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Preparatory study for solar photovoltaic modules, inverters and systems

(Draft) Task 2 Report: Market data and trends

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2.1. Generic economic data

As was identified in section 1.1.2.1 of the Task 1 report, with the exception of gross electricity generation from solar photovoltaics there is no official disaggregated production or trade data in the PRODCOM or EUROPROM databases for solar photovoltaic modules or system components produced for solar photovoltaic end-use applications.

Following a detailed check of the NACE economic activities and Classifications of Products by Activity (CPA) codes of potential relevance, it was identified that the only specific references to solar photovoltaics are made under:

- Section C ('photovoltaic cells'), which refers to the cell component of a module, and
- Section F ('electric solar energy collectors'), which relates to electrical installations.

The related activities for these production codes, together with others that are relevant but do not specifically identify solar photovoltaic products, are presented in Table 1. This can be used to map other sources of data onto existing EU and international classifications. The most directly relevant CPA code is 26.11.40, which includes solar photovoltaic cells and assembled modules within its definition. However, a cross check of this data revealed that it aggregates the import and export value of a range of other semiconductor devices, including Light Emitting Diodes (LEDs).

The same happens for the CPA code related to inverters, 27.11. which comprises the manufacture of electric motors, generators and transformers, being not possible to isolate inverters from the other equipment. The conclusion is that annual shipment data cannot be isolated from the data under this code. In section 2.2 data has therefore been collated from a range of non-official sources and these will later be mapped onto the CPA codes already identified.

Data is not currently collected for the installed capacity of solar photovoltaic systems. Instead the gross supply and consumption of solar photovoltaic electricity is reported in terajoules for each Member State as a dataset provided by Eurostat's SHARES tool[1].

[1] Eurostat, *Energy from renewable sources*, http://ec.europa.eu/eurostat/web/energy/data/shares

Table 1 NACE economic activities and Classifications of Products by Activity (CPA) codes of potential relevance to the product group

Section	Division	Class	Sub-class	Activities (CPA code)
C Manufacturing	26. Manufacture of computer, electronic and optical products	26.1 Manufacture of electronic components and boards	26.11 Manufacture of electronic components	26.11.10 – Manufacture of dice or wafers, semi-conductor, finished or semi-finished
				26.11.22 – Photosensitive semiconductor devices; solar cells, photo-diodes, photo-transistors, etc.
				26.11.40 – Parts of diodes, transistors and similar semiconductor devices, photosensitive semiconductor devices and photovoltaic cells, light-emitting diodes and mounted piezo-electric crystals
	27. Manufacture of electrical equipment	27.1 Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus	27.11 Manufacture of electric motors, generators and transformers	27.11.01/02 – Electrical apparatus for switching or protecting electrical circuits 27.11.04 – Electrical transformers
			27.12 Manufacture of electricity distribution and control apparatus	27.12.04 – Parts of electricity distribution and control apparatus
		27.2 Manufacture of batteries and accumulators	27.20 Manufacture of batteries and accumulators	27.20.10 – the manufacture of non-rechargeable and rechargeable batteries
		27.3 Manufacture of wiring and wiring devices	27.33 Wiring devices	27.33.10 – manufacture of boxes for electrical wiring (e.g. junction, outlet, switch boxes) – manufacture of bus bars, electrical conductors (except switchgear-type)
		27.9 Manufacture of other electrical equipment	27.90 Manufacture of other electrical equipment	27.90.10 – miscellaneous electrical equipment other than motors, generators and transformers, batteries and accumulators, wires and wiring devices, lighting equipment or domestic appliances.
D Electricity, gas, steam and air conditioning	35. Electricity, gas, steam and air conditioning supply	35.1 Electric power generation, transmission and distribution	35.11 Production of electricity	35.11.10 – Electricity (solar photovoltaic)
			35.14 Trade of electricity	35.14.10 – Sale of electricity to the user – Activities of electric power brokers that arrange the sale of electricity via power distribution systems operated by others – Operation of electricity and transmission capacity exchanges for electric power
F Construction	43. Specialist construction activities	43.2 Electrical, plumbing and other construction installation works	43.21 Electrical installation	43.21.10 – Electrical installation works of other electrical equipment, including electric solar energy collectors and baseboard heaters of buildings

2.2. Market and stock data

As reported in Task 1, section 1.1.2, official statistics provided by Eurostat for this product category are too broad since they present aggregated data for semiconductor devices, LEDs apart from PV modules. Therefore, in this section market and stock data have been compiled from market research conducted among other sources by GTM Research (inverters) and the Becquerel Institute (modules and systems). The module and system data is in part based on research carried in support of the IEA PVPS programme [2] and the PV Market Alliance [3]. A first section compiles general information of the sector from a report prepared by Ernst and Young for Solar Power Europe[4].

2.2.1. Sectorial figures – gross value added

The value chain for PV systems can be split between upstream and downstream activities.

- Upstream activities are the processing of raw materials: manufacturing of polysilicon, wafers, cells, modules, inverters, mounting and tracking systems and electrical components (Balance of System).
- Downstream activities are services provided within the PV industry such as engineering/studies/administration, installation, operations & maintenance and decommissioning.

The gross value added by the PV industry, considering this split can be seen in Figure 1. The manufacturing of electrical components (Balance of Systems components) created 43% of total upstream jobs and GVA in 2016.

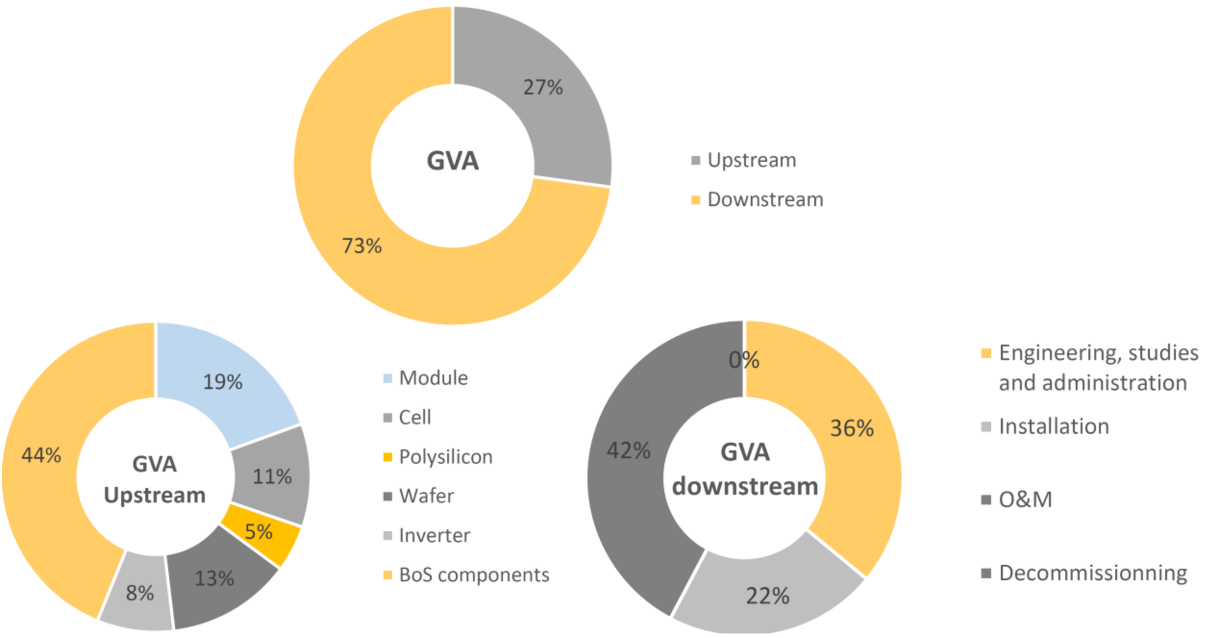

Figure 1. Gross Added Value (GVA) created by the PV industry in 2016, by value chain structure (upstream and downstream)

Source: Solar Power Europe, 2017

[2] IEA Photovoltaic Power Systems Programme (PVPS) http://www.iea-pvps.org/
[3] The PV Market Alliance, http://www.pvmarketalliance.com/about-us/the-pv-market-alliance/
[4] Solar PV Jobs & Value Added in Europe, EY Solar Power Europe, 2017

There is a strong correlation between jobs created and GVA in the activities of the value chain. Job support and GVA have decreased since 2008 for both upstream and downstream activities, as demonstrated in Figure 2.

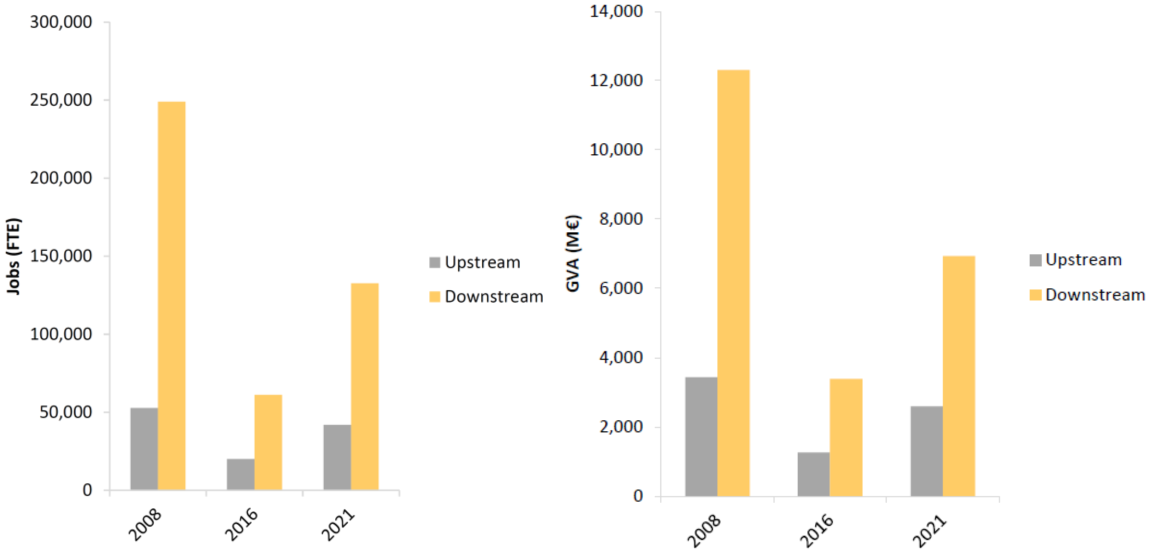

Figure 2. Direct and indirect jobs supported (left) and gross value added (right) by the PV industry in 2008-2016-2021, by value chain structure (upstream and downstream)

Source: Solar Power Europe, 2017

When comparing the unit cost (€/W) for PV modules (upstream) and installation (downstream) in 2008 and 2016 for example, the relative reduction for PV modules is almost 3 times more important than that of installation. According to Solar Power Europe report, the increase of job support and GVA between 2016 and 2021 will be mainly driven by the acceleration of new installed capacities in most European countries.

Table 2. Share of jobs support and gross value added per step of the value chain per year for EU28.

		Jobs supported (% total FTE)			GVA (% total M€)		
		2008	2016	2021	2008	2016	2021
Upstream	Polysilicon	3%	1%	1%	4%	1%	1%
	Wafer	1%	3%	2%	2%	4%	2%
	Cells	1%	3%	2%	1%	3%	2%
	Modules	1%	5%	3%	2%	5%	4%
	Inverters	4%	2%	2%	6%	2%	2%
	BoS components	6%	11%	15%	8%	12%	16%
Downstream	Engineering, studies, admin.	53%	23%	31%	54%	26%	32%
	Installation	28%	16%	22%	22%	15%	21%
	O&M	1%	36%	22%	1%	31%	20%

Source: Solar Power Europe, 2017

In the upstream segment, the majority of jobs and GVA creation will shift from PV modules and inverters to Balance of Systems (BoS) components over the 2016-2021 period (Table 2).

Job support and GVA per step of the value chain and per country is very heterogeneous, as installed capacity and production intensity differs from one country to the other. Job support and GVA in downstream activities is systematically higher than that of upstream activities.

As Figure 3 reveals, Germany has the highest number of upstream jobs, which is linked to relatively high national shares of production in Europe for upstream activities compared to other countries. This is one of the reasons why Germany has the highest jobs in 2016, although new installed capacity is more important in the UK (second highest level of jobs). Other countries, such as Belgium, Spain, Greece, Italy, Poland and Romania have low yearly new installed capacities and a low national share of production for upstream activities. This explains the limited number of jobs and GVA in these countries in 2016. Regarding downstream activities and as a consequence of their highest cumulative capacities, a large number of operation and maintenance jobs are supported in Germany and Italy.

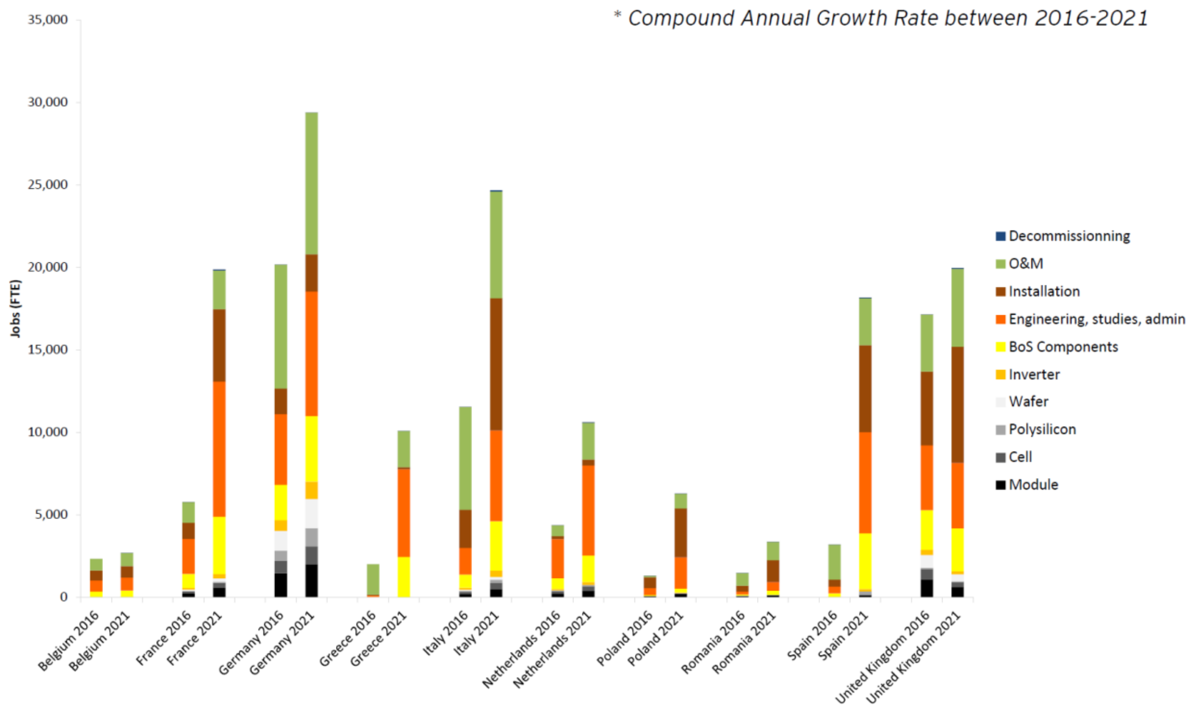

Figure 3. Number of direct and indirect job supports in 2016 and 2021, for both market segments (for ground-mounted and rooftop), by step of the value chain.

Source: Solar Power Europe, 2017

As installation and maintenance & operations are easier and less time-consuming for ground-mounted systems, these activities have a lower cost per MW. This means that fewer jobs are supported per MW compared to rooftop PV systems.

2.2.2. Photovoltaic modules

2.2.2.1. Technology segmentation and base assumptions

The shipment and stock data presented is segmented by technology. The main module technologies have been split in six categories, reflecting those with a market share greater than 1%: multi-crystalline, mono-crystalline, amorphous silicon thin films, cadmium telluride films, CIGS films and high efficiency technologies. The technologies have been compared according to their production (shipped capacity). However, reference to the shipment numbers as the basis for stock modelling should be treated with caution for three possible reasons:

1. Double counting of some of the production of OEM companies made without official reporting. This has been discussed many times within the industry but not quantified.

2. Replacements that are made due to failure or performance losses, which are not visible in recycling statistics (either because of recycling by the company itself, such as probably First Solar modules) or re-sales to other second hand markets.
3. Inventories awaiting for sales, or installations: the counting of installations based on commission date triggers a data glitch between shipments and installations in case of a growing market from one year to another.

It is therefore generally considered more accurate to base shipment estimates on reported installations. Here it can be assumed that the ratio of technology is similar within shipments as for final installations.

Modules capacity is generally expressed in watts of DC rated output (Wp). Because inverter market data is generally expressed in watts of AC rated output (W_{AC}), this issue will be dealt in the inverters section 2.2.3. to understand how the two may interrelate depending on the marker segment

In terms of the possible lag time between the arrival of modules in shipments and their use in an installation, this is considered to be no more than 3-6 months, depending on the number of intermediaries. For larger systems the modules may be supplied with a month of arrival directly to a site. A potentially more significant factor to take into account is the additional lag time before a system is connected to a network and formally reported on in statistics.

Each technology has a distinct manufactured price, which has often made them usable in some market segments rather than others. In relation to underlying pricing, the following generalized trends can be identified:

- Multi-crystalline is less expensive than mono-crystalline. Until 2015 mono crystalline was dominant at utility-scale but since then prices for mono-crystalline have declined as production has expanded.
- High-efficiency mono-crystalline has been used in all segments even if the residential segment has probably seen a higher penetration of that technology. But their share is difficult to measure over time.
- Cadmium Telluride has been used almost exclusively for utility-scale applications. Their use in other segments was extremely small.
- Copper Indium Gallium Selenide CI(G)S has been used in all segments, even if there is limited data to translate their application into a segmentation. This report considers to use an indicative share between segments.
- The share of amorphous silicon technology for residential applications has been very low due to space constraints.
- High efficiency technologies are defined as those achieving efficiencies indicatively greater than 22% with present technology, which may include modules based on heterojunction, back contact and bifacial cell structures.

Hence, it is not possible to estimate the monetary value of shipments, due to the lack of the official shipments data that is differentiated by module technology and pricing.

In terms of projected capacity this will be dealt with in the systems section 2.2.4. The base assumption is that modules will have a technical lifetime of 25 years, in line with the typical product performance warranty period provided by manufacturers (see section 2.3.2.3). However, further assumptions must also be made about the financial time horizon of a project and the buildings and land onto which a system has been installed in order to model lifetime. These assumptions are further discussed in section 2.2.3.

2.2.2.2. Stock data and forecasts

The global shipment figures for PV modules are shown in Figure 4 with a division per technology, i.e. multicrystalline Si (Multi), monocrystalline Si (Mono), cadmium telluride (CdTe), amorphous Si (aSi), CIGS and high efficiency modules[5] (HighEff). Concentration and Ribbon PV modules figures were found to be negligible. Cadmium telluride is the technology which has experienced the largest growth in the decade 2007-2016, followed by Multicrystalline and Mono silicon, and CIGS (around 500% each).

The total cumulative power of PV modules imported into Europe was approximately 87 GW up until the reference year, 2016. Adding the local production (23.92 GW) and subtracting the exports (9.43 GW)[6], we can have the installed base 101.86 GW for year 2016 that constitutes the stock. This figure represents one third of the cumulative global shipments up until the reference year (340 GW).

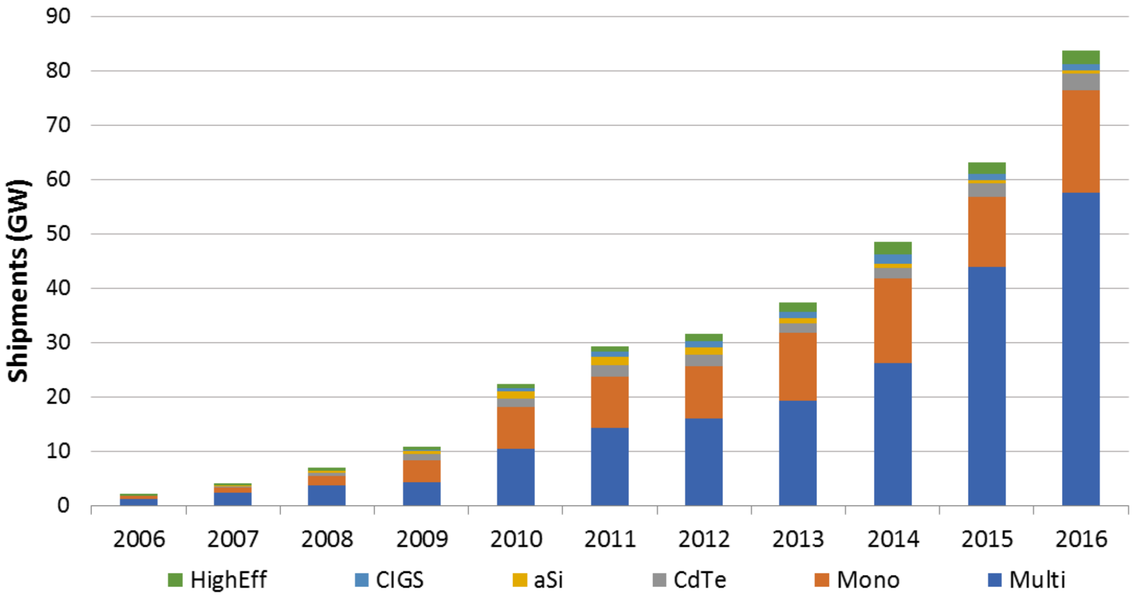

Figure 4. Cumulative global shipments of PV modules to the EU per technology. CPV and Ribbon PV data are negligible.

Source: Becquerel Institute, 2018

The evolution of the stock in Europe has seen years where the capacity installed was doubled (Figure 5), having received the momentum of feed in tariffs in the pioneer countries (e.g. Germany, Netherlands, see Task 1). From 2012 a decline was seen as a combination of factors: a retreat from the feed in tariffs that had driven the market and the impact of the economic crisis on properties and investments.

[5] Monosilicon with the addition of PERC technologies
[6] According to Becquerel Institute, 2018

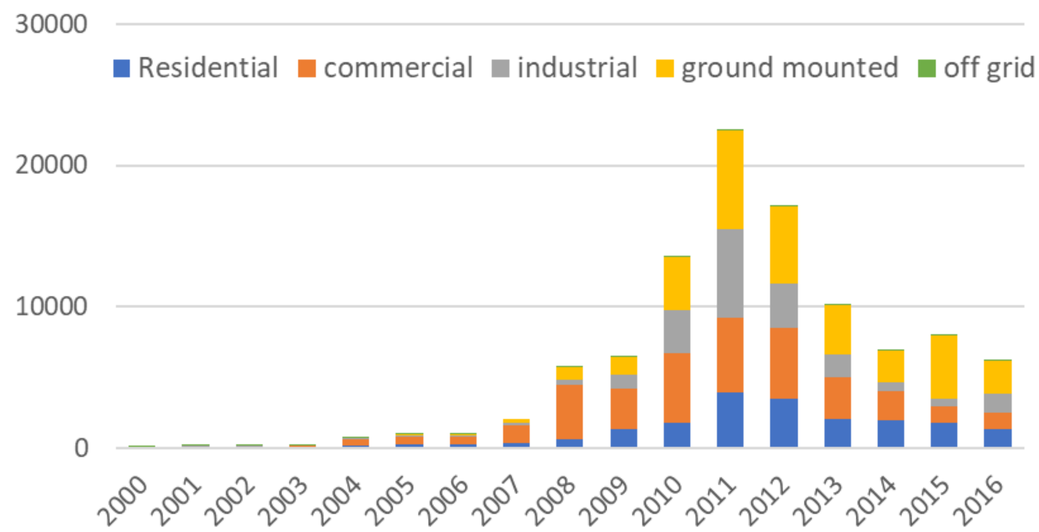

Figure 5. Evolution of the European PV stock showing the market segments, residential, commercial, industrial, ground-mounted and off-grid.

Source: Becquerel Institute, 2018

The PV technologies used in 2016 per market segment, i.e. residential, commercial, industrial, utility-scale and off-grid, are shown in Table 3. It is worth noting that there are technologies such as CdTe, aSI and CIGS that are barely used in sectors such as residential, commercial or even off-grid. These sectors are predominantly using more mature technologies, such as multi or monocrystalline silicon.

Table 3. Cumulative power of installations per market segment and technology at the end of 2016.

	Multi	**Mono**	**CdTe**	**aSi**	**CIGS**	**HighEff**	**Total**
Residential	11.38	6.55	0.00	0.00	0.54	1.01	19.48
Commercial	17.73	10.53	0.00	1.58	0.76	1.88	32.48
Industrial	9.95	6.18	0.00	0.92	0.50	0.83	18.38
Utility-scale	16.88	9.36	1.84	1.20	0.79	1.32	31.39
Off-grid	0.08	0.05	0.00	0.00	0.00	0.01	0.14
Total	56.02	32.67	1.84	3.69	2.59	5.04	101.86

Source: Becquerel Institute, 2018

The annual sales growth for the different market segments is reflected in systems section, 2.2.3.

The module prices are further analysed in Consumer expenditure section 2.4.

2.2.3. Inverters for photovoltaic applications

2.2.3.1. Technology segmentation and base assumptions

The main inverter technologies reported on in market data can be related to the categories for Power Conversion Equipment (PCE) identified from IEC standard 62093 in the Task 1 report, but with some modifications noted as follows:

- Category 1: Module-level power electronics (MLPE) – specified to operate at a PV module base level.
  - In general reference is made to inverters that interface with one module rather than up to four as described in the standard.

- Category 2: String-level power electronics – designed to interface multiple series or parallel connected modules and specified for wall, ceiling or rack mounting.
  - Distinction is made between single and three phase AC power delivered by a string inverter.
- Category 3: Large-scale power electronics – also designed to interface multiple series or parallel connected modules, but due to their complexity, size and weight are housed in a free standing electrical enclosure.
  - Distinction is made between those delivered as a standalone unit or packaged as a complete ‘solution’ with other power conditioning equipment such as transformers.

