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COVER NOTE

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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}

EN EN

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)[1]. The IRENA 1.5°C Scenario projects a global solar photovoltaics power of about 14 TW in 2050[2]. The investment required in the period 2020-2050 for the new solar power capacity is estimated at about USD 4.2 trillion[3,4].

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[5]. 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.

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1 A. Jäger-Waldau, Snapshot of Photovoltaics – March 2021, EPJ Photovoltaics, 2021, doi: 10.1051/epjpv/2021002
2 International Renewable Energy Agency (IRENA), World Energy Transitions Outlook: 1.5°C Pathway, 2019.
3 Conversion rate: 1 USD = 0.84 EUR.
4 Bloomberg New Energy Finance (BNEF), New Energy Outlook (NEO), 2020.
5 https://ec.europa.eu/info/sites/default/files/communication-industrial-strategy-update-2020_en.pdf.

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, 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[6].

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[7]. 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[8] and RMB 76 billion[9]. 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[10] 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* [11]. 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

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6 PSE/Fraunhofer ISE 2020.

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

8 EUR 6.1 billion (1 EUR=7.7139 RMB)

9 EUR 9.8 billion.

10 EUR 2.3 billion.

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

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 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[12].

- 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.

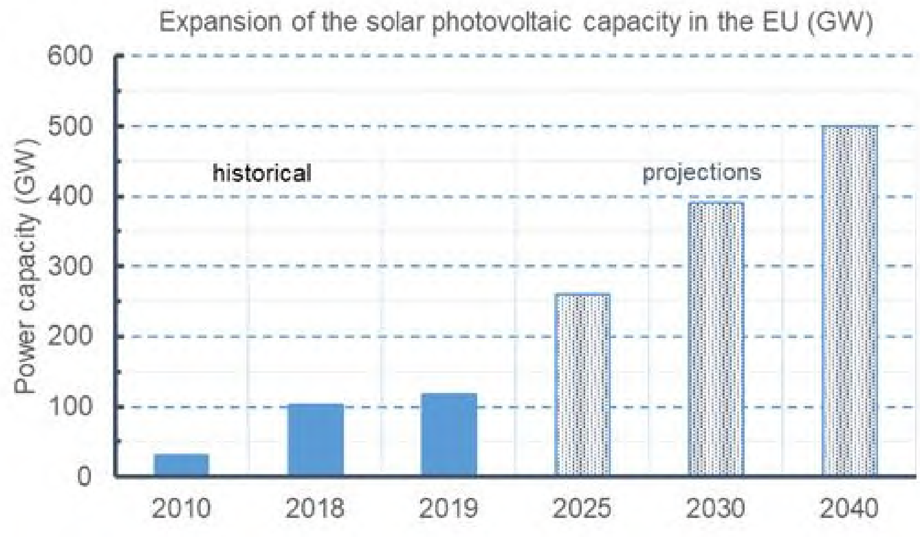
11.2. Capacity installed, generation/production

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

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

power capacity is about USD 4.2 trillion, with utility scale projects absorbing a share of 62% of the total amount[13].

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



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[14]. 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[15]. 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[16]. 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.

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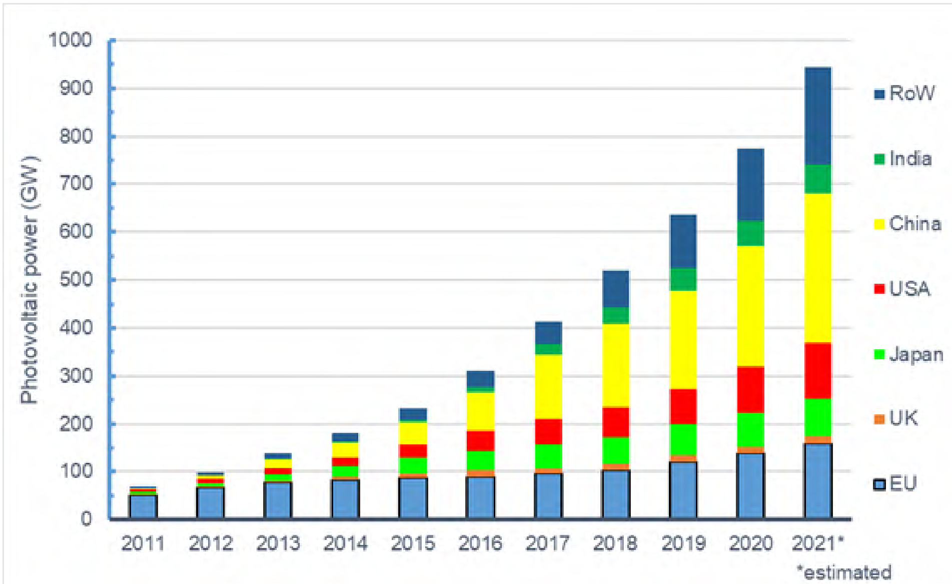
13 Bloomberg New Energy Finance (BNEF) New Energy Outlook (NEO), 2020.

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

15 SWD(2020) 176 final.

16 IEA World Energy Outlook, 2020

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



Source: AJW PV Snapshot 2021[17]

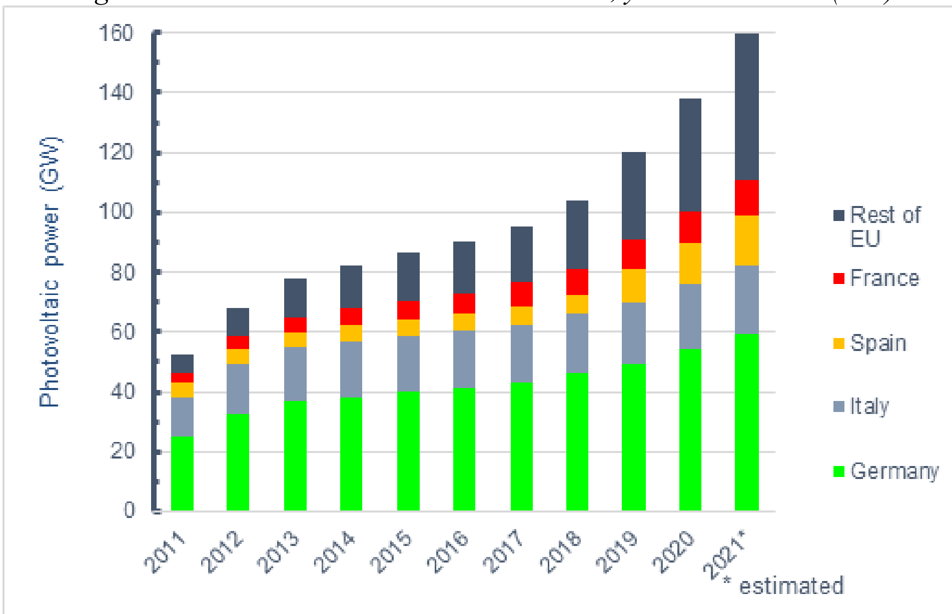
At the beginning of the period considered, the cumulated photovoltaic capacity installed worldwide was about 71 GW. It is estimated to reach more than 940 GW by 2021. In terms of compound annual growth rate (CAGR)[18], this growth corresponds to a CAGR close to 30%, in the indicated ten-year period. 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.

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

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

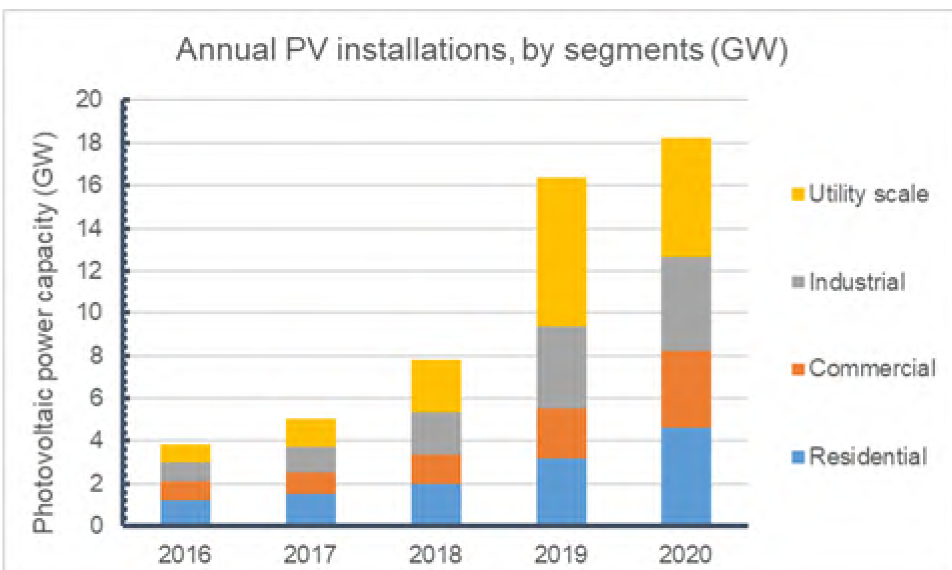
Figure 3: Photovoltaic installations in the EU, years 2011-2021 (GW)



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.

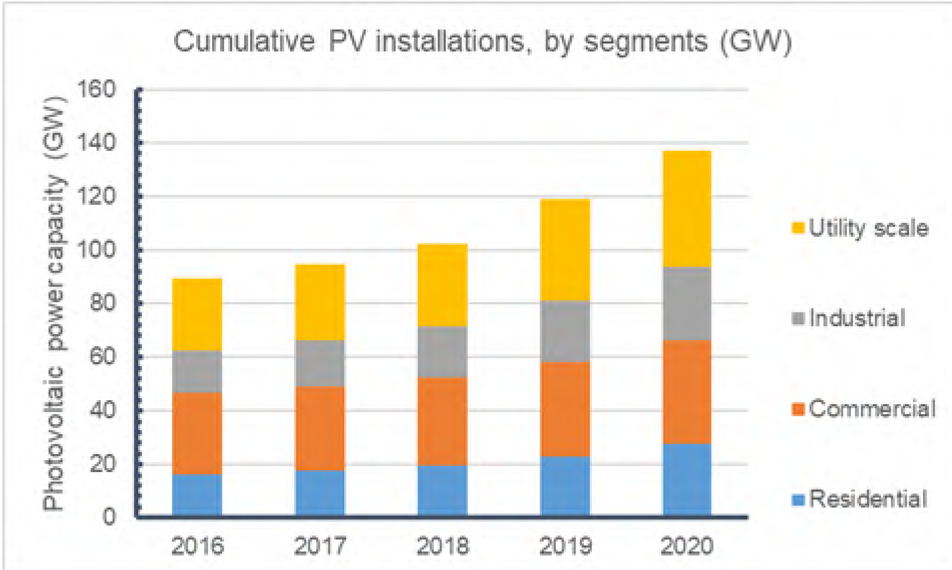
Figure 4: Annual photovoltaic installations in the EU, by segments, years 2016-2020 (GW)



Source: SPE 2021[19]

[19] 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[20]

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

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

technological improvements. With PV modules spot market prices as low as 0.20 EUR/W, 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[21] 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[22]. 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[23]. For rooftop systems there is still a wide spread in LCOE (61.9 to 321.5 EUR/MWh) across the EU[24]. 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) [25].

