SOLAR PHOTOVOLTAIC (PV) POWER IN EUROPE

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EXECUTIVE SUMMARY

2008, marks the “take-off” and subsequent boom in worldwide solar PV installations fostered by the climate agenda and enabled by generous government subsidies and an 80 percent price-fall since 2010. Another striking feature is the geographical diffusion of solar PV. In 2017, 29 countries had more than 1 GW of PV installed capacity. Seven countries had more than 10 GW; four exceeded 40 GW each, all dwarfed by China with 131 GW of installed capacity. Germany, a pioneer and leader for many years, with 43 GW of installed solar capacity lost out to the US with 51GW and Japan with 49 GW. China now leads in total solar energy capacity followed by Europe with 114 GW.

Global solar PV capacity is expected to double again from 306.5 GW in 2016 to 740 GW by 2022, ushering in another virtuous circle of cost reductions – the fruits of the “learning rate” and economies of scale.

The deployment of solar power in Europe owes much to the EU’s pioneering lead towards a low carbon economy through policies designed to increase energy efficiency and to reach ambitious CO2 reduction targets by 2020, incentivised by generous subsidies. Five countries, Germany, Italy, the UK, France, and Spain combined operate around 77 percent of Europe’s solar power fleet. Germany and Italy together account for over half.

Remarkably, 64 percent of solar systems in the EU are installed on rooftops, 26 percent of them residential, 18 percent commercial and 20 percent industrial. Investors, developers, and independent power producers with power purchase agreements dominate the ground-mounted utility-scale plants segment.

The key drivers of this solar revolution in Europe, over and above the EU’s climate agenda and availability of subsidies, were the plummeting price of solar PV, which fell by a staggering 40 percent between 2015 and 2016, and made solar cost effective against other power generation technologies and attractive to the rooftop market segment. These factors together with the availability of capital and willing investors have encouraged utility-scale solar farms. However, the era of generous government incentives is ending. Solar, like wind, must be able to compete in the market without government support.

The EU’s renewables target of 34 percent by 2030 would raise the share of renewable energy in the power sector to 50 percent and envisages solar PV being used in building materials, heating and cooling systems, powering of trucks, vehicles, and a greater uptake by energy intensive industries. The prospect of an effective price for carbon, advances in technology and improved cell efficiency combined with government targets provide a degree of confidence for future private sector investment in solar PV.

GLOBAL OVERVIEW

The year 2008 marks the "take-off" of solar photovoltaic (PV) power. Worldwide solar capacity grew from 15.2 GW to 40.3 GW between 2008 and 2010 leaping to 99.5 GW in 2012. Simultaneously, global investment in solar energy rose from US$ 61.3 billion to US $103.6 billion. New installations in the following two years rose by 38.3 GW and 36.3 GW respectively bringing the total installed solar capacity to 174.1 GW in 2014.

Advances in technology, including concentrated solar power generation, saw prices fall by 40 percent between 2015 and 2016, making solar cost-effective against other power generation technologies. 2016 was a record year for global solar, as new solar PV capacity worldwide rose by 50 percent to reach 76.6 GW, bringing the total installed capacity to 306.5GW. For the first time, solar PV additions rose faster than any other fuel, including wind at just 52 GW. Sharp cost reductions resulted also in record low auction prices, which fell to 30/megawatts per hour (MWh).

China accounted for more than half of new solar installations in 2016, adding 34.5GW, whilst the US added 14.7GW. Together, these two countries accounted for two-thirds of the growth in solar capacity. Japan lay in third place adding 8.6GW of new PV installations. Global growth continued in 2017 when an astonishing 99.1 GW of solar PV was installed.

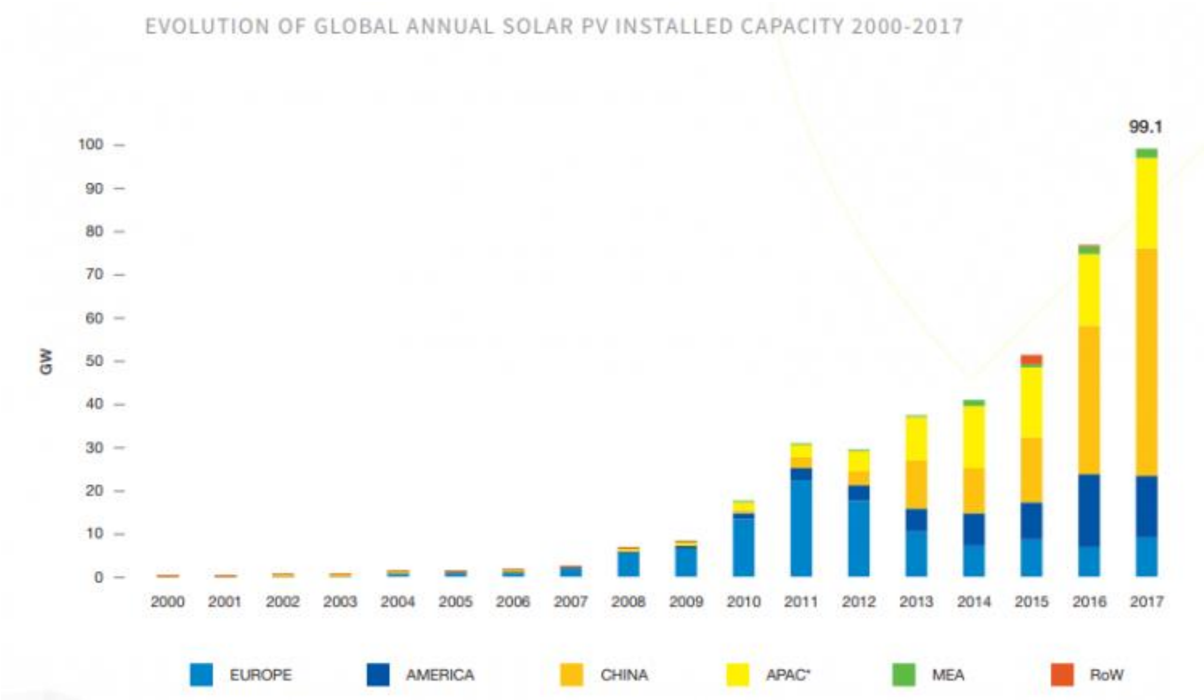
Beyond the rapid expansion of solar is another striking feature, the geographical diffusion of solar PV. In 2017, 29 countries had more than 1 GW of PV installed capacity. Seven countries had more than 10 GW; four exceeded 40 GW each, all dwarfed by China with 131 GW of installed capacity. Germany, a pioneer and leader for many years, with 43 GW of installed solar capacity lost out to the US with 51GW and Japan with 49 GW. China now leads in total solar energy capacity followed by Europe with 114 GW. International Renewable Energy Agency[i] Today, seven out of 10 solar modules produced in the world are made in China.[ii]

This exceptional rate of solar growth is expected to continue. The IEA forecasts that by 2022, total global solar PV capacity will reach 740 GW and solar will achieve grid parity, i.e. competitiveness with electricity grid retail prices by 2020 in many countries. Solar PV now represents around 2.1 percent of global electricity demand and 4 percent in Europe.[iii]

EUROPE

Europe has the oldest fleet of Photovoltaic (PV) power plants in the world and reached its 100 GW milestone of grid-connected solar power in 2016. Solar is now the fastest growing power generation source in Europe thanks to prices falling by some 40 percent between January 2016 and December 2017. [iv]According to SolarPower Europe, the region's photovoltaic (PV) installations grew by 28 percent from 6.72 GW in 2016 to 8.61 GW in 2017 bringing the total to 114 GW.