In addition to the definition of the technologies, a number of additional factors are important to take into account when interpreting inverter market data:

- Inverter capacity is generally expressed in watts of AC rated output (W_{AC}). Because inverter market data is generally estimated from module DC capacity it is important to understand how the two may interrelate depending on the marker segment:
  - in the residential segment for any given system the two tend to be closely related, although a ratio of up to 1.15 could be used.
  - In the industrial segment the inverter AC capacity may be less than the module DC power, with an indicative ratio of up to 1.22.
  - In the utility scale segment the inverter AC capacity will tend to be significantly less than the module DC power, with an indicative range for the ratio being 1.2 – 1.4.
- The presence of inverter distributors in the EU means that the final destination for a proportion of shipments will be off-grid markets in Africa.

In terms of relating the stock data to photovoltaic system market segments the following broad assumptions can be made:

- Micro-inverters attached to the module itself are less common but have experienced some market development in the last years. These are almost exclusively used in the residential market.
- Smaller installations of less than 1 MW have been using string inverters which collect electricity from a set of strings.
- In the last years, the cost decrease and capacity increase of string inverters (now up to 125 kW) has allowed to them to now be used in utility-scale plants instead of central inverters.
- Most utility-scale PV plants are using central inverters which collect the electricity from several PV module arrays through combiner boxes.

In order to ascertain the installed stock for any given year the data for installed systems must be used as the shipment data is an overestimate and does not account for the lag time to market and the redistribution of products to other markets (as noted in section 2.2.2.1).

In terms of projections for the evolution of the stock the following base assumptions and sources are proposed to be used:

- New capacity: newly installed module array capacity should be used as the reference point for estimation, as data is not collected for inverter installation. Forecasts for module array installed capacity are presented in section 2.2.3.
- Technical and economic product life: The very limited number of independent reviews of inverter failure rates suggest a 1%-15% annual failure rate. Peak failure rates have been estimated to occur in the first three years of product life, with average rates of between 3% and 4% quoted per annum. According to

an IEA Task 13 report on the financing of PV systems the technical life of an inverter is considered to be between 10-15 years. For the purpose of this study a minimum technical life time of 10 years is assumed for an inverter. There is some emerging evidence from the Solar Bankability project that longer technical life times of up to 13 years are now being used by investers in their financial planning for commercial PV systems. This is based on assumptions for PV systems up to 100 kW of a 15.5% replacement rate on average by year 10 and a 17% replacement rate on average by year 13.

- Replacement rates and time cycles: The typical failure modes for an inverter are assumed to trigger replacement. A minimum technical life time of 10 years is therefore assumed to also correspond to the minimum service life time, although it is to be discussed if this should be extended to reflect assumptions currently used by investors in larger scale systems.

2.2.3.2. Stock data and forecasts

Figure 6 presents the shipment data for inverters for the reference year 2016 and 2015. The shipment data is compiled from periodic surveys of manufacturers. In total 6,854 MW_{AC} of inverter capacity was shipped to the EU market in 2016. It can be seen that overall the EU market is dominated by three phase string inverter technology.

Estimates are then presented for 2017 through to 2022. These estimates are based on assumptions made about market trends and are cross-checked by manufacturers for their credibility before publication as a market intelligence source. Annual growth rates have been derived from this data and are presented in The total for new installed module array capacity was in the range of 6,216 to 6,734 MW_{DC} in the reference year 2016. With an adjustment for the undersizing of inverter AC capacity in proportion to module DC capacity on larger systems, the installed new stock in 2016 is estimated to be in the range of 5,678 and 6,151 MW_{AC}. Using similar assumptions the total installed stock until the end of 2016 is estimated to be in the range of 94,400 and 96,913 MW_{AC}.

Table 4.

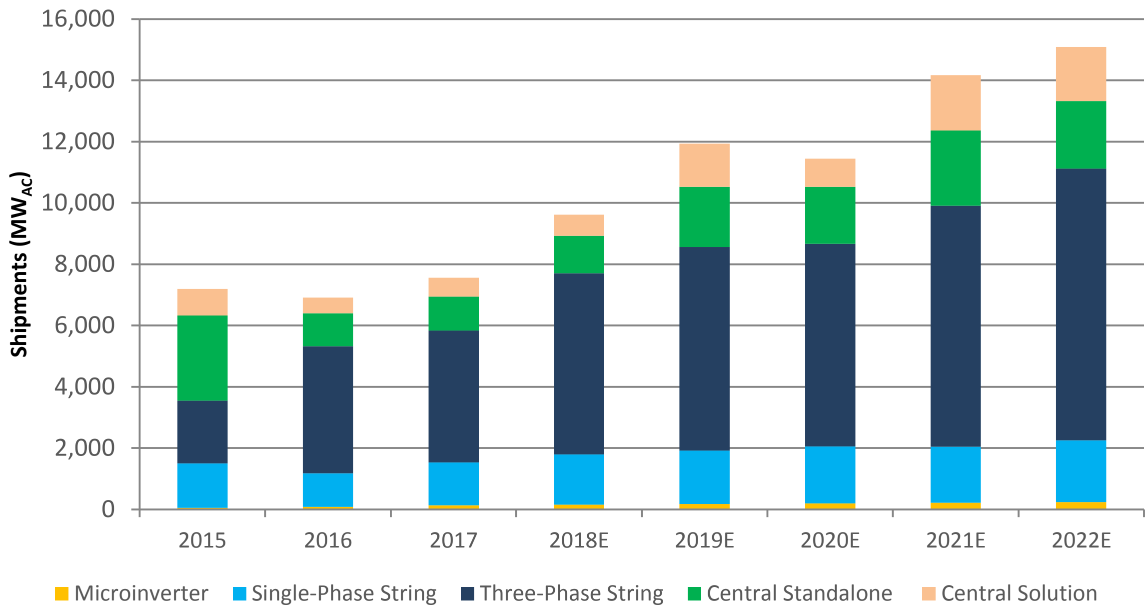

Figure 6 EU inverter shipments by technology (MWac) E=Estimate

Source: GTM Research (2017)

The total for new installed module array capacity was in the range of 6,216 to 6,734 MW_{DC} in the reference year 2016. With an adjustment for the undersizing of inverter AC capacity in proportion to module DC capacity on larger systems, the installed new stock in 2016 is estimated to be in the range of 5,678 and 6,151 MW_{AC}. Using similar assumptions the total installed stock until the end of 2016 is estimated to be in the range of 94,400 and 96,913 MW_{AC}.

Table 4 Projected annual sales growth rates for inverters

Inverter type	**2016**	**2017E**	**2018E**	**2019E**	**2020E**	**2021E**	**2022E**
Microinverter	81%	58%	11%	17%	13%	6%	10%
Single-Phase String	-24%	28%	17%	6%	7%	-1%	10%
Three-Phase String	103%	4%	38%	12%	-1%	19%	13%
Central Standalone	-62%	4%	10%	61%	-6%	32%	-10%
Central Solution	-41%	21%	11%	103%	-35%	97%	-2%
Total	*-4%*	*9%*	*27%*	*24%*	*-4%*	*24%*	*7%*

Source: calculated from data provided by GTM Research (2017)

2.2.4. Photovoltaic systems

2.2.4.1. Technology segmentation and base assumptions

Segmentation of systems depends on several parameters and, as was discussed in the Task 1 report, the definition can vary between Member States based on system size, the end-user and/or the type of site. In a post-feed-in tariff market there are some examples of segmentation based on the type of grid connection and interaction with the electricity market. Nevertheless, installed capacity thresholds have in the last ten years of PV market development segments been used as the basis for reporting by the IEA PVPS programme. In relation to this, the following segmentation has been followed, and is reflected in IEA PVPS national survey reports:

- Residential: systems up to 10 kW
- Commercial: from 10 to 250 KW
- Industrial: Systems above 250 kW, either on a building or used for self-consumption
- Utility-scale: systems above 1 MW, ground-mounted

In referring to these segments, it should be recognized that there can be overlaps between them. For example, the notion of a commercial building differs from country to country. Large industrial buildings can host larger PV plants than the smallest ground-mounted PV installations.

In order to estimate the segmentation in as accurately as possible, 90% of the installed capacity in Europe during one year is considered. The segmentation is then analysed at Member State level based on national reporting, and then from this an estimate for the EU is derived. In addition the overall dataset has also been cross-referenced with a dataset published by Solar Power Europe.

In terms of projections for the evolution of the installed system stock the following base assumptions are proposed to be used:

- Residential PV systems won't be decommissioned unless the roof requires replacing. While loss of performance will happen through for example degradation mechanisms, it is not a reason to consider decommissioning. It is assumed that the system lifetime will correspond to that of the modules, which could be higher than 20, 25, perhaps 30 years. Most probably some house owners will decide to replace their system with new panels but the probability of this occurring cannot easily be estimated. It is therefore assumed here that the systems as a whole will be decommissioned on average after 25 years.
- Commercial and industrial systems may be constrained by other factors such as the lifespan of the building itself on the site. However, assumptions that can be made from a PV system perspective are not readily available. A 25 year lifetime shall be taken as an initial assumption, but this will reviewed against EU data for typical building lifespans. For example, industrial buildings may have a shorter service life than that of the PV system.
- Utility-scale systems have mostly been developed based on 13 to 25 years incentives. It can reasonably be considered that they will be either decommissioned or repowered after 20 years on average. It could be possible to refine this assumption by looking at the amount of PV systems financed in each country under specific incentive schemes.
- Off-grid systems follow the same pattern as residential systems in terms of lifetime and decommissioning. They are out of the proposed scope, although data are presented in the tables below for completeness

2.2.4.2. Stock data and forecasts

Table 5 presents the evolution until the reference year 2016 of annual system installations in the EU. The data is segmented according to the five main system types and has been extrapolated from a detailed composition of 90% of the market to 100% of the market. The total installed system stock in 2016 is estimated to be 101,788 MW_{DC}. The majority of this stock was accounted for by commercial (32%) and ground mounted (31%) systems. Residential and industrial systems accounted for 19% and 18% respectively.

Table 5 Year on year EU installed system capacity by PV system market segment (MW_{DC})

	Residential	**Commercial**	**Industrial**	**Ground mounted**	**Off grid**
2000	43.17	18.23	3.73	0.00	15.40
2001	86.80	37.98	6.94	0.00	2.25
2002	80.72	43.30	8.42	0.00	4.53
2003	104.07	85.44	5.75	0.00	3.92
2004	152.61	470.02	58.34	44.99	3.27
2005	234.32	591.54	90.18	65.04	3.16
2006	261.95	579.01	86.37	66.44	3.11
2007	319.72	1316.30	151.03	243.47	0.00
2008	588.01	3884.60	332.97	931.81	5.52
2009	1352.28	2811.19	1036.91	1232.19	5.40
2010	1746.36	4929.61	3102.10	3766.29	6.84
2011	3954.43	5246.40	6269.12	6966.72	2.82
2012	3474.66	5051.45	3135.12	5410.80	1.45
2013	2099.02	2872.98	1610.58	3490.25	98.58
2014	1934.51	2090.14	607.60	2242.69	1.18
2015	1779.15	1203.04	468.85	4535.95	0.46
2016	1339.44	1190.44	1350.36	2333.55	2.61
Total installed stock	*19551,21*	*32421,66*	*18324,36*	*31330,20*	*160,49*

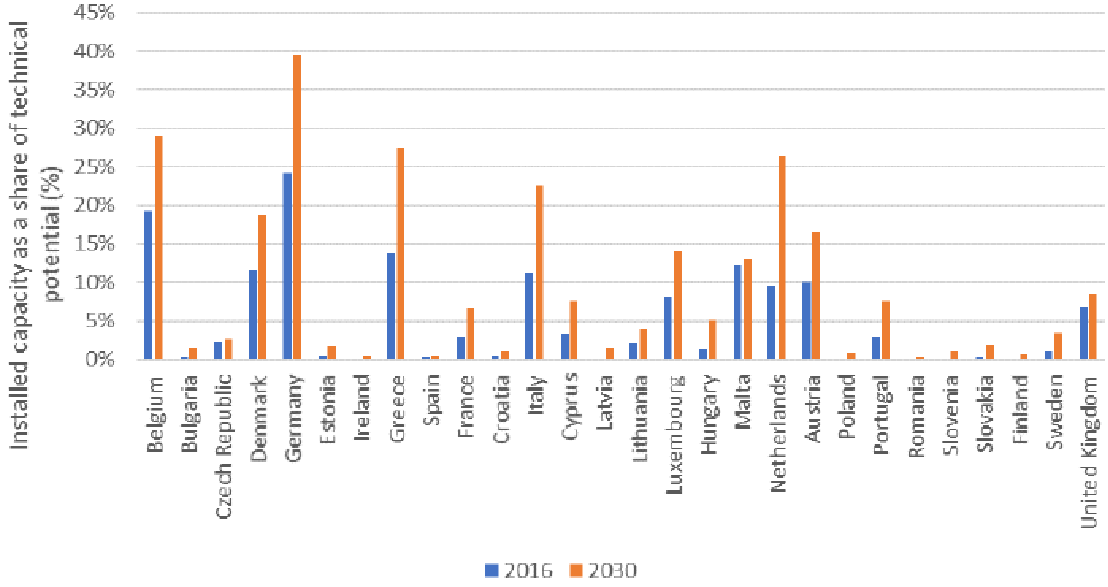

Figure 7. Installed capacity as a share of technical potential in 2016 and 2030

Source: GfK (2017)

The annual sales growth of the PV systems per segment is shown in Table 6. The ground mounted (which can be mainly considered as utility scale) which has experienced the largest growth in the years 2001-2016, followed by the industrial and commercial sectors where there were years especially between 2008 and 2011 that the growth doubled (over 100% each year). The total compound growth rate for the period 2001-2016 is close to 1000%.

Table 6. Annual sales growth of PV modules per segment in percentage. Derived from the data in Figure 5.

Year	Residential	Commercial	Industrial	Ground mounted	Off-grid	Total
2001	201%	208%	186%	-	15%	166%
2002	62%	77%	79%	-	26%	64%
2003	49%	86%	30%	-	18%	57%
2004	48%	254%	235%	-	13%	132%
2005	50%	90%	108%	145%	11%	77%
2006	37%	46%	50%	60%	10%	44%
2007	33%	72%	58%	138%	0%	62%
2008	46%	124%	81%	222%	15%	109%
2009	72%	40%	139%	91%	13%	58%
2010	54%	50%	174%	146%	15%	78%
2011	80%	36%	128%	110%	5%	72%
2012	39%	25%	28%	41%	3%	32%
2013	17%	11%	11%	19%	171%	14%
2014	13%	7%	4%	10%	1%	9%
2015	11%	4%	3%	19%	0%	9%
2016	7%	4%	8%	8%	2%	7%

Figure 8 takes the reference year of 2016 and presents the installed capacity per Member State and by market segment. The country with the largest capacity installed was United Kingdom, accounting for almost 2 GW_{DC} of capacity. Germany follows UK with 1,42 GW and in a third but further place lies France, with 559 MW. With the decline of feed-in subsidy for residential systems the installation figures are dominated by larger industrial and utility scale systems.

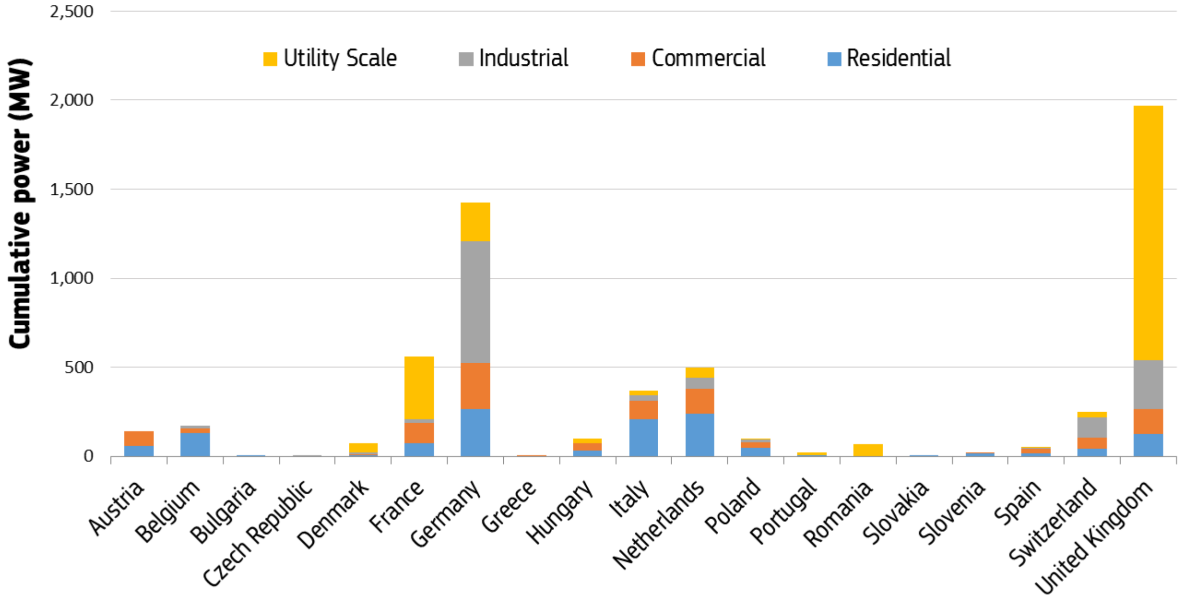

Figure 8. Capacity installed in most European countries in 2016 in MW_{DC}.

Source: Solar Power Europe, 2017.

Looking in turn at the cumulative power in Figure 9, it can be seen that Germany stands out among the other EU countries with 41.1 GW installed up to 2016. The second country is Italy with 18.98 GW historical data.

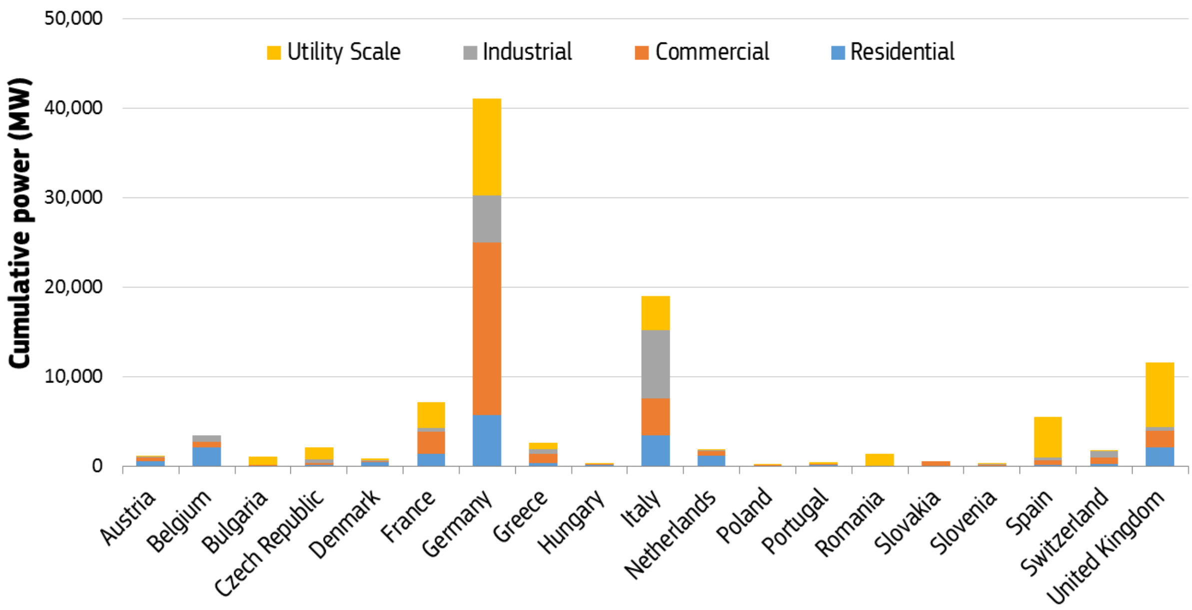

Figure 9. Cumulative Capacity installed in most European countries up to 2016 in MW_{DC}.

Source: Solar Power Europe, 2017.

Forecasts for the future PV system installations are fundamental in order to also develop stock models for modules and inverters, but a broad range of assumptions must be made and adjusted depending on the time horizon. The following assumptions for short, medium and long term forecasts are presented as the starting point for discussion:

- *Short term (until 2020).* Short term forecasts are based on bottom-up market analysis, including Member State policies supporting PV and the general trends in PV development. Such forecasts are in general valid for 2 or 3 years. Here the data published by the PV Market Alliance has been used. The relative stability of European policies for PV in the last two years indicate that until 2020, little changes can be expected. Starting from 107 GW in 2017, the installed capacity in 2020 could reach up to 137,5 GW according to the reference scenario and up to 146 GW according to the PV Market Alliance high scenario.
- *Medium term (2020-2030),* the situation is more complex since many countries have only defined policies to reach 2020 decarbonisation and RES targets. For the period until 2025, a mix has been used of the PV Market Alliance scenarios until 2022 and the European Reference scenario afterwards. It is notable that the numbers are quite low and show a significant market decline. The forecast is heavily dependent on EU policy. Development of the policy assumptions is explained further in the box below.

PV system forecasts to 2030

Modelling the influence of EU renewable energy targets

Major factors influencing that post 2020 situation relate to the political willingness in Europe to fulfill climate change commitments and the expected PV market developments due to price competitiveness (parity) in most European countries.

The decision to opt for a 35% RES target (or 63% RES-E target) could change the investment climate and lead to additional PV installations. In general it is estimated that the development of the PV market will continue, driven by the declining prices of PV systems, and its emerging competitiveness with wholesale market prices in several key countries.

This derives into two scenarios until 2025 and 2030. To assess the possible contribution of PV to these of a 35% RES, the number of RES-E TWh in 2030 is considered under such scenario (3528 TWh of electricity x 63% = 2223 TWh. Since 1210 TWh of RES-E could have been installed by 2020, the difference to be covered is 1013 TWh. Two main assumptions are then made:

- PV could provide one third of this difference, because according to scenarios published by EPIA (now SPE) in 2012-2013 the ratio between wind and PV could be 2:1.
- Most other renewables won't grow fast until 2030 given the competitiveness of wind and solar in the electricity sector.

This would translate into 334 additional TWh of PV electricity by 2030. These 334 TWh could translate into 281 GW (assuming 1200 kWh/kWp per year in average in Europe at that time). Since the starting point could be 146 GW in 2020, PV could increase up to 427 GW in 2030.

- *Long term (2030-2050)*, the main driver is likely to be decarbonisation of the energy mix in Europe under the reference scenario and a more ambitious one that is provided. The same methodology could be applied as for the RES as described for 2020-30. To reach 95% of decarbonisation in the electricity sector by 2050, based on the reference scenario, the additional amount of RES-E electricity compared to 2030 is calculated based on an assumed consumption of 4064 TWh in 2050. The reference scenario estimates nuclear production to 737 TWh in 2050, which leaves 3124 TWh to be produced with RES-E electricity. Or compared to 2030, an additional 900 TWh. This would translate into 300 TWh of additional PV, or using the same ratios, 250 Additional GW of PV or in total 678 GW by 2050.

The technical lifetime for the module component of a system is expected to differ more and more from the economic lifetime. PV modules conceived decades ago without cost limitations showed that, apart from the degradation of performance due to aging semiconductors, they could often last much more than 20 years. Since then the onset of mass production has raised concerns about manufactured quality and the lifespan of newer designs and bills of materials.

Once the current quality issues that are mentioned in several studies (IEA PVPS task 13 for instance) and which are currently the subject of intense interest within the industry are solved, PV modules should be capable of providing electricity more than 20 years. However, the economic lifetime depends on business choices and it is considered that 20-25 years will become a corresponding intended service lifetime for most PV plants (see the discussion in section 2.2.3.1 above).

2.3. Market trends

In this section the market channels and production structure are described in order to prepare the ground for the improvement potential to be analysed in Task 6. Firstly, meta trends for the development of solar photovoltaic sector are identified. Secondly, product level trends related to modules, inverters and systems are identified and then analysed. The following aspects are addressed in turn as part of the market analysis:

- Channels to market: direct to end-users, wholesalers & distributors, OEMs, own use, system integrator, etc., and its relation to placing on the Community market. B2B (business to business) versus B2C (business to consumer), distribution channels (retail versus wholesale), role of installation services;
- General trends in product design and product features; feedback from consumer associations
- Competitive analysis of the market: major players, main models, new players and new models, maturity of the market;
- Usual market segmentations: market shares of the major players and main models,
- Public procurement: tenders and auctions at member state level

The share of SMEs in the production and the segments of the markets in which SMEs are present are also addressed under these headings.

2.3.1. Meta trends – EU and Global solar photovoltaic market

In order to develop a global view of the major market trends that may affect the evolution of the market in the short to medium term (to 2020 or 2030), sets of major global trends identified by market analysts have been analysed. The trends identified have each been evaluated qualitatively in order to identify:

- the possible technological and market implications,
- the likely time horizon for their mainstream adoption, and
- the related degree of certainty.

The main sources of the trends synthesised are the IEA PVPS programme, Solar Power Europe, the PV Market Alliance and GTM Research. The results are presented in tabular form in Table 7. In summary the main trends identified can be categorised as relating to:

- the structure of global module production and supply,
- the type of the financial incentives and market arrangements that will be used by Member States to support further market growth,
- the relationship of utilities with their consumers and their extent of their role in providing solar PV systems,
- the extent to which self-consumption models will shape system designs in the future,
- a diversification in the range of digital and operational support services available to system owners, and the benefits these can bring.