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.

[21] IEA WEO 2020, 706 to 412 EUR/kW (1 USD = 0,84 EUR)
[22] BIPVBoost H2020 Project, Competitiveness status of BIPV solutions in Europe, January 2020, available on project web site
[23] 33 to 42 EUR/MWh, BNEF 1H LCOE update, 28 April 2020, (1 USD = 0.84 EUR)
[24] 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.
[25] ETIP- PV (2020) https://etip-pv.eu/publications/fact-sheets/

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 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.

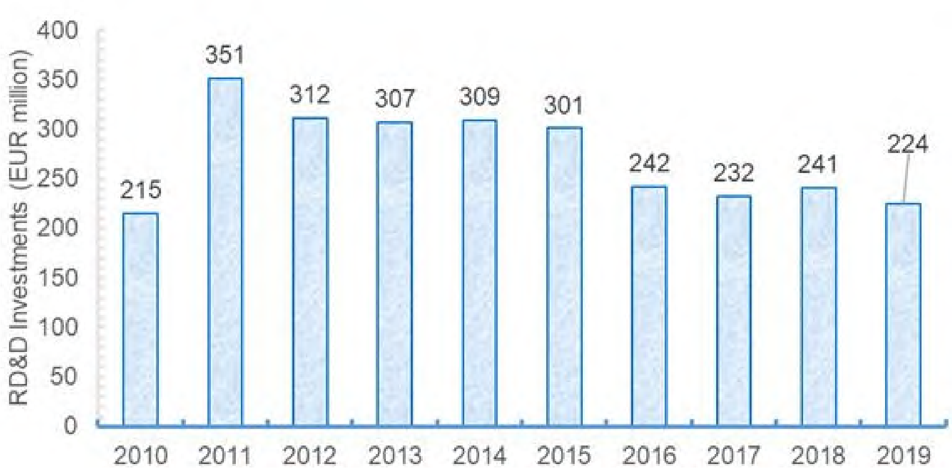
A Commission study published in June 2020 shows that both solar PV and wind power can be cost-competitive in almost all EU markets by 2030[28]. It underlines the importance of flexibility in power systems, e.g., grid interconnections, storage and demand management, to mitigate negative price trends at 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.

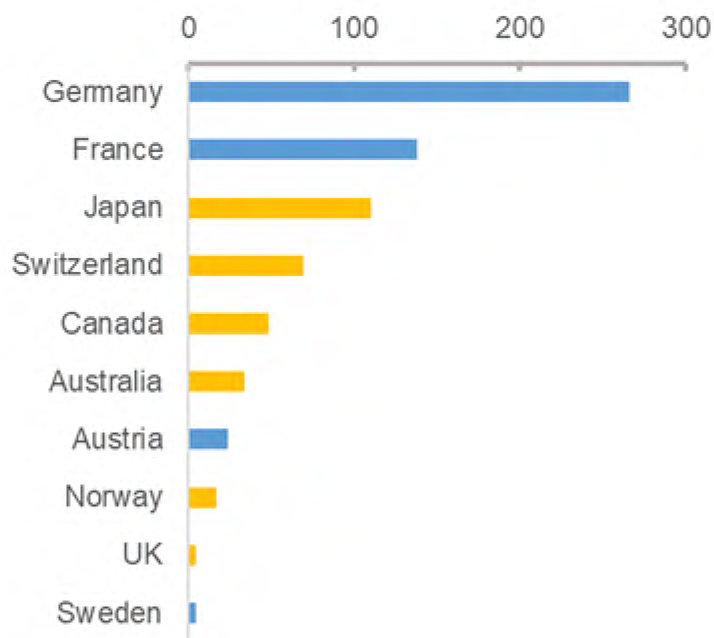
Figure 6: EU MSs Annual spending on solar RD&D as reported to the IEA (EUR million)



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)



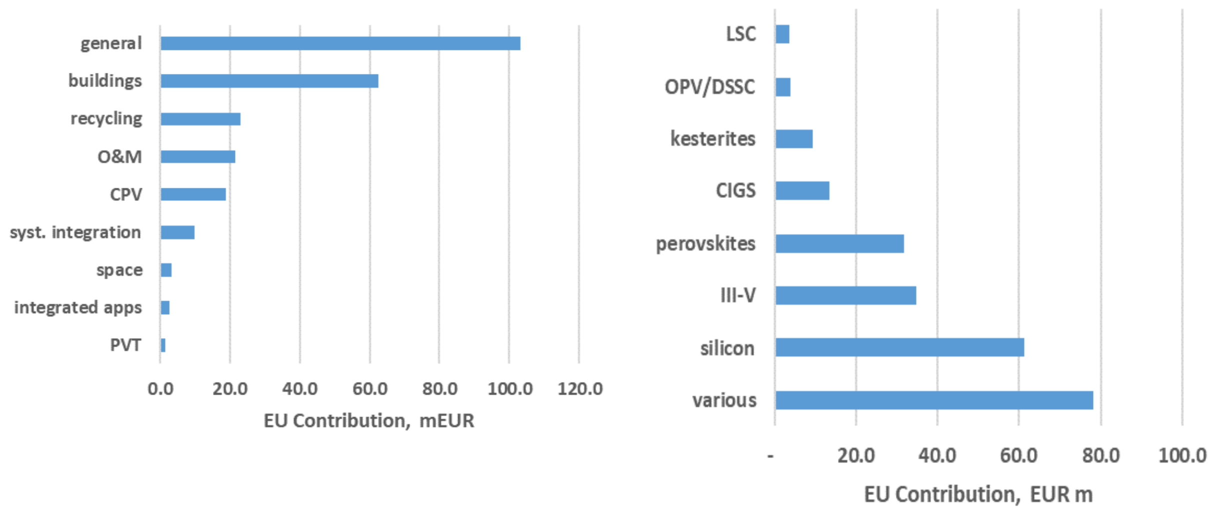
Source: JRC 2021, based on IEA data

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)



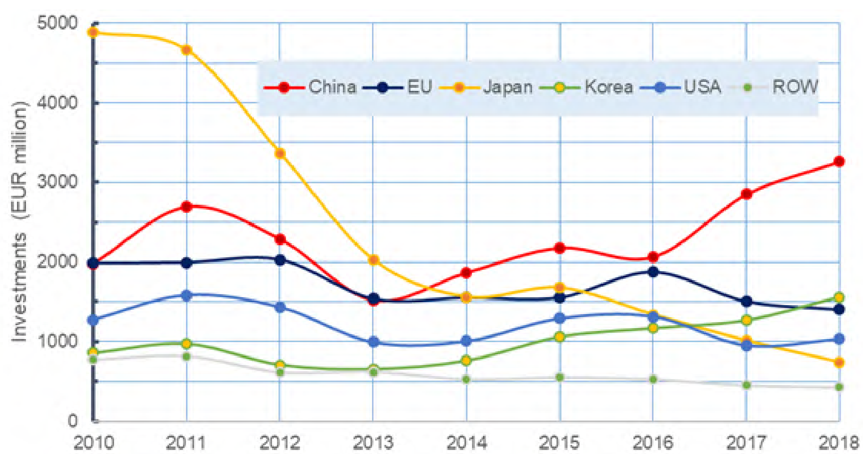
a) Application areas b) PV materials

Source: JRC 2021, analysis of COMPASS data [26]

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 [27]

[26] 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

[27] 2018 data still preliminary and to consolidate

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 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[28].

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[29] 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.

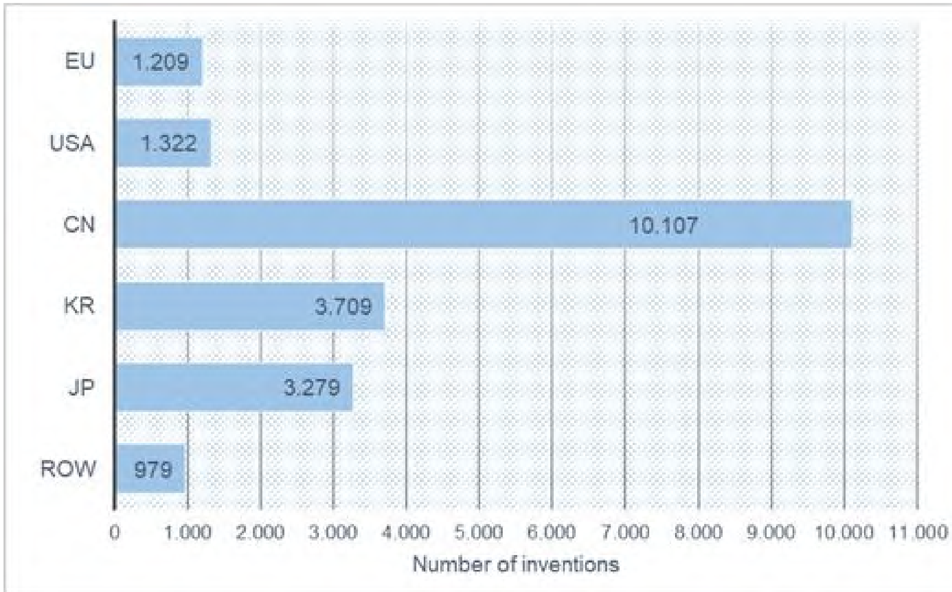
If the "high-value" patent families are considered, in the same three years period, a different picture emerges. Japan leads, followed by Korea and with the EU in the third positon (Figure 11). The “high

[28] 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

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

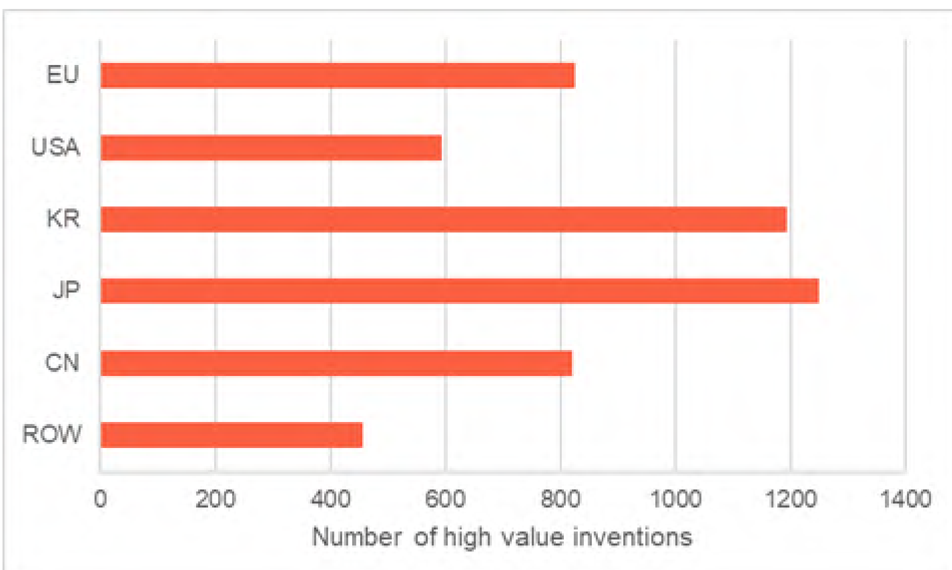
value" inventions domain is highly dynamic. In just one year, since the CPR 2020 analysis, the EU declined from the second, after Japan, to the third position, after Japan and Korea. In the same period, an increase of the Chinese "high value" inventions can be observed, which will soon surpass the EU.

