continuous increase from 2015. Germany and Italy together account for more than 50% of the total community production, as illustrated in Figure 26.

Figure 26 Total production value in the EU and top producer countries [EUR Million]



Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS)

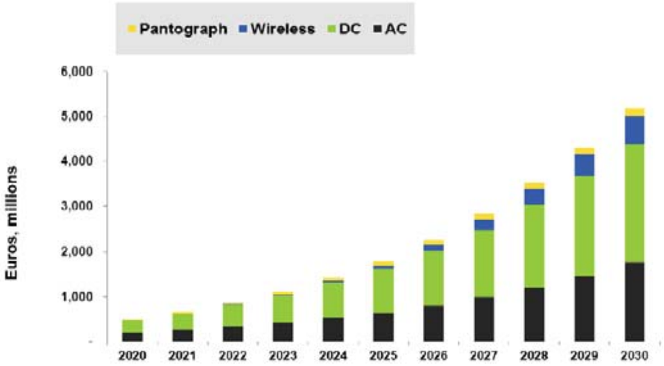
30.3. Global Market Analysis

By the end of 2019, there were 7.3 million electric vehicle chargers installed worldwide[632], of which 6.5 million chargers were private light-duty vehicle (LDV) slow or normal chargers[633]. The estimated number of private LDV chargers in 2020 is 9.5 million[634], of which 7 million are at residences and the remainder at workplaces. This represents 40 GW of installed capacity at residences and over 15 GW of installed capacity at workplaces.

30.3.1. EU market leaders

The market of EV charging equipment in the EU is estimated at nearly EUR 500 million in 2020, and the prediction is that it will surpass EUR 5.2 billion by 2030, as shown in Figure 27. Most of the market is captured via development of public infrastructure: destination chargers and fast charge services. These sectors together account for 65% of the market. However, substantial growth in home and fleet charging is expected on behalf of technological innovations in passenger EV on board charging capacity and vehicle grid integration and growing availability of commercial EV options. By 2030, home and fleet charging will represent 27% and 16% of market revenues respectively[635].

Figure 27 EV Charging Equipment Sales Revenue, EU market



Source: Guidehouse Insights, Asset Study on Digital Technologies and Use Cases in the Energy Sector, 2020

While smaller than the equipment's revenue, that of the O&M of the platform will grow similarly (Figure 28).

---

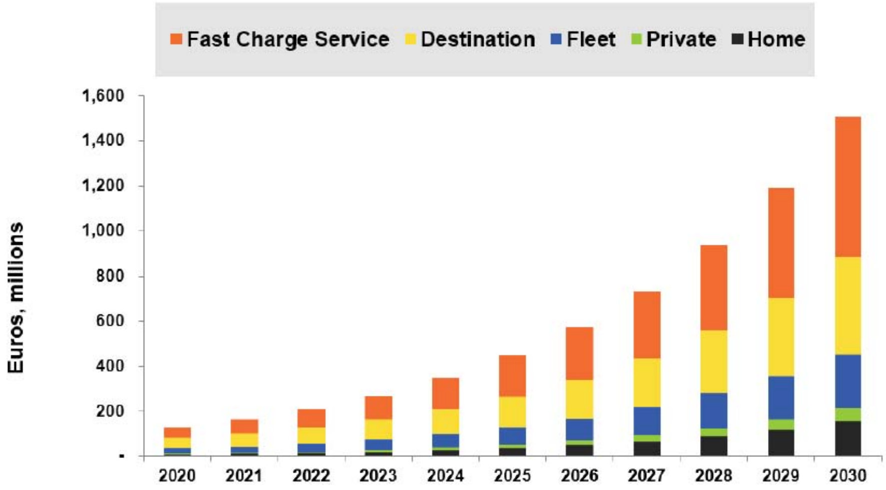
[632] International Energy Agency, Global EV Outlook 2020, Entering the decade of electric drive?, 2020

[633] Normal or slow charging refers to charging power less than or up to 22 kW and the distinction is mostly region specific. For example, in the European Union, the European Alternative Fuels Observatory (EAFO) classifies chargers rated up to 22 kW as normal, whereas in the United States, they are classified as slow charge (EAFO, 2020a; AFDC, 2020).

[634] International Energy Agency, Global EV Outlook 2021, Accelerating ambitions despite the pandemic, 2021

[635] Guidehouse Insights, Asset Study on Digital Technologies and Use Cases in the Energy Sector, 2020

Figure 28 EV Charging Platforms O&M Revenue, EU market



Source: Guidehouse Insights, Asset Study on Digital Technologies and Use Cases in the Energy Sector, 2020

30.3.2. Global market leaders

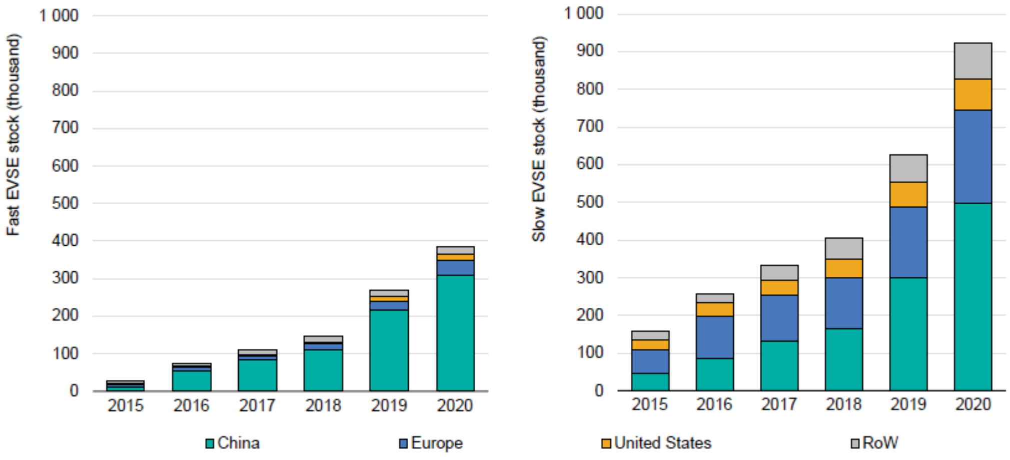
Publicly accessible chargers reached 1.3 million units in 2020, of which 30% are fast chargers. Installation of publicly accessible chargers increased 45%, a slower pace than the 85% in 2019, possibly because the pandemic interrupted work in key markets. China leads the world in availability of both slow (charging power less than 22 kW) and fast (more than 22 kW) publicly accessible chargers. In the EU, fast chargers are being rolled out at a higher rate than slow ones.[636]

The pace of slow charger (charging power below 22 kW) installations in China in 2020 increased by 65% to about 500 000 publicly accessible slow chargers. The EU is second with around 250 000 slow chargers, with installations increasing one-third in 2020. Installation of slow chargers in the US increased 28% in 2020 from the prior year to total 82 000. The number of slow chargers installed in Korea rose 45% in 2020 to 54 000, putting it in second place.

Figure 29 Stock of fast and slow publicly accessible chargers for electric light-duty vehicles over 2015-2020.

---

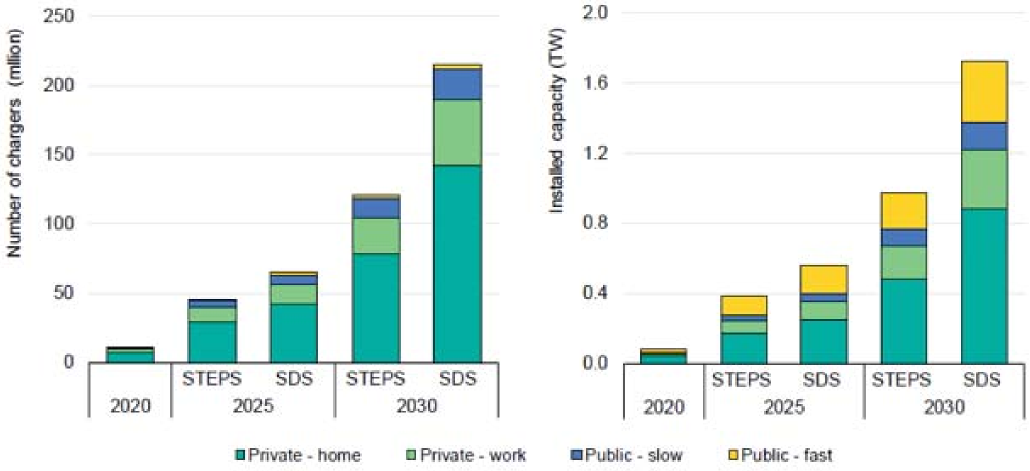
[636] International Energy Agency (IEA), Global EV Outlook 2021, Accelerating ambitions despite the pandemic, 2021



Source: Global EV Outlook 2021, Accelerating ambitions despite the pandemic, International Energy Agency

The number of *private chargers* for Long Distance Vehicles and dedicated chargers for buses and trucks is estimated around 6.4 million in 2019[637], while the estimated number of private LDV chargers in 2020 is 9.5 million, of which 7 million are at residences and the remainder at workplaces. This represents 40 GW of installed capacity at residences and over 15 GW of installed capacity at workplaces. According to a study of the IEA[638], private charging will dominate in numbers and capacity (Figure 30).

Figure 30 Electric LDV chargers and cumulative installed charging power capacity by scenario, 2020-2030



Source: Global EV Outlook 2021, Accelerating ambitions despite the pandemic, International Energy Agency

---

[637] International Energy Agency (IEA), Global EV Outlook 2020, Entering the decade of electric drive?, 2020

[638] International Energy Agency (IEA), Global EV Outlook 2021, Accelerating ambitions despite the pandemic, 2021

30.4. Conclusions (Smart charging)

The major drivers of smart EV charging are the need for reduced vehicle downtime through increased charging speed; improved charging convenience through wireless and on-demand mobile charging; and more efficient charging through grid and renewables integration. EV charging infrastructure and charging management platforms are the key components to meet these market demands.

Technology is there for most of the smart EV charging required system components (e.g., bidirectional converters, connectivity modules, smart energy optimisation software, e-mobility and roaming, etc.). It also seems that slow chargers (compared to fast chargers) are more suitable to support the smart EV charging ecosystem for a number of reasons (e.g., they can be used for longer charging periods providing a higher level of flexibility, there are less constraints on when and how the energy should be delivered, etc.). Another important factor for a potential successful implementation of smart EV charging is the presence of time-varying price energy tariffs in the residential sector.

The number of tests, pilots, and demonstrations have grown alongside development of the larger EV market. There are many pilots, programs and projects about smart EV charging, but it seems that overall, the market is not mature yet. It also seems that EVs smart charging is evolving more towards a services market. Nevertheless, as the adoption of DER and EVs will progress at speed during this decade, the smart charging sector will also consolidate as a growing part of a multibillion euro EV charging market.

31. CONCLUSIONS

Smart (digital) technologies are key enablers for the transformation (decarbonisation) of the power sector, as they allow for the integration of variable renewable energy resources at scale, flexibility services on the demand and supply side, more efficient asset control and management, and new, innovative energy services (business models). While in terms of technology readiness there are some differences among the four examined technology areas (distribution automation, smart metering, HEMS and smart charging), the revealed innovation efforts and perspectives for strong market growths make them clearly sit on the same trend.

The technology analysis showed that distribution automation and smart metering can rely on mature, market-ready devises and software, whose deployment has been ongoing from a few years (second generation of smart meters) to almost a decade (advanced distribution management or ADMS). On the other hand, HEMS and smart charging are in advanced testing phase, with many promising projects running in the EU and elsewhere. Standardisation, interoperability and cyber security are common challenges across the board. It is also clear that the systemic, large-scale deployment of all these tools will be critical for realising the potential of DERs and demand-side flexibility.