Table 7. Identification and evaluation of global market trends

Trend	Description	Potential technology and market implications	Time horizon	Degree of uncertainty	Source(s)
Continued overcapacity in global module production	The ratio between supply and demand for modules will continue to pass through periods during which there is excess capacity and oversupply, forcing module prices to be driven down further.	○ Further rationalisation of the leading manufacturers who will in turn lead on the mainstreaming of new module technologies.	Short term	Medium	IEA PVPS (2017) GTM (2018)
Phasing out of financial support schemes	A reduction or complete phase-out of financial support schemes and their replacement by self-consumption policies or competitive tendering or auction processes. Self-consumption is still incentivized through net-metering within existing financial incentive schemes.	○ Larger projects with greater cost reduction potential will be incentivised. ○ More efficient module technologies will receive greater attention.	Medium term	Low	PV Market Alliance (2018)
Increased use of solar auctions to drive down prices	EU state aid rules have driven an increase in the use of competitive auctions and tenders for electricity price subsidy contracts in order to support deployment.	○ Ensures that solar PV is supported on a continuous basis rather than leaving the market open to bid with the cheapest technologies. ○ Contracts will be indexed to changes in market electricity prices. ○ Auctions have been introduced at the larger end of the market. ○ Reverse auctions by municipalities on behalf of citizens may become more common.	Medium term	Low	Solar Power Europe (2017) PV Market Alliance (2018) GTM (2018)
An increase in Corporate Power Purchase Agreements for solar energy	Public and private entities wishing to purchase renewable electricity are increasing seeking the 'additionality' of on or near site installations.	○ Installations may be driven by municipalities and a range of manufacturing and service companies. ○ A diversity of sites and project sizes may be brought forward.	Medium term	Low	Solar Power Europe (2017)
An increased focus on operation & maintenance services	A shift from feed-in tariffs to grid parity is driving a focus on maximising the output from systems over the long term in order to repay higher financing costs and maintain asset value.	○ Service companies will offer a range of on-site services, which could include repair and replacement. ○ Data analytics will be a key component required to support real-time monitoring.	Medium term	Medium	Solar Power Europe (2017)
An increase in the number of utilities that provide solar PV services	An increase in the number of utilities that, in response to competition for residential energy services, seek to provide solar PV services to households and businesses.	○ A range of business models could emerge ranging from third party ownership to off site PV generation projects.	Medium term	High	PV Market Alliance (2018)
An increase in self-consumption by system owners	An increase in the number of consumers that seek to maximise self-consumption of the electricity generated by their photovoltaic systems, stimulated by reduced availability of subsidy.	○ The complexity of schemes together with distribution company charges may limit their take-up. ○ Self-consumption will drive further market penetration of battery storage as an integrated component of solar PV systems. ○ Integrated BoS packages incorporating batteries will become more commonly offered to customers at a range of scales. ○ Batteries are not yet considered to have the same level of reliability as modules and inverters, which may lead to market differentiation. ○ 'Virtual net-metering' at grid level will increasingly be offered by utilities in competition with battery consumption. ○ Collective self-consumption from PV systems installed across several buildings or a community will attract more interest/support.	Medium term	Medium to high	Solar Power Europe (2017) PV Market Alliance (2018) IEA PVPS (2018)
Digitalisation of PV systems and components	An increase in the devices integrated into a system design that support capture and analysis of data for a range of purposes, including fault diagnosis and demand side management.	○ Increased digital and smart integration in the offer for home systems. ○ Increased pooling of data from systems in order to identify common faults and to provide economies of scale for O&M services.	Medium term	Low	Solar Power Europe (2017)

2.3.2. Product trends – PV modules

2.3.2.1. Market segmentation

Figure 10 illustrates the global market share for the predominant crystalline silicon cell types for the reference year 2016 and as projected to 2027. It can be seen that the PERC family of cell types has quickly entered the market, achieving already a significant market share, and is projected to account for the largest market share by 2021.

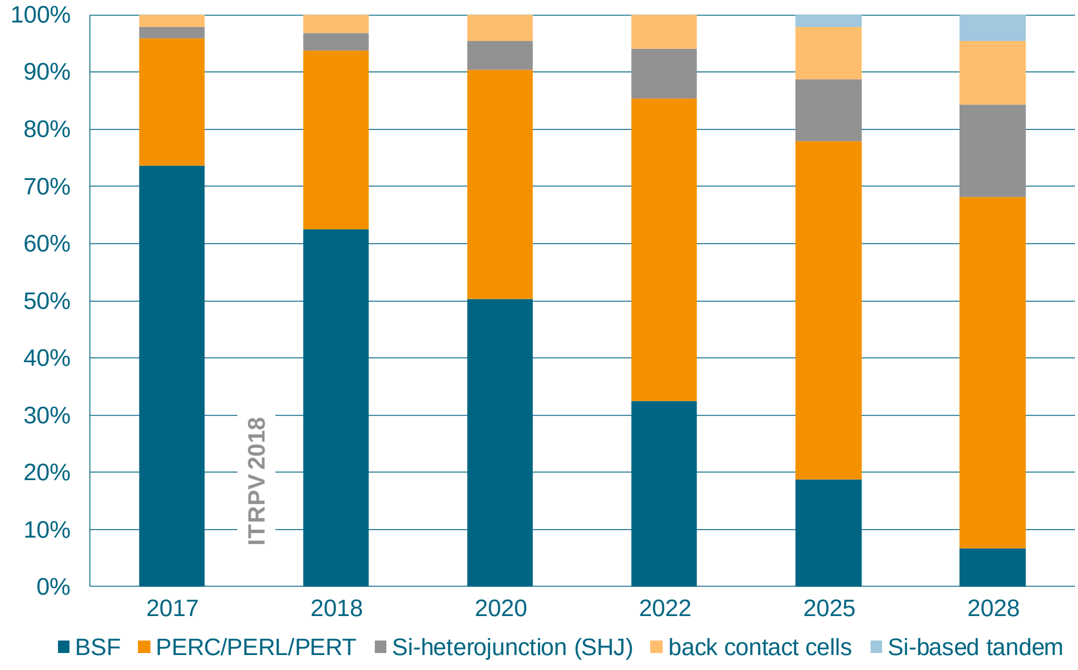

Figure 10. Worldwide market share for different silicon based cell technologies

Source: ITRPV (2018)

At a global level the market is increasingly being driven not only by the shipped price but also the module efficiency, which in turn influences the Levelised Cost of Electricity (LCOE) that can be achieved. In this respect the most significant innovations that have been introduced into the global market in the period 2014-2016 are modules based on:

- Back Surface Field (BSF) cells,
- Passivated Emitter and Rear Cell (PERC),
- Back contact cell types,
- Heterojunction cell types,

These innovations at cell level have also been accompanied by a shift from cast p-type polycrystalline silicon to grown n-type monocrystalline silicon wafer substrates.

Bifacial cell types are projected in Figure 11 to grow steadily, and to reach approximately 20% market share by 2021, driven largely by large rooftop and utility scale system installations. The ITRPV projection reflects the views of commentators that once PERC cell structures have become the mainstream industry standard then bifacial modules will quickly follow within as short as a 12-18 month period [7].

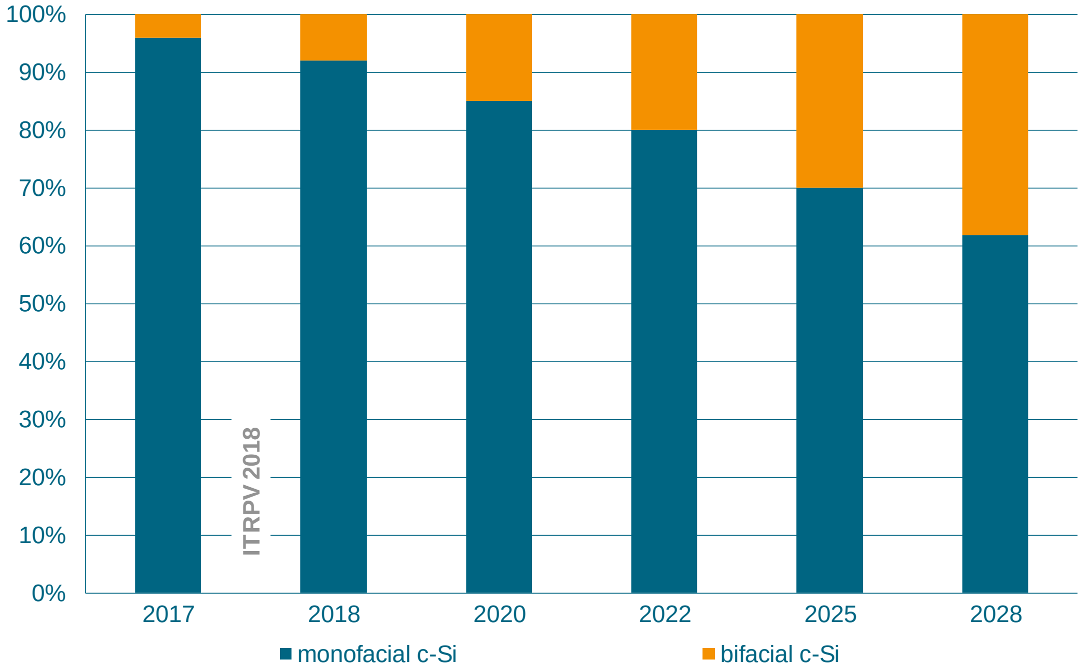

Figure 11. Worldwide market share for 'true' bifacial modules

Source: ITRPV (2018)

The market for Building Integrated PV is expected to continue to retain a niche in the market, accounting for an estimated 2% of the PV market as a whole. In 2015 Europe was estimated to account for approximately 42% of the installed global capacity, which translates into 967 MW or approximately 11.4% of EU installed capacity. France and Italy can be seen to have led the development of this market segment. Cumulative installations to 2016 and projections to 2020 are presented in Figure 12.

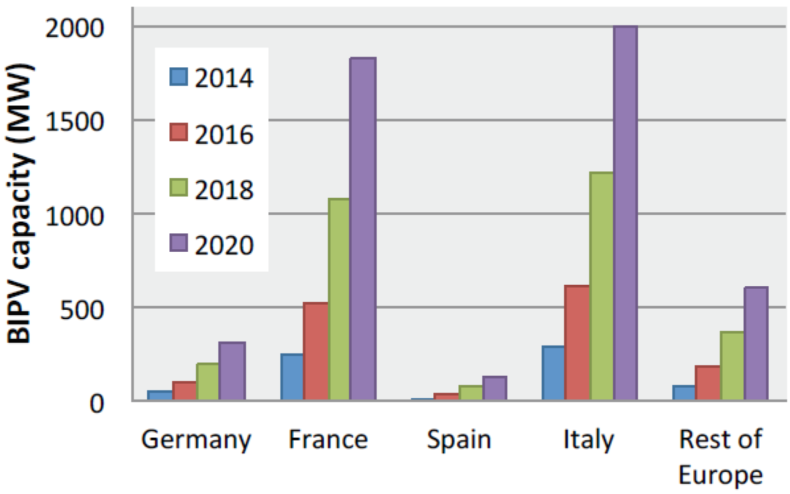

Figure 12 European recent past, current and future (2014-2020) analyses of BIPV market for Germany, France, Spain, Italy and the rest of Europe. Source: Global Industry Analysts (2015)

[7] PV Tech, Mono based PERC modules to drive bifacial market entry in 2018,

It has been claimed based on market analysis that two thirds of BIPV applications are to be found on new buildings. Moreover, In terms of the types of buildings the market split is been estimated to be as follows - residential buildings (19%), public infrastructure (14 %), showroom offices (13%), universities and schools (9%) and historical buildings (7%).

Studies have differed in which product applications are most significant in the market. The PV Sites project identified three main product applications have been identified – roofing, walling and glazing products (PV Sites 2016). Non-glass based roofing products can be seen in their market analysis in Figure 13 to account for the majority of the market value. Meanwhile a separate study of the EU BIPV market carried out in 2015 identified that the majority of BIPV applications were façades (over half), followed by roofs (one third), and combined roof/façade products.

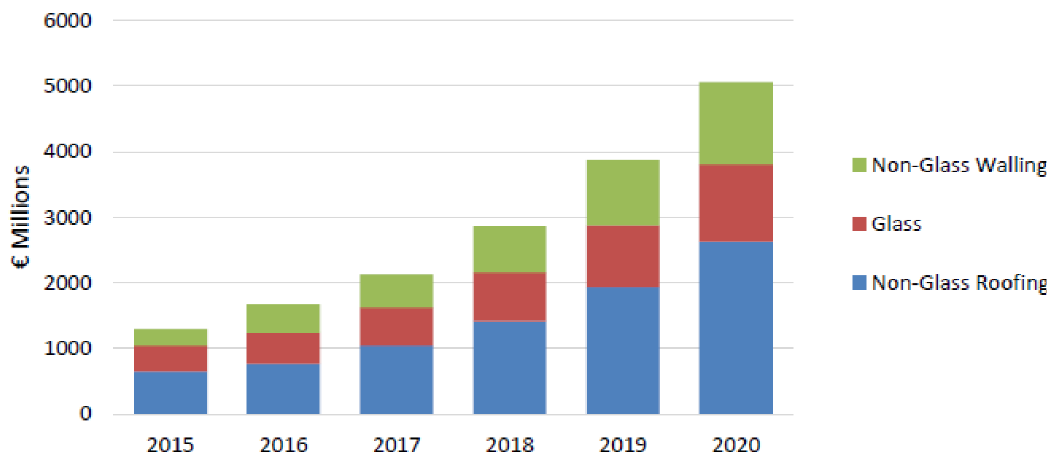

Figure 13 European BIPV market forecast 2015-2020 in € millions

Source: PV Sites project (2016)

2.3.2.2. Trends in product design and features

2.3.2.2.1. Crystalline silicon cell-based modules

The principal trends apparent to purchasers of crystalline silicon cell-based modules relate to the cell structure, with a number of new cell types, dimensions and bus bar arrangements having rapidly gained global market share. These improvements have in turn been reflected in higher stabilised efficiency values for the cells used to manufacture module and, for modules products as a whole, improved Cell to Module (CTM) power ratios.

It can be seen in Figure 14 that p-type polycrystalline cell types achieved an upper limit to efficiency levels of approximately 21% in 2016, projected to rise to 23% by 2027 (represented by PERC/PERT cell types) whereas n-type monocrystalline cell types supported efficiency levels in the range of 21% to 23% in 2016, projected to rise to 24 -26% by 2027 (represented by heterojunction and back contact cell types).

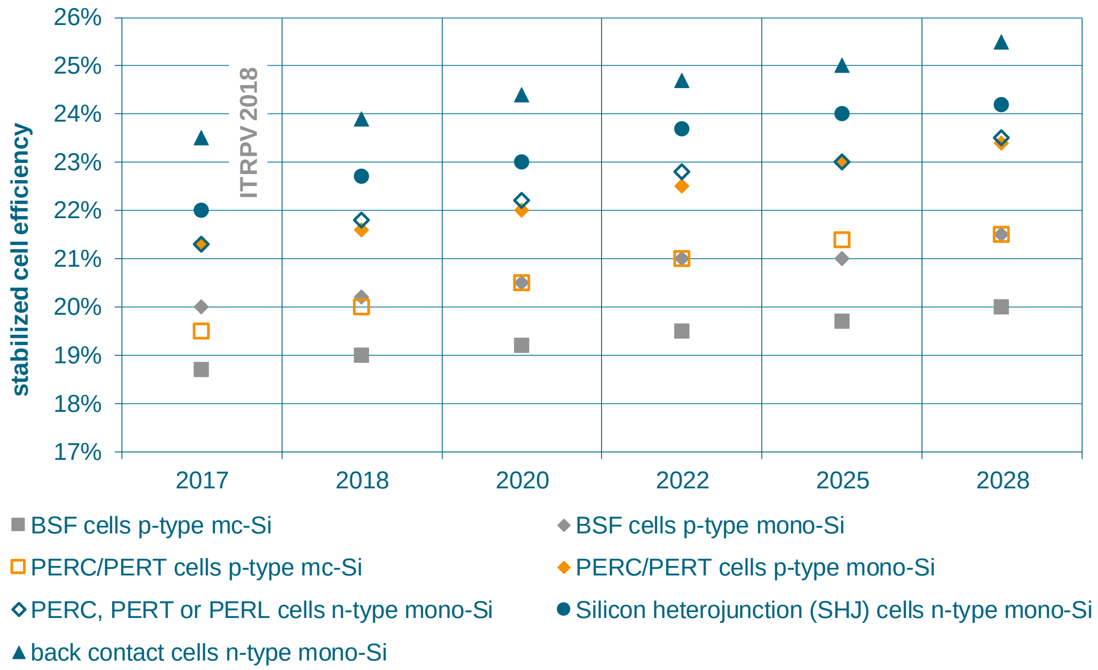

Figure 14. Average stabilised efficiency level for C-Si solar cells (156 x 156mm^2)

Source: ITRPV (2018)

In terms of cell technology trends, other than those that related to the PERC family, the following can be identified:

- *Back contact cell types* without visible front busbars have also been available for some time in the market as a niche product that provides both improved efficiency and distinct aesthetics. The market share cell type is projected to continue to grow steadily after 2017.

- *Silicon heterojunction cell types* have been available for some time in the market, as pioneered by Sanyo, but they are not projected to achieve a market share greater than 10% until 2021 - 2024.

- *Silicon-based tandem cells* can theoretically achieve higher efficiencies by layering an additional cell with a different spectral band gap on top of a silicon cell, but for the purposes of this study are still considered to be classified as a Best Not (yet) Available Technology (BNAT) They are currently projected to enter the market in some form from 2019 onwards, although the status of research into perovskite type cells, which are commonly identified as a potential tandem cell component, suggests that this is an optimistic.

- *Bifacial cell types* allow for both faces of a cell to generate electricity. Field tests suggest increases in yield of upwards of 20%. This cell type is considered to be particularly relevant to modules that will be installed on raised or ground mountings, usually in systems on commercial roofs or at a utility scale. It is anticipated that the predominant bifacial cell structure will be PERT with n-type silicon [8]. This module type will come at a higher cost due to the 5-10% premium for the n-type wafer, so commentators have also suggested that new cell structures that allow for use of cheaper p-type wafer substrates will gain market share – for example, mcPERT and pPERT.

[8] Kopecek,R, *Who's who at the leading edge of bifacial PV technology*, PV-Tech special report, September 2017.

Whilst the *number of cells* in a module is anticipated to increase, with the market standard number increasing from 60 to 72 by 2021, *the size of cells* is anticipated to now decrease in order to minimise *cell interconnection losses*. Half cells are projected to grow steadily, achieving a market share of 20% by 2024.

A number of *module level design innovations* are available in the market and are claimed to offer a range of life cycle and operational benefits. They include:

- Alternative framing materials: Steel instead of aluminium is claimed to give a reduction in life cycle embodied CO_2 emissions, as well as simplified manufacturing processes [9]. However, frame material changes are not projected to gain market significance in the medium term.
- Frameless modules: With associated reductions in framing materials and the advantage of greater protection of the cells from damage [10] whilst allowing for bifacial performance gains. Their market share is projected to rise to over 20% by 2028.
- Simplified fixing systems: With associated reductions in the bill of materials, the time of site required for installation and the spacing between modules.
- Anti-soiling coatings: The application of repellent coatings to the module glass which can reduce the accumulation of dust and dirt on the surface of each module [11].

Encapsulation and back sheet materials are both major cost contributors in module manufacturing. The intense efforts made in the recent years have lowered the cost of encapsulants. New materials such as polyolefins are expected to increase in the coming years, as seen in Figure 15. However, it is predicted that EVA will remain dominant encapsulant (above 60% share) over a ten year period according to ITRPV, 2018. According to the same roadmap, back glass is expected to gain a significant share over foils as backsheet material, reaching 40% share by the next decade.

In terms of the module junction box, the bypass diodes will increasingly be connected using solder and potting instead of clamps. Improvements in junction box sealing can provide improved moisture ingress protection. However, both of these specifications create a dilema as both are understood to have implications for the ease of access to and replacement of bypass diodes, as will be discussed further in section 3.3 of Task 3.

Decentralised junction boxes are a module design improvement that has the potential to both reduce cabling length per module and contribute to a marginal reduction in cable resistance losses across a module array.

A broader trend towards 'smart' junction boxes integrating a number of additional functions can be identified in Figure 16. Additional functions will largely include the integration of a micro-inverter and/or a DC/DC converter or optimiser that provides Module Level Power Management (MLPM). Both are projected to enter the market, but are not anticipated to make major inroads in the next 5-10 years. 'Cool' bypass switches designed to prevent overheating are understood to be becoming adopted in high output modules but have a cost implication.

The *quality and durability* of modules has become an increasing focus of attention for both manufacturers and buyers. This had led to action to improve design and manufacturing processes.

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[9] Bessing, N, *Q Cells – Steel frame and other module level innovations*, Presentation made by Q Cells at PV Module Technology & Applications Forum 2018, 29th January 2018.

[10] Verlinden,P. *Advance module concepts*, Chapter 10.4, p-502 in Reinders et al (2017) *Photovoltaic solar energy – from fundamentals to applications*, Wiley.

[11] Voicu et al, *Anti-soiling coatings for PV applications*, Presentation made by DSM at PV Module Technology & Applications Forum 2018, 29th January 2018.

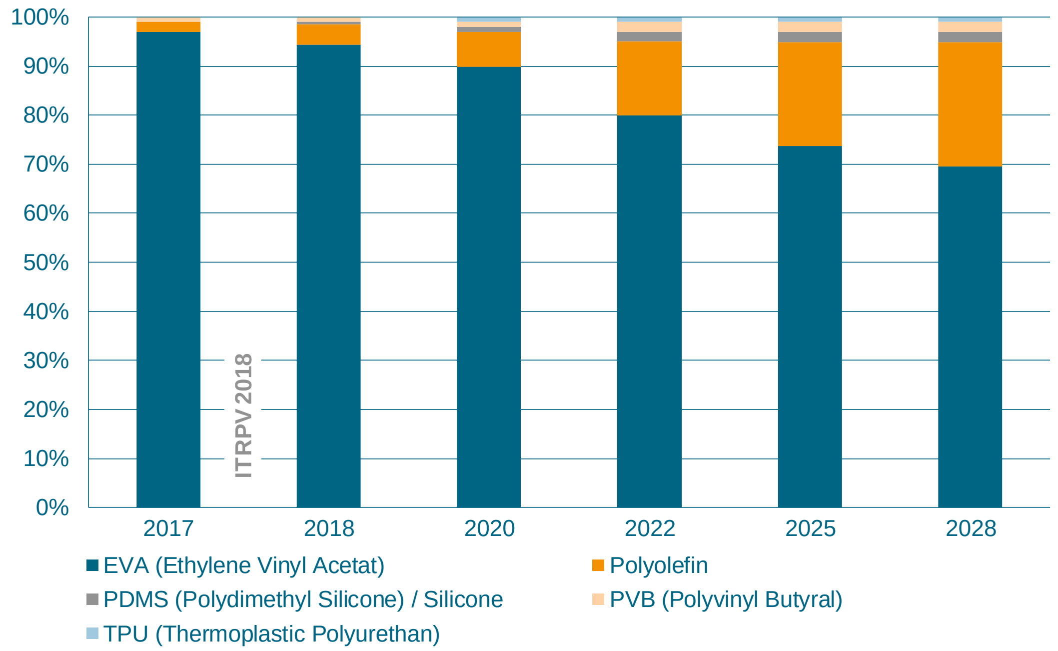

Figure 15. Expected trends in module encapsulation materials

Source: ITRPV (2018)

In line process control is a focus of attention to improve the reliability of modules in their first few years of operation. Reference to process control was made in Task 1 because some feed-in tariff schemes have established factory quality certifications for cells and/or modules as a pre-qualification requirement. Eleven control methods for cells and five for modules have been identified by the roadmap ITRPV, and are identified in Figure 17, Figure 18 and Figure 19. Over time these methods as applied to cell preparation are projected to become more common. Their contribution to reliability will be explored further in the Task 4 report.