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

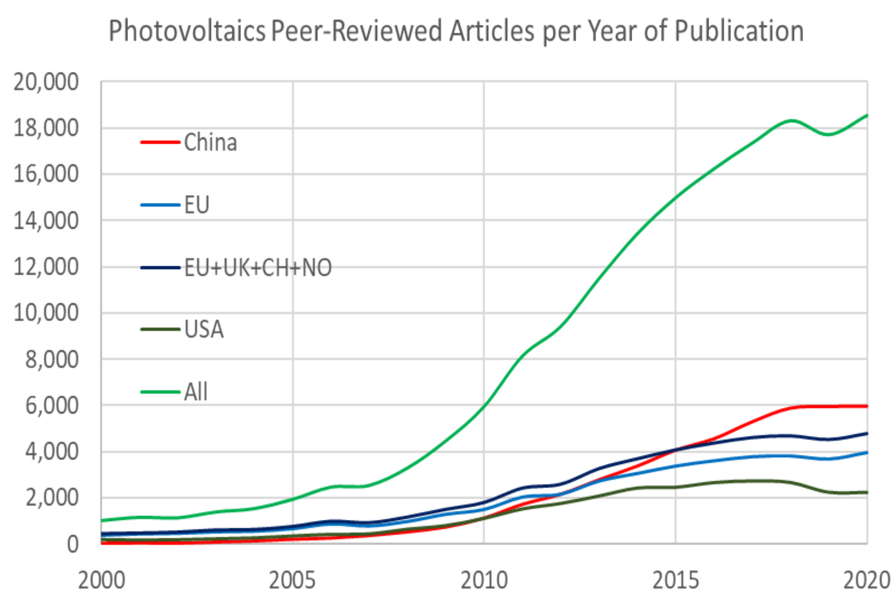
11.7. Level of scientific publications

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[30] 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).



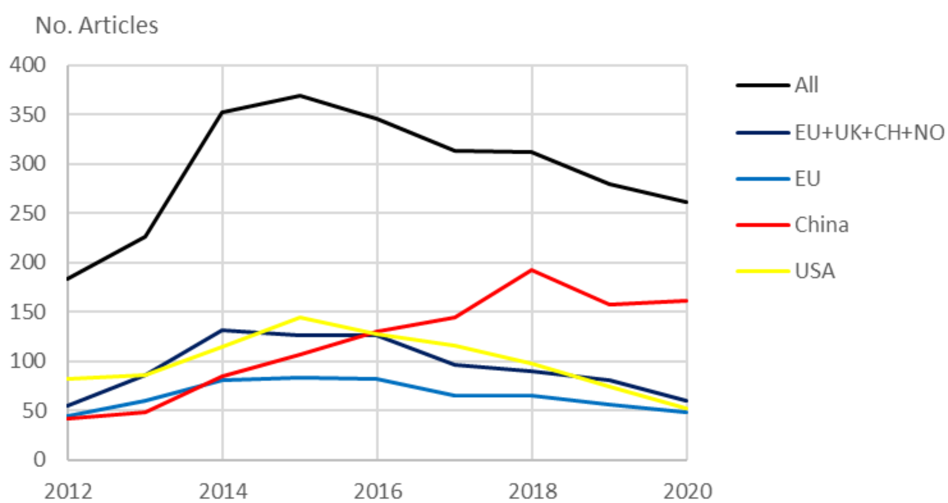
Source: JRC 2021

[30] 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.

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

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,	Medium	High

				Aluminium		
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[31].

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[32], 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[33], 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.

[31] *Solar PV Trade and Manufacturing, A Deep Dive, BNEF, February 2021*
[32] https://www.fs-unep-centre.org/wp-content/uploads/2020/06/GTR_2020.pdf
[33] Asset Study Competitiveness (2020)

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)

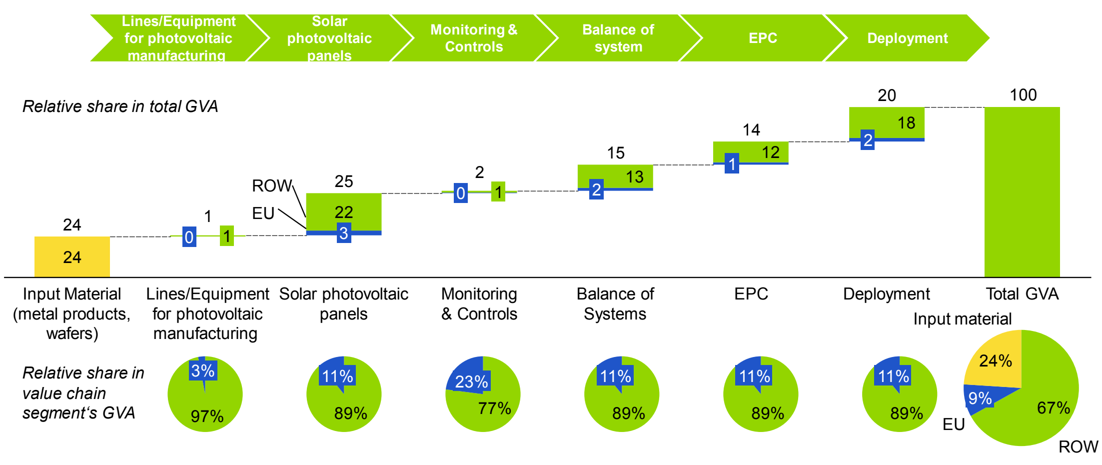
Segment	EU + Norway (USD billion)	World (USD billion)	Share (EU + Norway) (%)
Polysilicon	About 0.7	About 5	1.4
Ingot/wafer	Less than 0.1	About 9	1.1
Cell	Less than 0.5	About 15	0.3
Module	between 4-6	About 30	13
Total	About 6.4	About 59	11

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



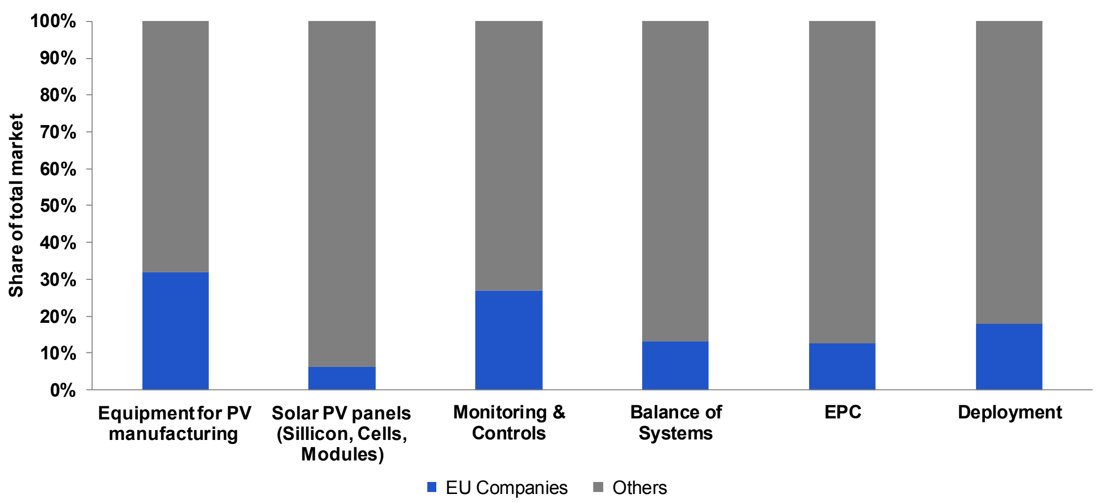
Source: Guidehouse Insights, 2020

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)[34].

[34] 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[35].

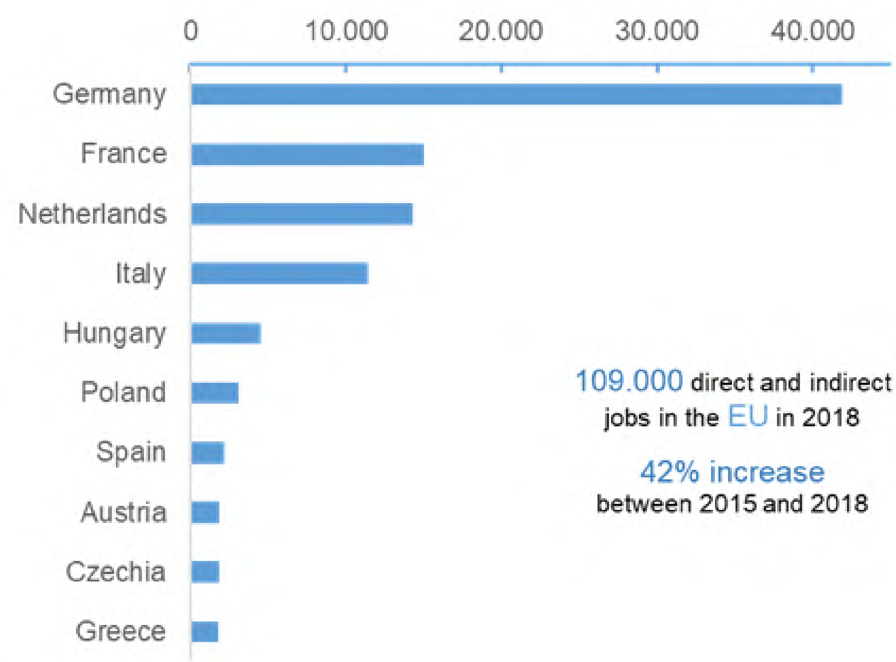
Source: "Climate neutral market opportunities and EU competitiveness", report written by ICF and Cleantech Group December 2020

35 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[36].