However, the digitalisation of end-use and low-voltage distribution may only happen in parts if it is simply let to market forces and cost-efficiency considerations. For instance, in some countries, DSOs have been strong promoters of smart meter deployment and substation automation, as they provided clear benefits in terms of consumption data and operational efficiency, while the implementation of a fully decentralised energy network based on bi-directional electricity flows and enhanced prosumer participation will probably require a stronger policy and regulatory push, since it will profoundly challenge existing practices and businesses.

Having said this, the direction of travel towards more digitalisation and growing markets, in all four technology areas, is clear. Distribution automation, the biggest global market among the four today with an estimated USD 12.4 billion value in 2020, is expected to grow by a 7.4 % CAGR to reach USD 17.7 billion by 2025. Smart meters are projected to follow a similar (global) trend, with the number of units shipped growing by 7% in a year until 2024 that could be even higher in the EU. The global HEMS revenue is projected to grow from nearly USD 4.4 billion in 2019 to more than USD 12 billion in 2028, at a CAGR of 12.3% (and of 12.1% in EU). Finally, EV charging infrastructure and platforms may experience a genuine boom in EU during this decade, with their combined markets expected to grow from EUR 0.63 billion in 2020 to EUR 6.7 billion by 2030, at a CAGR higher than 26%.

With ambitious policy objectives (e.g. European Green Deal, Energy system integration, etc.), favourable regulatory environment (e.g. the Electricity Directive) and public funding (e.g. Horizon Europe, European Innovation Fund, Recovery and Resilience Facility), the EU seeks leading the way in deploying smart grids, and this has contributed to the emergence of European market leaders and solid technology manufacturers in all four technology domains. However, the global market analysis reveals strong developments in the US, as well as in Asia Pacific (China, Japan, South Korea), too, which suggesting that EU will probably have to face tough competition along the way to 2030.

RENEWABLE FUELS IN AVIATION AND SHIPPING

INTRODUCTION

Renewable fuels are a cornerstone of the future EU energy system.[639] They are necessary where direct heating or electrification are not feasible or have high costs. Renewable gases including hydrogen can offer solutions to store the energy produced from variable renewable sources, exploiting synergies between the electricity, gas, waste and end-use sectors. Renewable synthetic fuels can be produced with excess renewable energy when its supply peaks exceed other energy end-use demands.

Renewable liquids provide high energy density where space and weight limit the viability of other solutions, particularly in the long-haul aviation and shipping sectors, as well as in heavy duty road transport. Renewable fuels will therefore be key in decarbonising these sectors.

Yet renewable fuels, and in particular advanced renewable fuels, still require demonstration, scaling up and market uptake. The high investment costs for their production are a strong barrier to competing with and replacing fossil fuels. However, they can use existing logistic infrastructure of fossil fuels for their distribution.

Renewable fuels for aviation and maritime sectors will be of strong policy focus in the coming years. The package for delivering the Green Deal presented in July includes the revision of the Renewable Energy Directive[640] as well as the introduction of two new regulations, ReFuelEU Aviation[641] and FuelEU Maritime[642]. Together these policy instruments aim to leverage demand for renewable fuels in the aviation and maritime sectors. The Renewable and Low Carbon Fuel Value Chain Alliance is a further instrument under the Sustainable and Smart Mobility Strategy[643] which will accompany these other measures to mobilise investment in the scaling up of renewable fuel production.

Renewable fuels in this document refer to liquid and gaseous biofuels produced from organic matter, as well as liquid and gaseous synthetic fuels produced from renewable energy. Biofuels include both conventional and advanced biofuels that are sustainable according to Article 29 of the Renewable Energy Directive[644]. They are defined as low indirect land use-risk according to Article 26 if they are made from food and feed crops or advanced if they are made from the feedstocks listed in Annex IX of the same Directive. Synthetic fuels in this document are those produced from renewable energy combining hydrogen and carbon or nitrogen.

---

[639] European Commission, Powering a climate-neutral economy: An EU Strategy for Energy System Integration, COM(2020)299,

[640] European Commission, Proposal for a Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652, COM (2021) 557

[641] European Commission, Proposal for a Regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport, COM(2021) 561

[642] European Commission, Proposal for a Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC, COM(2021) 562

[643] European Commission, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Sustainable and Smart Mobility Strategy – putting European transport on track for the future, COM (2020) 789

[644] Directive (EU) 2018/2001 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources

Conventional biofuels (i.e. first generation biofuels made from food and feed crops) have reached commercialization, but due to their indirect land use change impacts they have a limited role in decarbonising the transport sector. In accordance with the Renewable Energy Directive, they must meet the EU sustainability criteria set out in Article 29. They can also be certified as low indirect land use – in order to address concerns for emissions linked to land displacement. Economic indicators are only available for conventional biofuels and are often aggregated for all sectors. However, data from the road transport biofuels form the basis for the biofuels market in general and are essential to understand the potential of the market development for the shipping and aviation sectors.

Carbon capture and use/storage (CCUS) technologies are relevant for both bioenergy with carbon capture and storage (BECCS) and recycled carbon fuels (made with fossil carbon dioxide) but they are not addressed in this chapter. Renewable fuels also include hydrogen, which is an important feedstock for production of synthetic fuels. Hydrogen production from electrolysers is covered in a separate chapter titled “Hydrogen electrolysers”.

32. TECHNOLOGY ANALYSIS – CURRENT SITUATION AND OUTLOOK

32.1 Technology readiness level (TRL)

Renewable fuels are produced from diverse feedstocks and production pathways. The stages in their technical and commercial maturity are therefore equally diverse. Only conventional (and to an extent cellulosic) bioethanol, biodiesel (i.e. bio-oil), some advanced hydrotreated vegetable oils (HVO), and co-processed biomass pyrolysis oils have reached commercialisation. All other renewable fuels based on advanced feedstocks, particularly those relevant to aviation and shipping, are at various stages of demonstration or even only development. However, some hydroprocessed esters and fatty acids (HEFA) for aviation which are based on HVO and bio-oils for shipping start becoming available at large scale as the technology is demonstrated already.

Power-to-liquids are liquid fuels produced from electricity to obtain hydrogen through water electrolysis. Such hydrogen could be either liquified for use as a non-drop in fuel or to synthesize hydrocarbon fuels that can be blended to drop-in liquid fuels or ammonia that requires specific infrastructure to be used as a fuel.

32.1.1. Shipping

Diesel engines in modern merchant ships use Heavy Fuel Oil (HFO), Marine Diesel Oil (MDO) and Low Sulphur Heavy Fuel Oil (LSHFO). On the other hand, petrol- or gas-fired spark ignition engines usually propel smaller vessels. Steam turbines and gas turbines are also possible engines.

Alternative renewable options to reduce sulphur and GHG emissions include[645] biofuels, renewable hydrogen, and electricity. Ammonia has recently been gaining attention as an alternative energy carrier for ships.

Biofuels are good alternatives for ship engines because they contain little or no sulphur and are suitable for Emissions Control Areas. Bio-methanol, bioethanol, liquefied or gaseous bio-methane and bio-butanol are appropriate for spark ignition engines. Good substitutes for diesel engines are diesel-type bio-hydrocarbons

---

[645] Besides installing Sulphur Oxides scrubbers

like biodiesel (fatty acid methyl ester - FAME) and bio-dimethyl-ether (DME), along with bio-crude from hydrothermal liquefaction and HVO.

Marine fuel standards for fossil fuels accept FAME blends up to 7% by volume, HVO and fuels derived with Fischer-Tropsch technology based on biomass gasification to syngas, as well as fuels from co-processing of renewable feedstocks. Although most biofuels are drop-in alternative fuels, the use of certain options would require some changes to the engines and the on-board storage (e.g., bio-LNG), and require a secure bunkering logistic at ports.

Main barriers to the deployment of marine biofuels include the higher price compared to fossil marine fuels, insufficient logistic support at ports for fuels not compatible with bunker type fuels, and safety requirements when using methanol, ammonia or gaseous fuels.

The technology readiness levels (TRLs) range from lab or pilot scale to commercial production of conventional biofuels such as straight vegetable oil (SVO), biodiesel (FAME), ethanol and butanol from sugar and starch crops, renewable diesel from tall oil, and renewable diesel from hydro-treated vegetable oil (HVO).

Table 9 TRL of renewable fuels compatible with shipping

Energy carrier	**TRL**	**Energy carrier**	**TRL**
C2H5OH (sugar/starch hydrolysis)	9	Diesel (MSW, crop residues)	7
Diesel (20% FAME UCO)	9	eCompH2 300 bar (Renewable)	7
Diesel (20% FAME UCO, 30% HVO rapeseed)	9	CNG (organic waste)	6
Diesel (palm oil)	9	eCompH2 700 bar (Renewable)	6
Diesel (soybean oil)	9	LNG (organic waste)	6
Diesel (waste oil)	9	eLH2 (renewable)	5.5
CH3OH (black liquor, glycerin)	7	eNH3	5

Source: European Sustainable Shipping Forum MARIN 2021[646]

32.1.2. Aviation

Jet fuels in use are derived from the kerosene fraction of crude oil. Jet fuels are a mix of hydrocarbons, including mostly normal paraffins, iso-paraffins, cycloparaffins and aromatics, which comply with very strict specifications due to critical safety concerns. Renewable liquid fuels with a similar functionality to oil-derived jet fuels remain a strong candidate to replace traditional jet fuels in the short/medium and even long term. Drop-in aviation biofuels have the same properties as the jet fuels, therefore they can be blended readily in jet fuels after certification for full compatibility with aircraft and fuel logistics.

Power-to-liquid drop-in fuels (or e-fuels or electrofuels) are not yet commercially available, and their viability will depend on the cost of electricity, cost and supply of captured CO2, conversion efficiency to liquid fuels and life-cycle emissions performance. Their contribution is expected to be significant only after 2030.

As shown in Table 10 and Table 11, apart from Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK), most e-fuels are not yet certified for use in aviation and they are generally at a lower

---

[646] https://sustainablepower.application.marin.nl/energy-carriers/custom-bar-chart

maturity level than advanced biofuels. Only advanced biofuels are mature enough for commercial use and even these are still limited to HEFA and co-processed waste oils and fats.

Table 10 Maturity Level of Certified Advanced Biofuels for Aviation

Route	Feedstocks	Certification	TRL
Hydroprocessed Esters and Fatty Acids (HEFA)	Vegetable and animal lipids	HEFA-SPK, up to 50% blend	8-9
Co-processing waste oils/fats	Vegetable and animal lipids	D1655, 5 to 10% blend	8-9
Direct Sugars to Hydrocarbons (DSHC)	Conventional sugars, lignocellulosic sugars	HFS-SIP, up to 10% blend	7-8 or 5[647]
Alcohols to Jet (AtJ)	Sugar, starch crops, lignocellulosic biomass	ATJ-SPK, up to 50% blend	6-7
Biomass Gasification + Fischer-Tropsch (Gas+FT)	Energy crops, lignocellulosic biomass, solid waste	FT-SPK, up to 50% blend	7-8
Biomass Gasification + FT with Aromatics	Energy crops, lignocellulosic biomass, solid waste	FT-SPK/A, up to 50% blend	6-7
Catalytic Hydrothermolysis (CHJ)	Vegetable and animal lipids	CHJ, up to 50% blend	6
HEFA from algae	Microalgae oils	HC-HEFA-SPK, up to 10% blend	5

Source: Impact Assessment ReFuelEU Aviation Regulation 2021, SWD(2021) 633

For electrofuels based on the production of hydrogen through electrolysis, information is provided in the "Hydrogen electrolysers" chapter.