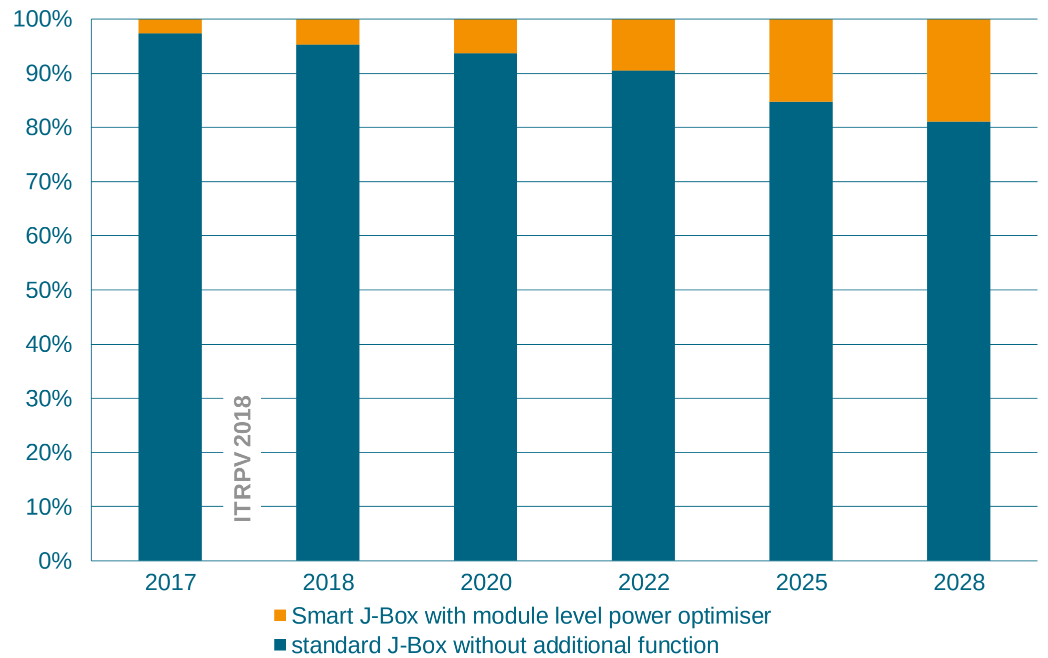

Figure 16. Expected trends in junction box technology

Source: ITRPV (2018)

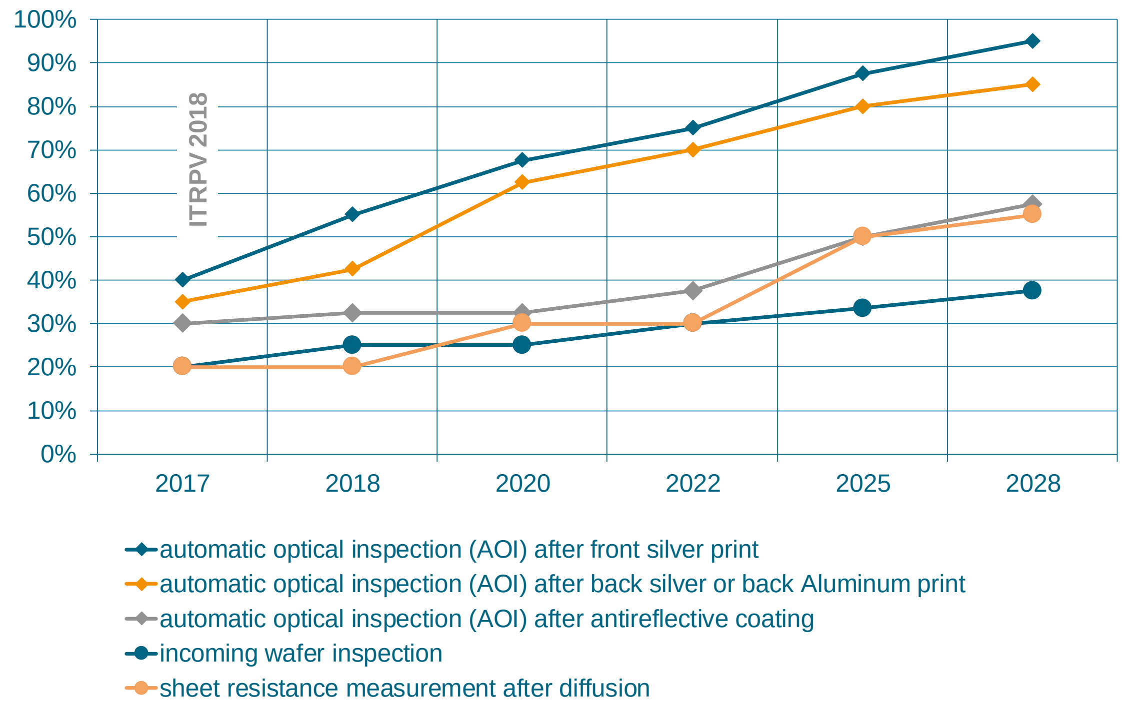

Figure 17. Expected trends for in line process control of wafers and cells (coating stage)

Source: ITRPV (2018)

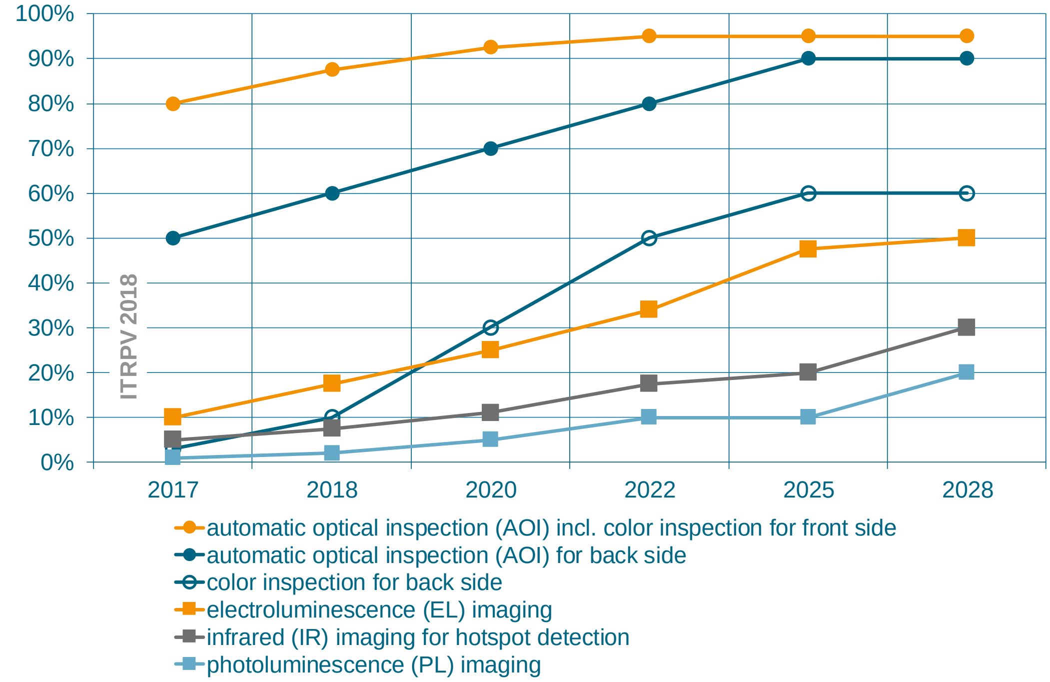

Figure 18 Expected trends for in line process control of cell testing and sorting

Source: ITRPV (2018)

Another important aspect of performance is degradation over time. This performance aspect, alongside other aspects that influence the overall functional life span (durability) of a module, are an increasing focus of attention for manufacturers and buyers. The initial degradation during the first year of operation, otherwise referred to as the burn in period, is projected to improve from 3% to 2% by 2019. Although the length of product (defect) warranties are not anticipated to increase in length above 10 years. The annual level of degradation during a performance warranty is projected to improve marginally from 0.7% to 0.5% over the next decade, allowing for performance warranties to be extended to up to 30 years. Although it is notable that some manufacturers already offer a product warranty that is the same length as the performance warranty (25 years, see Figure 20).

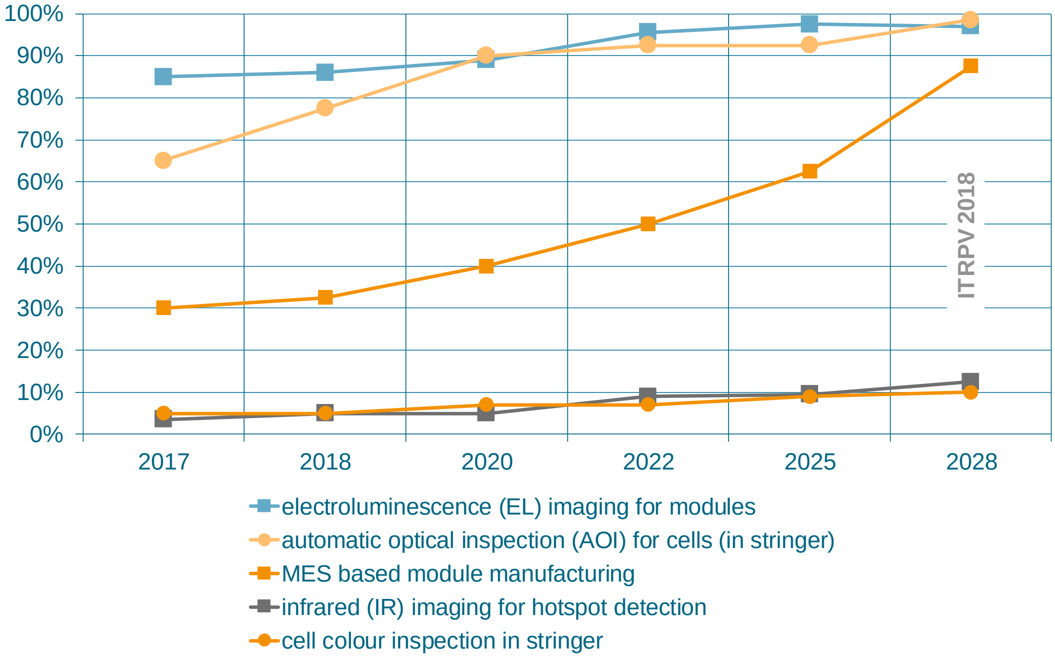

Figure 19 Expected trends for in line and manufacturing execution systems for modules

Source: ITRPV (2018)

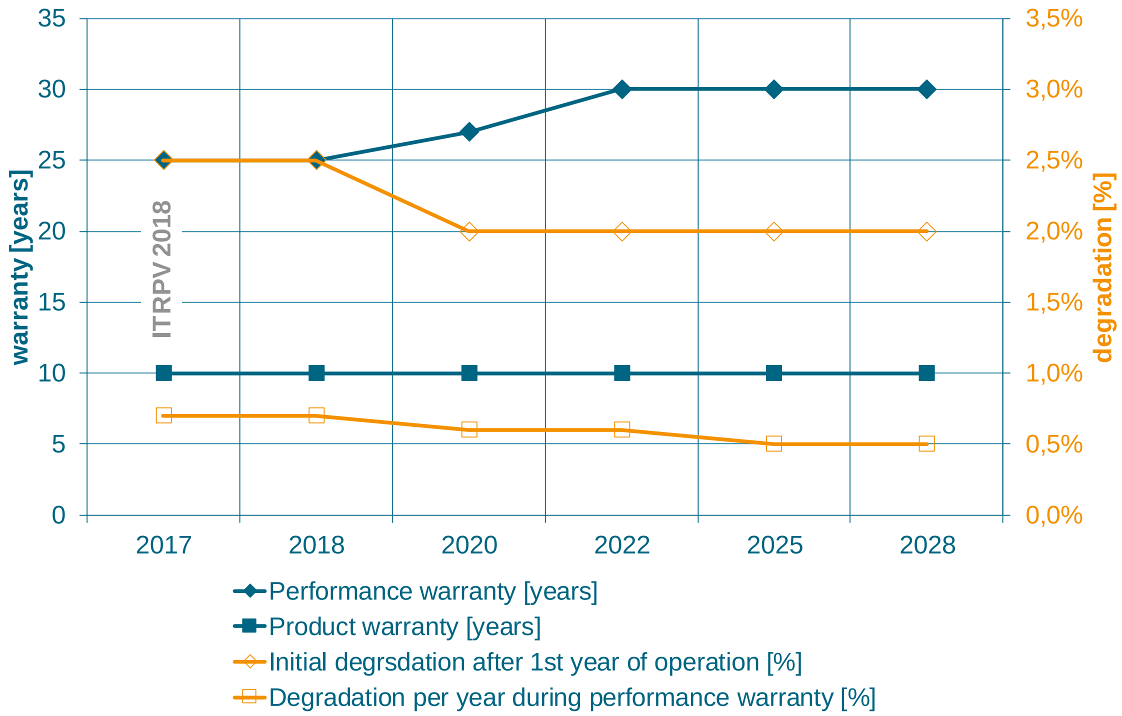

Figure 20 Expected trends for crystalline silicon module warranties and degradation

Source: ITRPV (2018)

2.3.2.2.2. Non-crystalline film-based modules

Compared with silicon based technologies the availability of information about the trends for thin film technologies is rather limited. Trends and improvements for the mainstream products mainly refer to cost reduction and improving material efficiency, i.e. solar cells with less material but with higher efficiency. Moreover, because of the encapsulation techniques used thin-film technologies fulfil most of the architects' and constructors' requirements for the building skin, hence the BIPV market is expected to gain importance for these technologies.

Thin Si solar technology, which includes amorphous thin film technology as well as nano and micro crystalline technology, has seen major progress made in terms of efficiency gains made using the multi-junction strategy (up to quadruple junction). This includes the use of:

- advanced light trapping schemes,
- deposition regimes and processing allowing high quality material or highly textured substrates,
- the use of proper supporting and buffer layers, and
- an optimized photocurrent matching[12].

Notwithstanding the objective of targeting record efficiencies, the low cost manufacturing and aesthetics of the thin films should still make this technology attractive for the BIPV market.

Cadmium Telluride (CdTe) technology seeks to reduce the demand for raw materials (e.g. tellurium) on a per watt basis, through bandgap engineering. Failure Mode and Effects Analysis (FMEA) has been incorporated by the main CdTe thin film producer, as well as a continuous Product Reliability Monitoring ("PRM") program to ensure product reliability is maintained globally during high-volume manufacturing. The reuse of glass from disposed PV modules for the production of new modules as well as semiconductor material (in 2016 new CdTe modules contained 8% recycled content) forms part of a global recycling program.

Copper Indium Gallium Selenide (CIGS) PV technology is starting to be produced in large volumes, and companies are pursuing different manufacturing pathways. One of these is the production of flexible modules that could be easily integrated in BIPV applications. As for reducing the cost and increasing production capacity, the main strategies are identified are[12]:

- cell thickness reduction,
- absorber materials with an increased band gap to enhance the open circuit voltage,
- lowering the series resistance and losses reduction in the transparent conduction oxide layers (TCO) and interconnects, and
- improved TCO materials and cells interconnect.

Interconnecting thin film modules with different strategies may lead up to 50% material saving with a potential to become commercial, as it has proven to give results in R&D (Cheetah project 2017)[13].

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[12] Photovoltaic solar technology: from fundamentals to applications. 2017 John Wiley & Sons. Several authors

[13] Cheetah project deliverable: D8.19, Interconnected thin film modules with up to 50% material saving. December 2017: http://www.cheetah-project.eu/fileadmin/user/Deliverables/CHEETAH_D8.19_VF.pdf

Beyond the evolution of the technologies this sector is more focused on module design, increasing the module area, junction boxes (e.g. two rear boxes), quick installation features, etc. The search for low cost encapsulants and packaging has also gained importance for flexible modules.

2.3.2.2.3. Building Integrated PV products

A market analysis carried out in 2014 defined eight main categories of roof and façade BIPV products in the EU market (see Figure 21)[14]. A 2015 BIPV status report identified 200 distinct BIPV products as being available on the market [15]. These products in general respond to existing architectural needs by substituting like for like an existing functional building fabric element. A BIPV producer survey carried out by Verberne et al (2014) found that crystalline silicon cells are preferred for roof applications and thin film large area cells for façade applications, as a result of price and aesthetics being more critical in commercial applications.

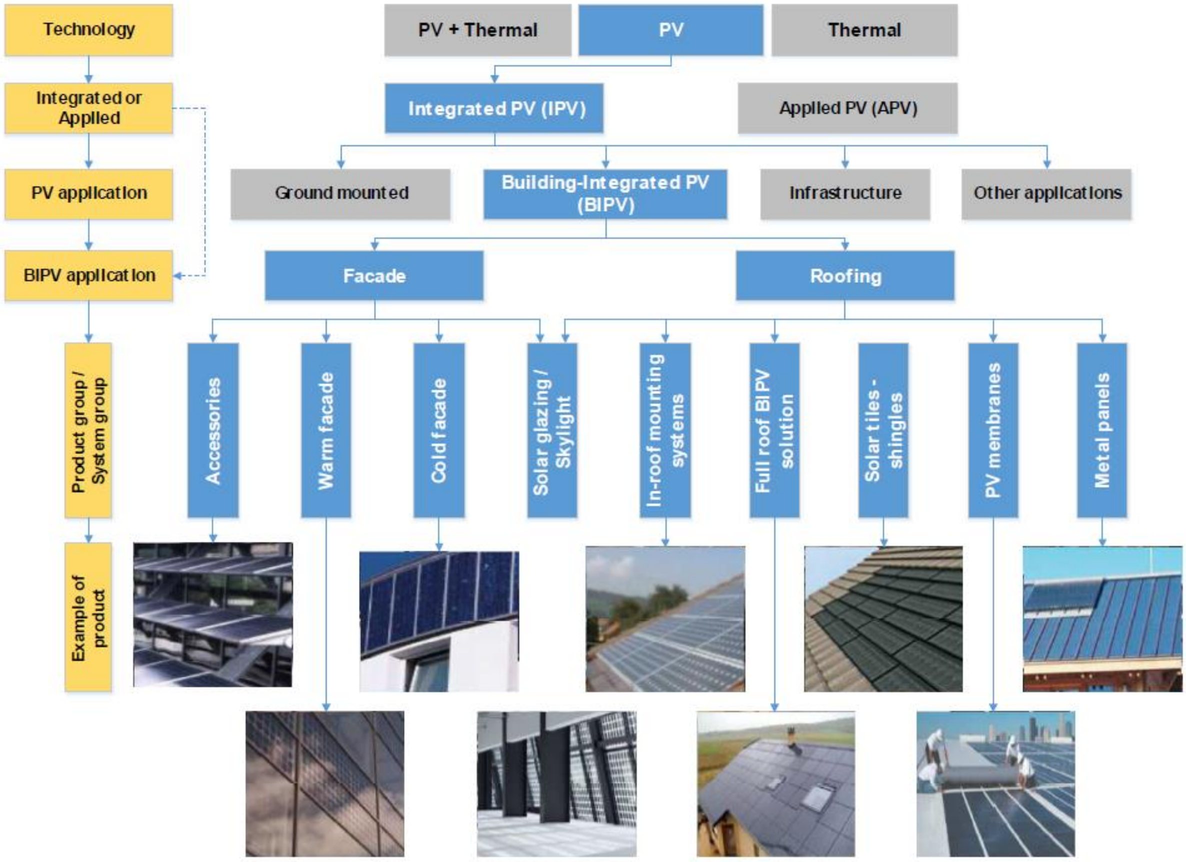

Figure 21 BIPV product categorisation according to a market study

Source: Verberne et al (2014)

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[14] Verberne.G, Bonomo.P, Frontini.F, van den Donker.M.N, Chatzipanagi.A, Sinapis.K and W.Folkerts, *BIPV products for facades and roofs: a market analysis*, Presented at the 29th EU-PVSEC in Amsterdam, The Netherlands, session 6DO.7, Thursday 25th, 2014

[15] F. Frontini, P. Bonomo, A. Chatzipanagi, G. Verberne, M. Van den Donker, K. Sinapis, W. Folkerts, *BIPV Product Overview for Solar Façades and Roofs - BIPV Status Report 2015*, Eindhoven (NL) & Lugano (CH), 2015

2.3.2.2.4. Feedback from the stakeholder questionnaire

The first stakeholder questionnaire included a question on what stakeholders considered as the commercial state of the art for module technology. The answers given by respondents are briefly summarised in this section.

Q1.5 Please indicate what you consider as the commercial state of the art for each of these technical aspects

- *Power conversion efficiency:* Six out of the 22 respondents suggested looking at the International Technology Roadmap for Photovoltaic (ITRPV) 2017, while a good fraction of them, 7, highlighted PERC technologies as the state of the art, with efficiencies ranging from 16% to 20%. Heterojunction technology with efficiencies from 19% up to 22.7% in 2018 were reported by 5 respondents. Monolithic integrated CIGS cells with an efficiency of 14% were cited by 2 respondents.
- *Quality, durability and lifespan:* Extending the module life to over 25 years, or that the warranty is both on product and power output was noted by 8 out of the 23 respondents. New standards were considered to be required to estimate the design service lifetime, IEC 61215 and 61730 test standard exist but there is no true durability or lifespan standard and the tests should be extended compared to the IEC standards. Tests should incorporate combined loads and stresses. Other technical improvements identified included glass glass modules, new encapsulants and edge sealing.
- *Material intensity and raw material use:* 5 out of 20 respondents focussed attention on the forecast reduction in silicon, the reduction in silver needs for contact fingers and busbars (below 50mg/Wp) was also mentioned by 4 respondents. Some respondents also stated that there are on-going initiatives for replacing silver with copper or other substitute materials.
- *Hazardous substance presence:* Three main issues were pointed out by the majority of 14 respondents: lead free soldering (10), REACH or RoHS conformity (4) halogen free backsheets (3).
- *End of life management:* the majority of respondents (14 out of 18) noted that compliance with WEEE through recycling is needed. Some suggested the possibility to have recycling facilities or that modules are designed for recycling, as well as the need for collecting systems or a payback system for the producer/importer. Reference was made to the PV Cycle scheme.
- *Other aspects:* A range of other technical aspects were identified:
  - use of copper plating to reduce silver consumption (TetraSun was cited),
  - several wafer production methods were cited that avoid cutting losses (e.g. Kerf less: http://1366tech.com/technology-2/),
  - methods to lower the energy demand of silicon (e.g. FBR solar grade silicon production https://www.elkem.com/no/elkem-solar/),
  - low temperature, solution based absorber deposition for perovskite solar cells to lower the energy demand of PV module manufacturing, though this is not commercialised yet.
  - sourcing PV manufacturing electricity from low carbon electricity sources such as PV itself (PV breeder concept)

2.3.2.3. Competitive analysis

The world PV modules market is dominated by the production of silicon technologies. China in particular can be seen to dominate the whole value chain, including polysilicon production, ingot production, wafer production and cell/module production. The country accounts for almost half of global module supply and deployment today. Figure 22 and Figure 23 show the Chinese shares in 2015 of the production volumes of cells and modules, being 65% and 69% respectively.

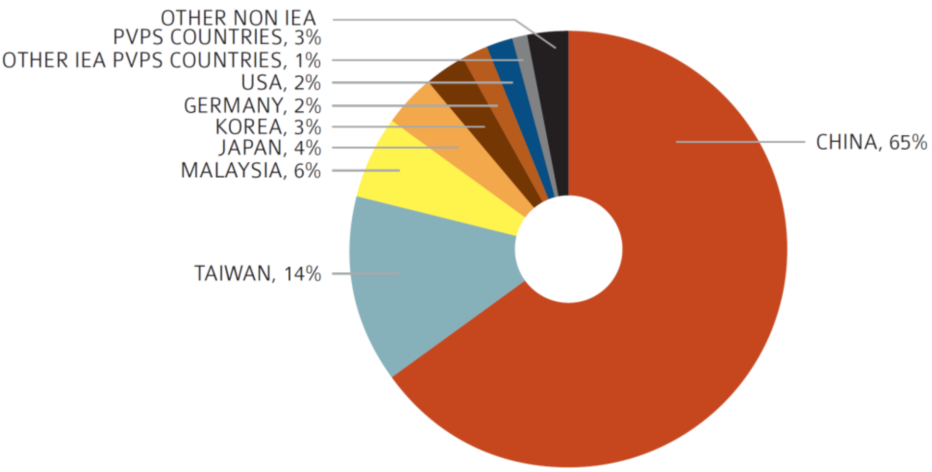

Figure 22. Share of production volumes of PV cells in 2015. Source: IEA Trends in 2016 PV applications

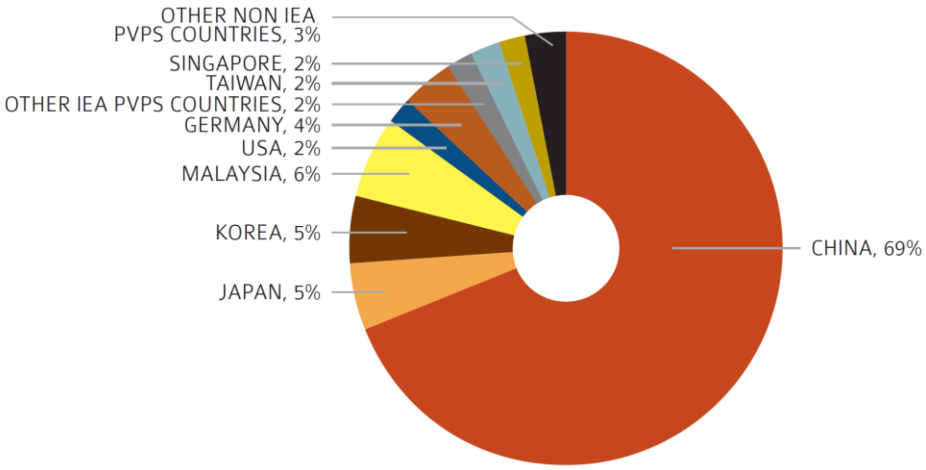

Figure 23. Share of production volumes of PV module in 2015. Source: IEA Trends in 2016 PV applications

Silicon based PV technologies are to be considered as mature technologies and the major producers can be identified as forming part of what has been referred to by commentators as the Silicon Module Super League (or SMSL)[16]. The SMSL is comprised of the seven companies that are expected to each ship in excess of 4GW of modules in 2018, well above the expected output of all other module suppliers to the industry and it is estimated that they will account for over 50% of global shipments (see in Figure 24 the leading companies). Initially formed by Canadian Solar, Hanwha Q CELLS, JA Solar, Jinko Solar, and Trina Solar, it was expanded in 2016 to include LONGi and GCL.

Six of the SMSL members are headquartered in China, with the seventh, Hanwha Q-CELLS (Korean), having about one-third of its cell/module capacity based at the former Solarfun facilities in China. Critically, all of the SMSL have the potential to supply multi-GW levels of modules to the largest market in the world today, China. Shipment levels of solar modules in 2017 appears to be well above 90GW, significantly higher than any of the market forecasts that other third-party market research firms have been giving for the past 12 months, at least. The two

[16] PV-Tech, *Silicon Module Super League defines key metrics for PV ModuleTech 2017*, 21st August 2017, https://www.pv-tech.org/editors-blog/silicon-module-super-league-define-key-metrics-for-pv-moduletech-2017-part

most recent members of the SMSL (GCL-SI and LONGi Solar) are relative newcomers to cell and module manufacturing having made their mark in the industry as poly/wafer dominant suppliers.

	2016 Global	Producer	
1	JinkoSolar	JinkoSolar	SMSL
2	Trina Solar	Trina Solar	SMSL
3	Canadian Solar	Canadian Solar	SMSL
4	JA Solar	JA Solar	SMSL
5	Hanwha Q-CELLS	Hanwha Q-CELLS	SMSL
6	GCL-SI	GCL-SI	SMSL
7	First Solar	LONGi Solar	SMSL
8	LONGi Solar	Risen Energy	
9	Yingli Green	Shunfeng (incl. Suntech)	
10	Shunfeng (incl. Wuxi Suntech)	Yingli Green	

Figure 24. Leading module suppliers to the China/non China industry in 2016 (left) and 2017 (right). Source: PV-Tech Solar Media (August 2017)[17]

In terms of destination for shipments Figure 25 illustrates the importance of China in sustaining the SMSL members. It has been the leading driver of shipment growth coupled with domestic initiatives such as Top Runner programme, which was described in the Task 1 report, have clearly helped the SMSL to prioritise investment in new production and cell technology. In comparison Europe and recently the USA, both with protective trade stances, have become relatively less important in sustaining large volume manufacturers such as the SMSL.