Figure 1

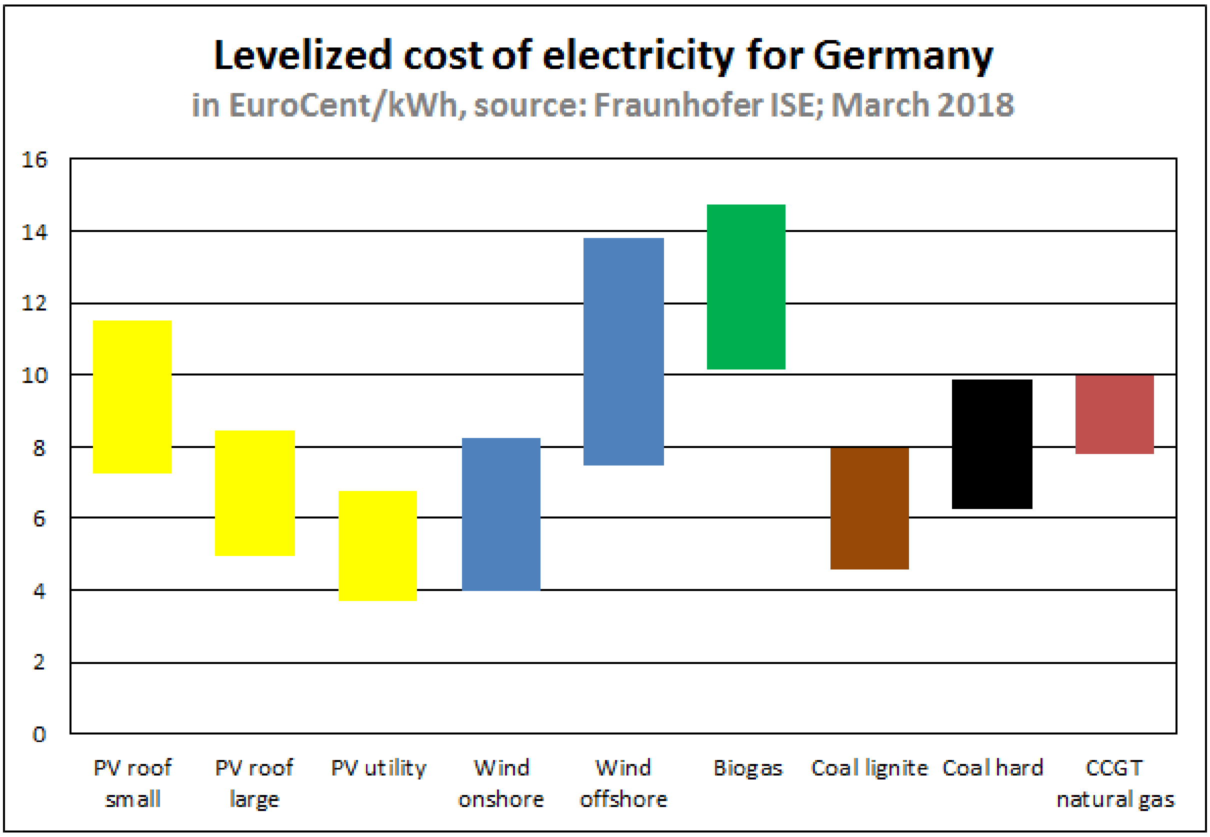


Source SolarPower Europe, Global Market Outlook 2018-2022,

The deployment of solar power owed much to the 80 percent decline in module prices since 2010 and the EU's pioneering lead towards a low carbon economy through policies designed to increase energy efficiency and reduce CO2 emissions with a shift towards renewable energy. Financed by initially very generous subsidies and feed-in-tariffs (FITs) nevertheless, in 2016, Europe lost its number one ranking in solar power generating capacity to China.

Growth of EU solar installations in the next two years will be driven by nationally binding 2020 CO2 targets and, in the case of Germany, compensation for the loss of 2.9 GW of nuclear capacity by 2020. In the medium term, solar growth will continue boosted by record low solar module prices, which enabled solar to become the lowest cost power generating technology. In Lazard's 2017 Levelized Cost of Energy Analysis, utility-scale solar was cheaper than nuclear, coal and new Combined Cycle Gas Turbines (CCGT). This conclusion is reinforced by SolarPower Europe's calculations, as illustrated.

Figure 2



Source https://upload.wikimedia.org/wikipedia/commons/8/87/Levelized_cost_of_electricity_Germany_2018_ISE.png

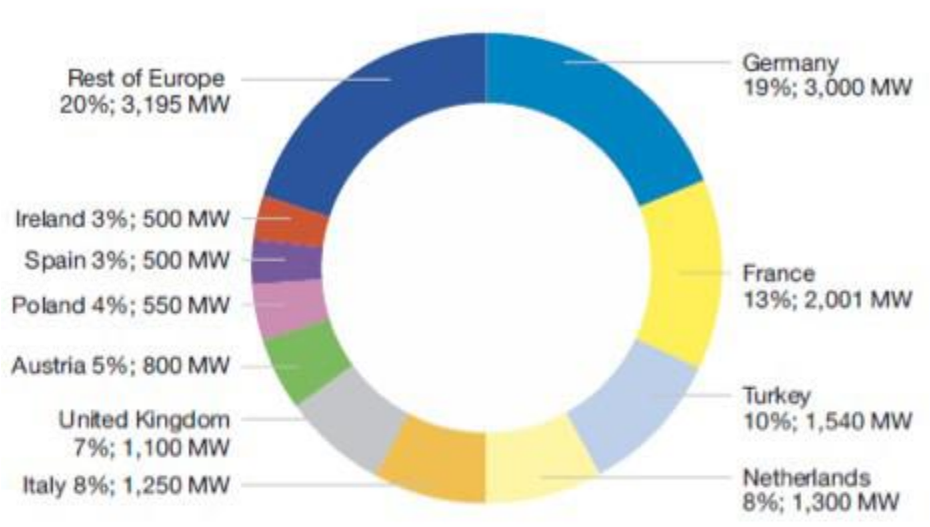
For these reasons, it is not surprising that the region is poised to install an average of 14 GW every year from now until 2022. While solar covers around 5 percent of the EUs current electricity demand, this could grow to 15 percent by 2030, if just 20 GW is installed each year.[v] In addition, according to the International Renewable Energy Agency (IRENA), the EU could double the renewable share in its energy mix cost-effectively from 17 percent in 2015 to 34 percent in 2030.