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[37]. 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

[36] SolarPower Europe study on employment 2021– The publication will be available in November 2021
[37] F. Liu and J.C.J.M. van den Berg, Energy Policy 138 (2020) 111234

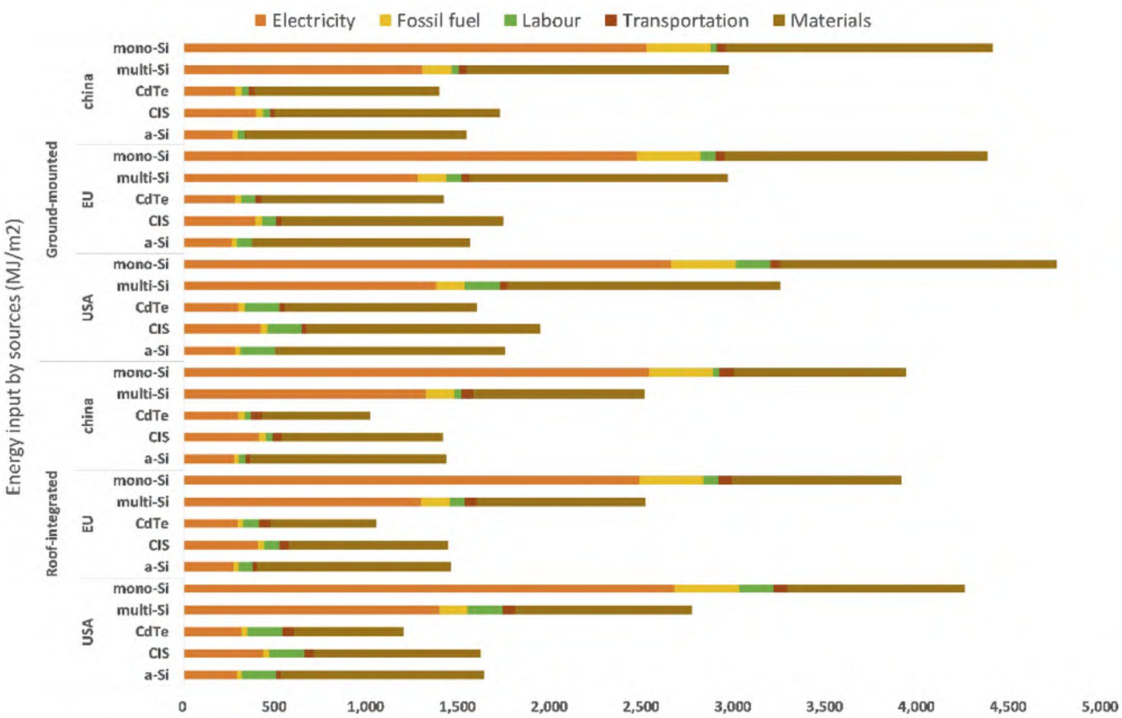
technologies are related to the solar cells manufacturing. Mono-crystalline silicon solar cells requires more energy than solar cells based on multi-crystalline silicon. Even less energy is necessary for the manufacturing of solar cells based on thin-film semiconductors. The EU shows the best performance 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 (

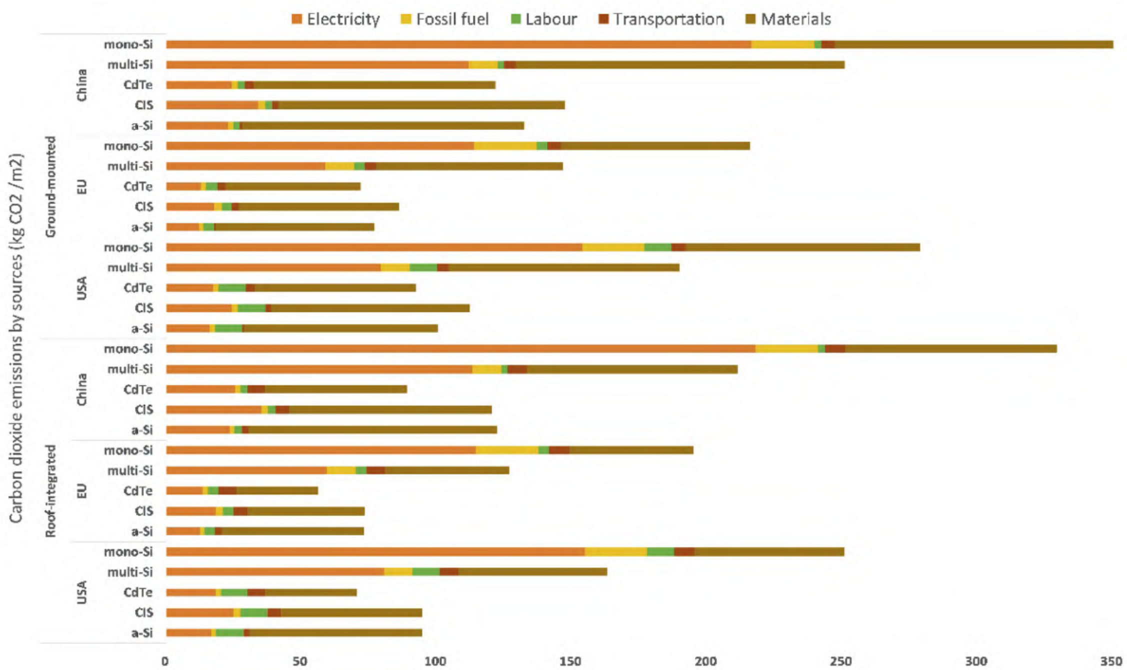
Figure 20).

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

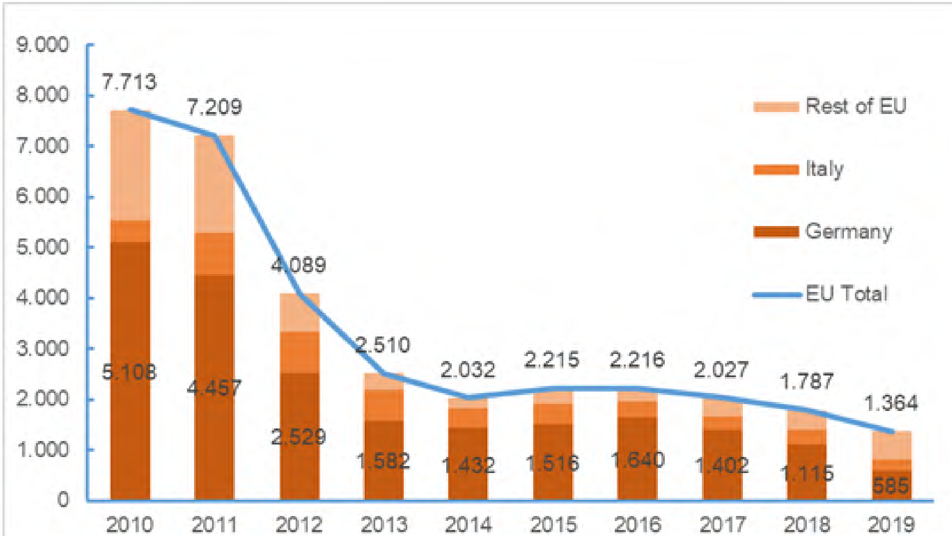


Source: F. Liu and J.C.J.M. van den Berg, Energy Policy 138 (2020) 111234

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[38].

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

13. GLOBAL MARKET ANALYSIS

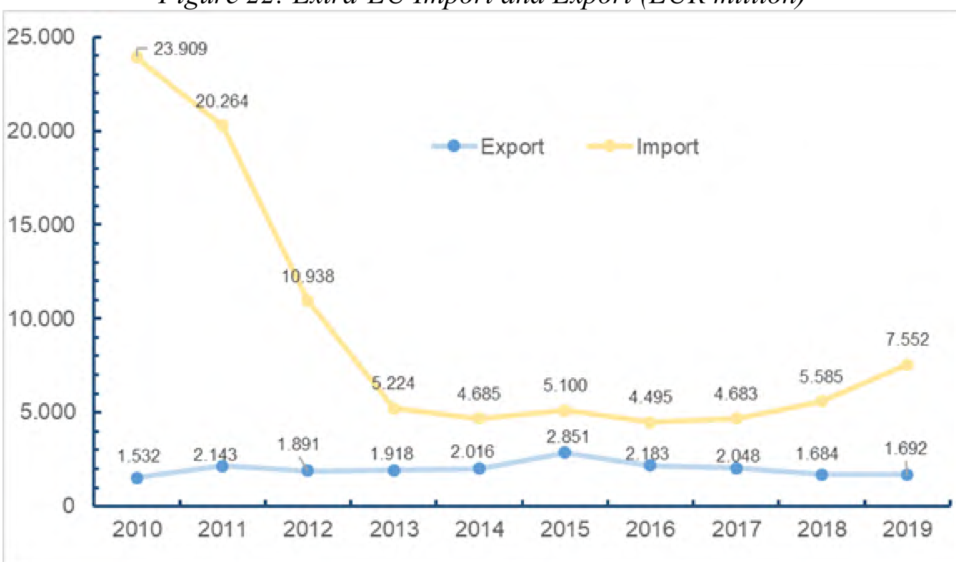
13.1. Introduction/summary

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.[39]

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)

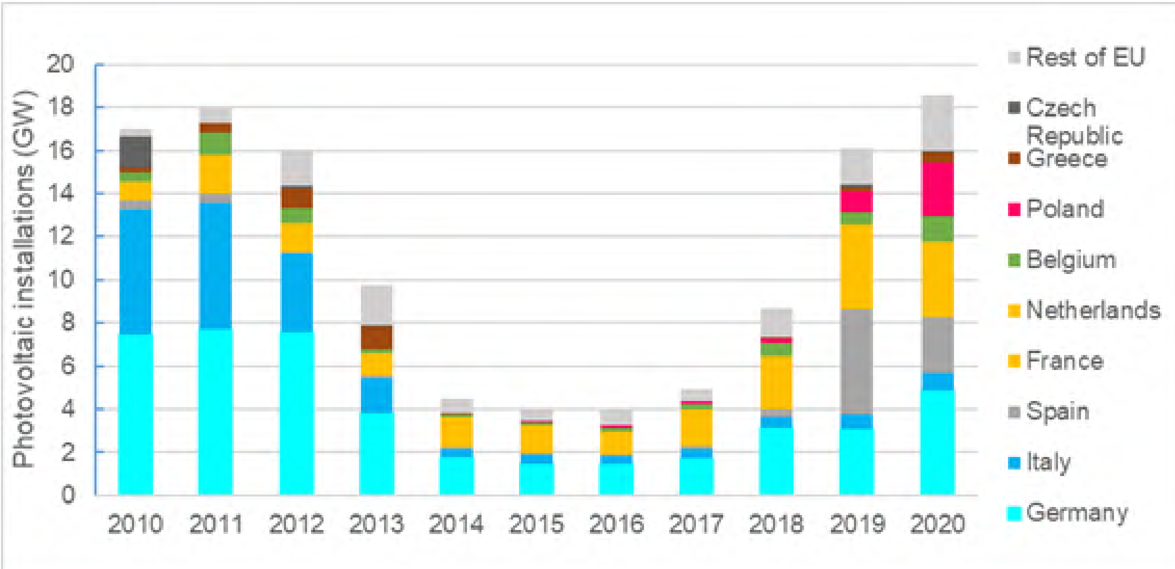


Source: JRC 2021, based on COMEXT data

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).