Module supply from the SMSL is understood to be setting the benchmarks for all PV module suppliers to the industry today, in part driven by their response to the Chinese market and its Top Runner programme. This group of companies have been investing heavily in new production technology and cell structures. Until the end of 2015, in-house cell production by the SMSL mainly consisted of standard (full-Al BSF) p-type multi cells, with upgrades confined to moving from 3 to 5 busbars. They have subsequently quickly moved from p-type polycrystalline cell-based modules to p-type monocrystalline cells with PERC-type structures and p-type polycrystalline cells based on black silicon that can be cut with diamond wire saw technology. The result is that, as can be seen in Figure 26, by the end of 2018, almost all in-house cell capacity will be through advanced cell processing (PERC and 'black-silicon' based cell variants on p-type mono and multi).

[17] PV-Tech, *Silicon Module Super League defines key metrics for PV ModuleTech 2017*, 21st August 2017, https://www.pv-tech.org/editors-blog/silicon-module-super-league-define-key-metrics-for-pv-moduletech-2017-part

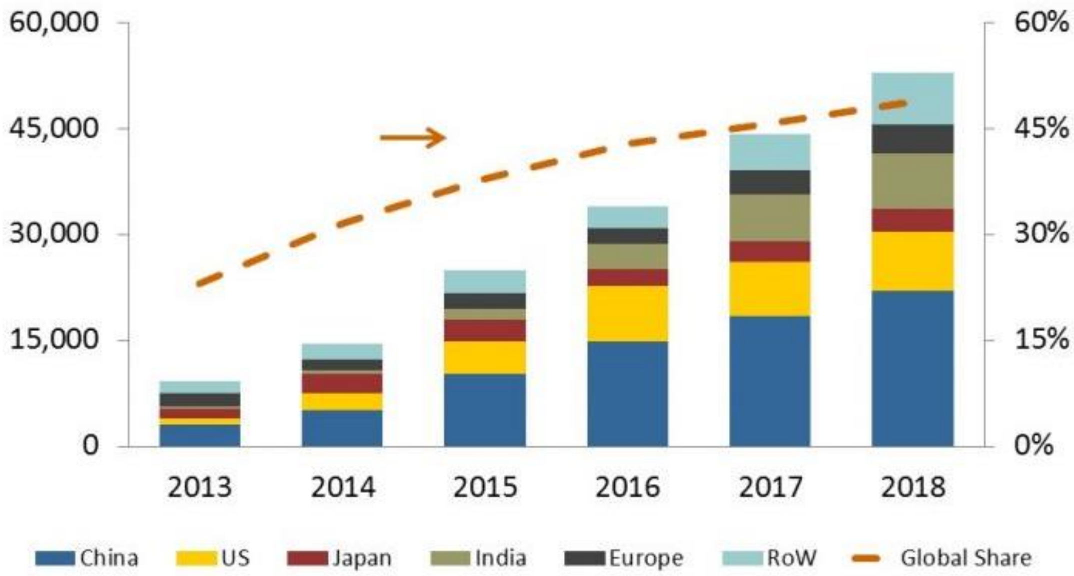

Figure 25. Silicon Module Super league (SMSL) shipments by geography (in MW). 2018 data is a forecast. Source: PV-Tech Solar Media (August 2017)[18]

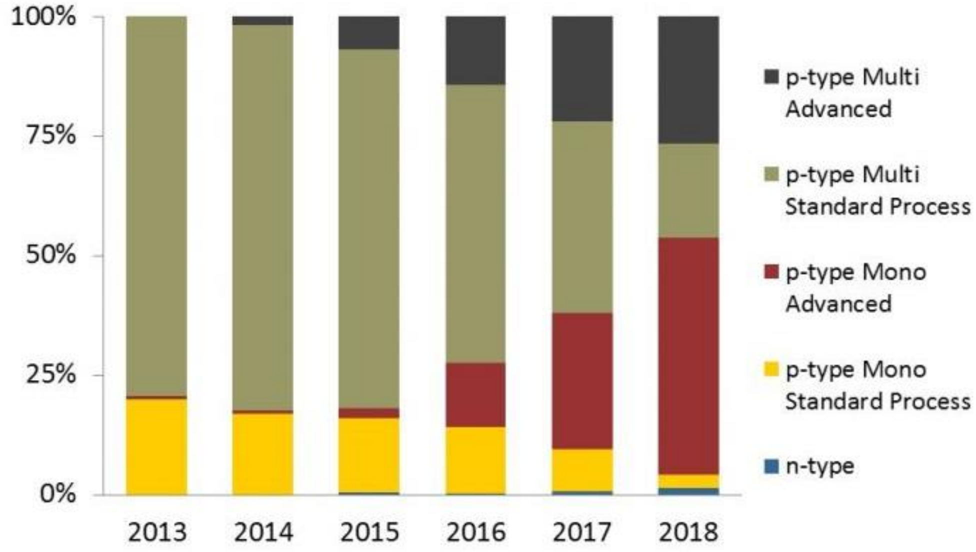

Figure 26 . In –house cell capacity by technology. Source: PV-Tech Solar Media (August 2017)

Source: Trinomics report, 2016. [18]

Following large scale adoption of new cell structures and module technologies it is now predicted that during 2019-2020 SMSL members will turn to bifacial cells and glass-glass module structures. Out of the top ten global manufacturers three of them are now (in 2018) producing bifacial technologies (Yingli, Trina and LONGi Solar). Although bifacial PV systems are currently based on PERT and Heterojunction (HJ) technologies, recently more

[18] PV-Tech, *Silicon Module Super League defines key metrics for PV ModuleTech 2017*, 21st August 2017, https://www.pv-tech.org/editors-blog/silicon-module-super-league-define-key-metrics-for-pv-moduletech-2017-part

PERC producers have decided to enter the bifacial market segment. They include PVGS, Yingli, LG, HT-SAAE, QXPV and Adani. [19]

While the manufacturing of modules now largely takes place outside of Europe, the manufacturing of turnkey production line solutions for silicon wafer-based and thin-film module production, as well as other manufacturing components such as grinding machines, screen printing, wafer saws or analysis tools, continues to be an European important competence with Germany companies in particular playing a key role by continuing to capitalise on their early establishment in the EU market [20]. It is claimed that PV machine tools made in Germany still account for 50% of the global market's production capacity.

While not all cell manufacturing production lines are the same, the following processes are among those used to fabricate silicon-based PV cells:

- wafer inspection,
- anti-reflective coatings,
- frontside and backside printing,
- (acid) texturing,
- doping,
- diffusion,
- testing and
- final classification.

All of these steps require specialised equipment. the situation for module manufacturing is relatively similar, with steps such as testing/sorting, string assembling, busing, lamination, framing and trimming also requiring specialist equipment. So whilst Chinese module manufacturers will be responsible for introducing new PERC, heterojunction and bifacial cell structures into the global and EU market, they will be to a great extent relying on European production line technology.

Table 8 Indicative examples of extended product and performance warranties

Module manufacturer	*Product warranty term*	*Performance stability and warranty term*
Sunpower – *Standard terms*	 25 years	 90% after 25 years
LG – *Mono type* – *Bifacial glass-glass*	 25 years 15 years	 80% after 25 years 86% after 25 years
Winaico – *PERC mono type*	 15 years	 80% after 25 years
Trina Solar – *Bifacial glass-glass*	 10 years	 80% after 30 years
Hanwha Q Cells – *Back contact type*	 12 years	 80% after 25 years

Source: compiled from manufacturers' publicy available literature

[19] Kopecek,R, *Who's who at the leading edge of bifacial PV technology*, PV-Tech special report, September 2017.

[20] Trinomics, *Assessment of photovoltaics, Task D - Opportunities for European Reindustrialisation*, Final report presented to the European Commission, 23rd November 2016

In terms of product (defect) warranties it is notable that some manufacturers have extended their warranties to cover the same term as performance warranties for which, as identified in section 2.3.2.2.1, the industry standard is 25 years. For example, Sun Power's X series of modules is covered by an extended 25 year warranty coverage for both product defects and power yield [21]. A summary of some of the extended product and performance warranties available in the market is provided in Table 8. There is also emerging evidence from the market that the anticipated greater durability and reduced degradation associated with bifacial module structures is already being reflected in longer warranty periods.

2.3.2.4. Channels to market

In general it can be seen that the photovoltaic modules market is highly competitive, which means that there are limited margins which in turn restricts the number of intermediaries. Manufacturers' channels to market for conventional modules are generally limited to:

- Direct sales to developers or large installers,
- Sales via local subsidiaries,
- Sales via distributors then to installers
- Products then sold under the brand name of another company.

Each of these will be discussed in turn in the following section. The market for Building Integrated Photovoltaics (BIPV) is rather more diverse, although also with a limited number of intermediaries, and is briefly also reviewed in the following sections.

2.3.2.4.1. Conventional modules

In general for systems of a size greater than 100 kW, the system developer will tend to go directly to the manufacturer. This is a question of price since distributers take a 15-20% margin on modules. The regional or country representatives of manufacturers are in general subsidiaries of the manufacturer. In some cases, they are established companies, which could be considered as distributers. In some cases competition can exist between local subsidiaries and international distributors.

Distributors have served as important intermediaries since the beginning of the mass deployment of PV in Europe by providing products (modules, inverters) to installers of small, mainly residential systems. They tend as a result to be well established companies (e.g. Krannich solar in Germany). Instead of a spot market, a market exists based on future prices. A customer can book for a designated price some quantities of PV panels for a delivery in the future. This is usually done in order to guarantee a fixed price for a project to be realised in the future. Both developers and distributors are working with such future contracts.

Table 9 provides an approximation based on an industry directory of the number of wholesalers and distributors in each Member State.

Due to cost pressure, the market share of distributors in the large-commercial and industrial segment is rather small, since the margins they take don't allow them to be competitive in these markets. Larger installations do not normally use distributers for the cost reasons already cited unless a manufacturer is unable to deliver on time and the project must be finished at all costs (often due to financial penalties).

[21] Sun Power, Accessed April 2018, https://global.sunpower.com/high-efficiency-solar-technology/

Instead of a spot market, a market exists based on future prices. A customer can book for a designated price some quantities of PV panels for a delivery in the future. This is usually done in order to guarantee a fixed price for a project to be realised in the future. Both developers and distributors are working with such future contracts.

Table 9. Number of wholesalers, wholesalers-distributors and distributors of PV modules in EU per country

	Wholesalers	**Wholesalers/ Distributors**	**Distributors**
Austria	22	2	2
Belgium	11	6	12
Bulgaria	9	2	3
Croatia	5	-	1
Cyprus	2	1	2
Czech Republic	11	7	12
Denmark	15	-	7
Estonia	2	1	1
Finland	4	1	2
France	31	9	14
Germany	148	29	39
Greece	15	5	7
Hungary	12	7	9
Italy	34	21	34
Ireland	3	-	5
Latvia	-	1	-
Lithuania	2	1	-
Malta	1	1	2
Netherlands	93	12	14
Poland	16	5	8
Portugal	5	2	5
Romania	19	2	4
Slovakia	3	-	1
Slovenia	5	1	1
Spain	25	17	18
Sweden	14	3	1
United Kingdom	33	17	13
Total	496	138	166

Source: ENF Solar (2018)

The question of how distribution will look in the future is a complex one. The distributors found their place on the market since small installers started to develop. As already seen in some countries (such as Germany for instance, or the USA), large companies, including traditional utilities are starting to offer PV products for residential and commercial applications. These companies compete directly with small installers, with a competitive advantage for well organised large players: the ability to buy directly from the manufacturer and propose reduced prices. Companies such as EON in Germany, Engie in Belgium, Iberdrola in Spain or Enel in Italy as proposing such PV products. Not all of them are targeting the residential segment but all are looking at rooftop installations. This could lead to a decrease in the price at which modules are invoiced for small applications, putting a high pressure on traditional distributors.

Re-branding exists for modules. Some modules could be sold under a different brand than the manufacturers' one. This is especially valid with packaged products, and for small installations. With the issue of quality having assumed a greater priority in recent years, the rebranding of modules and the use of OEM production is potentially problematic for verification and traceability, which will be required for a module product to be considered as 'bankable' [22]. This tends therefore to favour companies that have vertical integration of production and raw material supply.

The importance of Original Equipment Manufacturers (OEMs) for module manufacturing has been reduced significantly in the last few years due to the consolidation in the sector and the lack of competitiveness of European manufacturers. In a very fragmented value chain, the module manufacturers were buying cells from the cheapest providers in order to be competitive. Even companies integrated vertically (i.e. producing wafers, cells and modules) started to buy some wafers or cells on the market when it was more profitable for them to do so than to use their own products.

On the module side, many small actors with some dozens of MW of production capacity were either producing niche products or were used as OEM for larger manufacturers. JABIL in Poland, which close a few months ago in 2018, used to do OEM for large Chinese companies in Europe, in order to circumvent the anti-dumping taxes, but also to increase their production when the demand was higher. In China, former tier 3 companies are not selling directly anymore but are producing modules for Tier 1 companies. The lack of competitiveness of these small actors in Europe has led to a quasi-complete abandonment of OEM contracts.

System integrators have in general contracts with several module manufacturers but for large quantities will put out calls to any of them. As has already been mentioned, there is no real “spot” market for modules as such since the price of PV modules depends on the technology, amount and the delivery date. The cheapest (bankable) manufacturer is in general therefore able to sell. Large tenders favor the cheapest manufacturers, since quantities are important and the visibility is high. To reach a deal for these tenders, most manufacturers are proposing their lowest prices, often very reduced or no margin, in order to get the contract.

2.3.2.4.2. Building Integrated PV products

Building Integrated PV products represent a small segment of the market. This segment is significant for having distinctly different channels to market, originating from specialist suppliers and being largely distributed via the building trade rather than the wholesale distribution route identified for modules.

With roofing having been identified as the most significant BIPV market segment, a wide range of possible channels to market can be identified based on the diversity of roofing materials used across the EU (see Figure 27). Facades represent a more challenging market in terms of pricing and quality. Figure 28 identifies the predominant materials used for facades.

[22] Colville.F, *Module quality emerges as new marketing tool for the solar industry*, PV Tech Magazine, 3rd October 2017, https://www.pv-tech.org/editors-blog/module-quality-emerges-as-new-marketing-tool-for-the-solar-industry

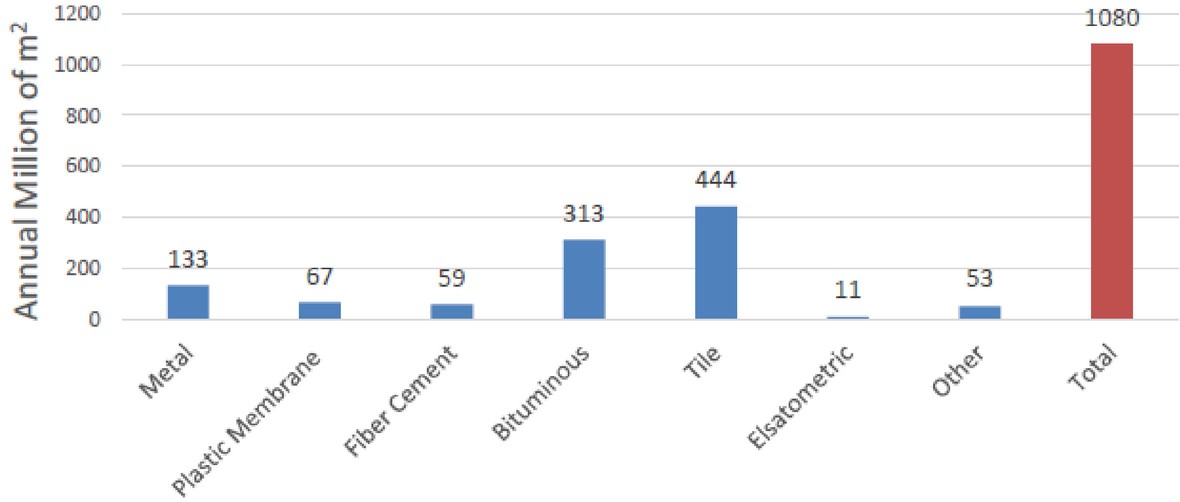

Figure 27 Overview of roofing material segmentation in Europe in 2014

Source: PV Sites project (2016)

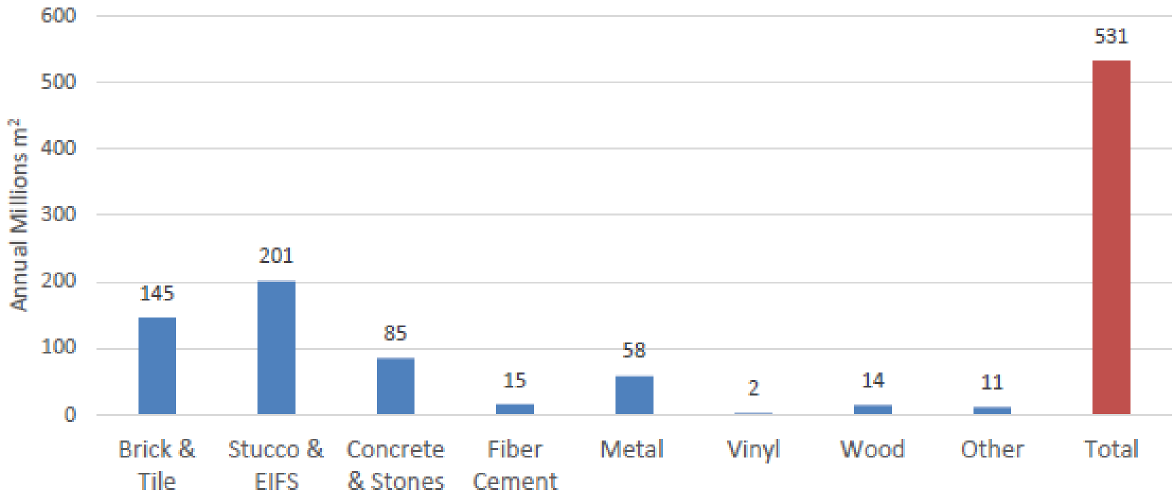

Figure 28 Overview of façade material segmentation in Europe in 2014

Source: PV Sites project (2016)

The building sector is recognised as being relatively conservative. Barriers identified to increased market penetration include:

- flexibility in design and aesthetics considerations,
- lack of tools integrating PV and building performance,
- demonstration of the long-term reliability of the technology,
- compliance with legal regulations,

As was identified in Task 1, targets at Member State level for all new buildings to achieve NZEB performance and a further recasting of the Energy Performance of Buildings Directive are likely to drive the uptake of BIPV products in the new-build and major renovation market segments.

2.3.3. Product trends - Inverters

2.3.3.1. Market segmentation

The European inverter market is dominated by single and three phase string inverter technology (73%), as can be seen in Figure 29. The remaining portion of the market is accounted for by centralised inverters (26%), delivered either as a standalone unit or packaged with other power conditioning equipment such as transformers, and micro-inverters (1%).

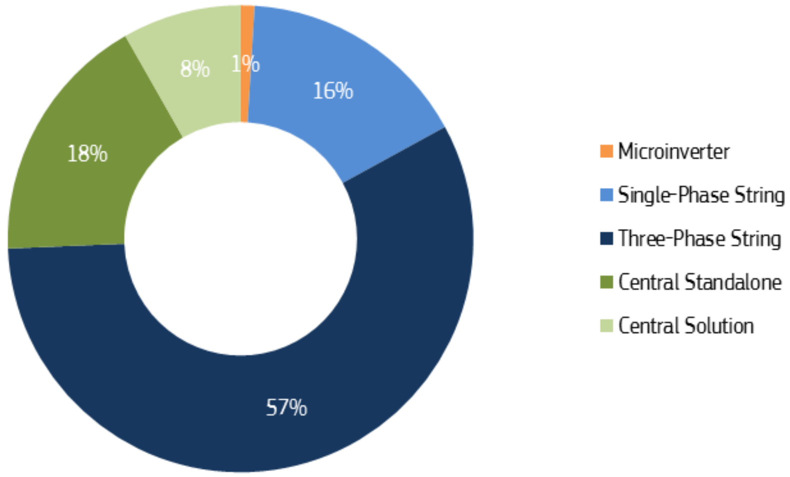

Figure 29. European inverter shipments by technology (2016)

Source: GTM Research (2017)

The main market for microinverters is currently the USA where they accounted for just over 5% of shipments in 2016 (Figure 30). The EU and Australia are identified as growth markets after the US, with a focus on the sub 5kW market, where the financial case is strongest.

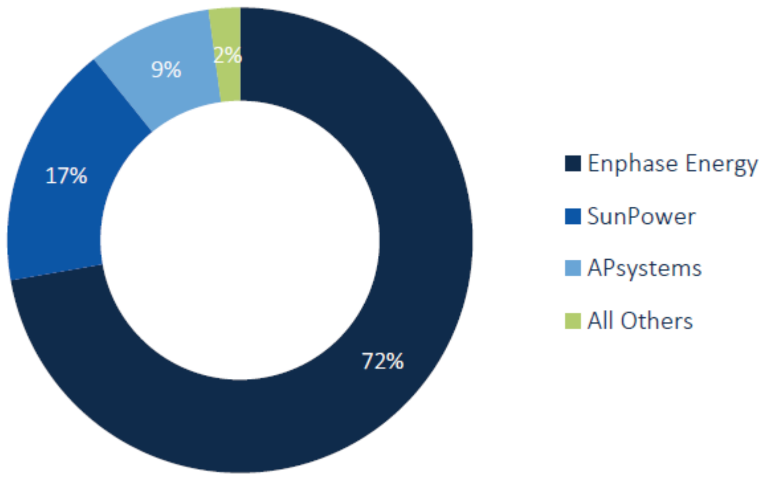

Figure 30. Global micro-inverters market share

Source: GTM Research (2017)

In terms of module level power electronics, the European shipments of DC optimisers in 2016 were of greater market significance than micro-inverters, being equivalent in capacity to approximately 7.7% of the total EU shipped inverter capacity and accounting for just under a third of the global shipments of DC optimisers.

2.3.3.2. Trends in product design and features

As the cost of modules has fallen the proportion of a system's costs accounted for by Balance of System (BoS) components has risen. At the same time inverter efficiency has increased to the point where the majority of system-level inverters have a declared efficiency in the region of 98%. With the exception of micro-inverters, which still appear to have potential for efficiency improvements, attention has therefore also turned to the role of inverter configurations and power electronics as means of improving system performance.

Inverters have therefore been the major focus of attention for BoS performance optimisation and cost reduction. Functional requirements that have influenced designs include:

- an increase in power density (or power to weight ratio),
- the need for higher reliability and the management of fault modes, and
- the use of smart grid control under different conditions.

In the field of string inverters with a power rating of up to 100 kW, transformerless circuit topologies with high switching frequencies and Maximum Power Point Tracking devices represent the state of the art. A so-called three level topology is widely used – conversion to high frequency AC, then to DC, then to distribution network voltage.

The application of three phase string inverters to larger utility scale systems is an important application trend. However, this has largely only been seen for systems requiring inverters of less than 1500 volts (<50 kW). The first 125 kW string inverter was launched in 2017, and represented at the time the largest available on the market. They are cited as having the advantage of being easier to handle, install and maintain than central inverters [23]. To achieve the necessary power density a five level topology must be used.

In terms of performance improvement, the most significant trend projected as taking place in 2018 is the potential introduction into the market of inverter designs with silicon carbide (SiC) and gallium nitride (GaN) switching components (transistors). It is claimed their introduction support increased power densities whilst reducing cooling requirements, thereby reducing the bill of materials, a large part (70%) of which is accounted for by mechanical and electromechanical components such as metal heat sinks [24]. This can be achieved by so-called 'hot core' architectures that require heat sinks to be made of composite materials with greater thermal conductivity [25].

As was identified in the analysis of module trends, there are indications that the integration of power electronics at module level will continue to increase. This will see the further development of modules with integrated micro-inverters and DC power optimisers. Interest in micro-inverters has been driven by the need to reduce installation costs, but also by the claimed improvements in system performance in the range of 5-25% that can obtained[26].

Module level power electronics are claimed to have become more popular due to a combination of system offers that aim to improve system efficiency and increased safety requirements. MLPE can include features that support a number of other functions that related to operational control of a photovoltaic system. Inverter and panel level

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[23] PV Tech, *1,500V and beyond – where next for inverter technology*, Special report – Next generation inverters, December 2017

[24] PV Tech, *Technical trends in next generation solar inverters*, Special report – Next generation inverters, December 2017

[25] Fraunhofer ISE, *PV-Pack – Innovative Solutions for New, Highly Integrated PV Inverters in the Power Range from 30 to 70 kW*,Accessed April 2018, https://www.ise.fraunhofer.de/en/research-projects/pv-pack.html

[26] US EPA, *Energy Star Market and Industry Scoping Report - Solar Inverters*, December 2013.

monitoring of power output and fault detection are now available. Smart inverters can be configured to notify installers of fault occurrences.

There are also indications that in the future inverter electronics will be integrated with battery storage systems – so-called hybrid inverters. There are already examples in the market where the DC charge controller electronics are integrated with the power electronics of an inverter and DC optimiser. The inverter architecture must be configured differently in this case because of the need to support two operating modes – grid parallel (or grid 'feeding') and islanding (or grid 'forming') – and to control the voltage and frequency. The inverter products expected design life must also reflect the associated extension in operating hours. The inverter will need to operate in the day-time operation during periods of sunlight and also at night time to supply power demands.

2.3.3.2.1. Feedback from the stakeholder questionnaire

The first stakeholder questionnaire included a question on what stakeholders considered as the commercial state of the art for inverter technology. The answers given by respondents are briefly summarised in this section.