This anticipated growth in solar and wind power will negatively affect the traditional business model of centralised fossil fuel power generation. Today the need is for rapid responsiveness – i.e. one second, rather than ten, shorter cold start times, and operations at lower minimum stable levels, which requires battery storage and peaking plants.

MARKETS

Germany with 42.9 GW (37.7%) and Italy with 19.3 GW (17.0%) together operate over half of the total European solar power generating fleet. The UK lies in third place with 12.6 GW (11.1%) followed by France with 7.9 GW (7.0%) and Spain in fifth place with 5.6 GW (4.9%) of Europe's total installed capacity.[vi] Figure 3 provides an overview of Europe's solar deployment by country.

Figure 3



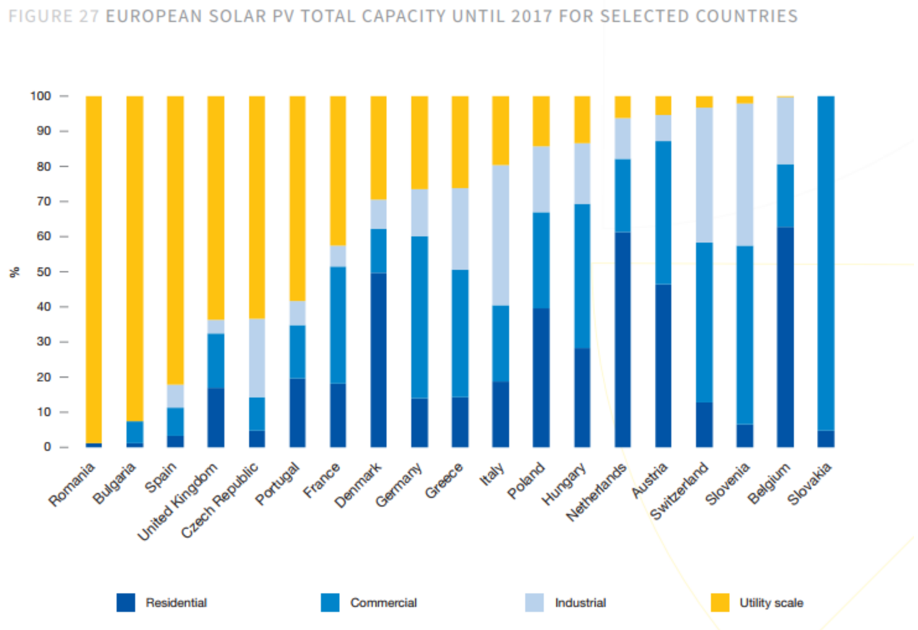
Source https://www.tsolar.com/recursos/img/portal/2017/10/24/perspectivas-3.jpg

PRODUCT/CUSTOMER SEGMENTS

Remarkably, 64 percent of solar systems in the EU were installed on rooftops, 26 percent of them residential, 18 percent commercial and 20 percent industrial. Just 36 percent of solar systems comprised ground-mounted utility-scale plants, a segment that is dominated by investors, developers, and independent power producers with power purchase agreements (PPAs).

As illustrated in Figure 4, countries that offered lucrative, initially uncapped feed-in-tariff (FITs) schemes are still dominated by utility-scale solar including the UK, Spain, Bulgaria, Romania, and the Czech Republic. In Germany, it was not really until 2008 that grid-connected utility-scale PV became significant and it is generally small-scale, at around just 10 MW. Since initially generous FITs were succeeded by a capacity auction system, the distribution of utility-scale and rooftop PV is becoming more even. However, in Austria, Switzerland and the Netherlands there is little utility-scale production.

Figure 4



Source SolarPower Europe, Global Market Outlook 2018-2022, June 27th 2018 1

The advent of a mass market in electric cars, the development of smart cities and the rise of a corporate segment of producers and energy-intensive customers could reinforce the predominance of rooftop installations in much of Europe. IT companies with big data processing centres, manufacturing as well as service enterprises such as Paris Airport and France is Railway Company SNCF, are beginning to purchase renewable energy with time-limited private power purchase agreements.

GERMANY

Germany, is a pioneer of wind and solar energy, kick-started its shift towards renewable energy with generous subsidies and feed-in-tariffs (FITs) alongside priority grid access. The German Development Bank also provided grants and low interest loans. Three quarters of solar capacity comes from residential, commercial, and industrial rooftop installations leaving the remainder to ground-mounted utility-scale systems. German retail electricity prices rose by 51 percent between 2006 and 2018 and is twice more expensive than that of France.[vii] It is therefore not surprising, that farmers, households and many businesses took the opportunity to escape ever-rising electricity prices to self-generate and self-consume solar energy, aided by plummeting prices of small-scale 10 to 100 kWp rooftop PV systems as shown in Figure 5.

Figure 5

Source Fraunhofer Institute

For utility-scale photovoltaic installations, costs fell from over 40 ct/kWh in 2005 to 9 ct/kWh in 2014 due to solar cost reductions and capacity auctions, which introduced competitive pricing for solar energy.[viii]

German government policies to decarbonise the economy have been effective. In 2017, clean power was the single largest source of net power generation accounting for 38.2 percent in comparison to gas and oil, (8.9%), nuclear (13.1%), hard coal (14.8%) and lignite (24.3%).[ix] Together, solar and wind power generation produced circa 142 TWh in 2017. Financial incentives, falling PV prices and German desire for sustainability combined to ensure a leading role for solar. According to the Fraunhofer Institute, at the end of 2017 Germany had 43 GW of installed solar capacity distributed over 1.6 million power plants? In July 2018, solar power production reached an all-time high of 6.7 TWh generating 15.1 percent of the total electricity produced and ahead of nuclear at 13.8 percent.

"Photovoltaic has become an indispensable source of electricity, without which, grid stabilization would be difficult to maintain," states Professor Bruno Burger of the Fraunhofer Institute.

However, this was still not enough to curb emissions. Renewable energy has barely compensated for the loss of baseload nuclear generating capacity and growth in electricity output. Between 2010 and 2016, nuclear power capacity almost halved from 20.4GW to 10.8 GW. A further 2.9 GW of nuclear capacity is set to close by 2020 and another 8 GW will be lost by 2022.[x] the danger is that coal, lignite and natural gas, will continue to be used to help fill the gap thereby increasing, rather than reducing, emissions.

Germany's Environmental Agency warned that CO2 emissions targets for 2020 would be missed. Consequently, Germany passed the Renewable Energy Sources Act 2017 (EEG). This sets a solar and wind growth target of between 2.3 GW and 2.5GW annually for 2018 and 2019, to be met by holding three tenders a year for 200 MW each of wind and solar power.