Table 11 Summary of aviation electrofuel production pathways and their critical technical processes

Route	Certification	Critical technical processes
FT route (LT electrolysis) Low Temperature Electrolysis	FT-SPK, up to 50% blend	Reverse water gas shift reaction (TRL 5-6)
FT route (HT electrolysis) High Temperature Electrolysis	FT-SPK, up to 50% blend	Solid oxide electrolysis (TRL 4-7) Reverse water gas shift reaction (TRL 5-6) or Co-electrolysis (TRL <5)

---

[647] TRL 7-8 when conventional sugars are used as feedstock; TRL 5 when the feedstock consists in lignocellulosic sugars

Methanol route (two-step methanol synthesis / LT electrolysis)	Not certified	Reverse water gas shift reaction (TRL 5-6) Final conversion to jet fuel (TRL 7-8)
Methanol route (two-step methanol synthesis / HT electrolysis)	Not certified	Reverse water gas shift reaction (TRL 5-6) Final conversion to jet fuel (TRL 7-8) Solid oxide electrolysis (TRL 4-7) or Co-electrolysis (TRL <5) Final conversion to jet fuel (TRL 7-8)
Methanol route (one-step methanol synthesis / LT electrolysis)	Not certified	Methanol synthesis (TRL 6-7) Final conversion to jet fuel (TRL 7-8)
Methanol route (one-step methanol synthesis / HT electrolysis)	Not certified	Methanol synthesis (TRL 6-7) Final conversion to jet fuel (TRL 7-8) Solid oxide electrolysis (TRL 4-7)

Source: Impact Assessment ReFuelEU Aviation initiative 2021, SWD(2021) 634 final

32.2. CAPACITY INSTALLED, GENERATION/PRODUCTION

The current EU installed capacity of conventional biofuel is 14.4 Mt/y for biodiesel and 3.7 Mt/y for bioethanol[648]. HVO installed capacity currently stands at 3.4 Mt/y, with an expected increase to reach 4.2 Mt/y in 2025[649]. The fuel consists of paraffin made through HVO technologies. On the other hand, advanced biofuel production technologies are by large still not commercial. Current EU installed capacity of advanced biofuels is 0.36 Mt/y, mainly from cellulosic ethanol, hydrocarbon fuels from sugars and pyrolysis oils. An additional 0.15 Mt/y is under construction, and another 1.7 Mt/y is planned with about half of it from biomass gasification[650].

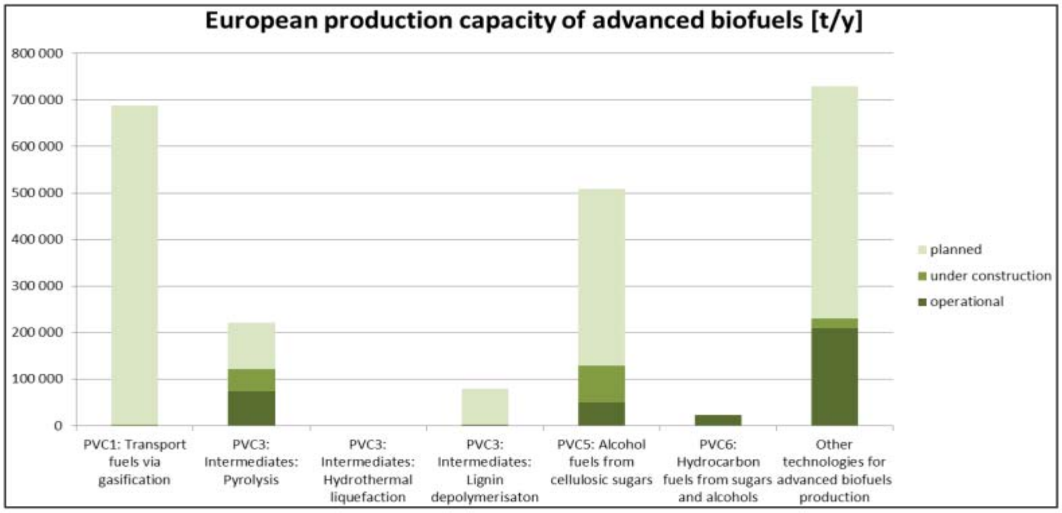
---

[648] European Commission, EU energy in figures – Statistical pocketbook 2020, 2020

[649] ETIP, Hydrogenerated vegetable oil (HVO), Bioenergy factsheet, 2020 https://www.etipbioenergy.eu/images/ETIP_B_Factsheet_HVO_feb2020.pdf

[650] ETIP, Current Status of Advanced Biofuels Demonstrations in Europe, 2020 https://www.etipbioenergy.eu/images/ETIP-B-SABS2_WG2_Current_Status_of_Adv_Biofuels_Demonstrations_in_Europe_Mar2020_final.pdf

Figure 31 European production capacity of advanced biofuels by pathway



Source: ETIP, 2020

32.2.1. Shipping

Capacity for intermediate bio-oils (installed, under construction and planned) is about 0.2 Mt/y[651]. Power-to-methanol capacity[652] in the EU is currently very limited, amounting to only 0.3Kt/y and power-to-liquid (petrol, diesel and kerosene) is about 0.005 Kt/y. Power-to-methane capacity[653] in the EU is about 0.003 Mt/y with an expansion potential to 0.007 Mt/y[654]. There is currently no installed capacity for power-to-ammonia.

The Commission proposal for the FuelEU Maritime Regulation is expected to increase the consumption of renewable and low carbon fuels (including electricity) to 8.6% of total maritime shipping fuels in 2030 and roughly 89% by 2050. Notably, nearly all (94 to 99%) of the electricity required is for at berth, while fuels with high energy density are required for actual transport at sea. Viewing just the advanced biofuel and renewable synthetic fuels, this would require a supply of 3 Mtoe by 2030 and approximately 28 Mtoe by 2050, while non-agricultural oils would cover the remainder of the biofuel demand (0,7 Mtoe by 2030 and 1,4 Mtoe by 2050). The total demand could theoretically be met entirely by EU domestic production, but is unlikely since ships are also capable of carrying enough fuel to make a round trip from a third country port and would not need to refuel in an EU port[655].

32.2.2. Aviation

To achieve net zero emissions by 2050, the IEA considers advanced biofuels will need to make up 15% of global aviation fuels in 2030 and 45% in 2050, with synthetic fuels accounting for roughly one third in 2050. The IEA expects hydrogen and electric applications to make just under 2% of aviation fuel

---

[651] ibid
[652] A. O'Connell, A. Konti, M. Padella, M. Prussi, L. Lonza, Advanced Alternative Fuels Technology Market Report 2018
[653] ibid
[654] Tonnes of bio-methane conversion factor to toe is 0.5 (1 toe=0,5 t).
[655] SWD(2021) 635 final

consumption in 2050 while the remaining 20% would still be fossil based (with residual emissions compensated by net CO2 removals in other sectors)[656].

So far, eight production pathways for sustainable aviation fuels (SAF) received approval for meeting the American Society for Testing and Materials (ASTM) international standard. The related technologies are mostly under development, demonstration and scale-up, except for the already commercial Synthesised Paraffinic Kerosene from Hydroprocessed Esters and Fatty Acids (HEFA), and co-processed vegetable and waste oils in refineries. However, current production capacities are limited. In the EU, new HVO plants are under construction or planning and announcements for HVO based aviation fuels (both HEFA and co-processed vegetable and waste oils) and power-to-liquid through Fischer-Tropsch reach a total capacity of 1.7 Mt/y. Table 12 summarises the announced capacities for sustainable aviation fuels by 2025.

Table 12 Announced capacity for sustainable aviation fuels in Europe

Country	Company	SAF type	Capacity in Europe Kt/y
Sweden	ST1	biofuel	40
	Preem		240[657]
Finland	Neste		100
Belgium	SkyNRG/ LanzaTech		30
France	TotalEnergies		270[658]
Spain	REPSOL		50
Netherlands	SkyNRG		100
	UPM		100
	Neste		500[659]
Italy (Sicily)	ENI		150[660]
United Kingdom	ALTALTO		45
Total Biofuel			***1715***
Netherlands	Synkero	e-fuel	50
Norway	Norsk e-fuel		8

---

[656] International Energy Agency, Net Zero by 2050, 2021.

[657] https://www.preem.com/in-english/investors/corral/renewable-fuel-projects/

[658] 170kt Bio-Unit in Grandpuits, 100kt for La Mède (July 2019 plant conversion) https://www2.argusmedia.com/en/news/2203248-total-starts-biojet-production-at-la-mede-biorefinery

[659] https://www.fuelsandlubes.com/neste-to-produce-sustainable-aviation-fuels-in-rotterdam/

[660] Q&A transcript of the Eni Q2 2021 results reports, pg 13 https://www.eni.com/assets/documents/eng/investor/presentations/2021/Transcript-ENI-Q2-2021-results.pdf

Total e-fuel	***58***
Total SAF	***1773***

Source: ETIP Bioenergy 2021

Co-processing in oil refineries already takes place in the EU. As regards the HVO biofuel, a roughly estimated volume potential is 3.45 Mt/y, provided that 30% of the EU refining capacity (230 Mt/y) use 5% bio-feed. Overall, capacity for commercial ready sustainable aviation biofuel could reach 3.5 Mt/y by 2030 if the HVO capacity is also used. Most of the HVO from current production facilities is used as a diesel blending component and in some cases as an alternative to diesel in road transport. In addition, the limited availability of sustainable feedstock for HEFA underpins the need of research and innovation to increase the production of sustainable feedstock and of building additional capacity for the many other biofuel and synthetic fuel technologies under development and demonstration.

Among these technologies, the most relevant are:

- gasification of biomass Fischer-Tropsch process, a primary pathway for mid to long-term[661],
- fermentation of alcohol to jet, but slow to commercialise, due to additional steps and costs after bioethanol production[662].

The Commission proposal for the ReFuelEU Aviation Regulation[663], according to the impact assessment, could generate a demand of 2.3Mtoe of SAF per year by 2030 (5% of total jet fuel consumption) and 28-29Mtoe (63%) by 2050[664]. Assuming most of the fuel is produced in the EU with average plant capacities[665], the installation of roughly 105 additional plants will be required between 2021 and 2050. Current EU installed capacity of 1.7 Mt/yr is approximately 75% of expected EU consumption in 2030.

As shown in figure 4, a global comparison of current and planned installed capacity of sustainable aviation fuel production by 2025 indicates that US companies have a large head start over the rest of the world, with a total planned annual capacity of 3.6 Mt.

---

[661] ETIP, Fischer-Tropsch synthesis, Bioenergy factsheet on technology and demonstration sites, 2021 https://www.etipbioenergy.eu/new-etip-bioenergy-factsheet-fischer-tropsch

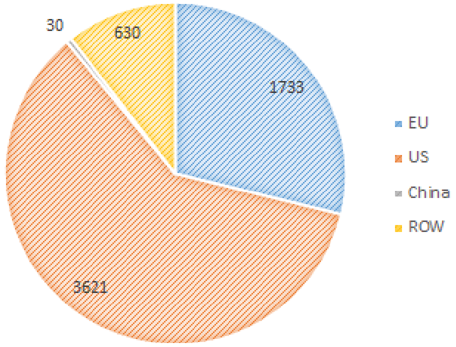
[662] ETIP Bioenergy https://www.etipbioenergy.eu/index.php?option=com_content&view=article&id=273

[663] SWD(2021) 634 final

[664] SWD(2021) 633 final

[665] Average plant capacity according to Energy Transition Commission Analysis for the Clean Skies for Tomorrow Coalition (2021) for this analysis was: HEFA - 0.5 Mt/yr, FT-Bio- .15 Mt/yr, ATJ – 0.2 Mt/yr., PtL – 0.4 Mt/yr.