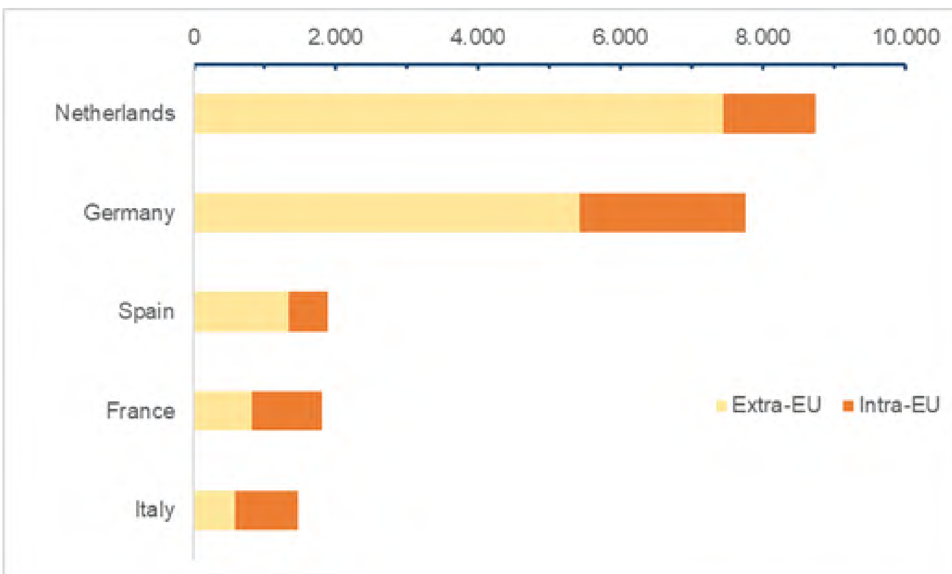
Figure 23: Annual photovoltaic installations in the EU (GW)

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



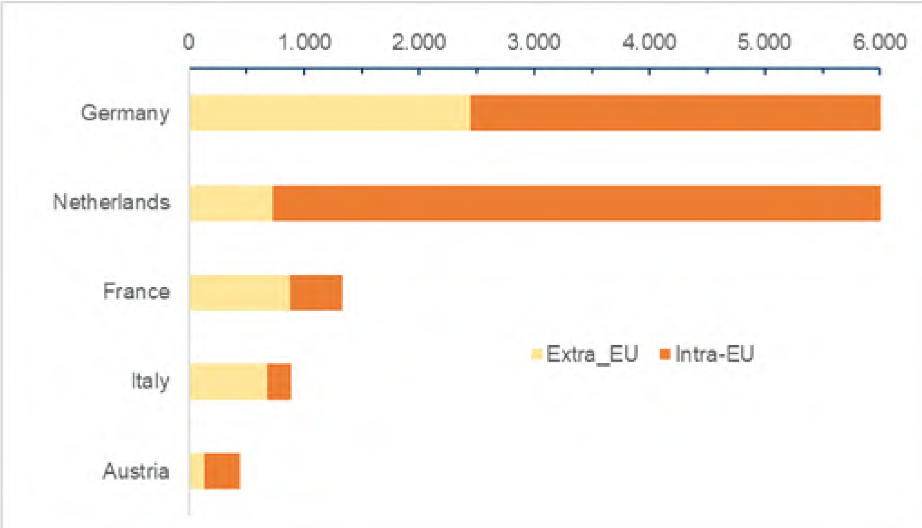
Source: AJW PV Snapshot 2021

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)

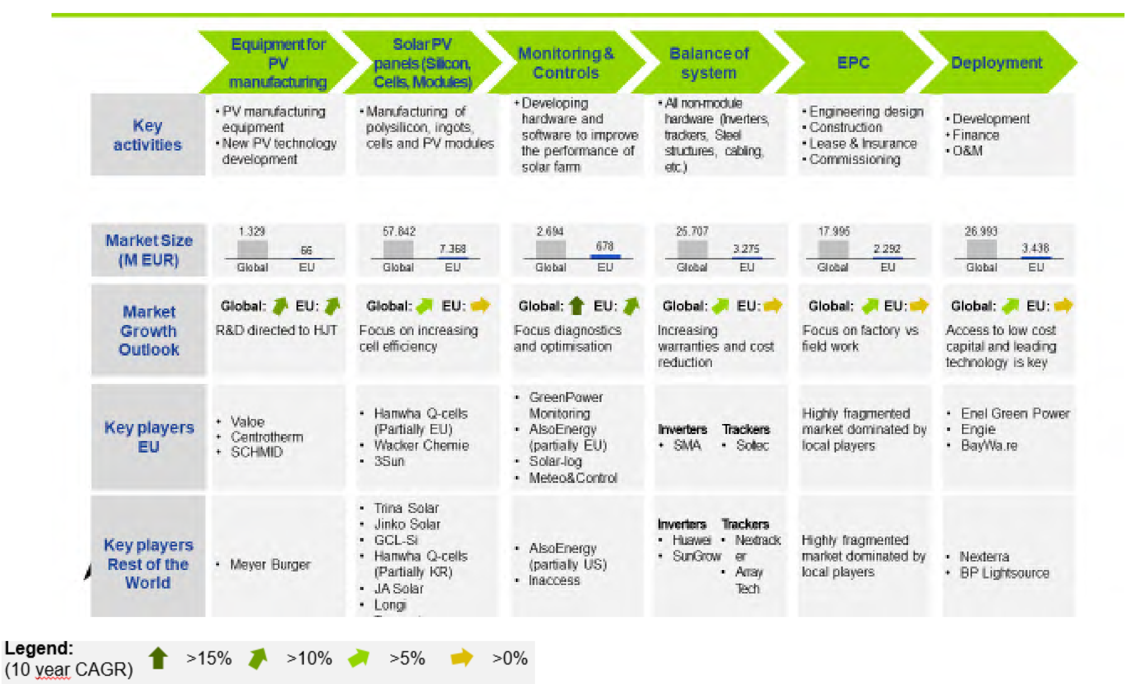


Source: JRC 2021, based on COMEXT data

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.



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[40].

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[41]

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.

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.

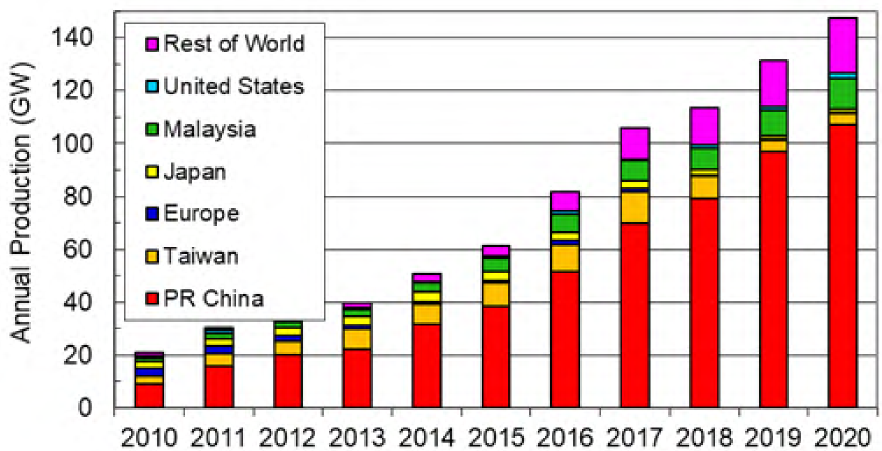
Even limited differences in absolute prices can have a large impact on the competitiveness of power intensive export goods in global markets.

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 monocrystalline 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[42].

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.

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[43] and Energy Labelling[44] 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

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42 IEA PVPS Task 12 Report "Environmental Life Cycle Assessment of Residential PV and Battery Storage Systems" (2020), ISBN 978-3-906042-97-8

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

44 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.

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

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

HEAT PUMPS FOR BUILDINGS

INTRODUCTION

The Energy Performance of Buildings Directive (EPBD)[46], 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[47] 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[48] 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)

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

47 COM(2020) 299 final.

48 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

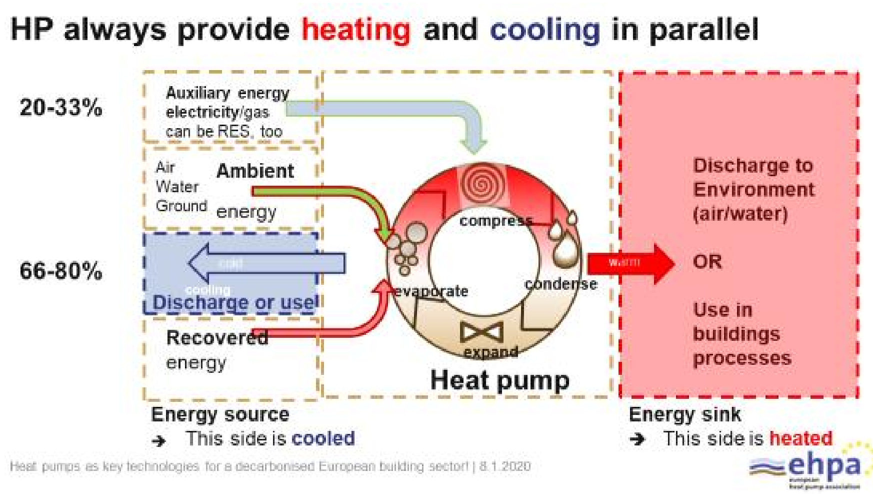
15.1. Introduction/technology maturity status (TRL)

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



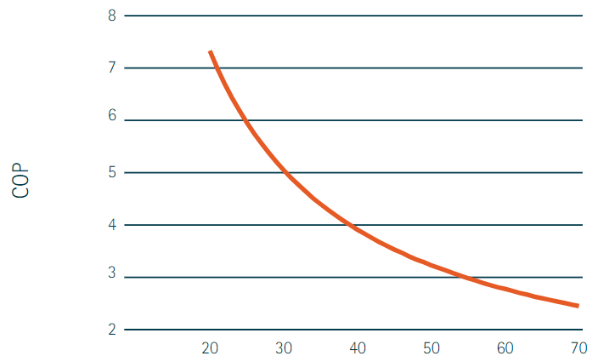
Source: EHPA

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[49] and/or BACS[50]), for autonomous or remote inspection of systems (state, performance and failures).

In order to comply with the F-gas regulation[51], 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

49 BEMS – Building Energy Management System

50 BACS - Building automation and control systems

51 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. R&I applicable to the light commercial heat pump segment

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[52], 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.