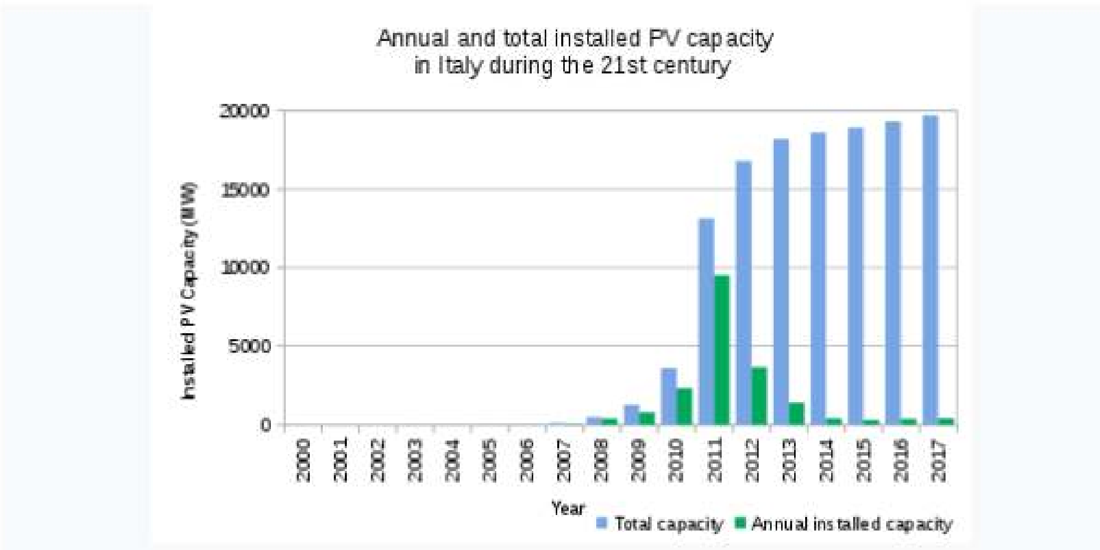
The EEG simultaneously supports and restricts growth in PV capacity by its terms and conditions. For example, the EEG law states that FITs payments will not be allowed once total PV installations reach 52 GW. By the end of April 2018, Germany had 43.8GW of PV installed and is therefore likely to reach the cap before 2020. Moreover, self-consumed PV energy above 10 kW is taxed. However, depending on the system size, the FIT for small roof systems in operation by April 2018 can be up to 12.20 e-cts (euro cents) /kWh and is guaranteed to the operator for 20 years. After 2020, FITs will gradually end for the oldest plants as they reach 20 years.

Over the coming decade, renewables will be strongly supported since the Coalition Agreement of March 2018 raised the share of renewables in the electricity mix from 50 percent to 65 percent in 2030. To reach this target, 5 GW of PV will need to be installed each year.

ITALY

In line with efforts to decarbonise the Italian economy and take advantage of available excellent sunlight levels, the government introduced generous incentives for solar PV generating schemes. The five Conto Energia or feed-in-tariffs schemes of 2005-2012, each with different terms and tariffs, resulted in 18.2 GW of installed solar PV capacity at a total cost of 6.7 billion euros.[xi] Of these, the fourth and the last FIT schemes had the most impact. The fourth, in 2011 brought an additional 7.6 GW of solar capacity on stream - the single largest increase of the programme - at an annual cost of 2.47 billion euros. The fifth and final FIT in 2012, brought a further 2,095 MW of PV installations before its expiry in 2013. After the expiry of government subsidy programmes installations fell to around 300-400 MW.[xii] Nevertheless, this was sufficient to rank Italy second only to Germany in solar electricity production.

Figure 6



Annual and cumulative installed photovoltaic capacity (in MW) during the 21st century.

Source https://www.gse.it/dati-e-scenari 2

At the end of 2017, total installed PV capacity reached almost 20 GW of which, small-scale systems up to 10 k/w, took the lion's share. 730,000 plus small-scale rooftop installations supplied 7 percent of Italy's electricity in 2017. Notably, the commercial and industrial segment includes, large installations totalling 63 MW, shared by five solar plants, the largest of which, is the Montalto di Castro PV power station established in 2010 with a capacity of 85 MW. For utility-scale plants, solar power reached grid parity in Italy as early as 2013. Government investment into three Concentrated Solar Power (CSP) plants in the south of the country could be augmented, in the not-too-distant future, by an expected increase in capacity to 360MW and make an important contribution to meeting EU targets for CO2 emissions.

Despite the expiry of government subsidies, PV installations in 2018 are being boosted by the need to repower and refurbish between 90 and 100 MW of installations due to failures of junction boxes, lamination, and silicon. A further 55 MW of modules, out of 485 MW of incentivized power plants, have been replaced whilst, the halving of tax on residential PV installations is expected to boost new installations. Likewise, the introduction of higher efficiency standards in 2018 will add to market buoyancy through diffusion of PERC technology. Tax incentives introduced in 2018, are expected to attract another 500 MW of utility-scale installations and the utility-scale segment could be further boosted by the ability to sell wholesale energy at a fixed price under a two-year PPA. Unlike Germany, Italy allows owners of up to 20 MW plants, to sell all or part of the produced power, to a single final client through a corporate or private PPA unburdened by grid and system fees.[xiii]

THE UK

To meet the EU's 2020 emission targets, the government in 2010 introduced the feed-in-tariff to be paid for all grid-connected renewable electricity at the initially very generous rate of 41.3p per kWh, subsequently reduced on a sliding scale to bottom out at 4.39 kWh in February 2016. In parallel, another payment, the Export Tariff, allowed small solar generators to sell their surplus to the national grid at a fair market price. These generous financial incentives had the desired effect. Thousands of residential, commercial and community building rooftops became homes for solar panels and utility-scale solar became a reality. As Table 1 below illustrates, solar generation capacity exploded from 95 MW in 2010 to reach 12,760 MW in 2017 and solar provided 3.4 per cent of the UK's total electricity consumption.

Table 1. UK electricity production from solar panels as a percentage of total final consumption.

Year end	2000	2009	2010	2011	2012	2013	2014	2015	2016	2017
Capacity[1] (MW)	22	27	95	965	1,736	2,822	5,378	9,118	11,562	**12,760**
Generation (GW·h)	17	20	33	259	1,328	2,015	4,050	7,561	10,292	**11,479**
% of total electricity consumption	**<0.01**	**<0.01**	**0.01**	**0.07**	**0.37**	**0.64**	**1.33**	**2.49**	**3.1**	**3.4**

Source: DECC – Department of Energy & Climate Change, Statistics – Solar photovoltaics deployment (period from 2010 onward

Large-scale solar farms now contribute around 1.51 GW to the UK grid. Medium-scale solar PV, of between 5 and 25 MW, provides the most at 4.30 GW whilst small plants of between 50 kW to five MW capacity contribute 3.42 GW. The largest segment numerically, the residential and commercial segment, contributes just 2.55 GW to the grid.[xiv]

Cuts to incentives in 2016 for householders to fit solar panels and the ending of subsidies for large-scale solar farms inaugurated a collapse of new installations from 4.1 GW in 2015 to 1.97 GW in 2016 and just 950 MW in 2017. [xv]

Nevertheless, this compares favourably with France, which added 873 MW, Spain which nearly tripled installation to 135 MW and the Netherlands with 500 MW of solar additions.[xvi]

Issues of new FITs cease at the end of 2019 and solar industry stakeholders currently fear the ending of the Export Tariff, the loss of which would mean that new projects would no longer be subsidised. Compounding this, the commercial rooftop segment has to cope with the shock announcement of an 800 percent rise in business rates for an on-site-self-owned-self-consumed installation.