Figure 32 Sum of companies' current and planned installed annual production capacity of Sustainable Aviation Fuels in thousand tonnes per year by country of origin, by 2025.



Source: Compiled from internal database of Flightpath 2020

32.3. COST / LEVELISED COST OF ENERGY

32.3.1. Shipping

Conventional biodiesel and HVO have reached commercial production and a relative cost of USD 0.02-0.039 per MJ, competing with fossil fuel costs of USD 0.016 per MJ. Advanced biofuels for shipping require higher upfront capital costs, despite larger feedstock availability. Current costs of advanced biofuels for shipping are much higher. Due to slow pace of refinery construction, commercial costs of lignocellulosic biomethanol highly uncertain, yet estimated at USD 0.021 - 0.037 per MJ. FT diesel relative costs are even more uncertain and therefore difficult to compare to conventional biodiesel, yet estimated at USD 0.024-0.066 per MJ[666].

Particularly for FT-diesel and bio-methanol based on lignocellulosic waste, scaling up demonstration as well as low interest financial products can bring production costs closer to fossil fuel costs by 2030 but have not reached commercial production levels and will therefore require stable incentives and long-term policy support before parity is possible[667].

Meanwhile technologies are emerging as promising cost-competitive biofuels for shipping aiming at costs less than EUR 0.43 and 0.36 per litre respectively in 2030 and 2050[668] which is comparable to Ultra-Low Sulphur Fuel Oil (ULSFO). Other technologies are expected to reduce the cost of biomethane and marine biodiesel by 30-35% from current levels by 2030, that is to EUR 0.16 and 0.75 per litre respectively[669].

For hydrogen, ammonia and synthetic carbon-based fuels, production via electrolysis is likely to remain more expensive than pathways using fossil fuels for the near-to-medium term. Sufficiently high electrolyser load hours (around 4 000 hours per year) and low electricity costs (in the range of EUR 10-30 per MWh) are required to reach cost-competitive production. Production costs for ammonia via electrolysis are approximately EUR 110 per MWh (with electricity at EUR 40 per MWh at 3 000 full load hours for

---

[666] ICCT- International Council on Clean Transportation, The potential of liquid biofuels in reducing ship emissions, 2020.
[667] IEA, Advanced biofuels- potential for cost reduction, 2020
[668] H2020 project IDEALFUEL https://cordis.europa.eu/project/id/883753
[669] (Project FlexSNG... and GLAMOUR https://cordis.europa.eu/project/id/884197)

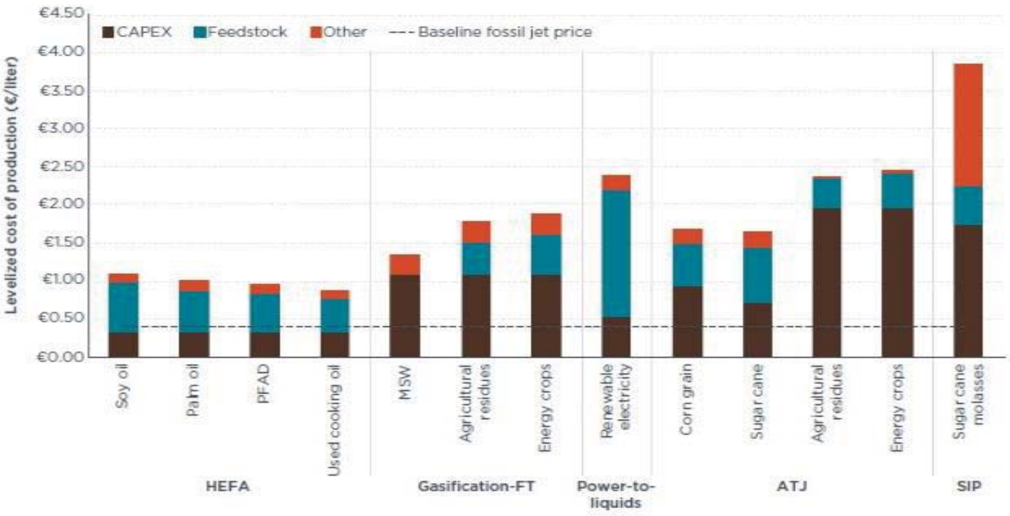
hydrogen electrolysers), possibly falling to EUR 55 per MWh with lower electrolyser costs and electricity at EUR 20 per MWh[670]. The cost of ammonia from steam methane reforming today is approximately EUR 40 per MWh.

32.3.2. Aviation

As shown in Figure 33, for all existing sustainable aviation fuels the current levelised cost of production is well above the current fossil jet fuel price, with a broad set of ranges depending on feed stock and conversion pathways. The least expensive pathways are via vegetable and waste oils, while the most expensive are the alcohol to jet when processing advanced bioethanol, as well as the power-to-liquids through Fischer-Tropsch.

Waste and residue generally have the lowest feedstock costs, being by-products of other goods (agriculture residues) or services (municipal waste – no feedstock cost). HEFA is the most mature conversion pathway and has the lowest capital expenditures (CAPEX), but relatively high feedstock costs, resulting in the lowest total cost of EUR 0.88 - 1.09 per litre[671]. However, if wasted animal fats are used as feedstock the total cost can be lowered to EUR 0.51 per litre[672].

Figure 33 Current levelised costs of aviation fuels



Source: ICCT, The cost of supporting alternative jet fuels in the European Union, 2020

The high feedstock costs make it unlikely for technological improvements to greatly reduce the total cost of HEFA fuels[673] unless cheaper feedstocks are utilised, such as waste animal fats. The expansion of such feedstocks is challenging, and scaling up SAF will require additional fuel technologies beyond HEFA fuels.

---

[670] IEA 2019?

[671] ICCT – International Council on Clean Transportation, The cost of supporting alternative jet fuels in the European Union, 2020.

[672] IEA Bioenergy, Advanced Biofuels – Potential for Cost Reduction, 2020 https://www.ieabioenergy.com/wp-content/uploads/2020/02/T41_CostReductionBiofuels-11_02_19-final.pdf

[673] WEF 2020; IEA 2020; ICCT 2020

Gasification-FT fuels are driven by high capital costs but currently have low to no feedstock costs[674] (depending on feedstock), and low operational costs. Though scaling up and learning effects offer significant cost reduction potential, they will likely remain more costly than HEFA in future[675].

Emerging technologies using waste bio-based feedstock are expected to reduce the cost levels of aviation synthetic paraffin kerosene FT-SPK by 35% and 65% in 2030 and 2050, to EUR 1.17 and 0.63 per litre respectively[676]. Other technologies will make aviation and maritime biofuels available at a selling price of EUR 0.7-0.8 per litre[677].

While power-to-liquid (e-fuels) jet fuels currently display large production costs, these are almost entirely driven by capital expenditures (CAPEX) and operating expenses (OPEX) of the hydrogen feedstock. As hydrogen production costs decline with the scale up of solar power electrolysis, particularly in highly productive regions, power-to-liquid jet fuels are expected to drop by roughly 50% by 2030 and could even achieve HEFA production costs by 2050[678]. Still, the cost for e-fuels is at present relatively high at EUR 7 per litre because of high conversion losses and high distribution costs of hydrogen feedstock.

32.4. PUBLIC RESEARCH AND INNOVATION (R&I) FUNDING

Under the Horizon2020 programme, R&I support to advanced biofuels, bioliquids, biomass fuels and renewable synthetic fuels encompasses 167 grants from 2014 to 2021 amounting to EUR 531.4 million EU contribution and EUR 655.5 million total costs. The highest part of support lies with the thematic priority of Secure, clean and efficient energy, with 107 signed grants of EUR 377.6 million EU contribution and EUR 458.9 million total costs.

Data is limited on national funding from EU Member States after 2014. From 2009 to 2014 EU 28 R&I funding spending was just under EUR 400 million annually. For the period 2012-2016 the amount of national funding for all bioenergy more generally was about EUR 4 billion euro from 24 EU Member States according to the 2016 SET Plan report[679]. Assuming half of this would be for biofuels, would imply a constant annual funding since 2009. However, granular data is not available to differentiate Member States R&I funding between bioenergy and biofuels, much less for aviation and shipping sectors.

32.4.1. Shipping

Although there were no distinctive projects for shipping fuels under the FP7 programme between 2012 and 2016, road fuels are also compatible with shipping. Therefore, nearly EUR 400 million funded the development of renewable fuels relevant for shipping.

Under dedicated Horizon2020[680] calls in secure, clean and efficient energy for maritime energy supply, EU support for technologies related to targeted lower cost advanced biofuels and renewable fuels reached EUR

---

[674] Biobased waste may be used for many material goods in future, posing potential resource scarcity for energy resources. Circularity may however increase the efficiency of resource use and therefore also the availability. These may cause changes in feedstock prices, but it is unclear to what extent.

[675] WEF – World Economic Forum, Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, 2020.

[676] ref project GLAMOUR https://cordis.europa.eu/project/id/884197

[677] ref project BioSFerA https://cordis.europa.eu/project/id/884208

[678] WEF – World Economic Forum, Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, 2020.

[679] European Commission, Transforming the European Energy System through Innovation, Integrated SET Plan Progress in 2016, 2016.

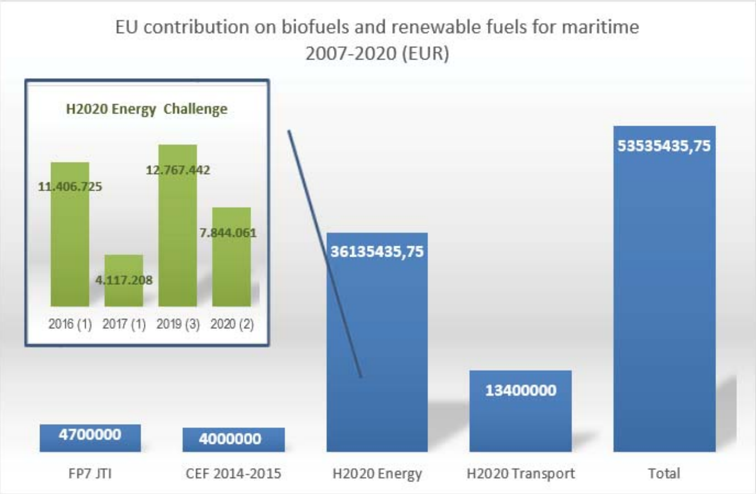
[680] European Commission database of EU-funded research and innovation projects https://cordis.europa.eu/projects/en

36 million for 7 projects, distributed per year in funds and number of projects as illustrated in Figure 34 below.

Horizon2020 provided further funding for sustainable shipping fuels under the smart, green and integrated Transport thematic priority, amounting to an additional EUR 13.4 million between 2016 and 2020. Similarly, between 2011 and 2014, two Joint Technology Initiatives of FP7 provided a further EUR 4.7 million.

Additionally, the Connecting Europe Facility funded two infrastructure projects between 2014 and 2015 for the development of renewable fuels in shipping, totalling roughly EUR 4 million.