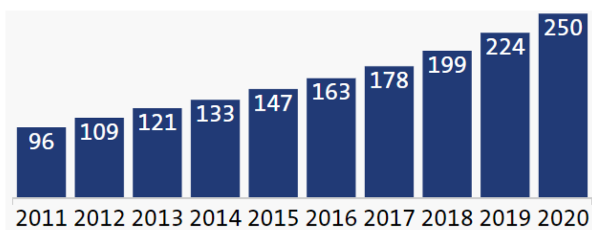
d. R&I applicable to the district heating heat pump segment

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[53] 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[54]

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[55] and 1.7 million GSHPs[56]), 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[57].

52 DHW : Domestic Hot Water
53 EU-21 (including UK, NO, CH and 18 EU MS, not including: BG, CY, EL, HR, LV, LU, MT, RO, SL)
54 EHPA database, http://www.stats.ehpa.org/hp_sales/cockpit/
55 ASHP : Air-Source Heat Pump
56 GSHP: Ground Source Heat Pump
57 Eur'Observer Heat Pump Barometer, 2020

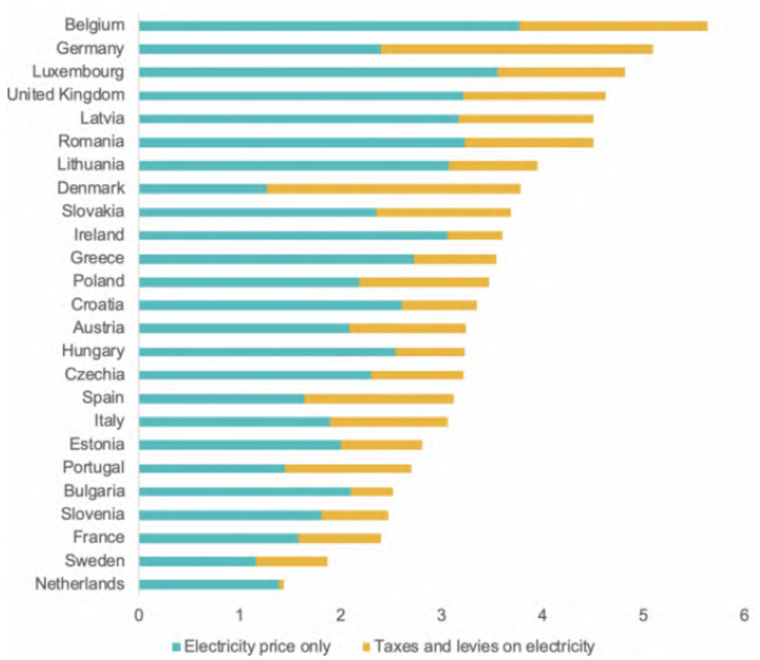
According to Eurostat[58], the total renewable energy contribution of heat pumps in the EU amounted to 12.4 Mtoe[59] in 2019 (or 12.2% of all renewable heating and cooling).

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)



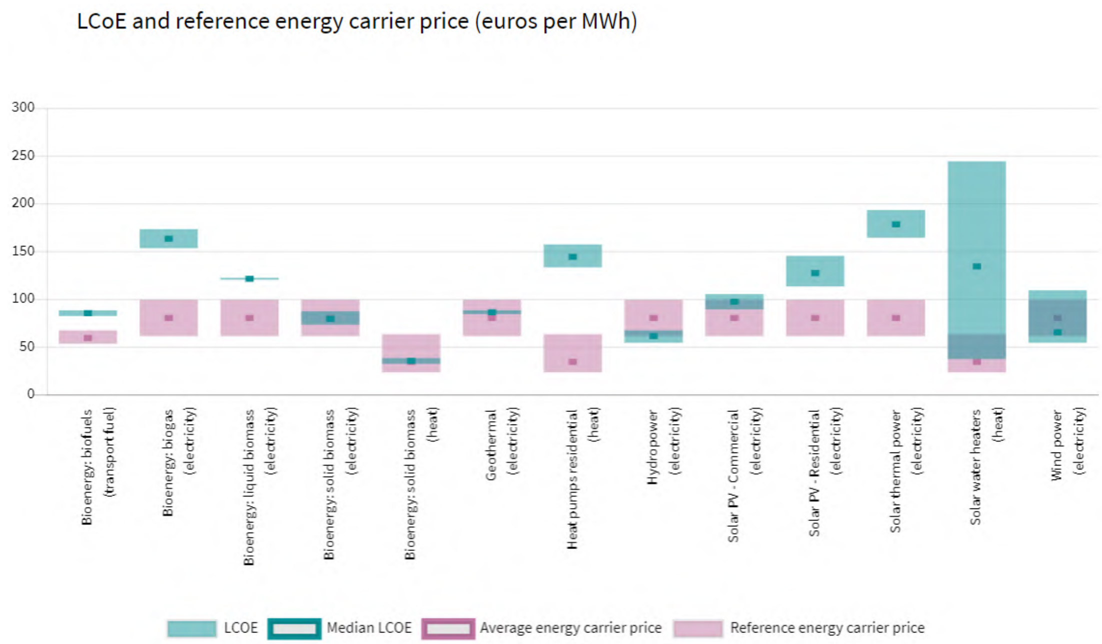
Source: figure EURACTIV, data from 'Energy prices and costs in Europe', COM(2020) 951 final.

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)

58 Eurostat SHARES

59 *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

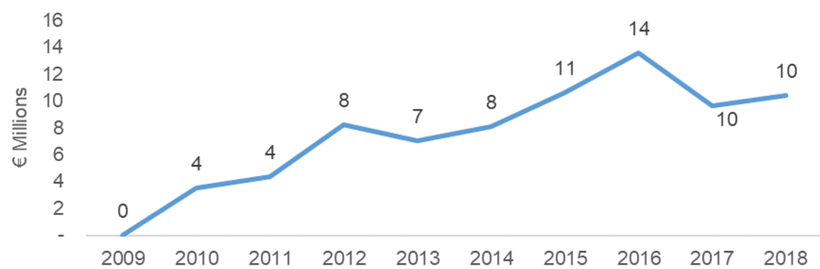
Country	EU Contribution (EUR million)	
Grand Total	**146.8**	**100.0%**
Spain	24.2	16.5%
Italy	21.3	14.5%
Germany	11.9	8.1%
Sweden	10.3	7.0%
Denmark	7.6	5.2%
Belgium	7.3	5.0%
Greece	6.4	4.4%
France	6.1	4.2%
Norway	5.4	3.7%
The Netherlands	5.2	3.5%

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[60].

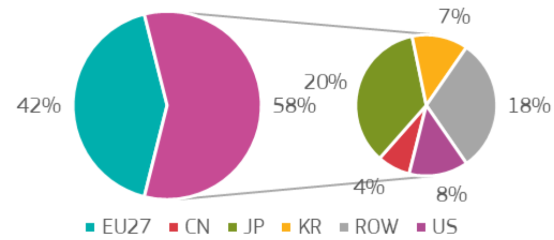
a) <u>'Mainly-heating heat pump for building applications'</u>[61]

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.

[60] 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

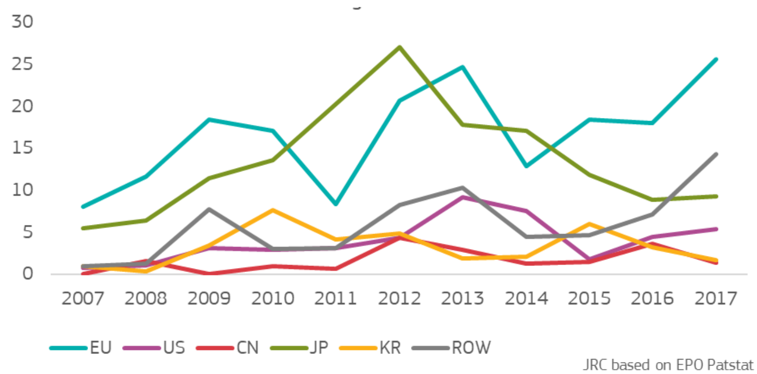
[61] CPC codes included: Y02B (climate change mitigation technologies related to buildings), Y02B 10/40 (geo-thermal HP), Y02B 30/12 (Hot water central heating systems using heat pumps), Y02B 30/13 (Hot air central heating systems using heat pumps), Y02B 30/52 (Heat recovery pumps, i.e. heat pump based 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

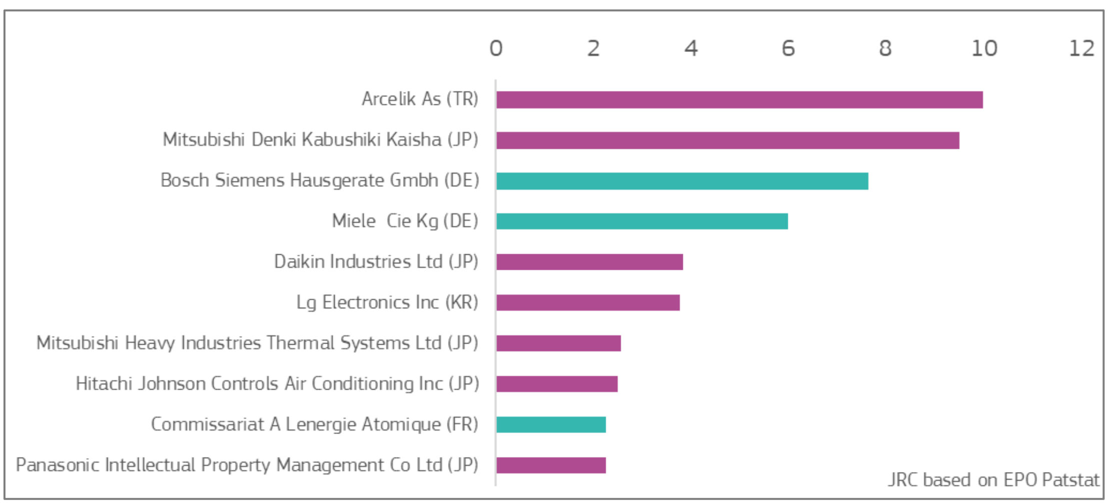
Figure 35: Number of high-value inventions