Notwithstanding this, plummeting costs, improved efficiency, and advances in battery storage have combined to enable the establishment of the UK's first subsidy-free solar farm in Bedfordshire, albeit an extension to an existing farm, co-located with a six MW battery storage facility. In addition, Buckinghamshire is now home to the first solar subsidy-free business park. However, the planned super- size 350 MW solar power farm destined for the north Kent coast has been stalled, even though this would benefit from economies of scale hitherto unavailable.

Lacking policy clarity on a post FIT future and level playing field utility-scale solar installations are currently stalled. The cost of utility-scale solar PV since 2014 has fallen by approximately 20 percent a year and is now estimated at £50-£55/MWh. This compares with the agreed "strike price" of £77.5 for power from the Wylfa Newydd nuclear power station! https://www.solar-trade.org.uk/press-release-billions-for-wylfa-nuclear/ [xvii]

In the medium term, some industry veterans are predicting that the UK is on course for a subsidy-free renewable revolution that could add 18GW of new capacity by 2030 and attract £20 billion in investment.[xviii] However, it is unclear post- Brexit, whether the UK would remain committed to the EU's target to generate 32 percent of energy from renewable sources by 2030.[xix]

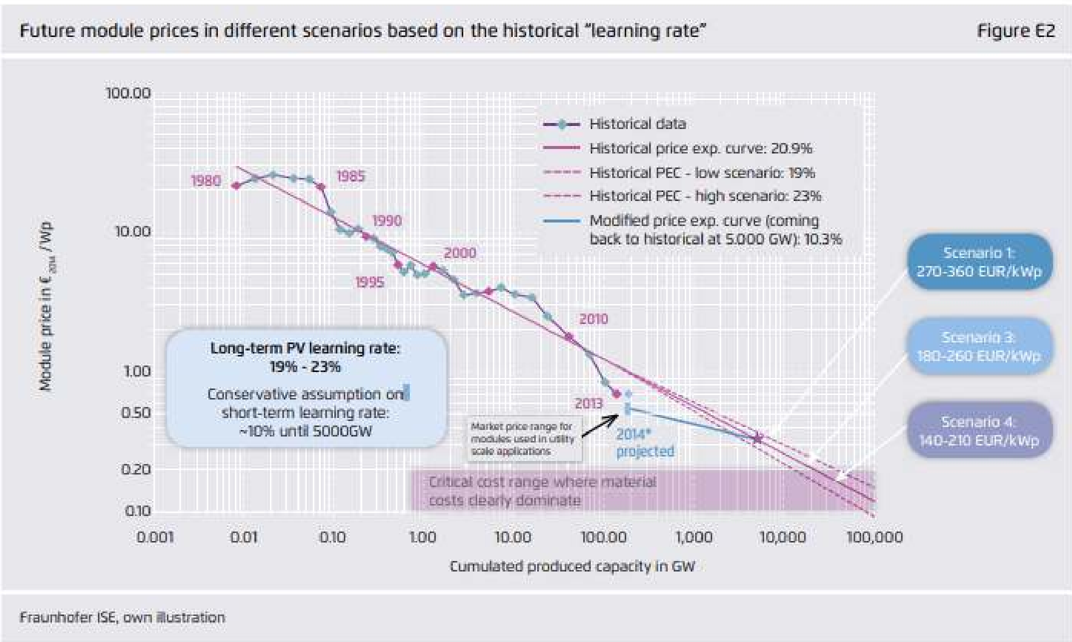
KEY DRIVERS

Solar is green, flexible and increasingly the lowest cost power-generating technology. Falling costs and technical improvements have *encouraged* uptake whilst EU emission reduction targets have *required* adoption of renewables.

PRICE

Price is the key to the competitiveness and market penetration of renewable energy. Price is also the key driver for people and companies to adopt renewable self–generation. What is remarkable is that the price of crystalline silicon (c-Si) PV modules has fallen by more than 80 percent since 2010 thanks to the PV "learning rate" and economies of scale. The former, allows that for every doubling of cumulative installed capacity PV, module costs decline by between 20 and 22 percent as illustrated in Figure 7.

Figure 7 PV Learning Rate and Price Decline 1980-2014



Source Fraunhofer Institute. Current and Future Cost of Photovoltaics. February 2015

Thanks to burgeoning solar PV installations particularly in China, global PV module capacity at the end of 2017 reached 291 GW and is forecast to more than double by 2022 to 740GW worldwide thus potentially ushering in another substantial fall in costs and prices[xx].

The International Technology Roadmap's cost breakdown of the solar PV value chain found that the panel alone accounts for nearly half of the total system capital cost with the inverter or "brain" the mounting and system design accounting for the rest. This limits opportunities for cost reductions to three areas: materials, processes, and products. In the case of materials, options include dematerialization i.e. using less material or substitution of existing materials with less costly ones. A case in point is the ten- fold reduction in the silver content of a panel since 2005[xxi] and or, increasing efficiency through smarter manufacturing. With regard to processes, new technology and materials and or, more productive manufacturing equipment, could help reduce the cost of products such as ingots, wafers, and c-Si solar cells. Lastly, science and technology could improve the overall efficiency of PV systems. "The combination of reduced manufacturing costs and increased cell and module performance will support cost reduction and competitiveness of PV power generation," states the International Technology Roadmap for Photovoltaic 2017[xxii]

ENERGY STORAGE

Improvements and the falling cost of battery storage will be key to future market expansion and penetration of renewable energy. Battery storage, by smoothing the short term variability of renewable power, and eliminating production and load peaks, makes solar fully despatchable. Above all, small capacity battery storage is economic for the dominant rooftop segment whereby users can store electricity when prices are low and use it when prices are high. For grid operators, large-scale battery storage helps balance the system and could reduce the need for grid upgrades and future expansion.

In Austria and Switzerland 95, percent of solar installers now market battery storage systems. In 2017, nearly half of all newly built PV systems on the Continent were built with battery storage. In March 2018 there were over 50,000 solar storage systems installed in Germany. Indeed, according to the German Solar trade association, BSW-Solar the number of energy storage systems will double in the next two years because battery storage costs have fallen by more than 50percent since 2013.[xxiii]

EXPIRY OF IMPORT TARIFFS

The EU's imposition of tariffs on imports of solar crystalline cells and modules from China, Malaysia, and Taiwan in 2013 effectively set a minimum price of roughly 30 percent above market levels. This was ended on 3rd September 2018, just in time to help the EU meet its own renewable energy targets. "By removing the trade duties, the European Commission has today lifted the single biggest barrier to solar growth in Europe," stated Dr Christian Westermeier, President of SolarPower Europe. "The expiry of tariffs on solar means that solar will be the cheapest form of electricity in many European countries," stated James Watson, CEO of SolarPower Europe.[xxiv] This single measure could also encourage investment and stimulate growth in subsidy-free PV in coming years.

UTILITY-SCALE PV FINANCING

According to Solar Asset Management UK, investors, developers, and independent power producers are increasingly financing utility-scale solar systems in the Netherlands and Spain.