Figure 34 EU R&I funding for renewable fuels in the maritime sector



Source: data compiled from CORDIS database

32.4.2. Aviation

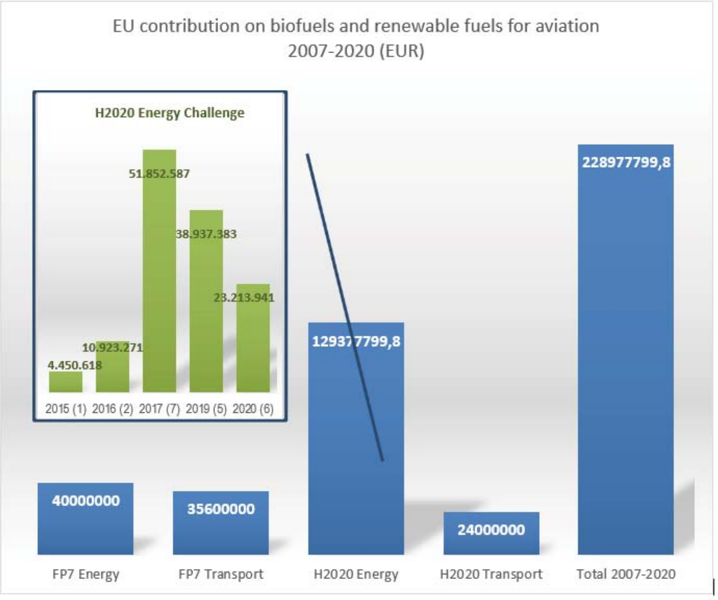
Between 2012 and 2016, the FP7 programme[681] funded EUR 430 million in biofuel projects with approximately EUR 40 million designated to aviation. Under Horizon2020 and the secure, clean and efficient energy thematic priority, EU support for technologies related to advanced biofuels and renewable fuels for aviation reached EUR 130 million for 21 projects overall, distributed per year in funds and number of projects as illustrated in Figure 35.

The Horizon2020 programme provided further funding for sustainable aviation fuels through the smart, green and integrated transport thematic priority, totalling EUR 35.6 million between 2016 and 2020. Between 2008 and 2013, FP7 funded an additional EUR 24 million for sustainable aviation fuel projects under the Transport Programme.

---

[681] European Commission database of EU-funded research and innovation projects, CORDIS https://cordis.europa.eu/projects/en

Figure 35 EU R&I funding for renewable fuels in aviation sector



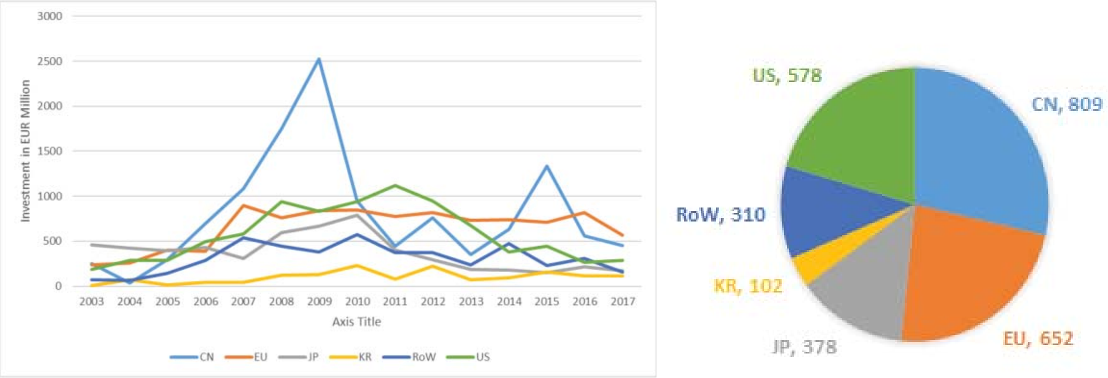
Source: Data compiled from CORDIS database

32.5. PRIVATE R&I FUNDING

Private investment tracked by the European Commission's Joint Research Center (JRC) includes data on biofuels and fuels from waste, but does not provide enough granularity to assess specific sectors or technologies. This data can still provide an indication of geographic emphasis and leading companies developing renewable fuel technologies which may be relevant for these sectors.

On average between 2003 and 2017, companies based in China invested EUR 809 million annually in R&I for renewable fuels, followed by the EU companies with EUR 652 million and US companies with EUR 578 million. However, the R&I investment from China based companies fluctuated with major peaks in investment around 2009 and 2015, while the EU companies reflect a more constant investment. In general, investments globally have slightly declined throughout the last decade.

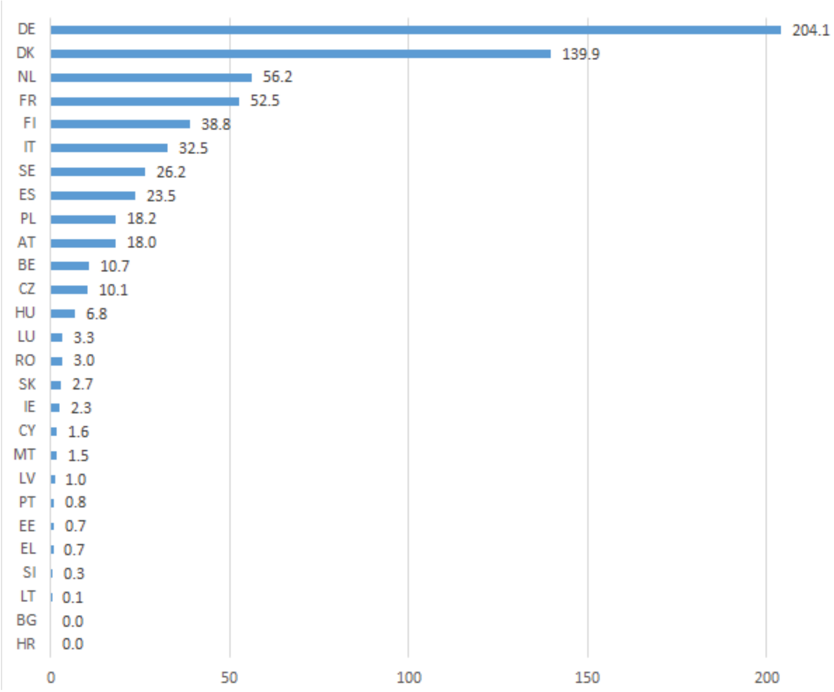
Figure 36 Annual (left) and average (right) private R&I investment in biofuels and fuels from waste in EU compared to other countries during 2003-2017 (EUR million)



Source: JRC SETIS 2021

Within the EU, companies in Germany and Denmark show the largest annual average R&I investments by far, accounting for slightly more than half of the EU total. In ten other Member States, private R&I investments average between EUR 10 and 56 million. Overall, there is a strong focus of private investment in western EU.

Figure 37 Average private R&I investment in biofuels and fuels from waste by EU Member State of the private investors during 2003-2017 (EUR million)



Source: JRC SETIS 2021

Of the top twenty private R&I investors, six are EU companies, while five are located in China and five in the US. The top global R&I investors located within the EU are from Denmark, Finland, Netherlands, Hungary and France, while German companies are absent from this group and only two appear in the top twenty EU R&I investors. Since the highest average private R&I investments were in Germany, this implies a distribution of investments across multiple companies. For other Member States such as Hungary, this suggests a concentration of R&I investments in one or few companies[682].

32.6. PATENTING TRENDS - INCLUDING HIGH VALUE PATENTS

32.6.1. Shipping

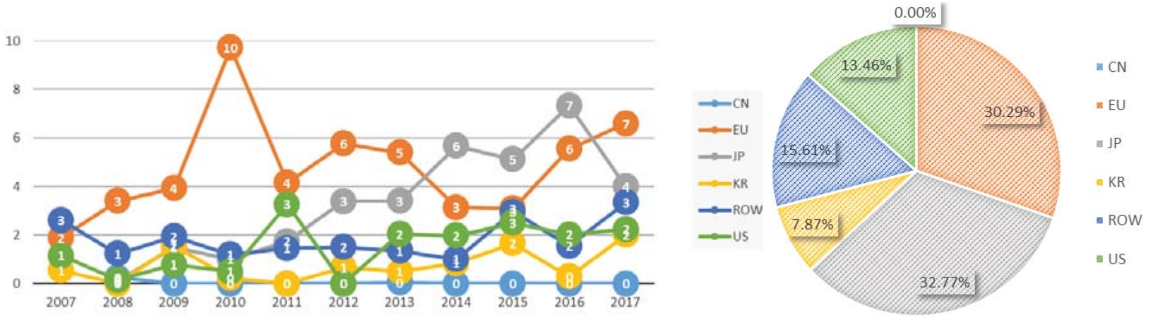
The Patstat database of the European Patent Office includes data on high value inventions for alternative maritime fuels, which includes some non-renewable fuels. The data lacks the granularity to distinguish between different fuel types.

---

[682] JRC, SETIS, 2021

Overall, there is a modest amount of high value inventions regarding fuels in this sector. Yet there is indication they may have been increasing in recent years. Roughly two thirds of high value inventions are from either Japanese or European entities.

Figure 38 Annual distribution of high value inventions for alternative maritime fuels (including non-renewable fuels) in leading countries (left) and global distribution in percent for the years 2015-2017 (right)

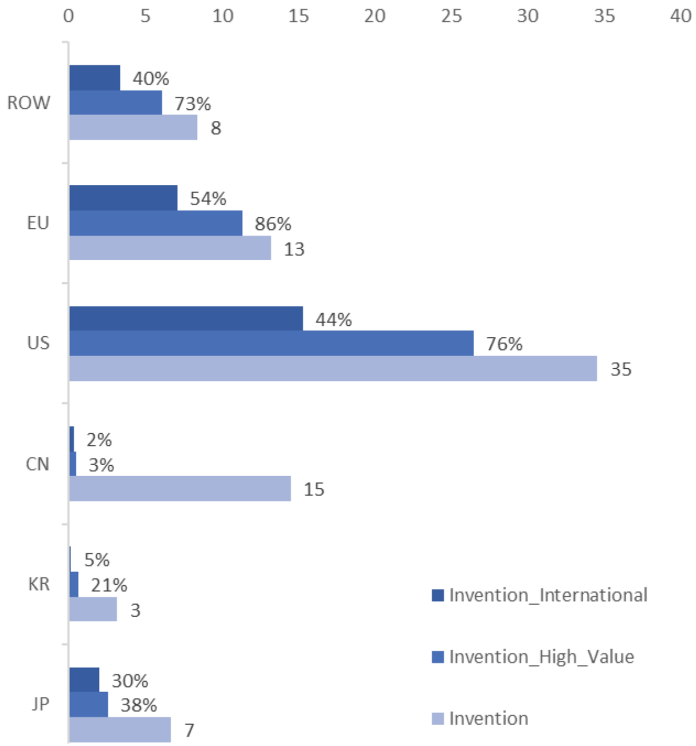


Source: JRC based on EPO Patstat data 2021

32.6.2. Aviation

The Patstat data on sustainable aviation fuels suggest a modest amount of high value inventions between 2007 and 2017, of which US companies have just over twice as many as companies based in the EU. Companies in China show slightly more inventions than companies in the EU, but few are high value or international.

Figure 39 Number of sustainable aviation fuels inventions by country 2007-2017



Source: JRC based on EPO Patstat data 20201[683]

Six of the ten leading inventors are US companies. However, between 2015 and 2017, the only additional high value inventions were from two companies in the EU; Neste (FI) and Total (FR) with 1 high value patent each.