Source: JRC, based on EPO Patstat

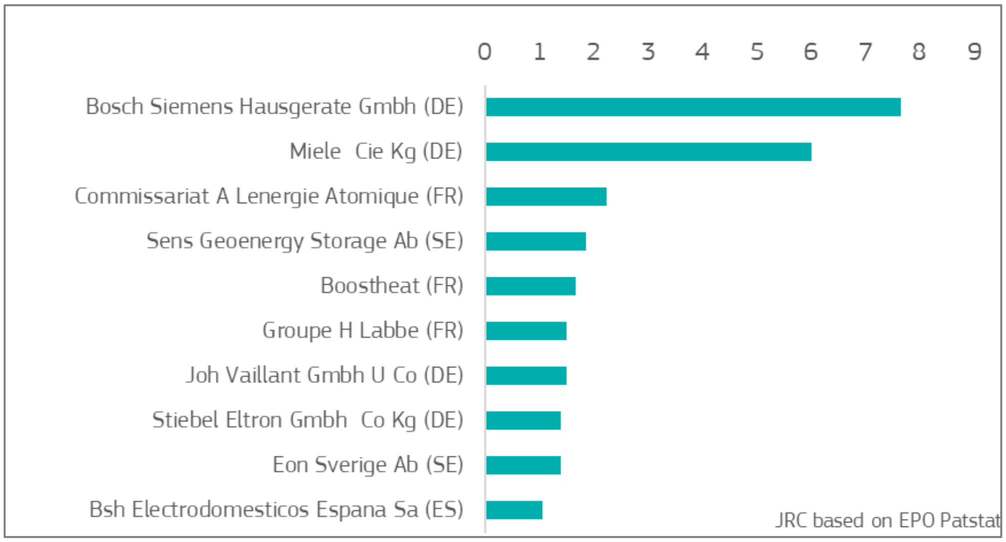
However, out of the top ten most innovative companies, six are located in Asia (5 in Japan and 1 in South Korea), while three are in the EU and one in Turkey. This seems to show a higher concentration of larger companies in Asia than in Europe. Germany, France Sweden and Spain have companies in the top 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)



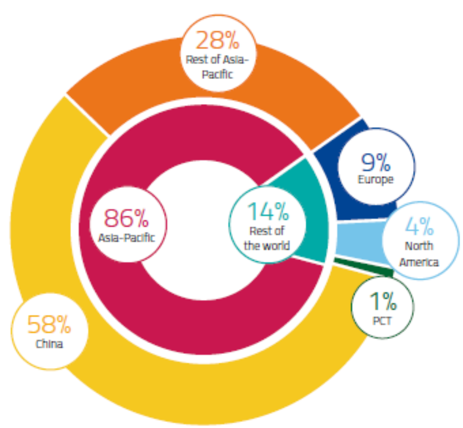
Source: JRC, based on EPO Patstat

b) Heat pumps in space and water heating systems, incl. standalone / portable air-conditioning and water heating units, as well as industrial heat pumps

For this wider range of heat pumps, the EIT-Top-10-innovators report from 2018[62] 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

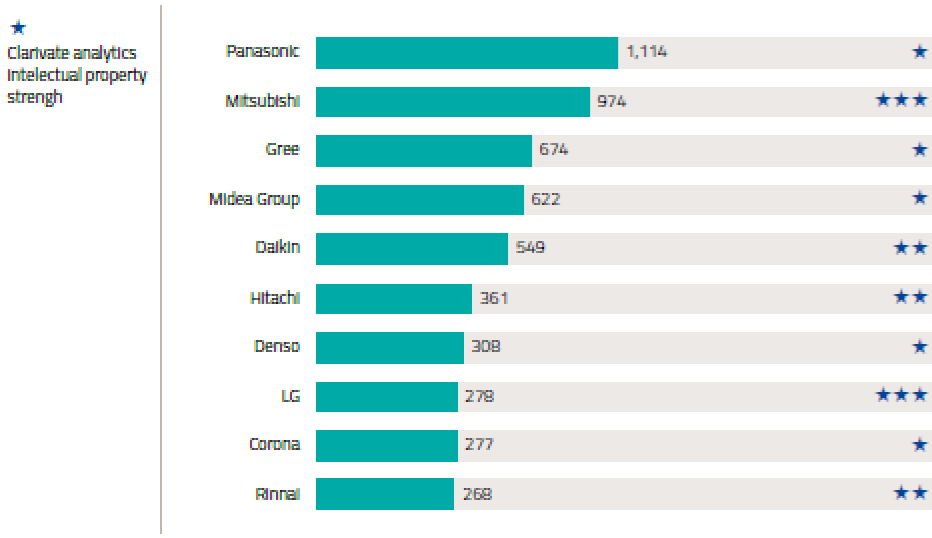


Source: EIT Top-10 innovators report, 2018

[62] 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

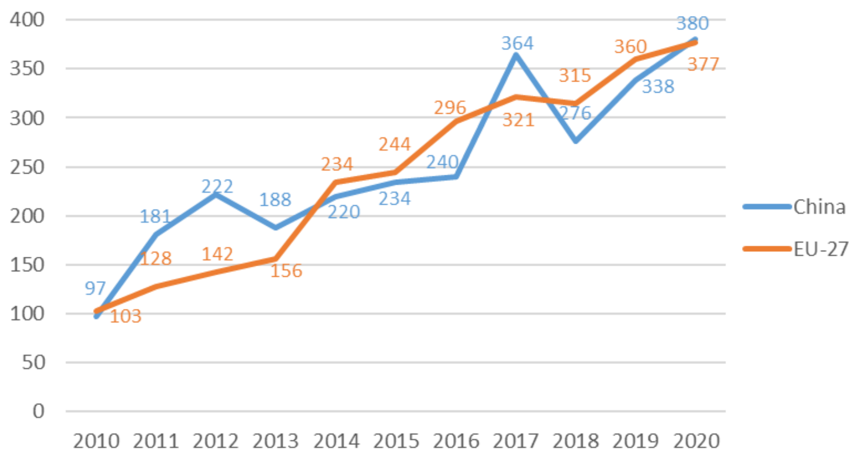
Of the top 10 players from Europe, Stiebel Eltron and Robert Bosch are the most prominent, with the highest number of inventions. Siemens, Électricité de France, Robert Bosch, Vaillant, Atlantic Climatisation & Ventilation SAS and Viessmann Group remain active since 2010, and have high quality patent portfolios.

15.7. Level of scientific publications

Regarding the scientific publications on 'heat pump' technology[63] (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[64] and 27% under Web of Science (WoS)[65]. 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.

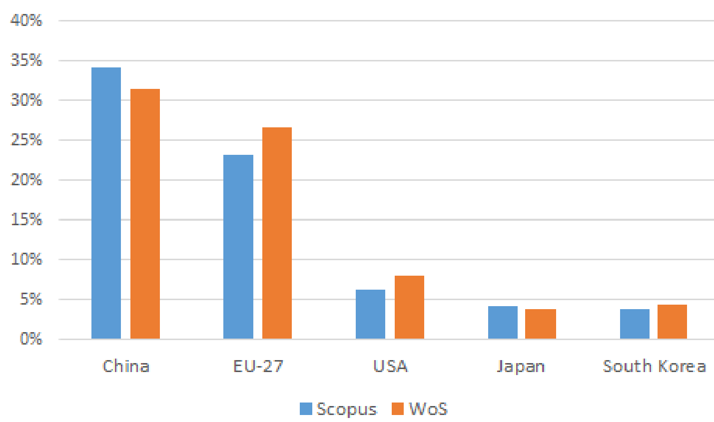
[63] based on the number of publications resulted by **searching 'heat pump' in title and keywords**
[64] https://www.scopus.com/
[65] https://www.webofscience.com/wos/woscc/basic-search

Figure 40: Scientific publications trends over the last 10 years



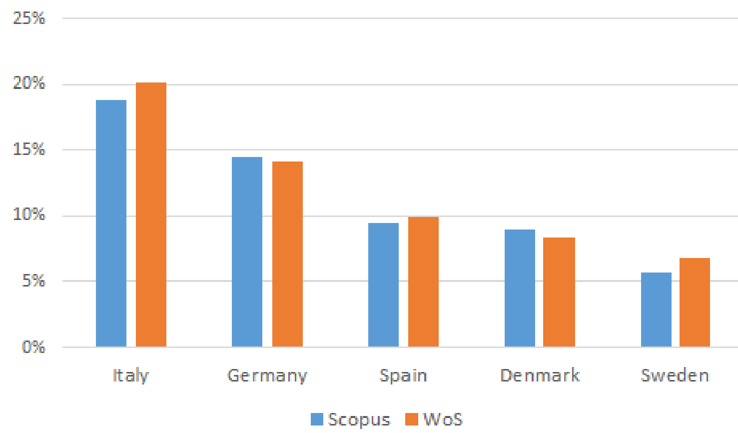
Source: WoS

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

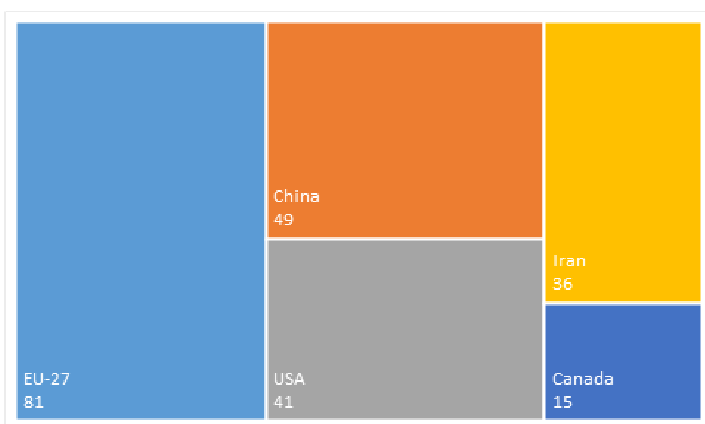
Figure 42: Top 5 EU-27 countries with scientific publications on heat pumps indexed in Scopus and WoS (2010-2020, based on year of publication)



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[66] 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).

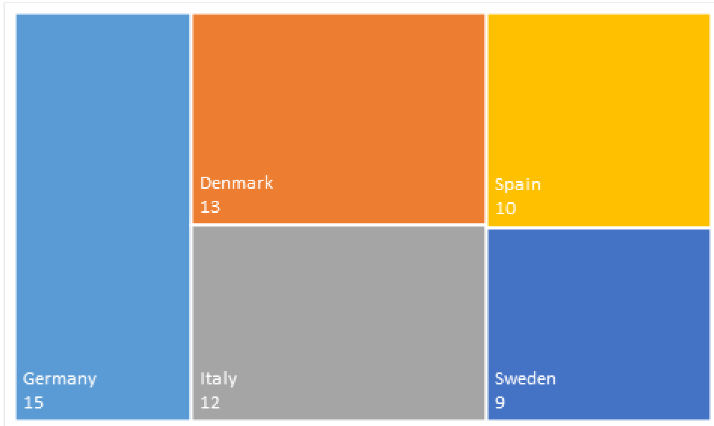
Figure 43: Top 5 worldwide regions in highly cited scientific publications on heat pumps (2011-2021, based on year of publication)



Source: WoS

[66] 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)

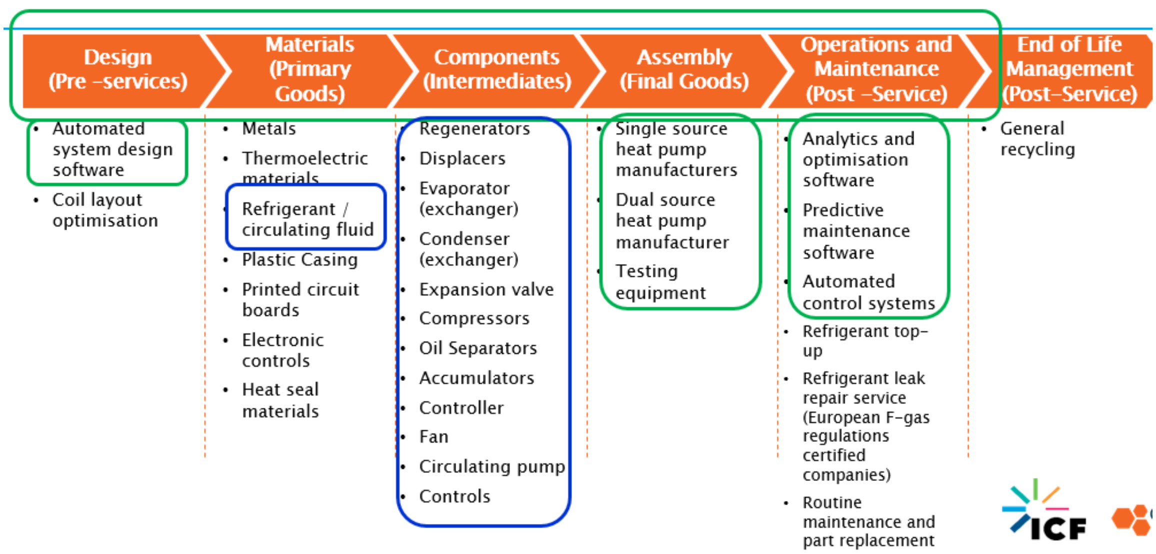


Source: WoS

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[67], 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[68] 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.