In Europe, investors managing their assets account for over half or 55.7 percent of utility-scale solar megawatt capacity whilst solar developers and Independent Power Producers each account for 18.6 percent. What is surprising is that only one utility, namely German Enerparc AG, is ranked in the top ten portfolios of solar PV. See Table 2.

Table 2. Top 10 European Solar Portfolios

#	Name	Country HQ	Size '18*	Size '17*
1	Octopus Investments	Germany	1,080.00	1,085.00
2	Enerparc AG	Germany	1,050.00	984.02
3	Encavis	Spain	830.17	640.20
4	Foresight Group	UK	674.00	900.00
5	NextEnergy Solar Fund	UK	569.00	501.00
6	Aquila Capital	Germany	505.00	625.00
7	Bluefield Solar Income Fund Ltd	UK	498.70	401.40
8	Abengoa Solar	Spain	492.00	492.00
9	Sonnedix	UK	489.00	339.20
10	Greencoat Capital	UK	470.00	108.00
	* Sizes in Mega Watt peak, a solar power measure in photo-voltaic (PV) industry to describe a unit's nominal power			

Source *Solar plaza*[xxv]

As from January 2017, under State Aid Guidelines, tenders for solar PV above one MW in capacity are *de rigueur* in Germany and France. These auctions have been instrumental in lowering solar prices. For example, the winning bid of 4.33 Euro-cent per KWh in Germany's December 2017 tender, was half the price of that of April 2015.

Interestingly, just 1.1GW of Europe's solar power was produced under Power Purchase Agreements (PPAs). The greatest obstacle to solar corporate PPAs is the lack of an enabling framework setting out the conditions under which corporate PPAs and self-consumption are possible. Clarification is also lacking on the compatibility of subsidies and corporate PPAs. For example, a key problem in Germany and France is their unwillingness to let corporates have access to "so-called guarantees of origin" for subsidised green power. However, progress is underway, for in June 2018, the European Commission launched the RE-Source Platform, which is dedicated to uptake of corporate renewable PPAs.

PROSPECTS FOR SOLAR PV

According to SolarPower Europe, the region is poised to install an average of 14 GW of solar PV annually until 2022. However, to reach the EU's ambitious renewables target of 34 percent by 2030 would require an estimated average investment in renewable energy of a huge 62 billion euros a year. Such an expansion would raise the share of renewable energy in the power sector to 50 percent compared with 29 percent in 2015.[xxvi] This ambitious target also envisages more end-uses for renewables, ranging from heating and cooling of buildings to electrification of transport and increased uptake by energy intensive industries.

INFLUENCES AND KEY FACTORS

The EU's ambitious targets for renewables provide a degree of certainty to investors and developers in solar energy. For example, in Germany, the Coalition Agreement of March 2018 specifies that renewable power should provide 65 percent of gross electricity consumption by 2030. This necessitates an annual PV increase of 5 GW which, given development of an enabling regulatory framework, could be met principally by investors and developers of utility-scale plants alongside small-scale self-generation and self-consumption. This is especially the case when self-production and self-consumption of solar is currently cheaper than retail electricity and is set to fall further.

INCREASE IN END-USES OF SOLAR

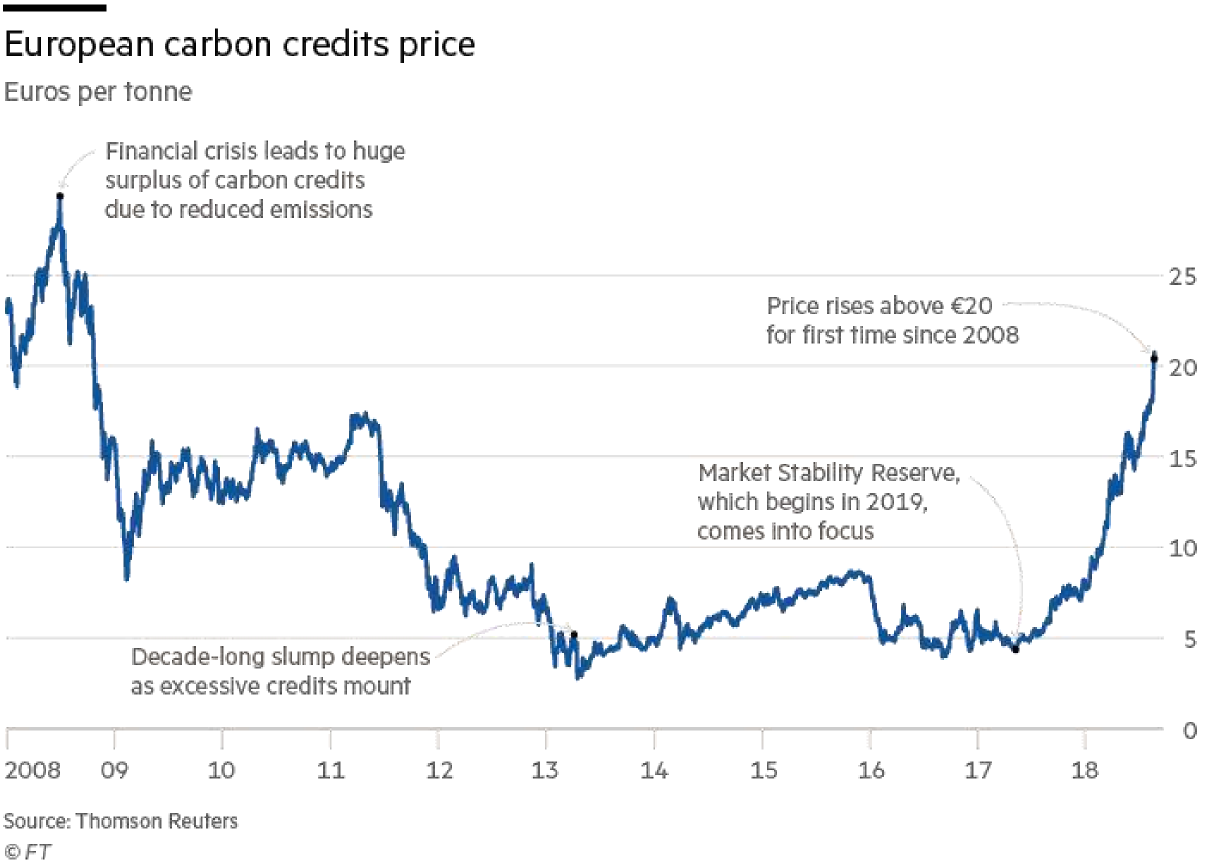
Diversification of solar PV into buildings, heating and cooling systems, powering of trucks, vehicles, and increased uptake by energy intensive industries are emerging trends. There is first, the EU Covenant of Mayors, an initiative to promote the energy transition towards renewables in cities. It envisages smart cities in which solar panels would be turned into building materials and solar would power smart equipment, heating and cooling systems. Increasingly, solar cells could be integrated into windows, carports, urban lighting, and charging points for the upcoming electric vehicles revolution. The Cambridge Econometric study 2017, forecasts that to accommodate the increasing number of electric vehicle charging points in cities would require an increase of between 5 and 40 percent in installed solar PV capacity by 2030. In addition, transforming the EUs truck fleet numbering 6.2 million in 2015, to electricity and hydrogen from diesel engines, could cut emissions from a sector that numbers 5 percent of all road vehicles but accounts for a hefty 22 percent of EU transport emissions.[xxvii]

There is an emerging trend for the corporate sector to adopt renewable power. According to Bloomberg New Energy Finance, the business community procured just 7.2 GW of clean energy in the first 7 months of 2018. Notable examples of companies going green include Google, Facebook and Microsoft in the US and Nissan, IKEA and Unilever in Europe. In France, faced with the likely reduction of nuclear power from 75per cent today to 50 percent in 2025, two major energy consumers, Paris Aeroport Group, and state-owned French nationalised railway company SNCF, will purchase renewable energy with a private PPA from renewable energy providers to meet part of their energy demand.[xxviii] Indeed, IRENA has concluded that if large energy intensive companies voluntarily aimed for 100 percent renewable consumption and or production, the demand for solar and wind would soar.