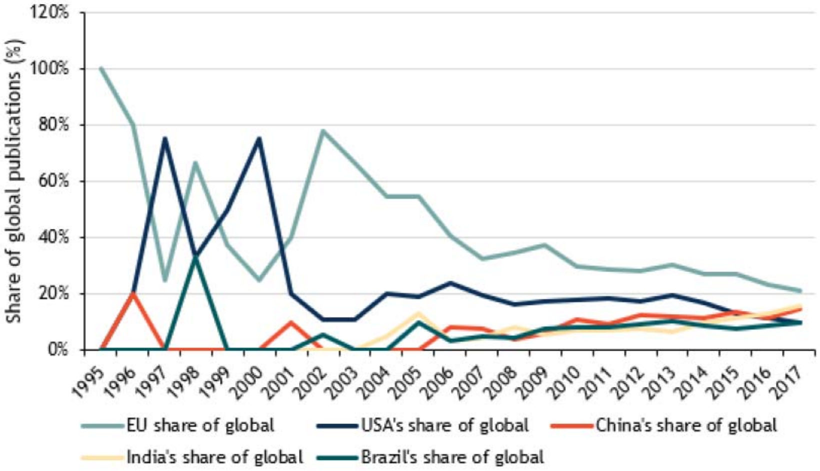
It is worth noting that vegetal biomass feedstock and fatty oil and fatty acid feedstock are assigned to 43% and 41% of patent families[684] respectively, suggesting a strong focus of innovation on HEFA-SPK and D1655 fuels, which are the most mature and the only commercial renewable aviation fuels.

32.7. LEVEL OF SCIENTIFIC PUBLICATIONS

32.7.1. Shipping

An analysis of publications related to renewable fuels was not available, particularly since publications on maritime transport decarbonisation differentiate in scope and research of renewable fuels relevant for maritime shipping is generally not sector specific. However, publication trends of biofuels in general may also be relevant insight for the maritime sector. The EU maintains the highest share of global biofuel publications. This lead has slowly decreased more recently due to the rapidly growing number of publications in India, China and Brazil.

Figure 40 Global biofuel publications



Source: Trinomics, commissioned by the European Commission, Study on impacts of EU actions supporting the development of renewable technologies, 2019.

---

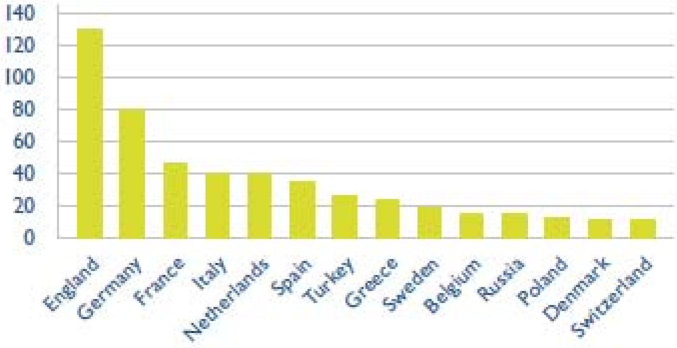
[683] JRC SETIS reseach and innovation data: https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en

[684] European Energy Research Alliance Bioenergy, Bioenergy Technology Watch Report Number 8, EERA Bioenergy, 2021

32.7.2. Aviation

The global leader in publications related to SAF is the US with 37% of total publications between 2000 and 2019, followed by European institutions with 33%. More than 50% of publications were between 2016 and 2019, both worldwide and within Europe. The UK and Germany lead the publications within Europe[685].

Figure 41 Number of scientific publications on sustainable aviation fuels in Europe, by country



Source: European Energy Research Alliance Bioenergy, Bioenergy Technology Watch Report Number 8, EERA Bioenergy, 2021

32.8. CONCLUSIONS

Advanced biofuels are at varying stages of maturity, but many have reached large scale demonstration plants. Therefore, installed capacity is limited compared to conventional biofuels. Commercialisation and scaling up are hindered by high investment costs. Large scale deployment supported by long-term, low interest financing could reduce costs significantly. However, without strong policy support to overcome the price gap between advanced biofuels and conventional kerosene and bunker fuel, upscaling will remain slow.

The expected trend of demand for renewable fuels (from mainly road transport in the next few years to increasingly more for aviation and shipping in the medium term) offers the potential of cost reduction. In the case of a new manufacturing plant, in fact, the capital cost – heavily impacting the production cost of renewable fuels – can be repaid in the first years of the investment life. During this period, road transport, driven by existing (Renewable Energy Directive) and new (EU Emission Trading Scheme, Energy Taxation Directive) regulatory instruments, can absorb the higher cost of renewable fuels. Over time, the demand of fuels for road will shrink (due to electrification of especially light duty vehicles) while demand for ships and airplanes will progressively pick up. Once the capital cost of renewable fuels is repaid, the cost gap between renewable and fossil fuels for aviation and shipping may reduce very significantly.

HEFA, alcohols from sugars, lignin depolymerisation and pyrolysis oil are the closest fuels that can be used or further processed to jet or used directly for shipping, with total annual capacity in the EU of about 1.5 Mt for aviation fuel and 0.2 Mt for shipping fuel[686.]

Expansion of HEFA feedstock will likely be challenging due to feedstock availability, preventing cost reduction. Less mature technologies based on diverse feedstock will be required yet face the challenge of

---

[685] European Energy Research Alliance Bioenergy, Bioenergy Technology Watch Report Number 8, EERA Bioenergy, 2021

[686] ETIP Bioenergy 2021

much higher investment costs. Shipping faces a similar challenge for expanding beyond waste oil-based fuels.

Public R&I funding from Member States for biofuels may have remained constant at roughly EUR 400 million since 2008, but data after 2014 depend on how funding is allocated between biofuels and other bioenergy technologies. Granularity of funding data is generally an issue. The EU research programme Horizon Europe has significantly increased R&I funding beyond the pervious FP7. Support to aviation is more evident than shipping after FP7 because the shipping sector can use road biofuels and lower grade biofuels. Yet ongoing R&I is focusing on dedicated marine biofuels as it can significantly decrease their production costs.

Evidence is limited for private R&I investment but suggests that Chinese companies lead in annual investments in renewable fuels in general, followed by EU based and US companies. The largest share of top R&I investing companies are in the EU, followed by China and the US. Within the EU, investments are highest from Danish and German companies, with the rest well spread throughout western EU.

Patenting trends suggest strong leadership of EU based institutions in renewable fuels in general. Japan and EU based companies each make up for one third of all patents in the maritime sector, but this may be misleading due to inclusion of some technologies beyond renewable fuels and a lack of granularity. The strong position of EU companies for renewable fuels in general suggest the influence of other technologies in shipping. Particularly in sustainable aviation fuels, the EU is well behind the US when it comes to patents, leading innovators and research. In general, patents indicate global innovation may risk too strong of a focus on HEFA fuels, due to the challenges for large-scale expansion.

33. VALUE CHAIN ANALYSIS OF THE ENERGY TECHNOLOGY SECTOR

33.1. INTRODUCTION/SUMMARY

Fuel production is the most relevant part of the value chain when discussing renewable fuels for aviation and shipping. Due to the limited commercialisation of advanced biofuels and synthetic fuels, particularly in these sectors, it is often only possible to consider conventional biofuels for the current state of indicators. Where possible this information is used as a reference for considering the potential for shipping and aviation or even estimating the impact of future policy developments.

33.2. TURNOVER

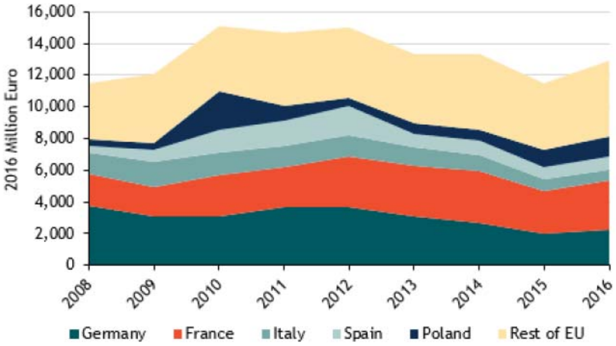
The turnover data in the EU is limited to the conventional biofuel industry since advanced biofuels, particularly with relevance to the aviation and shipping sectors, have a relatively small installed capacity and miniscule contribution to total turnover. The Joint Research Centre (JRC) estimates a combined revenue of advanced biofuels of EUR 21 million[687], or 0.1% of the biofuel industry turnover (EUR 11.5 -15.1 billion) between 2008 and 2016[688].

---

[687] A. O'Connell, M. Prussi, M. Padella, A. Konti, L. Lonza, Sustainable Advanced Biofuels Technology Market Report, 2019

[688] Trinomics, commissioned by the European Commission, Study on impacts of EU actions supporting the development of renewable technologies, 2019.

Figure 42 Biofuels industry turnover in the EU

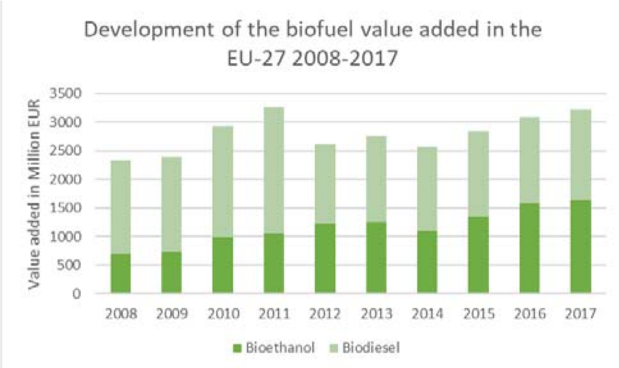


Source: Trinomics, commissioned by the European Commission, Study on impacts of EU actions supporting the development of renewable technologies, 2019.

33.3. GROSS VALUE ADDED (GVA) GROWTH

Biofuels (bioethanol and biodiesel) represented EUR 3 billion of the bioeconomy's gross value added. Since 2008, the GVA of biofuels has grown by 38%[689] as Figure 43 displays.

Figure 43 Liquid biofuel value added growth in the EU27



Source: European Commission, Bioeconomy, 2020

33.3.1. Shipping

Since a market for renewable shipping fuels has not yet developed, no data exists for gross value added. Assuming domestic production for all renewable shipping fuel required for achieving the targets in the Commission proposal for the EU Fuel Maritime Regulation, as well as the same ratio of GVA to employment as with current biofuels (not including resource sourcing), renewable maritime fuels could bring as much as EUR 2.5 billion GVA annually by 2030 and EUR 26 billion by 2050.

---

[689] Data compiled from European Commission, Bioeconomy, 2020, https://ec.europa.eu/knowledge4policy/bioeconomy/topic/economy_en

33.3.2. Aviation

Similarly for aviation fuels, assuming domestic production for all renewable aviation fuels required to achieve targets in the Commission proposal ReFuelEU Aviation and ratio of GVA to employment as with current biofuels (not including resource sourcing), sustainable aviation fuels could add EUR 450 million to EUR 1.5 billion GVA by 2030 and EUR 207 billion by 2050.

33.4. NUMBER OF EU COMPANIES

There are approximately 40 companies within the EU with advanced biofuel facilities in production, under construction or planned. Each specialises in different production pathways so market leaders are difficult to determine. The company UPM produces HVO from tall oil, Clariant advanced bioethanol. St1 operates more, smaller and decentralised bioethanol plants. Neste specialises in HVO and HEFA production, and SkyNRG in HEFA and ATJ.

At the same time oil and gas companies (Total, Repsol, ENI, Shell) are increasingly mobilised in the production of advanced biofuels, participating in joint ventures or co-processing bio-oils in fossil refineries. As the refineries already exist, there are no additional investment costs for producing bio-blends, a major advantage considering the high investment costs for biorefineries.