Q2.5 Please indicate what you consider as the commercial state of the art for each of these technical aspects

- *Power management*: Two out of the eight respondents who addressed this aspects identified Module Level Power Management (MLPM) in conjunction with DC optimisers. Two further respondents identified Maximum Power Point Tracking (MPPT) including the potential for 2-3 devices on one inverter. Two further respondents identified new power semi-conductor technology such as silicon carbide. Benefits identified include faster switching speeds, an improved power density, reduced losses and reduced heat rejection requirements. In addition connectivity, intelligent home energy systems, integrated storage, reactive power management, and active power management were also mentioned.
- *Lifespan:* There were six respondents to this aspect. A design life of between 10 and 20 years was identified. IP (Ingress Protection) standards, as well salt and ammonia resistance tests, were identified. Case design to facilitate heat rejection but also provide ingress protection was highlighted. One respondent identified the need for the *'identification of critical components and enhancements to inverter reliability'*. Standards of potential relevance under development were listed:
  - ANSI/TUV-Rheinland 71830, "Microinverters and Microconverters – Design Qualification and Type Approval,"
  - IEC 62093 ed. 2, "Photovoltaic System Power Conversion Equipment Design Qualification Testing,"
  - IEC 63157 ed 1 - inverter quality assurance technical specification with guidelines for increased confidence in design qualification and type approval.
  - Material intensity and raw material use: One respondent identified the exclusion of *'tantalum, tin, tungsten and gold from suppliers that are considered "conflict minerals"'* and an additional respondent identified *'responsibility in the supply chain'*. Another respondent identified weight to power ratio as a metric.
- *Hazardous substance present*: Two respondents identified lead-free solder. One respondent identified that some larger inverter products (> 1MW) on the market are liquid cooled and the need for practical alternatives to the coolant HFC-134a, such as propylene glycol and ethylene glycol. New semi-conductors will support air cooling. RoHS and REACH compliance were identified by two respondents.
- End of life management: Five out of the eight respondents to this aspect identified recycling and refurbishment, with one noting that *'typically, defective inverters get refurbished and defective components get recycled or disposed off'* and that *'disposal without recycling would only happen in case of severe damages, i.e. after a fire incident'*. The recyclability of materials and components were identified by two respondents. WEEE compliance was identified by two respondents.

2.3.3.3. Competitive analysis

The European inverter market is led by three companies (SMA, Fronius and ABB) that are also in a favourable position in the world market. SMA Solar (Germany) is the world's highest ranked company with regard to R&D investment in the PV sector.

Global solar PV inverter shipments grew 23% on 2016 (34% in EU), reports GTM Research in its latest Global Solar PV Inverter Market Shares and Shipment Trends 2018 report. Revenues, meanwhile, increased by 11%.

Manufacturers supplying three phase string inverters for sub 1MW systems – namely SMA, ABB, Huawei, SolarEdge Technologies, Fronius and Ginlong Solis, who together are estimated to account for 67% of the shipped capacity for these types of products in 2017 (Figure 31).

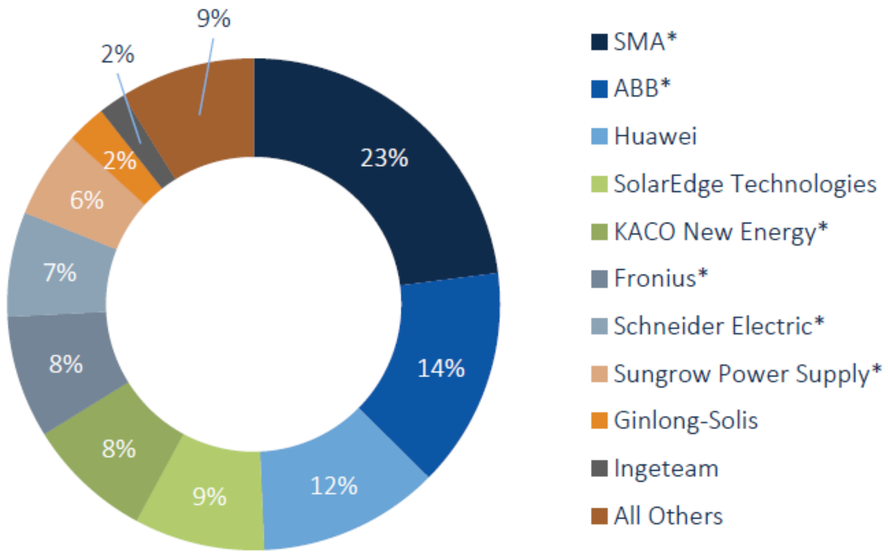

Figure 31 European inverter shipments (2017)

Source: GTM Research (2017) **estimates*

The leading manufacturers supplying centralised inverters were KACO New Energy, Schneider Electric, Sungrow Power Supply and Ingeteam, who together are estimated to account for 23% of the shipped capacity in 2017.

European manufacturers play an important role in the market, being estimated to account for just over 50% of shipments in 2016. These manufacturers are considered as mature suppliers, having inverter products with a relatively long track record, and whose competitiveness is proved by their survival of the downturn in the market during 2010-15. Their products are valued as being cost effective given the advanced features they incorporate, including advanced grid integration and control systems.

GTM Research identify that there are 13 EU manufacturers of significance at a global scale, with SMA (Germany), Fimer (Italy), Fronius (Austria), KACO New Energy (Germany), Power Electronics (Spain) and Schneider Electric (France) each achieving a global market share of greater than 1% in 2016. Swiss company ABB also has an important market share, and has some production facilities in the EU (e.g. Poland and Czech Republic).

Approximately 1.5 GWac of SMA's 8.2 GWac shipments made in 2016 were into Europe. Fronius were the next most significant EU supplier, shipping 754 MWac out of 1.4 GWac, followed by Schneider Electric with 649 MWac out of 2.0 GWac..

It is notable overall that Chinese manufacturers accounted for 25% of shipments into Europe in 2016, up from 17% in 2015 and 11% in 2014. The three leading Chinese manufacturers were Sungrow Power Supply, Huawei and and Ginlong Solis.

Sungrow Power Supply and KACO New Energy are notable for having introduced in 2017 high voltage 125kW string inverters aimed at the >1MW market. General Electric is cited as being likely to be the first inverter manufacturer to introduce higher switching frequency inverters in 2018. Other manufacturers likely to follow suit are, for silicon carbide transistors and high voltage inverters - Delta, SMA, ABB, Fuji Electric, Omron, Sungrow and Schneider Electric – and for gallium nitride transistors and low voltage inverters - Yaskawa, Enphase, Tata, SMA and SolPad. Of these manufacturers, only SMA, ABB, Sungrow, Schneider Electric and Enphase currently have a significant presence in the European market.

Enphase Energy are the most significant manufacturer globally of micro-inverters for integration into AC modules. Jinko Solar, LG and Solar Power are notable suppliers of AC modules. Most micro-inverters products in the EU are understood to form part of the shipped AC module products of Jinko Solar and LG. SunPower are understood to only presently supply AC module products to the US market.

In terms of module level power electronics, SolarEdge, Tigo Energy and Maxim Integrated can be identified as the leading manufactures of DC power optimisers for use in combination with transformer-less string inverters. Manufacturers currently offering inverter level power electronics that support battery integration include SolarEdge , Huawei and SMA [27].

Labour costs seem to be an important factor for international competitiveness, which is indicated by ABB's choice for locating inverter production in the Czech Republic and Poland, where SMA also maintains a production facility. The relationship between regional R&D capacities, specialisation and chosen production sites is not as clear as in other parts of the PV value chain.

2.3.3.4. Channels to market

In general it can be seen that the photovoltaic market is highly competitive, which means that there are limited margins which in turn restrict the number of intermediaries. Manufacturers' channels to market are generally limited to:

- Direct sales to developers or large installers,
- Sales via local subsidiaries,
- Sales via distributors then to installers
- Products then sold under the brand name of another company.

Each of these will be discussed in turn in the following section.

In general for systems of a size greater than 100 kW, the system developer will tend to go directly to the manufacturer. This is a question of price since distributers take a 15-20% margin on inverters. The regional or country representatives of manufacturers are in general subsidiaries of the manufacturer. In some cases, they are established companies, which could be considered as distributers. In some cases competition can exist between local subsidiaries and international distributors. For example, in the case of Spanish distributors delivering in Belgium at a cheaper price than the Belgian subsidiary for SMA inverters.

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[27] SMA, *Sunny Boy Smart Energy*, https://www.sma.de/en/products/solarinverters/sunny-boy-3600-5000-smart-energy.html

Distributers tend to be well established companies (e.g. Krannich solar in Germany) that sell mostly to the residential and commercial segments. Larger installations do not normally use distributers for the cost reasons already cited unless a manufacturer is unable to deliver on time and the project must be finished at all costs (often due to financial penalties). Table 10 provides an approximation based on an industry directory of the number of wholesalers and distributors in each Member State.

Instead of a spot market, a market exists based on future prices. A customer can book for a designated price some quantities of inverters for a delivery in the future. This is usually done in order to guarantee a fixed price for a project to be realised in the future. Both developers and distributors are working with such future contracts.

The question of how distribution will look in the future is a complex one. The distributors found their place on the market since small installers started to develop. As already seen in some countries (such as Germany for instance, or the USA), large companies, including traditional utilities are starting to offer photovoltaic products for residential and commercial applications. These companies compete directly with small installers, with a competitive advantage for well organised large players: the ability to buy directly from the manufacturer and propose reduced prices. Companies such as EON in Germany, Engie in Belgium, Iberdrola in Spain or Enel in Italy as proposing such PV products. Not all of them are targeting the residential segment but all are looking at rooftop installations. This could lead to a decrease in the price at which inverters are invoiced for small applications, putting a high pressure on traditional distributors.

Table 10. Number of wholesalers, wholesalers distributors and distributors of inverter for photovoltaics in EU per country

	Wholesalers	**Wholesalers/ Distributors**	**Distributors**
Austria	25	3	3
Belgium	10	1	5
Bulgaria	11	2	2
Croatia	5	-	-
Cyprus	4	1	1
Czech Republic	10	5	14
Denmark	18	1	9
Estonia	2	1	-
Finland	3	1	3
France	32	11	12
Germany	177	36	30
Greece	17	6	8
Hungary	16	8	8
Italy	47	23	25
Ireland	2	-	3
Latvia	1	1	-
Lithuania	6	-	-
Malta	1	1	2
Netherlands	99	12	13
Poland	14	4	8
Portugal	4	1	6
Romania	21	-	4
Slovakia	3	-	1
Slovenia	5	1	1
Spain	37	16	10
Sweden	17	4	1
United Kingdom	33	15	9
Total	*620*	*154*	*178*

Source: ENF Solar (2018)

Re-branding exists, for inverters. Some inverters could be sold under a different brand than the manufacturers' one. This is especially valid with packaged products, and for small installations. For instance SolarWorld used to sell inverters under its own brand, while they were produced by a specialised manufacturer. This can also be seen for central inverters which could be partially installed by third parties, which are selling them under their brand, while a large part of the components and the technology would come from a specialist in the inverter sector.

2.3.4. Product trends – Systems

The PV industry is moving away from the early approach in which the customer not only owned and financed the PV system, but also managed most aspects of installation. A classification of the PV system business models has been made to reflect the evolution of them[28]. The first or zero generation model is referred to a relatively small group of so-called pioneers who were committed to PV's environmental, energy security, and self-generation benefits. The PV industry has evolved to 1st Generation PV business models where the product is more attractive to a broader market, moving into the so-called early adopter customer category (see Table 11). 2nd Generation business models have yet to emerge, but will emphasize greater integration of the PV systems into the grid because emerging technologies and regulatory initiatives are likely to make such integration more viable and valuable.

Table 11. Evolution of PV systems business models.

0 Generation	**1st Generation**	**2nd Generation**
PV System Supply	**Third-party Ownership and Operation**	**Full integration**
• Business models focused on manufacturing, supply and installation of PV systems • End-user is the owner • Utility is largely passive, providing net metering and standard/simplified interconnection, but otherwise, unaffected.	• Business models driven by third parties which develop projects and own PV systems, resulting in: –Reduction of hassle & complexity for end-user –Better access to financing –Leveraging of current incentives structure (especially for commercial building applications) • Utility gradually takes on a facilitation role as PV market share grows	• Business models allow PV to become an integral part of the electricity supply and distribution infrastructure • Business models emerge with variation of system: –Ownership –Operation –Control • Utility becomes more deeply involved, as PV becomes major consideration • PV product supply chain becomes "commoditized"

Source: Frantzis, L., Graham, S., Katofsky, R., & Sawyer, H. (2008). Photovoltaics Business Models.

2.3.4.1. Market segmentation

This section reviews the market segmentation with a focus on the ownership of the PV systems. As seen above, the requirements of the owners of the systems (being end users, third parties or utility) are creating new market demands for e.g. new technologies, contracting services, and maintenance services. In the EU, there are two major applications for grid-tied PV: residential and utilities. Of the nearly 6216 MW of PV deployed in EU in 2016, grid-tied residential and utility comprised 22% and 38%, respectively[29]

[28] Frantzis, L., Graham, S., Katofsky, R., & Sawyer, H. (2008). Photovoltaics Business Models.

[29] Bequerel Institute, 2018

2.3.4.1.1. Residential scale

Up to the year 2016, almost 20GW residential solar PV had been installed in the EU (Becquerel Institute, 2018). The further expansion of residential self-generation requires the dedicated analysis of the interests of a variety of market players such as energy suppliers, grid operators, technology suppliers etc.

Residential prosumers have installations to produce electricity for their own use while they also have the possibility to feed the surplus that they do not consume into the grid. According to DG JUST study[30], in all EU Member States we assumed that 47% of electricity generated is self-consumed and the remaining 53% of electricity is exported to the grid.

Across Europe, the situation with regard to remuneration for feeding electricity into the grid is not uniform and different rules apply: in many countries Feed-in Tariffs are (still) available, alongside net-metering, or the electricity fed into the grid can benefit from premiums. Besides, other forms of support are available depending on the country, including green certificates, tax reductions, loans and investment support. Falling solar PV prices coupled with high retail electricity prices have made it possible for residential prosumers in some EU Member States to achieve grid parity[31]

[30] Study on "Residential Prosumers in the European Energy Union" JUST/2015/CONS/FW/C006/0127
[31] Deutsche Bank Market Research, Solar Industry, 2015.
https://www.db.com/cr/en/docs/solar_report_full_length.pdf

Table 12. Take up of residential solar PV – baseline results with a share of prosumers.

	Residential solar PV capacity in 2015 (MW)	Residential solar PV capacity in 2030 (MW)	Growth rate, 2017-2030 (% pa)	Share of total potential residential solar PV capacity (2030)	solar PV prosumers as a share of all households (2030)
Belgium	1,976.9	3,255	3.5%	29.0%	8.2%
Bulgaria	8.9	40.6	10.2%	1.4%	0.5%
Czech Rep.	95.0	106.3	0.8%	2.6%	0.7%
Denmark	454.1	838.1	4.2%	18.7%	6.8%
Germany	5,240.5	9,137.8	3.8%	39.5%	5.8%
Estonia	1.1	5.6	8.2%	1.7%	0.2%
Ireland	1.1	12.4	15.3%	0.4%	0.2%
Greece	350.0	950.2	4.4%	27.4%	6.7%
Spain	48.6	57.9	1.2%	0.4%	0.1%
France	1,049.0	2,622.7	6.3%	6.6%	2.6%
Croatia	12.1	30.3	6.3%	1.2%	0.5%
Italy	2,640.0	5,614.1	5.1%	22.6%	5.9%
Cyprus	20.6	55.7	6.7%	7.6%	3.1%
Latvia	0.4	5.6	14.9%	1.5%	0.3%
Lithuania	19.7	31.2	3.1%	3.9%	1.1%
Luxembourg	33.6	80.6	6.0%	14.1%	5.0%
Hungary	60.5	282.8	10.0%	5.0%	2.3%
Malta	19.7	23.6	1.3%	13.0%	3.6%
Netherlands	1,086.0	3,684.0	8.1%	26.4%	9.5%
Austria	377.5	684.2	4.3%	16.4%	5.1%
Poland	10.2	151.2	16.5%	1.0%	0.4%
Portugal	147.1	382.9	6.5%	7.5%	4.1%
Romania	13.3	18.7	2.3%	0.3%	0.2%
Slovenia	1.8	13	12.9%	1.1%	0.5%
Slovakia	5.9	40.4	12.5%	1.9%	0.6%
Finland	4.0	24.5	12%	0.7%	0.2%
Sweden	52.0	257.6	9.4%	3.4%	1.1%
UK	2,499.0	3,539.9	2.1%	13.1%	3.5%
Iceland	-	-	-	0.0%	0.0%
Norway	11.3	25.6	5.5%	0.4%	0.3%

Source: DG JUST study "Residential Prosumers in the European Energy Union"[30]

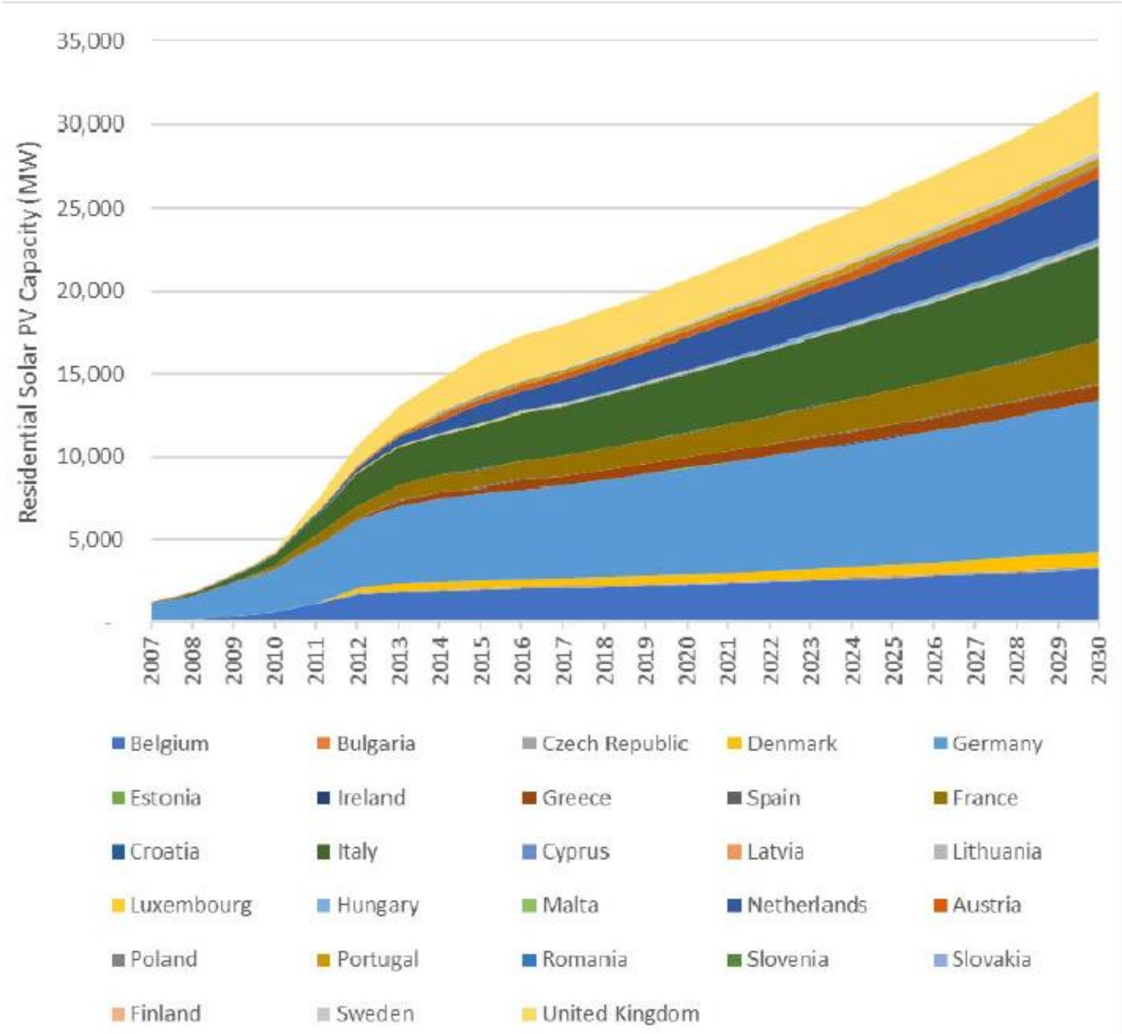

Figure 32. Take up of residential solar PV: base line results.

Source: *GfK (2017)*

2.3.4.1.2. Large, utility scale systems

Solar investment portfolios

The investment community considers Europe to be a mature market for solar photovoltaic investments. Notwithstanding the uncertainty created by changing Member State subsidy regimes, as was discussed in section 1.3.2 of the Task 1 report, solar systems continue to be a bankable investment as a fixed asset. The split of ownership for the top 70 EU portfolio owners of large solar photovoltaic plants is illustrated in Figure 33. The majority are reported as being investors, followed by Independent Power Producers (IPPs), developer/owners and utilities.

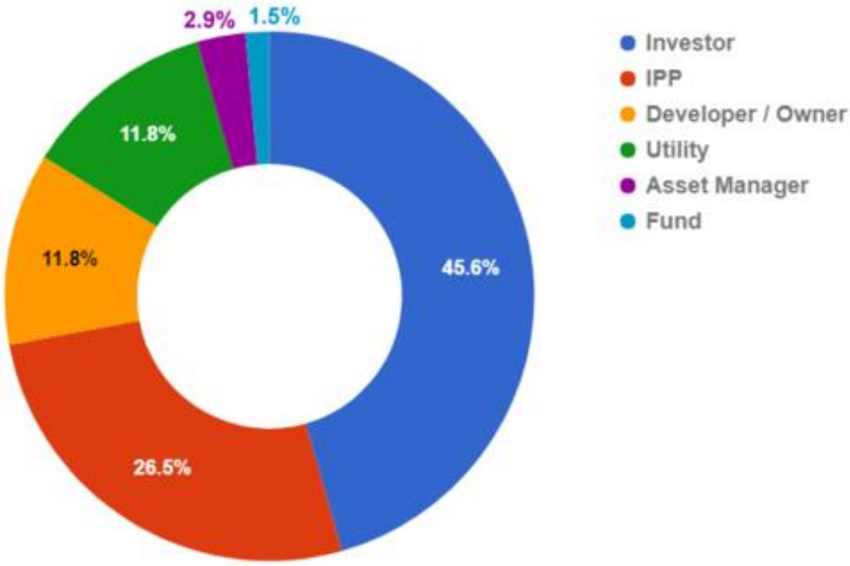

Figure 33. Breakdown of ownership types for the top 70 EU solar investment portfolios

Source: Solar Asset Management Europe (2017)

The ten largest investment portfolios, measured in terms of installed capacity and as illustrated in Figure 34 accounted for approximately 6.6 GW of installed capacity in 2017 [32]. The capacity identified in the figure is largely understood to be located in the three countries of registration of the investors. The leading funds were Octopus Investments (UK), Enerparc AG (Germany) and the Foresight Group (UK). The average capacity at each site in the portfolio of the largest investor, Octopus Investments, is estimate to be 5.4 MW.

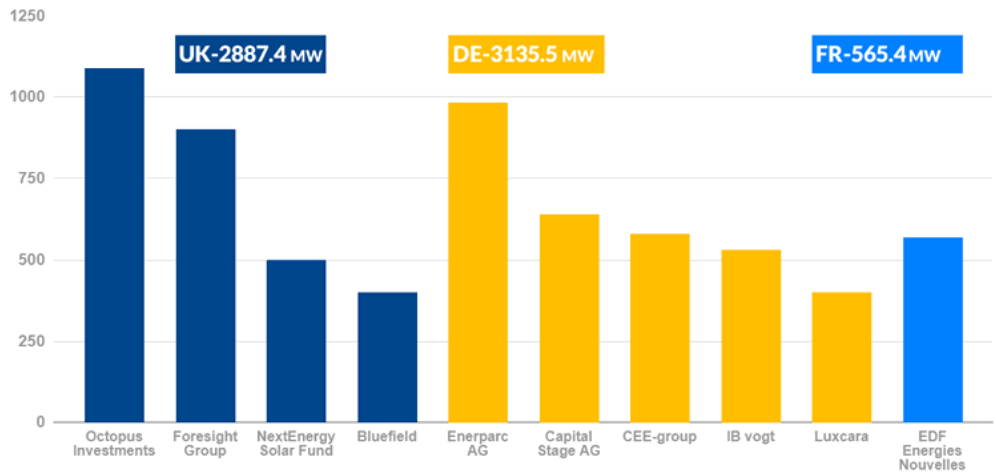

Figure 34. The top 10 EU solar investment portfolios in 2017

Source: Solar Asset Management Europe (2017)

[32] Solar Asset Management Europe, *Top 70 European solar portfolios*, Accessed February 2018, https://www.solarassetmanagementeu.com/new-updates-source/2017/7/31/top-70-european-solar-portfolios-2017

2.3.4.2. Trends in photovoltaic systems and features

In order to identify and understand how trends may affect different parts of a system a number of different elements have been identified, some of which relate to component choices at the design stage, others of which relate to services provided during the operational phase of a system.

- Design stage: new components for the module array and balance of system that have overall implications at a system design level.
- Operational stage: new IT systems and operational services that facilitate better monitoring and maintenance of performance.

For each component, system or service their relevance to the four PV system types is also identified – namely residential, commercial, industrial and utility scale.

2.3.4.2.1. Design stage

Dynamic energy yield simulation

The use of dynamic simulations (those with an hourly and shorter time series without averaging) of a PV system's performance improves its precision. Relative errors of up to 5% in precision are found for annual energy yield simulations have been found between those using either hourly or averaged weather input [33]. This precision is particularly important for PV system designs that are integrated with batteries or connected to a congested electrical grid.