67 EurObserver- https://www.eurobserv-er.org/online-database/
68 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[69]

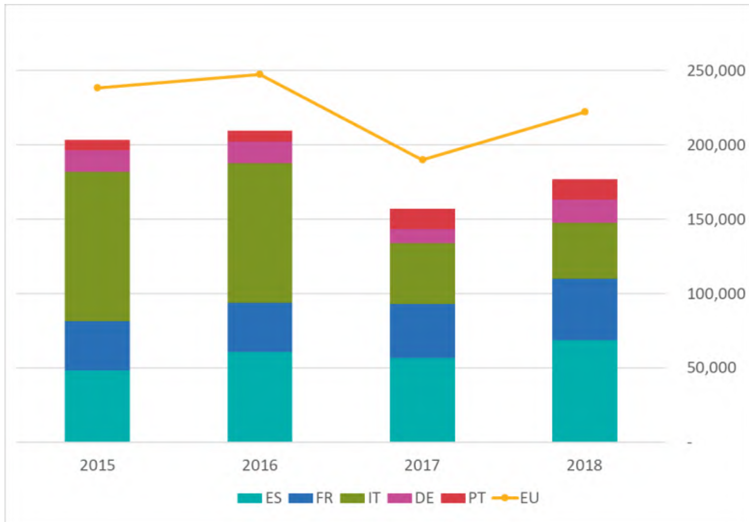
More information on the relative strength of the EU vs. other continents can be found in section 17.2, while more information on European and global market players can be found in section 17.3.

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

According to EurObserver[70], 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.

69 https://www.ehpa.org/about/members/ Excl.: Associations and Research/Academia. CIAT (FR) added.
70 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.

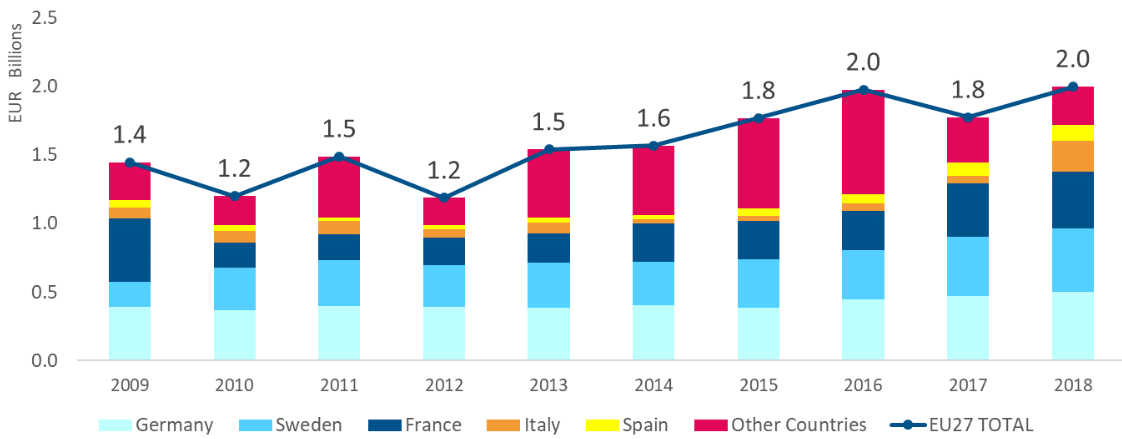
16.6. Energy intensity considerations, and labour productivity considerations

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[71].

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

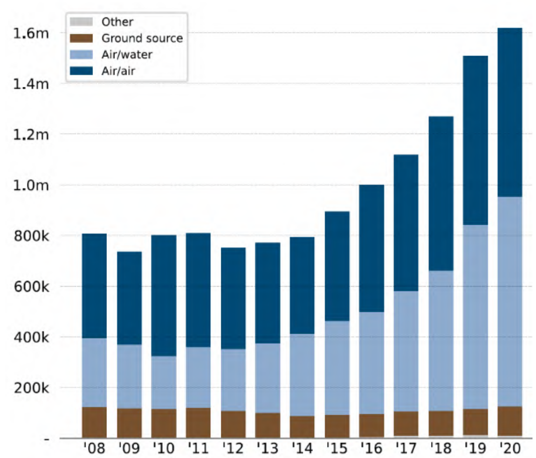
[71] EurObserver

(identified in 23 EU countries), having already increased by 19.2% between 2017 and 2018. Growth in this 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[72].

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[73].

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.

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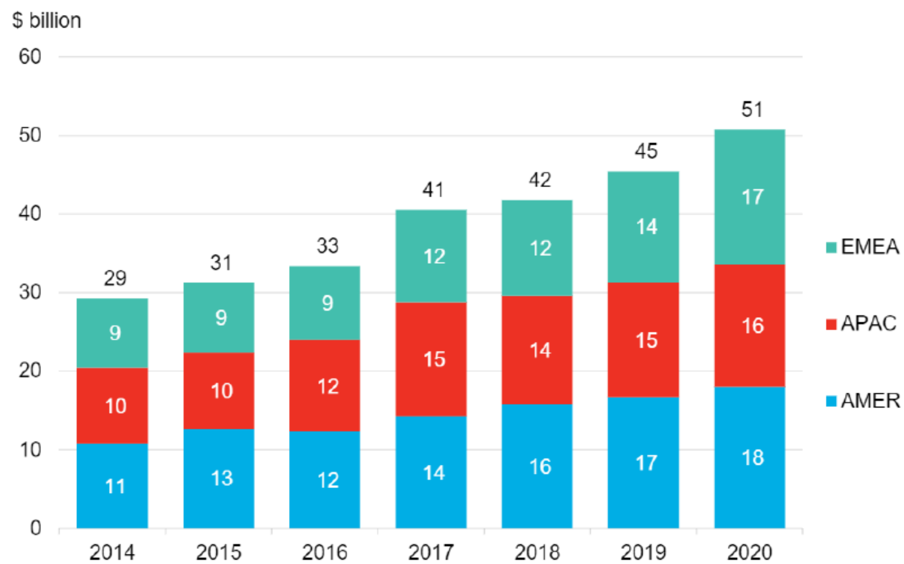
[72] EurObserver
[73] EurObserver

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)

Market prospects, considering only the heat pumps used as main heating system:

In the 1.5TECH scenario of the EU Long Term Strategy (LTS)[74], 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)[75], 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[76], 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.

[74] In-depth analysis in support of Long Term Strategy COM(2018) 773, fig 43, p104
[75] An EU Strategy for Energy System Integration, COM(2020) 299, p8
[76] IEA - Net zero by 2050 – May 2021, p24 and p72

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 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[77]:

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.

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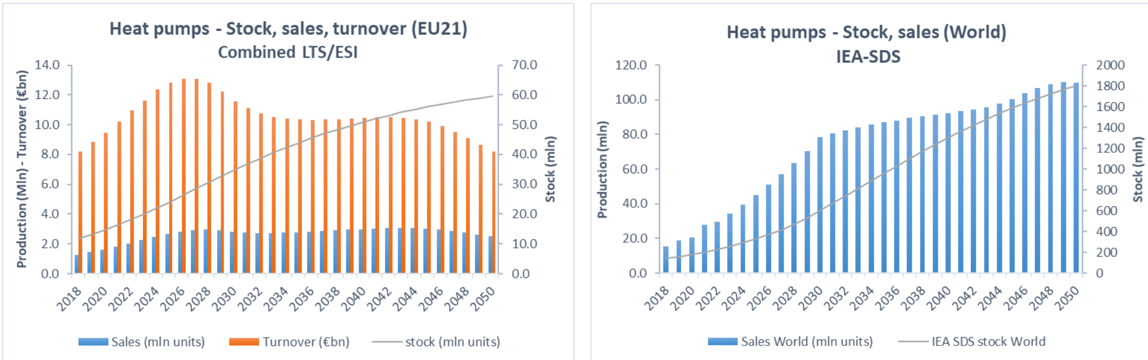
[77] Assumptions:

- 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
- 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)
- 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)
- The EU industry maintains a neutral trade balance, i.e. it grows at the same rhythm as the EU market.
- The production accounts for new installations and replacements of units after 16 to 20 years
- 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).
- 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[78] 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[79], where Asian countries (Thailand and China) are still leading, followed by European (Spain, UK, Italy), as can be seen in Table 11 below.

[78] 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'.

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[80], 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*.

79 COMTRADE code 841581
80 COMTRADE code 841861

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 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)[81], 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

81 Liechtenstein, Norway, Russia, Switzerland, Turkey, Ukraine, United Kingdom, and also Israel

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**
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[82]. In 2020, the Swedish company NIBE Industrier AB acquired the German manufacturer Waterkotte[83].

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)

[82] ITP.net, Hisense acquires Slovenian home appliances firm Gorenje, 7 April 2019
[83] EurObserver-HP-baro-2020 and EHPA

Region	Company (Country)
	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)
	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[84].

[84] Trinomics, Study on resilience of the critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis, 2021

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 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[85]. The unbalance is already less pronounced when considering reversible air conditioners[86] which can operate also in heating mode. When considering ‘mainly-heating heat pumps’[87], European countries are leading world exports.

[85] UN-COMTRADE 8415 ‘air conditioning machines’, refer to section 3.2 for more details
[86] UN-COMTRADE 841581 ‘air conditioning machines incl. a valve for reversal "reversible heat pumps’
[87] UN-COMTRADE 841861 ‘heat pumps, excluding air conditioning machines of heading 8415’

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.

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.