33.4.1. Shipping

The Finnish Wärtsilä and the Dutch biofuel distributor GoodFuels jointly work to supply marine biofuels to ships in the Port of Rotterdam. The ship owner is aiming to use a diesel blend consisting of 30% biofuels with goal of using a blend of up to 100% biofuels by 2030.

33.4.2. Aviation

There is a high concentration of companies developing and scaling up operations for sustainable aviation fuel production within the EU (Neste, Total, SkyNRG, Preem, Lanzatech) and the US (Fulcrom Bioenergy, Red Rock Biofuels, Velocys, Shell, AltAir Fuels, and Gevo). Lanzatech is also expanding operation in China. Several biojet producing companies have also established partnerships with airlines and in a few cases even airports. Joint ventures are also common between oil majors and biojet companies.

33.5. EMPLOYMENT IN THE SELECTED VALUE CHAIN SEGMENT(S)

In 2019 the liquid biofuels industry employed 228 983 people within the EU[690].

33.5.1. Shipping

Since a market for shipping fuels has not yet developed, no data exists for current employment specifically in maritime renewable fuels. The employment values for the entire liquid biofuels industry imply approximately 9 700 jobs for every million tonnes of biofuel produced. Therefore, assuming domestic production for all renewable shipping fuel required for achieving the targets in the Commission proposal

---

[690] Data compiled from IRENA jobs database: https://irena.org/Statistics/View-Data-by-Topic/Benefits/Renewable-Energy-Employment-by-Country

for the EU Fuel Maritime Regulation, as many as 29 000 additional jobs could be created by 2030 and 270 000 by 2050.

33.5.2. Aviation

Similarly for aviation fuels, assuming domestic production for all renewable aviation fuels required to achieve targets in the Commission proposal ReFuelEU Aviation, 4 200-4 800 additional jobs could be created by 2030, roughly 97 000 jobs by 2040 and roughly 202 000 jobs by 2050[691].

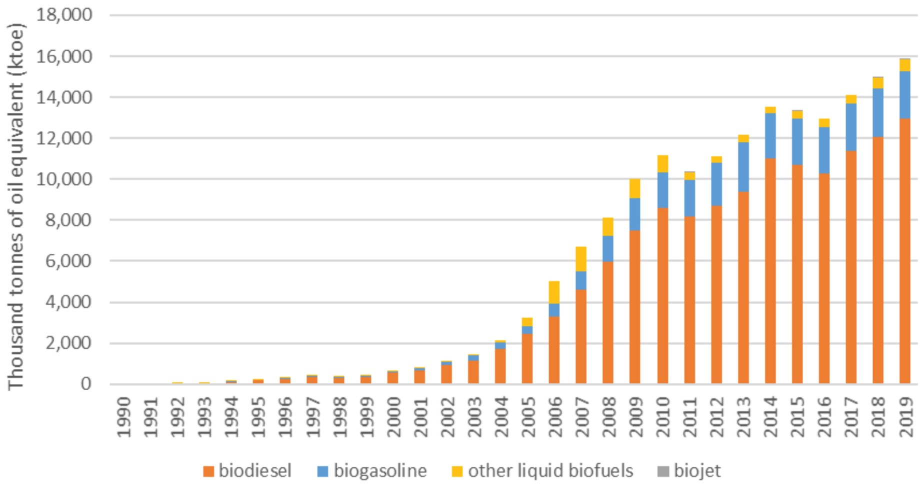
33.6. ENERGY INTENSITY CONSIDERATIONS, AND LABOUR PRODUCTIVITY CONSIDERATIONS

Employees of the EU biofuels industry (bioethanol and biodiesel) generate an average annual value of EUR 157 000[692]. Because no renewable fuels market for aviation and maritime shipping sectors has unfolded yet, there is no data for these sectors. However, similar average annual values could be expected with the expansion of production to meet these future markets.

33.7. COMMUNITY PRODUCTION (ANNUAL PRODUCTION VALUES)

Community production has grown steadily in the past few years, achieving 16 Mtoe in 2019. Biodiesel dominates EU production. As only some advanced biofuels and no synthetic fuels are reaching commercialisation these do not make up a significant part of production. Sustainable aviation fuels only made up a miniscule part of the annual production. In Finland 24,700 toe were produced in 2019, an increase from 7 206 toe in 2018.[693]

Figure 44 EU27 Annual production values of biofuels



Source: Eurostat 2021

---

[691] SWD(2021) 634 final

[692] Data compiled from European Commission, Bioeconomy, 2020, https://ec.europa.eu/knowledge4policy/bioeconomy/topic/economy_en

[693] Eurostat 2021

33.8. CONCLUSIONS

Conventional biofuels have recently provided a constant growth to the EU economy. If primarily domestic, combined production of renewable shipping and aviation fuels could grow the economy by EUR 4 billion and create 25 000 additional jobs by 2030. By 2050 this could grow to EUR 230 billion and 470 000 jobs.

There is a strong representation of advanced biofuel producing companies in the EU with variation in technology pathway and feedstock focus. Particularly multinational fuel companies move into co-processing bio-oils in fossil refineries, thus reducing required investment costs per unit of product. Moreover, renewable liquid fuels do not need new dedicated infrastructures for their transport and distribution, as the well-developed logistics of fossil fuels can be re-used for this purpose. Competition will likely be strong in other parts of the world, particularly in the US where there is also a strong concentration of companies and demonstration plants.

34. GLOBAL MARKET ANALYSIS

34.1. INTRODUCTION

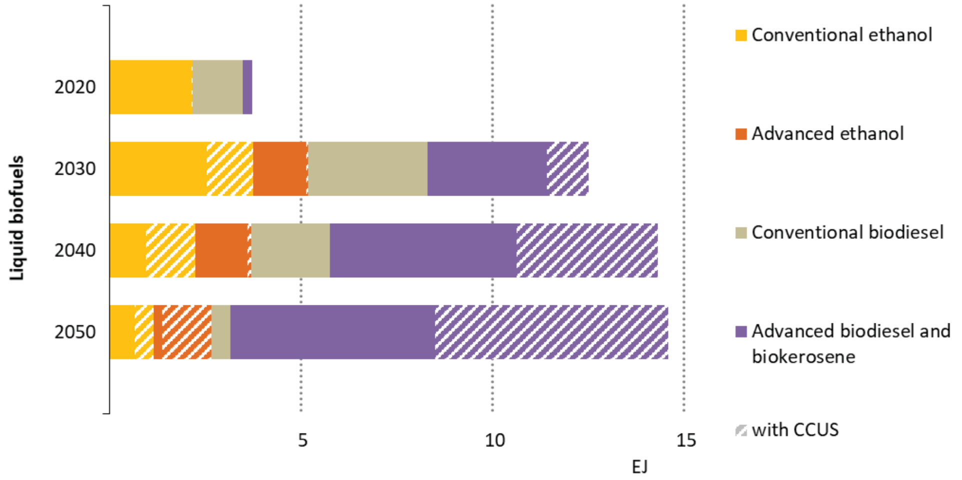
The global combined annual production of advanced biodiesel and biokerosene is roughly 6 Mtoe (0.25 EJ), while conventional biodiesel production is around 31 Mtoe (1.29 EJ) and conventional bioethanol 51 Mtoe (2.15 EJ).[694] In the recent global energy scenario for reaching net-zero emissions by 2050, the IEA projects that a rapid expansion of advanced liquid biofuels is required already within this decade. Driven by the need for biodiesel and biojet kerosene until 2030 and primarily by biojet kerosene towards 2050, particularly Bio FT and cellulosic ethanol production pathways would have to scale up production to 2.7 million barrels of oil equivalents per day (mboe/d) by 2030 and to 6 mboe/d by 2050. This would imply installing one biorefinery every 10 weeks with a capacity of 55 tboe/d (or roughly twice the capacity of the largest biorefinery today)[695].

---

[694] International Energy Agency, Net Zero by 2050, 2021

[695] International Energy Agency, Net Zero by 2050, 2021.

Figure 45 IEA projection of global liquid biofuel production in Exajoules (EJ) in a net-zero-emission pathway for 2050



Source: International Energy Agency, Net Zero by 2050, 2021

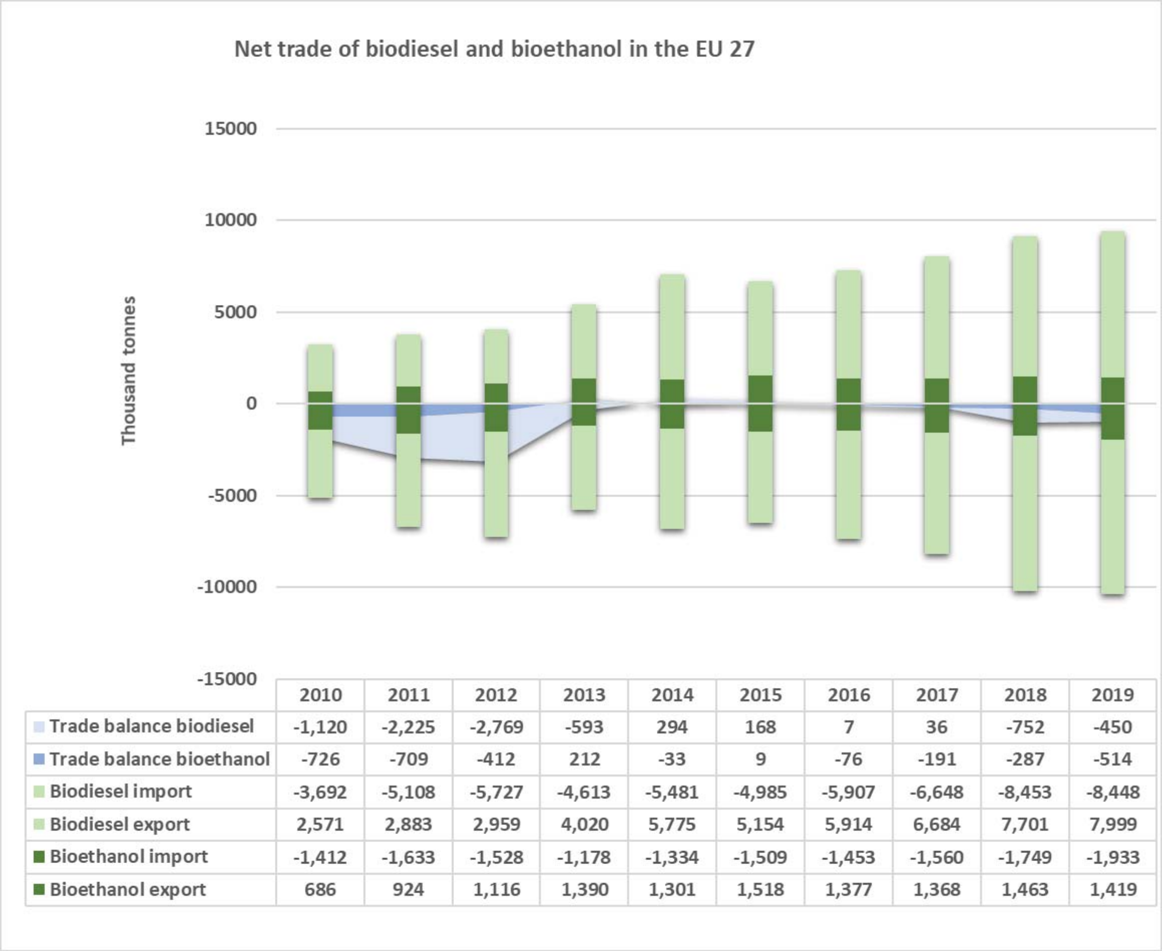
34.2. TRADE (IMPORTS, EXPORTS)

Eurostat data show the gross export of conventional biofuels from the EU is slightly less than gross imports, leading to a net import. Figure 46 shows that there was a larger net import in the beginning of the decade which was then evened out. Since then, both imports and exports have steadily increased. The return of a net import since 2017 implies that growth in consumption is not matched by growth in domestic production. Recent market analysis of the United States Department of Agriculture (USDA) Foreign Agriculture Service confirms this, showing the EU is the largest producer of biodiesel globally, while consumption slightly exceeds domestic production for both biodiesel and bioethanol[696].