The use of dynamic simulation software is already prevalent in the design of larger, commercial systems. For example, the tool PV Sys is understood to be widely used for commercial and utility scale projects. It is also used for commercial buildings that may incorporate BAPV or BIPV systems such as offices, but rarely in the residential sector. Software tools of this kind allow for more complex modelling, taking into account for example geographic location, orientation, shading, module efficiency, module technology, inverter efficiency, etc.

Tracking systems

Tracking systems have traditionally been of most significance to larger systems. These systems allow the module array to track the path of the sun, thereby maximising the energy yield. Two axis tracking is generally more expensive and its complexity can create maintenance issues. However, one axis trackers are receiving greater attention as a cheaper, lower maintenance alternative to increase yield.

The projected market share of tracking systems in large scale PV plants is shown in Figure 35. According to the ITRPV roadmap, 1-axis systems will increase the market up to almost 50% by 2020 onwards. While bifacial modules may capture up to 10% more light than monofacial modules, single-axis trackers typically add 25% to that bifacial gain, resulting in a roughly estimated 12.5% gain from the two technologies combined. [34] Bifacial panel use in combination with single-axis trackers is expected to grow to a double digit share within a year, and eventually become the dominant design.

[33] Thomas Huld, Gottschalg, Beyer, & Topič, 2010
[34] PV magazine, Solar trackers: Record 2017 shipments; up to 20 GW expected in 2018. https://www.pv-magazine.com/2018/02/22/solar-trackers-record-2017-shipments-up-to-20-gw-expected-in-2018/

Another substantial step forward in tracker design is adding storage, this has been seen in a 100 MW of double-axis trackers along with a 50 MW vanadium redox flow battery to provide a greater energy supply in the late afternoon and evening hours when demand is highest. The stored energy provides voltage variability services [35].

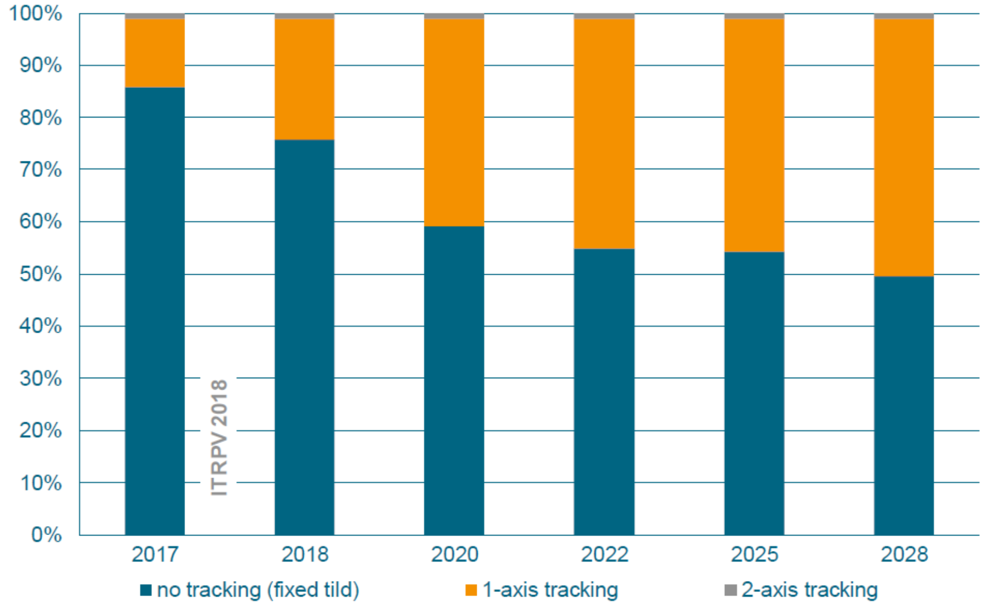

Figure 35 Projections for tracking systems used for crystalline PV based systems

Source: ITRPV (2018)

Design to maximise array bifaciality

The projected mainstream entry in the market of modules with bifaciality – meaning that the cells and glass encapsulation allows for energy from sunlight to be harvested from the front and rear – will have an implication for array designs. This is particularly the case where the structure and roofing substrate is relatively unconstrained *e.g. on buildings with flat roofs*.

From the point of view of investors the claims made for additional energy yield are still unsubstantiated. Commentators have therefore emphasised the importance of array designs that are optimised to support bifaciality. This optimisation can include consideration of the type of mounting structure, the use of tracking systems and can even extend to include the treatment of flat roof or other underlying surfaces in order to reflect light onto the rear side of modules.

Storage components of Balance of System

Li-ion batteries are the most common storage technology, regardless of application. Lithium-ion batteries can typically deliver more cycles in their lifetimes than lead-acid. This makes them a good choice for applications where batteries are cycled to provide ancillary services to the grid. The most important benefit lithium-ion provides for solar is its high charge and discharge efficiencies, which help to harvest more energy. Lithium-ion batteries also lose less capacity when idle, which is useful in solar installations where energy is only used occasionally.

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[35] PV Magazine, *Trackers spread globally as designs improve*, July 2016, p-40

An increase in the demand for self-consumption is driving greater market penetration of battery storage as an integrated component of solar PV systems. Trends in storage are as mentioned in the market segmentation and also in the inverter section, the adaptation of inverter products to off-grid solutions combined with battery storage, and their integration at module level.

Module Level Power Electronics

As was mentioned already in the module section 2.3.2.2, there is a trend in residential systems to include a number of module level power electronic solutions. The integration of micro-inverters and DC optimisers at module level is claimed to facilitate improvements in overall efficiency at Balance of System level of anywhere between 5% and 25% are claimed, but this requires further substantiation. Moreover, a move to dual junction boxes is claimed to ease the installation time and reduce the cabling required for the interconnection of modules, offering potential reductions in the overall bill of materials.

Connectors

One of the trends for the connectors and cabling of the PV modules is the use of combiner boxes. A PV Combiner Box serves to bundle the output lines of individual strings and to connect them to the inverter. The design of the box has to be customized for each customer's application. Advanced surge protection devices, fuse links are usually included in combiner boxes. This trend is understood to largely relate to the recent entry into the market of string inverters that can be used instead of central inverters in larger systems.

2.3.4.2.2. Operational stage

Monitoring and data analytics

There is increasing interest at a commercial level in accurate monitoring in order to optimise operational activities. A key focus has been on the potential to accumulate performance data at array, BoS and system level which can then be analysed. Monitoring systems in this way can support the optimisation of maintenance tasks and the early detection of any need for intervention such as e.g. module washing frequency, ascertaining if string fuses have blown.

Tools for data analytics are now available based on artificial intelligence and machine learning. These can be used to verify the performance behavior of PV plants and at a later stage improve and automate the optimization of performance [36]. These types of tools can be used to detect early faults and performance degradation and to give actionable recommendations on the root causes.

Data analytics of this kind will increasingly form part of operation and maintenance contracts, as will be discussed in the following section.

Operation and maintenance services

Both preventive and corrective maintenance are generally considered as part of contracts for larger PV systems. For preventive maintenance detailed visual and physical inspections (e.g. aerial Infra-red imaging, on-site characterisation for selected modules) are standard practice. This type of maintenance can be supported by mobile testing labs, whereby modules can be deinstalled and tested on site. One of the latest trends involves the use of drones to remotely monitor module arrays.

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[36] 3E, Retrieved March 2017, http://www.3e.eu/data-services/pv-health-scan/ and http://www.3e.eu/pv-performance-verification-meets-big-data/

Maintenance services can also a range of other factors relating to the external environment, and which can be detrimental to the Performance Ratio of systems. This can include cleaning, vegetation cutting and snow/sand removal. To minimise the downtime of the PV system the keeping of critical spare part stock also forms part of servicing. Examples of the full range of possible services are presented in Table 13.

Table 13. Example of some O&M services already available in the market

<table>
<tr><th></th><th colspan="2">Operation & Maintenance services</th></tr>
<tr><th></th><th>Commercial</th><th>Domestic</th></tr>
<tr><td>System Health Check</td><td>– Visual check of all rails and mountings
– Visual check of module condition
– Full string test
– Visual & physical check of all module connectors
– Interrogation of inverter display error codes and logs
– Full inverter diagnostic testing and checking of monitoring connectivity
– Visual check of all system AC & DC electrics
– Inverter & fan dust and clean
– Irradiance test and other tests using Seaward diagnostic technology
– Full report of system condition & operation provided to system owner</td><td>– Visual check and test of key connections, switches and electrical components;
– Visual check of panels, mountings and other hardware components;
– Inverter diagnostics;
– Irradiance & DC circuit test;
– Clean inverter and fan;
– AC electrical safety certificate compliance
– Thermal transfer fluid check and top-up (recommended)
– System re-pressurisation (recommended)
– Report and recommendations</td></tr>
<tr><td>Solar Panel Cleaning</td><td colspan="2">– Use of specialist equipment and super-clean water to clean the panels (with low water usage)
– Extremely pure water produced on-site by mobile 3 stage filtration, reverse osmosis and de-ionisation equipment to ensure near zero deposits
– Specialist brushes clean and rinse panels thoroughly without damaging delicate mysophobic coatings
– Water-fed pole system offer up till a certain lateral reach
– Visual check of array condition</td></tr>
<tr><td>System Upgrades</td><td></td><td>– Battery Storage technology
– Air Source Heat Pumps
– Immersion Controllers (to convert the excess electricity produced by the PV system into piping hot water)</td></tr>
</table>

Source: Solarsense 2018

2.3.4.2.3. Feedback from the stakeholder questionnaire

The first stakeholder questionnaire included a question on what stakeholders considered as the commercial state of the art for system design and specification. The answers given by respondents are briefly summarised in this section.

Q3.4 Please indicate what you consider as the commercial state of the art for each of these technical aspects

- *Design and optimisation:* of the eight respondents to this aspect:
  - *Simulations:* five identified dynamic simulations of energy yield taking into account the 'real' ambient conditions.
  - *Real energy yield conditions*: One respondent highlighted the importance of using a spectral response based on real conditions within energy yield simulations. A reference was provided for a specific simulation software used for utility scale systems.

- *Module Level Power Electronics:* One identified Module Level Power Electronics as being an important aspect.
- *Installation quality and performance:* of the ten respondents to this aspect:
  - *Monitoring:* three identified module level monitoring and two went further to identify module level optimisation as a further step. Linked to this, three respondents identified smart fault identification and reporting. One respondent identified systems >100 kW as being those that are normally monitored. The point of data collection could be a DC optimiser or a combiner box.
  - *Installation quality:* One identified the potential to focus on installation quality as a means of avoiding *'latent defects'*. One respondent highlighted the potential for installation criteria to ensure correct future functioning.
- *Active self-consumption:* of the nine respondents to this aspect:
  - *Demand-side management:* four identified smart metering and demand side management. One respondent additionally identified *'whole-home platforms via common standards'* such as EEBUS.
  - *Collective self-consumption*: two identified micro-grids and collective self-consumption based on the sharing of the output from systems between several end-users in the immediate vicinity (citing France law as an example).
- *Energy storage:* of the nine respondents to this aspect:
  - *Battery storage:* Four identified battery storage as state of the art.
  - *Grid interaction:* Three identified the need for grid interaction and support services. Systems should be able to contribute to the stabilisation and reliability of the grid.

2.3.4.3. Competitive analysis

Europe also has strong firms in more specific PV domains such as manufacturing of connectors, (sun) trackers, encapsulants and polymers in general, and solar glass. Most of these champions invest heavily in research and development (R&D). In order to identify and understand how trends may affect and relate to different segments of the market the competitive analysis has been divided into the design and the operational stage.

2.3.4.3.1. Design stage

Storage components of Balance of System

While there has been an overall downturn in residential installations, for example in the major EU markets of Germany, Italy and the UK, a diversified offer of components and services for 'prosumers' has emerged and there is evidence that it is growing. For example, in section 2.3.3 it was already mentioned that inverter manufacturers such as SolarEdge, Huawei, SMA are already offering inverter level power electronics that support battery integration.

The leading market for battery storage systems is Germany, where the introduction of financial incentives has led to the installation of more than 75.000 PV + storage systems by the end of 2017 (BSW - Bundesverband Solarwirtschaft e.V.) and where a total installed capacity of 500 MW is predicted by 2021[37]. The leading supplier is Sonnen (Germany), although Fenec, LG Chem and E3/DC are also identified by commentators.

SonnenBatterie from Germany, also called Sonnen, is located in the German region of Schwaben, but also has a strong presence in the US market. The company has received several awards recently, among them the EUPD recognition of best product in the class “Lithium-Ion-batteries under 5 kW”. Sonnenbatterie has managed to

[37] Colthorpe, A, *Germany showing the way for storage*, PV Tech magazine, May 2017

reduce the cost of its hybrid solar-battery by 20% thanks to the elimination of the external inverter. Sonnenbatterie has created its own community, which includes 12,000 families already using the battery and is expected to reach 20,000 by the end of 2016. This community also benefits from energy efficiency services provided by the company. The combined generation capacity of Sonnenbatterie's clients ascends to 2.5 GWh per week.

The data available for this emerging sector confirms the rather pessimistic viewpoint that the European position is rather weak, despite the promising results of some firms such as Sonnenbatterie. Soluxtec GmbH, also from Germany, is another company directly targeting the off-grid market, and the main inverter producers are also adapting to off-grid solutions combined with battery storage, as explained in more detail in 2.3.3. Spanish and Austrian companies are also understood to be launching products.

Tracking systems

A survey of the top international tracker companies shows that more than five dozen countries now have installed PV tracker arrays totalling more than 14.8 GW of cumulative capacity. The tier of countries with installed trackers totalling over 100 MW include: India with 466.4 MW; Spain with 296.2 MW; Italy with 238.5 MW; South Africa with 180 MW; Jordan with 161.7 MW; Greece with 153.2 MW; Honduras with 146 MW; China with 133.4 MW; France with 129.9 MW; Canada with 122.5 MW; and Germany with 115.9 MW.

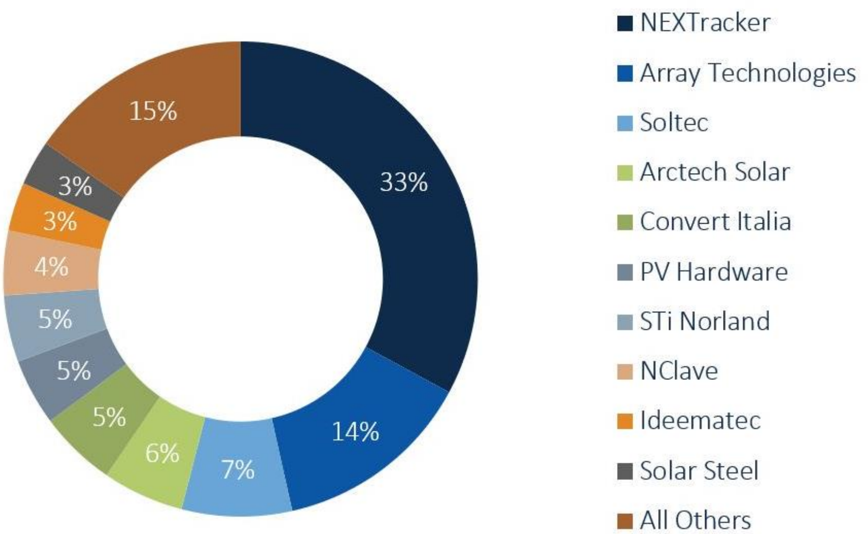

Figure 36. Global solar PV tracker market shares by MW shipped, 2017.

Source: GTM Research (2017)

The commercial and industrial (C&I) market is set for exponential growth in tracking technology in 2018 at least in the US (PV magazine[38]). With diminishing utility-scale site availability and rapidly increasing tracker competition, the C&I segment seems poised for exponential growth in tracking technology, on advances in marketing with models like community solar, and advances in financing and technology.

[38] PV Magazine article: *Shifting demand and pricing pressure main solar tracker challenges – GTM Research*. https://www.pv-magazine.com/2018/02/23/shifting-demand-and-pricing-pressure-main-solar-tracker-challenges-gtm-research/

Among the top five tracker manufacturers companies globally, two are European, Soltec (SP) and Convert Italia (IT), as seen in Figure 36. Trackers are an obvious choice in most developing solar markets; a 30 percent growth is expected globally in 2018, with shipments approaching 20 gigawatts.[39]

Connectors

Connectors must also be mentioned in this context, since their quality heavily influences the performance of the PV system as a whole. The main European company in this field is Multi-Contact AG, which manufactures connectors for diverse domains such as electric utilities, robotics/manufacturing, medical equipment and renewable energy. Multi-Contact's competitive advantage is based on stringent quality control procedures, as it discovered that the interface between the module, connectors, wires and the combiner boxes caused up to 50% of the errors in PV-systems (one crystalline module has at least twelve interfaces between the junction box, the connector and its cable branch) and that such errors increase considerably between year four and eight of the useful life of the module. The company is struggling with unfair competition from counterfeit products from Asia, especially in the field of plug-in connections.

2.3.4.3.1. Operational stage

No data about Monitoring and data analytics and operation and maintenance services could be gathered.

2.3.4.4. Channels to market

As seen in previous sections, when dealing with systems, the channels to market can be quite diverse depending also on the scale of the system, whether it is large scale or small residential installer market. Project developers and engineering procurement and construction (EPC) companies are normally present in large installations, while system installers normally act at all scales.

Project developers initiate solar generation projects and are responsible for the initial design and early consent. With regard to capacity, the main project developers in Europe are found in Germany (with an accumulated value of 2,040 MWp), France (811), Austria (469), the UK (358) and the Netherlands (307) (Wiki-Solar, 2016b).

Analogously, EPC contractors are primarily responsible for the engineering, procurement and construction of the plant. This usually includes selecting the suppliers of solar modules, inverters and other key items of equipment; and finalising and underwriting the final design and output projections for the plant. In the case of EPC contractors, the Member States whose firms have the highest accumulated capacity are Germany (3,569 in MW_{AC}), Spain (631), the UK (585), Austria (466), France (369) and Portugal (318).[16]

The sector of engineering, studies and administration has shown less sensitivity to the downsizing of the PV market (Ernst & Young 2015). Europe has a strong position in electrical installations and related service areas. However, smart grid solutions are not primarily aimed at promoting solar uptake, but a wider range of objectives (including service quality, energy management, billing and electric vehicle connection) and crucial questions such as financing of smart grid investments and burden-sharing are not yet solved, so that immediate impacts on solar uptake are doubtful.

Unlike the USA, where better margins are understood to have driven growth of a number of large installation companies who now account for a significant share of the residential PV systems, the EU market is understood to

[39] https://www.pv-tech.org/news/latin-america-was-largest-market-for-solar-trackers-in-2017-gtm-research

be more fragmented [40]. The ENF Solar database lists 14953 installers (see Figure 37), although a size class distribution for these installers is not available.

Table 14 Numbers of solar photovoltaic system installers listed in a leading trade directory

Member State	**Number of installers**
Germany	2930
Italy	2511
United Kingdom	2460
Netherlands	1510
Spain	912
France	860
Belgium	596
Austria	429
Denmark	364
Poland	359
Czech Republic	249
Greece	231
Portugal	158
Others	1384
Total	*14953*

Source: ENF Solar (2018)

There is emerging evidence that large retailers, utilities and conglomerates are now seeking to enter the market for solar photovoltaics, offering consumers a single point of contact to obtain information, provide advice, make arrangements for installations and provide aftercare services. A major example is the international home retailer IKEA which in Belgium, the Netherlands and the UK has worked in collaboration with the installation company Solar Century. Other examples include the utilities E.On [41], EDF and RWE, as well as car manufacturer Nissan [42].

2.4. Consumer expenditure base data

2.4.1. PV Module prices

The module prices in the selected countries Germany, France, Spain, Italy and others, have followed the same trend along 2001 to 2016 (**Error! Reference source not found.**) . They all had a peak around 4.5 -5 EUR/Wp in 2005 (or 2006 in the case of France and Spain) and then a continuous reduction down to 0,5 EUR/Wp, which is an average of a -90% decrease.

According to Solar Power Europe report[43], unit costs for modules and cells are indeed expected to decrease, with unit costs for modules (-52%) falling more significantly than that of cells (-19%). These percentages are based on the average difference between the global market prices and the 2017 prices under the EU trade defence measures.

[40] Recharge, *What's holding back rooftop solar?* http://www.rechargenews.com/solar/1183555/whats-holding-back-european-rooftop-solar
[41] E.On Solar, https://www.eonsolar.co.uk/
[42] Nissan Energy Solar, https://www.nissanenergysolar.com/
[43] Solar PV Jobs & Value Added in Europe, EY Solar Power Europe, 2017

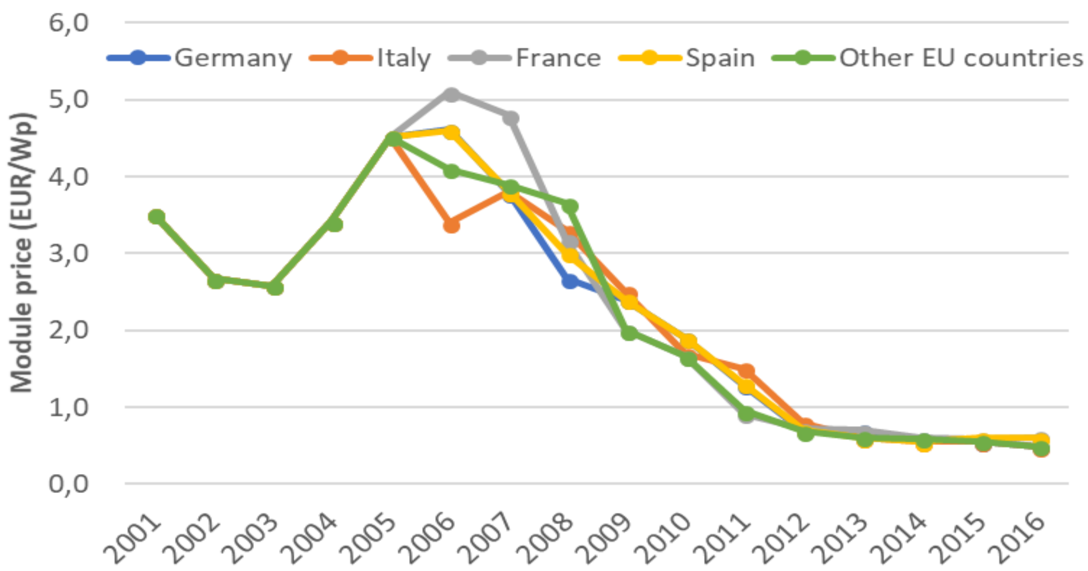

Figure 38. PV module prices in EUR/Wp for the years 2001-2016 for the selected countries

Source: created with data from Becquerel Institute, 2018

2.4.2. Inverter prices

Figure 39**Error! Reference source not found.** and Table 15 present the historical factory gate prices for five different inverter types in 2015-2017, together with estimates made through to 2022. The prices have been converted from dollars using the European Central Bank's average published exchange rate for 2016 [44]. The historical prices are nominal values including inflation and the forecast prices are real terms. The unit of comparison is EUR per watt of rated AC power output.

The most notable trend is the sharp decline in micro-inverter pricing, which reflects aggressive cost reductions by the market leader Enphase Energy, as well product innovation, such as dual module inverters. It is anticipated that further moves towards AC module integration will contribute to the downward price trend.

The relatively low unit prices of three phase string inverters reflects their historical path to large scale production of units for smaller systems as well as the global reach of manufacturers such as Huawei. String inverters have the broadest applications by system size, so the overall figures mask significant price variations. In particular the entry of string inverters into the utility scale PV system market segment (>40 kW) has contributed to continuing downward pressure on prices with, for example, utility scale models requiring less Maximum Power Point Trackers (MPPTs). The price difference between this segment and more expensive 10-40 kW models can typically be in the range of 36% and 66%.

Single phase string inverters are understood to be subject to the most price constraints, which may explain their continued relatively higher pricing. Their application in Europe has been mainly in smaller systems of <5 kW, in which this type of inverter tends to have a higher unit price.

[44] European Central Bank, US Dollar (USD)
https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

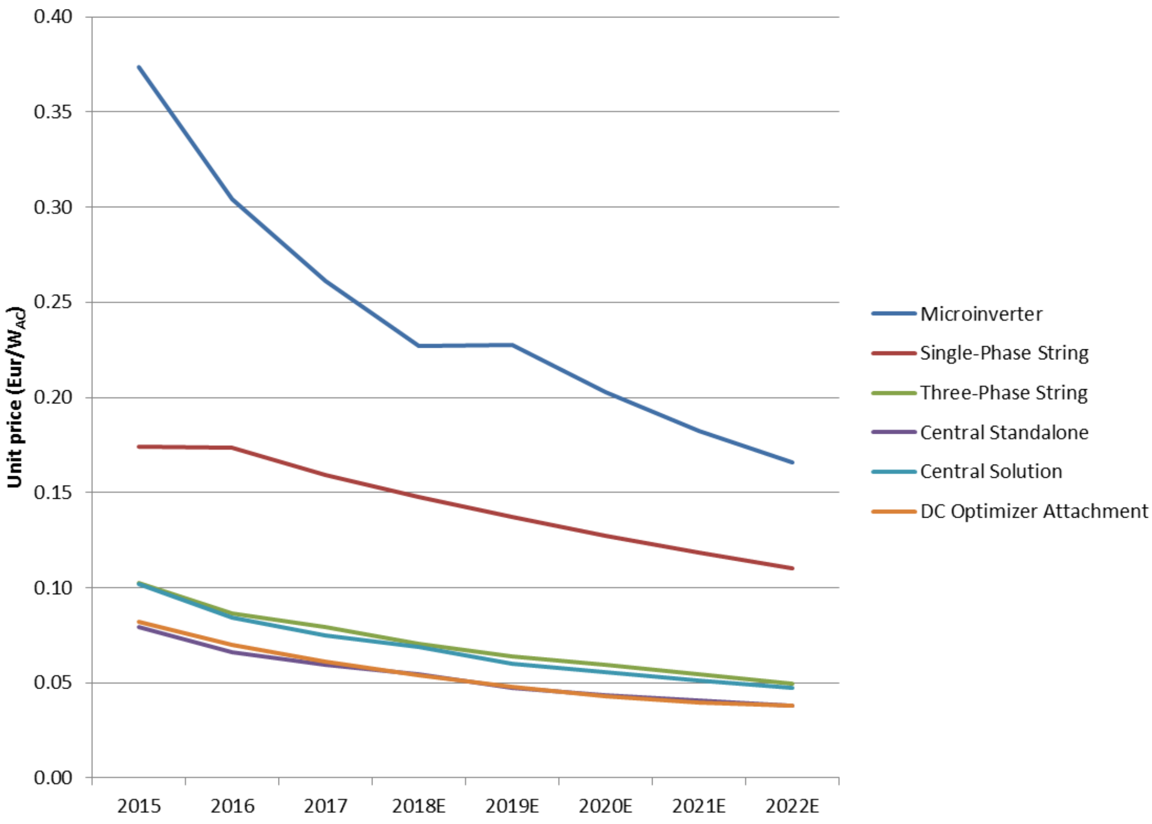

Figure 39. Inverter factory gate prices 2015-2017 and forecast to 2022   E=Estimate

Source: GTM Research (2018)

In terms of future price forecasts, up until 2019 prices are estimated to decline on average between 10% and 20%, slowing to between 5% and 10% between 2019 and 2022. Future cost reduction potential exists in the shift from 1,000 volt to 1,500 volt utility scale applications, as well as the already identified entry into the market of inverters with new semi-conductor designs and greater power densities. Cost reductions resulting from manufacturer consolidation and learning are estimated to be in the range of 3-7% per annum.