THE PROSPECT OF AN EFFECTIVE CARBON PRICE

A rising carbon price could give a major boost to renewables in coming years. The carbon-trading scheme was introduced to spearhead the EU's efforts to cut emissions by 40 percent by 2020 compared with 1990 levels. Until now, carbon prices have been too low to curb emissions owing to a 1.7 billion glut of carbon permits.

Figure 8



This is about to change. The European Parliament has empowered the Market Stability Reserve to eliminate, from 2019, the surplus carbon contracts and is lowering the carbon cap. Carbon Tracker, a think tank, states that the carbon price would have to go above 30 euros a tonne to force a major shift from coal to gas and renewables. [xxix] Will it work? Germany's Berenberg Bank estimates that the carbon price could double from the current 20 euros to 40 euros and possibly even rise as high as 100 euros. However, is this realistic? Would European politicians allow such a huge and rapid increase when coal remains important in the generation mix and some regional economies? According to the Fraunhofer Institute 2018, hard coal and lignite accounted for 39.1 percent of German net power generation in 2017. There are 40 coal regions in the EU, including six in Germany. Chancellor Merkel is under pressure from coal-reliant states to postpone the date of the EU's exit from coal by as much as 25- to-30 years to give them time to adjust their economies.[xxx]

ADVANCES IN TECHNOLOGY AND INCREASED CELL EFFICIENCY

Solar PV panels capture sunlight to generate electric power whilst CSP harnesses the sun's heat and uses it to generate thermal energy to power heaters and turbines. The efficiency of silicon solar cells in new production is now averaging 17-22 percent, which is higher than Germany's 43 GW solar installations, which, in 2017, had an average efficiency of just 14 percent. Companies and universities around the world are working to raise the solar energy conversion efficiency rate and to reduce costs. One promising line of development is the Perovskite solar cell, which is easier and cheaper to manufacture, as it does away with expensive and bulky silicon. Another is the development of half-cells, which increase power and reduce resistance. Also under development are PV cells based on a thin coating of cadmium telluride, which absorbs sunlight so well that it needs to be about one hundredth of the thickness of silicon. In addition, work on modules has produced bi-facial modules, in which the panel can generate power on both sides to increase yields by 10-30 percent. Currently, a niche product with just a 5 percent market share last year, bi-facial modules is forecast to capture a 40 percent share of the market by 2028 according to the International Roadmap of Photovoltaic.

REPLACEMENT DEMAND

There will also be increasing demand to replace decommissioned solar PV panels. For example, decommissioning of PV modules in the EU is forecast to rise sharply from 2024 onwards, from less than 100 MW a year to over 700 MW by 2032.[xxxi] This is in line with the Fraunhofer Institute, which calculates that once the cap of 200 GW of solar is reached and assuming an operational life of 30 years, 6-7 GW of solar must be replaced each year.

THE PRE-REQUISITES

Solar PV and CSP need a level playing field to capitalise on their cost and technical advantages over inflexible centralised power plants. For example, investment and operation of centralised power generation is often subsidised. Notable examples include the UK's Hinckley C nuclear plant and the Wylfa Newydd nuclear power station.

There needs also to be a suitable regulatory framework for solar PV and energy storage. Perhaps the EU Market Design Directive will set the right conditions by, for example, exempting small scale PV from disproportionate financial and administrative burdens. A case in point is that self-consumed solar power is highly taxed in Germany and installation and connections are subject to the cost of metering and or billing services from DSOs and TSOs.

The European Commission and national governments are beginning to address the need for a flexible renewable energy system and new electricity market design with new regulations. Currently in the pipeline, the Solar Trade Association is viewing the upcoming Renewable Energy Directive, positively, as it is said to include several important measures:

- Potential to run technology-specific tenders for large-scale solar.
- Simplified and less costly red tape for installing solar power.
- Potential to sell surplus power via aggregators, PPAs, peer-to-peer trading and receive the market price.
- Exemption on fees and charges for self- consumption solar up to 25kW.[xxxii]

DECOMMISSIONING AND RECYCLING OF SOLAR PV

THE SECOND-HAND MARKET

Private owners of old modules see used solar panels, unless they are badly damaged, as a potential bargain for cannibalising parts for re-use (after cleaning and repair). There is also a second hand market for PV modules and inverters accessed through e-Bay, magazine, and newspaper advertisements. The second hand market in the EU consists of three segments: (a) refund modules for failures, burglary, and outfall, which amounted to 20-30 MW; (b) repaired modules for re-powering which came to 100-150MW and (c) sales of modules from company insolvencies.[xxxiii]

Currently the Solar PV product warranty is just 10 years and the performance warranty is around 25 years by which time a PV panel with average degradation is working at around just 78.8 percent efficiency. Investors consider old PV modules past their guarantees as worthless and ready for decommissioning.