---

[696] Foreign Agriculture Service, United States Department of Agriculture (USDA), Biofuels Annual, 2020. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_The%20Hague_European%20Union_06-29-2020

Figure 46 EU Net trade of biodiesel and bioethanol



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
■ Trade balance biodiesel	-1,120	-2,225	-2,769	-593	294	168	7	36	-752	-450
■ Trade balance bioethanol	-726	-709	-412	212	-33	9	-76	-191	-287	-514
■ Biodiesel import	-3,692	-5,108	-5,727	-4,613	-5,481	-4,985	-5,907	-6,648	-8,453	-8,448
■ Biodiesel export	2,571	2,883	2,959	4,020	5,775	5,154	5,914	6,684	7,701	7,999
■ Bioethanol import	-1,412	-1,633	-1,528	-1,178	-1,334	-1,509	-1,453	-1,560	-1,749	-1,933
■ Bioethanol export	686	924	1,116	1,390	1,301	1,518	1,377	1,368	1,463	1,419

Source: Data compiled from Eurostat 2021

34.2.1. Shipping

Currently less than 1% of the marine fuel supply uses biofuels, mostly in inland or short-sea shipping. Because there is no current market, it is not possible to assess trade balance. However, new policies are expected to unfold a new market, increasing demand within the EU to 3 Mtoe by 2030 and 32 Mtoe by 2050. It would be possible for the EU to produce these levels domestically and avoid a trade deficit. It is also unknown how the global market and production supply will develop.

34.2.2. Aviation

In the EU, the current consumption is very low when compared to the potential production capacity. In 2018, the global production of 15 million litres of aviation biofuels accounted for less than 0.1% of the total consumption of aviation fuels. The EU exported 24 000 tonnes of bio-jet fuels in 2019 and recorded no imports[697], suggesting a momentary edge in the global market, although these amounts are miniscule compared to fossil kerosene.

34.3. GLOBAL MARKET LEADERS VS. EU MARKET LEADERS (MARKET SHARE)

The current market is dominated by conventional biofuels, and only few advanced biofuels have entered or are close to market entry. It is not yet possible to determine share of the market, particularly specific to aviation or shipping fuels. The IEA foresees Japan, UK and US taking the lead to bring cellulosic ethanol and Bio FT fuels to market entry within the next few years[698]. Yet with one quarter of companies and one third of Bio FT plants based in the EU, the EU may also be well positioned to house market leadership of these fuels.

34.3.1. Shipping

In the EU, important market actors are GoodFuels (Dutch fuel producer and distributor), Maersk (Danish shipping company), BMW (German cargo owner), Wärtsilä (Finnish engine manufacturer). Wärtsilä and GoodFuels jointly work to supply marine biofuels to ships in the port of Rotterdam. The ship owner is aiming to use a diesel blend consisting of 30% biofuels with a goal of using a blend of up to 100% biofuels in the near future.

34.3.2. Aviation

Global market leaders in the sector of renewable aviation fuels are Neste (Finland), Gevo (USA), World Energy (USA), Eni (Italy), SkyNRG (The Netherlands), Fulcrum BioEnergy (USA), Velocys (UK), Ametis Inc. (USA), Lanzatech Inc. (USA), Red Rock Biofuels (USA), Total S.A. (France), SG Preston Company (USA), Amyris Inc. (USA) and Swedish Biofuels AB (Sweden)[699, 700].

In 2020, Neste produced about 120 million litres of aviation biofuels (5 million litres in 2018). Neste plans to increase the capacity to 1.5 million tons in 2023[701]. The majority of this capacity will not be located within the EU, rather in Singapore[702].

---

[697] EUROSTAT 2021

[698] International Energy Agency, Net Zero by 2050, 2021

[699] Absolute Market Insights, Renewable Aviation Fuel Market 2019-2027, 2020. https://www.absolutemarketsinsights.com/reports/Renewable-Aviation-Fuel-Market-2019-2027-366

[700] Markets and Markets, Sustainable Aviation fuel Market by Fuel Type, 2020. https://www.marketsandmarkets.com/Market-Reports/sustainable-aviation-fuel-market-70301163.html

[701] Neste to enable production of up to 500,000 tons/a of Sustainable Aviation Fuel at its Rotterdam renewable products refinery: https://www.neste.com/releases-and-news/renewable-solutions/neste-enable-production-500000-tonsa-sustainable-aviation-fuel-its-rotterdam-renewable-products

[702] Tavares Kennedy, H., SAF, please prepare for take-off…even with aviation industry turned upside down due to pandemic, 2021 https://www.biofuelsdigest.com/bdigest/2021/05/02/saf-please-prepare-for-take-offeven-with-aviation-industry-turned-upside-down-due-to-pandemic/

In the EU, Copenhagen Airport, Schiphol Airport at Amsterdam and Frankfurt Airport have biofuel distributions for airplanes. However, Schiphol Airport depends on imports from the United States to cover much of its supply. SkyNRG therefore plans to install a 125 million litre plant to begin local production of bio-kerosene based on conversion of waste fats and oils by 2022[703].

While the top ten global SAF producers include four EU based companies (Total, Preem, Neste, SkyNRG), the two largest producers are in the US. There are also more SAF producers in the US which are expected to have a total production capacity twice the size of the EU by 2025 (according to existing and planned installations)[704].

Table 13 Top 10 worldwide SAF producers by 2025 based on current and planned production capacity

Top 10 producers by 2025	Country	Expected yearly production by 2025 (Kt/yr)
Phillips 66	US	831
World energy paramount	US	501.64
Total	EU	285
Preem	EU	222.57
Northwest Advanced Biofuel	US	171.93
Neste Oil	EU	167.92
Pertamina	IDN	150
SkyNRG	EU	95
Norsk e-Fuel	NOR	83.27
Readifuels	US/CAN	69

Source: data compiled from internal project database of Flightpath 2020

---

[703] Flightpath 2020.

[704] Data compiled from internal project database of Flightpath 2020.

34.4. RESOURCE EFFICIENCY AND DEPENDENCE

Advanced biofuels are not dependent on any of the critical raw materials presented in either the 2020 Commission communication or Foresight Study on critical raw materials. Particularly since they can also be produced throughout the EU and the rest of the world, this gives them a strategic advantage over other technologies. It is therefore possible to reduce foreign dependency through local and regional value chains.

The choice of biomass feedstock may have implications for sustainability, production costs and potential supply bottlenecks. Particularly regarding scaling up of biofuels, using alternative production pathways will enable the use of diverse feedstock from woody biomass or waste and residue. While these are currently less mature, their maturity will be necessary to avoid feedstock bottlenecks.

Feedstock expansion is also necessary to reduce the impact of aviation and maritime sectors absorbing local feedstock at cost of biodiesel for the road sector. Revitalising degraded and abandoned land with sustainable biomass production will likely also be necessary to help prevent such bottlenecks.

Feedstock production may be more labour intensive, generating less labour productivity than other segments of the value chain. Yet locally produced value chains strengthen operational resilience as well as regional economy.

Synthetic fuel production depends on availability of renewable hydrogen and renewable electricity. Due to the dependence of power-to-liquid on low-cost renewable electricity, production could results in a certain dependence on Middle East and North Africa (MENA) region for hydrogen feedstock (for which the US and China will likely also compete).

Any critical raw material dependencies of technologies producing renewable electricity and hydrogen are assessed in those sections of this report. Also the GHG reduction capacity of power-to-gas and power–to-liquid fuels will depend on the life-cycle emissions assessment of the entire value chain for power production, including critical materials, systems and components.

34.5. FINAL CONSIDERATIONS

While the EU is currently a global leader in production of conventional biofuels, a market for advanced biofuels and renewable synthetic fuels has not yet unfolded, particularly for aviation and shipping sectors. Yet the EU already has net exports in sustainable aviation fuels, even if the amount is insignificant compared to conventional biofuel trade. New policies are expected to drive market growth in both sectors in the next few years. The EU already has a strong global market position as well as a concentration of leading advanced biofuel producers including various joint ventures with airlines, airports and oil majors, suggesting the EU could maintain market leadership. Competition, particularly from the US or Brazil, may be strong as well as similar cooperation structures are forming. Utilising local and regional supply chains for waste and residue feedstock not only strengthens the regional economies, but can increase the resilience of the EU as a global market leader.

35. SWOT AND CONCLUSIONS

The EU shows strength in R&I funding, ensuring the development of multiple renewable fuel technologies for aviation and shipping. As a leading producer of conventional biofuels, with strong concentration of innovative advanced biofuel producers, the EU is also in a good starting position for driving aviation and shipping fuels market. Yet the hurdle of very high investment costs for new plants as well as the lower cost of fossil fuels present large risks to producers and potential investors. Co-processing in existing refineries and other industries is maturing and presents an advantage for lowering capital costs. Overcoming these barriers requires policy incentives to level the cost, to ensure a demand and to establish a market.

The dynamics of the demand for renewable fuels has the potential to support the progressive of the cost gap between fossil and renewable fuels. In the case of a new manufacturing plant, in fact, the capital cost – heavily impacting the production cost of renewable fuels – can be repaid in the first years of the investment life. During this period, road transport's demand for renewable fuels, driven by existing (RED) and new (ETS, ETD) strong regulatory instruments, can absorb the higher cost of renewable fuels. Over time, the demand of fuels for road will shrink (due to electrification of especially light duty vehicles) while demand for ships and airplanes will progressively pick up. Once the capital cost of renewable fuels is repaid, the cost gap between renewable and fossil fuels for aviation and shipping may reduce very significantly.

Although the EU biofuel industry currently has a strong footing there is also a risk of opening a market to be dominated by foreign production capacity. Particularly the US is a strong competitor for advanced biofuels production while Brazil is also rising in the global market as a strong player, followed by China and India which put forward expanding policies. Developing large scale production facilities to achieve economies of scale and lower production costs requires extremely large investment costs often up to 80% of total costs. Synergies with existing industries to explore installed facilities should be seriously investigated. To ensure EU leadership in a market created by EU policy, support is also necessary, such as government grants and low interest finance for large scale demonstration and First-of-a-kind commercial plants in addition to a steady long-term policy framework and market up-take measures including standardisation and higher blending limits.

Technology and feedstock diversification are the tools to mitigate risks of lock-in to dependencies, like focusing innovation and investments in technologies for which feedstock expansion is challenging, such as HEFA-SPK. While this pathway may be of advantage in the short term due to low investment costs and competitive feedstock and production costs, in the long run competition for supply may drive the production costs much higher. Nevertheless, new feedstocks from intermediate crops, catch and cover crops and those based on marginal and contaminated lands, as well as waste animal fats and algae or aquatic biomass present an opportunity to expand commercial production of HEFA-SPK and should be supported. If investments are made early enough in novel production pathways relying on a diverse set of more abundant feedstocks, their investment and production costs could be reduced in time to outcompete HEFA from crops as feedstock costs become a liability.