Table 15. Inverter factory gate prices 2015-2017 and forecast to 2022 (Eur/W_{AC})

Inverter type	**2015**	**2016**	**2017**	**2018E**	**2019E**	**2020E**	**2021E**	**2022E**
Microinverter	0.37	0.30	0.26	0.23	0.23	0.20	0.18	0.17
Single-Phase String	0.17	0.17	0.16	0.15	0.14	0.13	0.12	0.11
Three-Phase String	0.10	0.09	0.08	0.07	0.06	0.06	0.05	0.05
Central Standalone	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.04
Central Solution	0.10	0.08	0.07	0.07	0.06	0.06	0.05	0.05
DC Optimiser Attachment	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.04

E=Estimate

Source: GTM Research (2018)

2.4.3. PV System pricing and cost structure

2.4.3.1. Final system prices

The final system price has declined even faster than the module price in the recent years and for ground-mounted systems, prices below 0.70 EUR/Wp in Europe and below 0.65 USD/Wp have been registered in emerging markets such as India, thanks to very low cost for manpower. But the price decrease hasn't been that tremendous in all countries and market segments. In countries where the level of incentives remains sufficiently high, the decrease of prices was less significant. In Japan and in the USA, prices for rooftop system remain much higher than in the most competitive countries such as Germany for instance. The potential for price decline is still high in many segments and countries, while the current price of ground-mounted installations will continue to decline at a slower pace. Due to the increasing competition on tenders, the real price of PV systems cannot be estimated with precision but simple LCOE calculations show that most announcements are now in line with feasible prices.[45]

Concerning installation, rooftop PV installations support almost three times as many jobs and Gross Value Added than ground-mounted installations. This can be explained by their installed capacities, unit cost per MW and labour needs for installation, maintenance and operations. e.g. installation and maintenance & operations are easier and less time-consuming for ground-mounted systems, having a lower cost per MW. This means that fewer jobs are supported per MW compared to rooftop PV systems.

The cost of operation and maintenance becomes increasingly significant with the decline of PV system prices. Experience tends to show that it could be more important than initially calculated and actually influences the LCOE. This seems to be valid especially in humid or desert and hot climatic countries where PV is expected to develop further now. Some uncertainties due to quality issues in these environments could increase the cost of operation and maintenance in several countries compared to the expected numbers. It appears more and more that PV installations should take into account the location of the plant, not only with regard to the energy yield but also to the additional costs incurred due to anticipated the failure of systems components (modules, inverters…).

The expected lifetime of PV plant is evolving in various ways, with the idea that PV plants could be completely refurbished, including new modules after a certain lifetime, in such a way that they could compete with conventional power plants with lifetimes greater than 40 years.

2.4.3.2. System cost structure

The cost structure of a photovoltaic system has until recently been dominated by the modules. With the entry into the market of Chinese mass producers this cost structure has both reduced overall and the Balance of System components have become more important as an overall proportion of system costs, as can be seen in Figure 40 which illustrates a projected continuation of the downward price trend, albeit for a generalised cost structure.

The proportion of system costs accounted for by Balance of system is projected to increase from 46% to 52% in 2020 and 55% by 2028. This represents only the elemental (capital) costs, as well as land (ground) costs in the case of ground-mounted systems and excludes 'soft' costs associated with system design, permitting and installation/commissioning. These costs have been estimated based on an analysis of completed projects in the Germany PV market (see Table 16). The breakdown dates to 2013, so further component cost reduction will have subsequently occurred, however it is useful as an insight into the whole cost of an installation.

[45] Global PV market report 2018 – 2022. PV Market Alliance, 2018

In the case of BIPV systems the module cost may account for a greater proportion of the cost structure because the product must also fulfil the building component function. BIPV products are also more bespoke, being produced in much smaller production lots than modules, which to an extent have become more standardised. Figure 41 illustrates the possible ranges and outliers for different typical BIPV products based on a survey of 128 BIPV sector representatives conducted in 2013-14.

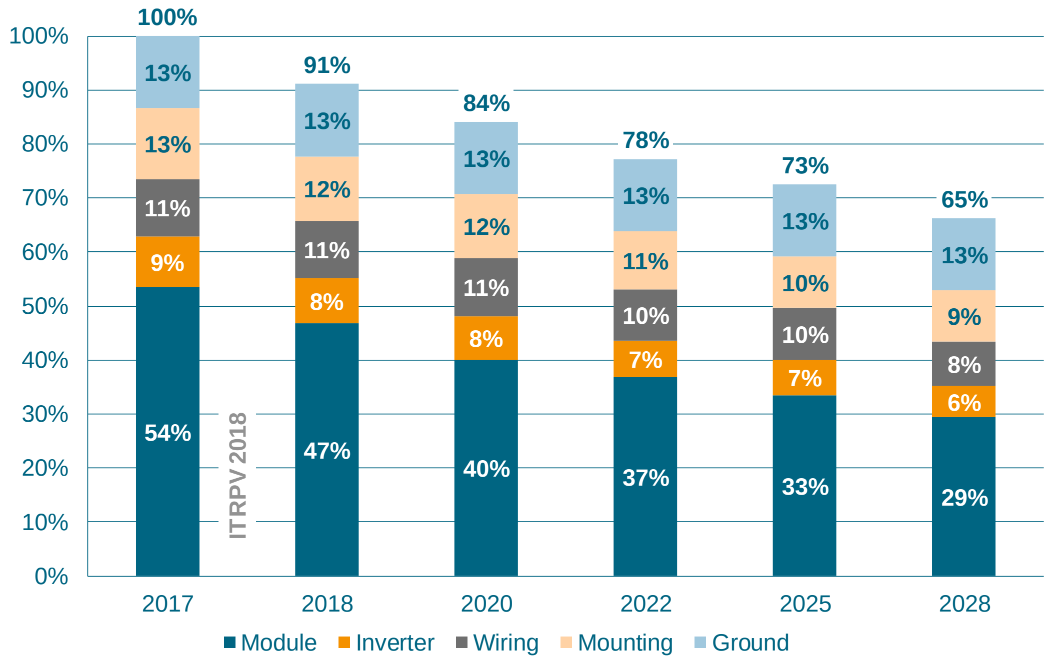

Figure 40. System costs and cost projections

Source: ITRPV, 2017

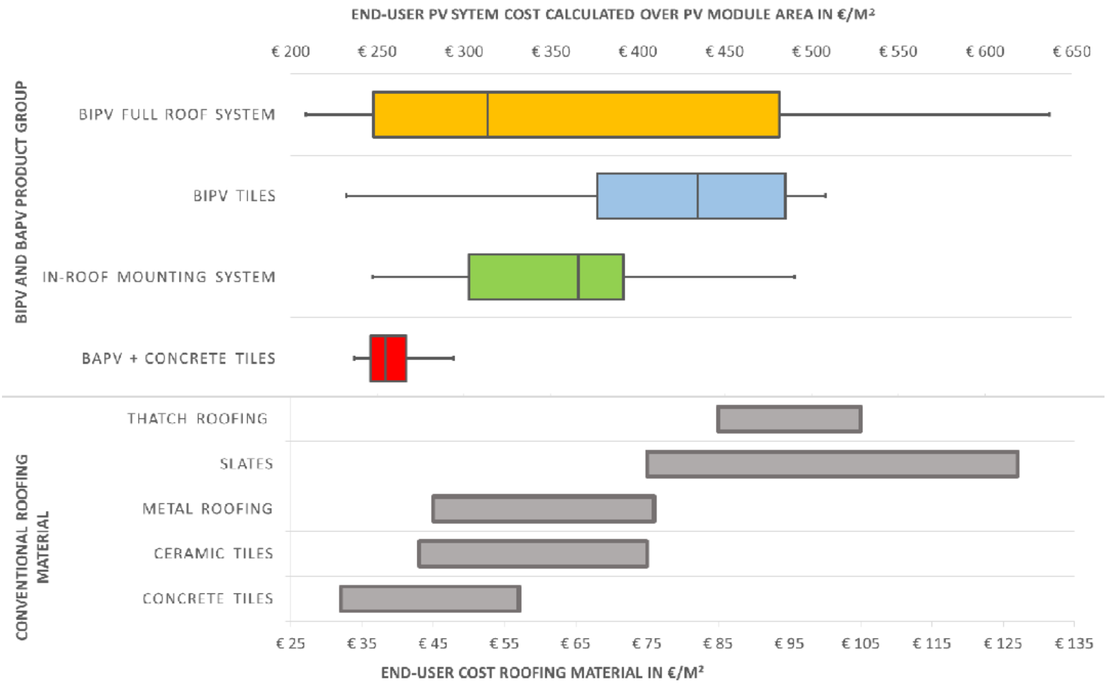

Figure 41 benchmark results from an end-user price survey, comparing conventional roofing materials with BAPV and BIPV roofing solutions

Source: Verberne et al (2014)

Table 16. Breakdown of labour costs and costs for 5 kWp add-on systems in Germany 2013.

Item	Labour	Costs		Cost share
PV module costs	[person-hours]	[EUR]	[EUR/kW$_p$]	[%]
Module (Si crystalline, Dec. 2013)	-	3000	600	37.8
"Hard" deployment costs	-			
Inverter (Dec. 2013)	-	1150	230	14.5
Mounting system	-	700	140	8.8
Cabling	-	100	20	1.3
"Soft" deployment costs and related transaction costs				
Customer acquisition (sales calls, site visits, system design, bid preparation, contract negotiation) *	5	175	35	2.2
Administrative processes related to building law*	0.67	23	5	0.3
Administrative processes related to grid connection permit*	1.5	53	11	0.7
Installation of PV system*	45	1575	315	19.9
Grid connection and commissioning*	2.5	88	18	1.1
Marketing and advertising		72	14	0.9
Overhead & profit installer firm		993	199	12.5
SUM		7929	1586	100
Time provided by building owner/client				
Information search	unknown	-	-	-
Site visit with installers	unknown	-	-	-
Contract negotiation with PV installer firm	unknown	-	-	-
Administrative processes related to financing	1	-	-	-
Corporate legal fiscal work	0.08	-	-	-
Registration to the federal Network agency	0.16	-	-	-
SUM	1.24	-	-	-

* Cost data calculated based on person hours and hourly rates

Source: Strupeit.L and Neij.L (2017)

2.5. Conclusions and recommendations

Initial conclusions and recommendations have been formulated in this section based on the work carried out in the present task. The definition of the product scope proposed in Task 1 for modules, inverter and systems is still considered to be valid in the light of these findings.

The main outputs provided by Task 2 are summarised according to the chapter headings used in this report. Barriers and opportunities for the implementation of eco-design and other policy measures are also highlighted and discussed.

2.5.1. Market and stock data

In the upstream segment of the market (i.e. component manufacturing), it is expected that the majority of jobs and GVA creation will shift from PV modules and inverters to other Balance of Systems (BoS) components over the 2016-2021 period, whereas downstream activities (i.e. services provided within the PV industry), which represent more than two thirds of the gross value added (GVA) in EU 28, are expected to rise again from more than 3500 M€ in 2016 to up to ca. 8000 M€ in 2021.

PV Modules

The total cumulative power of PV modules imported into Europe was approximately 87 GW up until the reference year, 2016. Adding the local production (23.92 GW) and subtracting the exports (9.43 GW), the installed base that constitutes the stock is estimated at 101.86 GW for year 2016. This figure represents one third of the cumulative global shipments up until the reference year (340 GW).

The six categories of PV modules with a market share greater than 1% are: multi-crystalline, mono-crystalline, amorphous silicon thin films, cadmium telluride films, and CIGS films. Until 2015 mono crystalline was dominant at utility-scale but since then prices for mono-crystalline have declined as production has expanded.

Although Cadmium telluride is the technology which has experienced the largest growth in the decade 2007-2016, in 2016 Mono silicon represented almost 70% of the market, Multi around 23%, CdTe ca. 4%, closely followed by high efficiency almost 3%, and CIGS (around 500% each). Concentration and Ribbon PV modules figures were found to be negligible.

Due to the lack of the official shipments data that is differentiated by module technology and pricing, it is not possible to estimate the monetary value of shipments.

Inverters for photovoltaic applications

Inverter capacity is generally expressed in watts of AC rated output (WAC). Because inverter market data is generally estimated from module DC capacity it is important to understand how the two may interrelate depending on the market segment. There also exists a mismatch between shipment data and sales because stock destined for Africa is shipped first to the EU.

In total 6,854 MW_{AC} of inverter capacity was shipped to the EU market in 2016. It can be seen that overall the EU market is dominated by three phase string inverter technology.

With an adjustment for the undersizing of inverter AC capacity in proportion to module DC capacity on larger systems, the installed new stock in 2016 is estimated to be in the range of 5,678 and 6,151 MW_{AC}. Using similar assumptions the total installed stock until the end of 2016 is estimated to be in the range of 94,400 and 96,913 MW_{AC}.

PV systems

In terms of the installed stock for systems, the ground mounted installations (which can be mainly considered as utility scale) experienced the largest growth in the years 2001-2016, followed by the industrial and commercial sectors where there were years especially between 2008 and 2011 when the growth doubled (over 100% each year).

The total installed system stock in 2016 was 101,788 MW_{DC}. The majority of this stock was accounted for by commercial (32%) and ground mounted (31%) systems. Residential and industrial systems accounted for 19% and 18% respectively.

2.5.2. Market trends

According to the insight from the trends given in section 2.3, the main EU and global trends are identified and categorised as relating to:

- the structure of global module production and supply,
- the type of the financial incentives and market arrangements that will be used by Member States to support further market growth,
- the relationship of utilities with their consumers and their extent of their role in providing solar PV systems,
- the extent to which self-consumption models will shape system designs in the future,
- a diversification in the range of digital and operational support services available to system owners, and the benefits these can bring.

The seven main trends identified from four authoritative market analysis reports are summarised in Figure 17.

Table 17. Identification and evaluation of global market trends

Trend	**Time horizon**	**Degree of uncertainty**
Continued overcapacity in global module productio	Short term	Medium
Phasing out of financial support schemes	Medium term	Low
Increased use of solar auctions to drive down prices	Medium term	Low
An increase in Corporate Power Purchase Agreements for solar energy	Medium term	Low
An increased focus on operation & maintenance services	Medium term	Medium
An increase in the number of utilities that provide solar PV services	Medium term	High
An increase in self-consumption by system owners	Medium term	Medium to high
Digitalisation of PV systems and components		Low

PV Modules

Market segmentation: The global market share for PV modules is dominated by crystalline silicon cell types for the reference year 2016 and projected to 2027. The PERC family of cell structures has quickly entered the market, achieving already a significant market share, and is projected to account for the largest market share by 2021. Bifacial cell types are projected to grow steadily, reaching approximately 20% market share by 2021, driven largely by large rooftop and utility scale system installations. The ITRPV projects that once PERC cell structures have become mainstream then bifacial modules will quickly follow in a 12-18 month period.

Product trends: Within a module, the number of cells is anticipated to increase, and despite the efforts to decrease the cost of encapsulants and back sheet materials these will be both main contributors in module manufacturing; new materials are being developed (EVA still having the major share). With the quality and durability of modules being a major focus, in line process control and automated optical inspections and testing/sorting are rising techniques in modules and cells manufacturing.

For thin film technologies information on trends is rather limited. Improvements for the mainstream products mainly refer to cost reduction and improving material efficiency, i.e. solar cells with less material but with higher efficiency. Moreover, because of the encapsulation techniques used thin-film technologies fulfil most of the architects' and constructors' requirements for the building skin, hence the BIPV market is expected to gain importance for these technologies.

Competitive analysis: The world PV modules market is dominated by the production of silicon technologies. China in particular can be seen to dominate the whole value chain, including polysilicon production, ingot production, wafer production and cell/module production. The country accounts for almost half of global module supply and deployment today. The seven companies that dominate the silicon market are grouped in what is known as Silicon Module Super League and six of them are headquartered in China.

The photovoltaic modules market is highly competitive, which means that there are limited margins which in turn restricts the number of intermediaries. Manufacturers' channels to market for conventional modules are generally limited to:

- Direct sales to developers or large installers,
- Sales via local subsidiaries,
- Sales via distributors then to installers
- Products then sold under the brand name of another company.

The market share of distributors in the large-commercial and industrial segment is rather small, due to the small margins, and larger installations do not normally use distributors for cost reasons.

Inverters

Market segmentation: The European inverter market is dominated by single and three phase string inverter technology (73%). The remaining portion of the market is accounted for by centralised inverters (26%), delivered either as a standalone unit or packaged with other power conditioning equipment such as transformers, and micro-inverters (1%).

Product trends: With the exception of micro-inverters, which still appear to have potential for efficiency improvements, inverter efficiency has increased to the point where the majority of system-level inverters have a declared efficiency in the region of 98%.

In the field of string inverters with a power rating of up to 100 kW, transformerless circuit topologies with high switching frequencies and Maximum Power Point Tracking devices represent the state of the art. Although still limited, the application of three phase string inverters to larger utility scale systems is an important application trend. Reducing the bill of materials through the introduction of silicon carbide (SiC) and gallium nitride (GaN) switching components (transistors) is a main trend in inverters. As was identified in the analysis of module trends, there are indications that the integration of power electronics at module level will continue to increase. This will see the further development of modules with integrated micro-inverters and DC power optimisers.

Competitive analysis: Global solar PV inverter shipments grew 23% on 2016 (34% in EU), reports GTM Research in its latest Global Solar PV Inverter Market Shares and Shipment Trends 2018 report. Revenues, meanwhile, increased by 11%. European manufacturers play an important role in the market, being estimated to account for just over 50% of shipments in 2016. The European inverter market is led by three companies (SMA, Fronius and ABB) that are also in a favourable position in the world market. SMA Solar (Germany) is the world's highest ranked company with regard to R&D investment in the PV sector.

Channels to market: for systems of a size greater than 100 kW, the system developer will in general tend to go directly to the manufacturer. The regional or country representatives of manufacturers are in general subsidiaries of the manufacturers. Distributers tend to be well established companies (e.g. Krannich solar in Germany) that sell mostly to the residential and commercial segments.

PV systems

Market segmentation: The early demand for systems came from a relatively small group of so-called pioneers who were committed to PV's environmental, energy security, and self-generation benefits. The PV industry has now evolved to so-called 1st Generation PV business models where the product is more attractive to a broader market, moving into the so-called early adopter customer category. 2nd Generation business models have yet to emerge, but will emphasise greater integration of the PV systems into the grid because emerging technologies and regulatory initiatives are likely to make such integration more viable and valuable.

Product trends: New market demands are being created by customers e.g. new technologies, contracting services, and maintenance services. In the EU, there are two major applications for grid-tied PV: residential and utilities with 22% and 38% of the total EU capacity, respectively. Residential prosumers are anticipated to increase although the remuneration conditions are not uniform across EU. For large installations, the major investments portfolios are principally located in three countries, UK, Germany and France.

The trends in systems can be seen at two main project stages: *design* and *operation*:

At the *design stage* it is expected that dynamic energy simulation grows, especially for large installations where it is already common its use, but also in small installations. Also in the design stage, 1 axis trackers are foreseen to increase a 50% by 2020, coupled together with bifacial modules, and eventually becoming the dominant design. The expected increase in the self-consumption will stimulate further storage options to be developed. There are already some manufacturers offering inverter products combined with batteries, or their integration at module level. Also at module level, there is a trend to include power electronic solutions. To then connect the modules, the trend expected to continue is the use of combiner boxes.

At *operational stage*, monitoring and data analytics are increasingly forming part of operation and maintenance contracts. These services are growing in complexity and range from vegetation trimming to modules cleaning.

Competitive analysis: Europe has strong firms in more specific PV domains such as the manufacturing of connectors, (sun) trackers, encapsulants and polymers in general, and solar glass. Most of these companies invest heavily in research and development (R&D). While there has been an overall downturn in residential installations, for example in the major EU markets of Germany, Italy and the UK, a diversified offer of components and services for 'prosumers' has emerged and there is evidence that it is growing. The leading market for battery storage systems is Germany, where the introduction of financial incentives has led to the installation of more than 75.000 PV + storage systems by the end of 2017.

Among the top five tracker manufacturers companies globally, two are European, Soltec (SP) and Convert Italia (IT). With diminishing utility-scale site availability and rapidly increasing tracker competition, the commercial and industrial segments seems poised for substantial growth in tracking technology.

Channels to market: As seen for previous PV components, when dealing with systems, the channels to market can be quite diverse depending also on the scale of the system, whether it is large scale or small residential installer market. Project developers and engineering procurement and construction (EPC) companies are normally present in large installations, while system installers normally act at all scales. The main developers in Europe are found in Germany (with an accumulated value of 2,040 MWp), France (811), Austria (469), the UK (358) and the Netherlands (307). In the case of EPC contractors, the Member States whose firms have the highest accumulated capacity are Germany (3,569 in MW_{AC}), Spain (631), the UK (585), Austria (466), France (369) and Portugal (318).

PV system trends and competitive analysis
Stakeholder consultation points

2.1 Are there any significant trends that haven't been captured for PV modules, inverters and systems?
2.2 Is there any trend amongst those presented for PV modules, inverters and systems that you do not agree with? If so, please give your reasoning.
2.3 Does the description of routes to market for PV systems match the experience across different EU Member States?

Requests for information and case studies

- Further information on which market segments are anticipated to create demand for the new silicon technologies identified in this study.
- For conducting a competitive analysis we would like further information on monitoring and data analytics, and operation and maintenance services
- Further information on BIPV products trends, segmentation of products

2.5.3. Consumer expenditure

The cost structure of a photovoltaic system has until recently been dominated by the modules. With the entry into the market of Chinese mass producers both the overall cost structure and the proportion accounted for by modules have reduced..

Module price evolution in the selected countries (Germany, Italy and Spain) has followed the same trend along 2001 to 2016. They all had a peak around 4.5-5 EUR/Wp in 2005/06 and then a continuous reduction down to 0.5 EUR/Wp, which is an average of a -90% decrease.

In terms of future inverter price forecasts, up until 2022 prices of all type of inverters are estimated to decline. The most notable trend for inverters prices is however the sharp decline in micro-inverter pricing, which reflects aggressive cost reductions by the market leader Enphase Energy, as well product innovation, such as dual module inverters. It is anticipated that further moves towards AC module integration will contribute to the downward price trend.

The final system price has declined in the recent years even faster than the module price and for ground-mounted systems, prices below 0.70 EUR/Wp in Europe and below 0.65 USD/Wp have been registered in emerging markets such as India, thanks to very low cost for manpower. However, the price decrease hasn't been as marked in all countries and market segments. In countries where the level of incentives remains sufficiently high, the decrease of prices was less significant. In comparison with most competitive countries such as Germany, prices for rooftop system have declined more In Japan and in the USA, . The potential for price decline is still high in many segments and countries, while the current price of ground-mounted installations will continue to decline at a slower pace.

System cost structure

Stakeholder consultation points

2.1 What could be the variance in the PV system pricing at the smaller end of the scale compared to the headline figures presented *i.e. commercial and residential*?

2.2 What are the factors that can influence this price variation?

Requests for information and case studies

- Module price evolution for EU countries other than those analysed: by technology (e.g. Si based, thin film) and by segment (residential, commercial, utility scale),
- Microinverters integrated in modules prices
- Updates on 'soft' costs[46] for PV systems , especially for utility scale. Further price information on operation and maintenance costs

[46] According to Strupeit and Neij (2017) soft costs relate to *'customer acquisition, technical and legal-administrative planning, installation work as well as the transaction costs associated with financing'*.

List of abbreviations and definitions

AC	Alternated current
aSi	Amorphous silicon
BAPV	Building attached photovoltaics
BSF	Back Surface Field
BIPV	Building integrated photovoltaics
BOS	Balance of system
CIGS	Cadmium Indium Gallium Selenium
CPA	Classifications of Products by Activity
CTM	Cell to module
EoL	End of Life
EPC	Companies that are prepared to provide services linked to the Engineering, Procurement and Construction disciplines of a project
ErPs	Energy-related Products
ESCO	Energy service company
FiT	Feed-in tariff
GPP	Green public procurement
GVA	Gross value added
IEA	International energy agency
IPP	Independent power producer
ITRPV	International Technology Roadmap for photovoltaics
LCA	Life cycle analysis
LED	Light emitting diode
MPP	Maximum power point
MPPT	Maximum power point tracking
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
NZEB	Nearly zero energy buildings
OEM	Original Equipment manufacture
PERC	Passivated Emitter and Rear Cell
PPA	Power purchase agreement
RES	Renewable Energy Systems
WEEE	Waste Electrical and Electronic Equipment

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