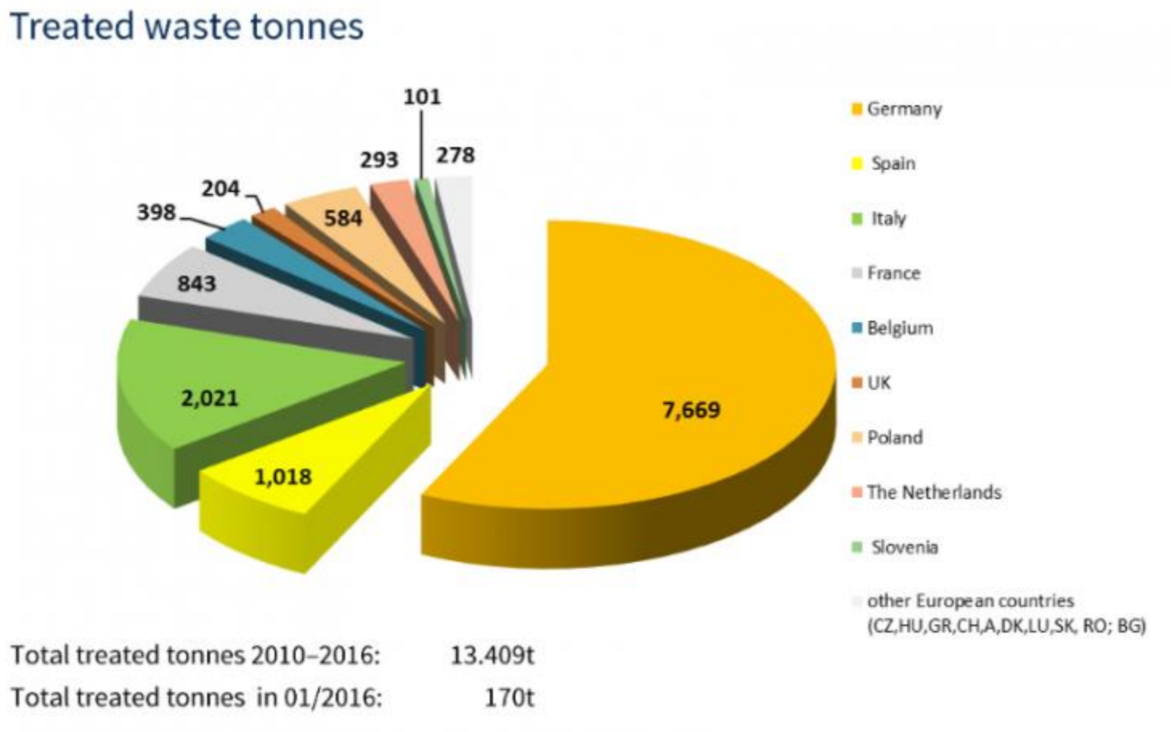
DECOMMISSIONING AND RECYCLING

Disposal of end-of-life crystalline photovoltaic panels or modules is governed by the ***Waste Electrical and Electronic Equipment (WEEE) Directive*** 2012[xxxiv] and **Restriction of Hazardous Substance Directive**[xxxv] which governs the disposal methods for injurious to health components such as lead and cadmium.

In Europe, significant installation of solar panels began in 2001, which means that around 60 MW of capacity will reach its end-of-life between 2020-2024, accelerating to over 700 MW, in 2032 alone.[xxxvi]

However, the first ageing PV panels are now beginning to come off rooftops in Germany, Italy, and Spain. Retail owners of PV systems can return their old modules to the retailer, or alternatively, deliver them to WEEE municipal collection points. PV CYCLE, a non-profit member organisation founded in 2007, by and for the European PV industry, offers manufacturers and importers a dedicated waste disposal and recycling solution. In 2014, PV Cycle collected 10,000 tonnes of waste PV modules for recycling in general purpose glass recycling facilities. Anything not recycled is now normally burned in cement ovens, rather than placing it in landfill. Between 2010 and 2016, PV Cycle treated 13,409 tonnes of waste solar panels, collected in 350 collection points across 20 European countries. Germany, the pioneer of renewable energy and particularly solar accounted for more than half of solar decommissioning and recycling, as illustrated in Figure 9.

Figure 9 PV CYCLE's COLLECTION AND RECYCLING OF PV MODULES



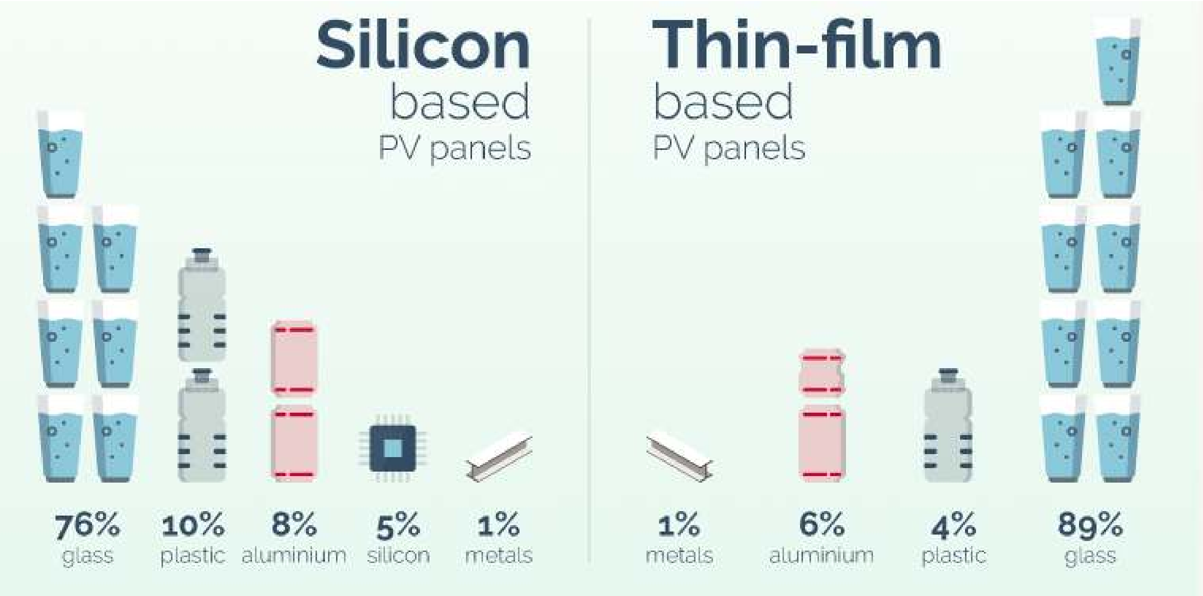
Source https://www.pv-tech.org/news/pv-cycle-achieves-record-96-recycle-rate-for-silicon-based-pv-modules 3

DECOMMISSIONING TECHNIQUES

Decommissioning proceeds in reverse order of the installation. PV facilities are disconnected from the utility power grid and modules are collected and given to recycling groups such as PV CYCLE. Electric interconnection cables, aluminium racking, transformers and inverters are removed for recycling.

In 2015, crystalline silicon cells had a 90 percent market share leaving just 10 percent to thin film cells produced with copper, indium, selenium, or cadmium telluride techniques. [xxxvii] A typical crystalline silicon solar panel is made up of glass (65-75%), Aluminium (10-15%), plastic (10%) and silicon (3-5%) as illustrated in Figure 10 below. These, along with copper and silver, can be recycled. In fact, about 80 percent of a PV module by weight can be re-cycled.

Figure 10



Source https://www.civicsolar.com/sites/default/files/embedded_assets/module_composition.png

In 2016 PV CYCLE achieved a recycling rate for silicon-based PV of 96 percent and 97 percent for non- silicon based PV modules.

SILICON- BASED SOLAR PANEL RE-CYCLING TECHNIQUE

First, disassemble the silicon-based solar panel to separate the aluminium and glass components. In fact, 95 percent of the glass content can be re-used and all of the metal parts including the cell frame can be re-used. The remaining materials can be treated at 500°C in a thermal processing unit in order to ease the binding between the cell elements. The extreme heat removes any plastic, which evaporates, leaving just the solar cells ready for further processing.

Once the thermal treatment is completed, the green hardware is separated. About 80 percent of this can be reused, whilst the rest can be further processed. Silicon particles called wafers are etched away using acid. The broken wafers are melted to be used again for manufacturing of new silicon modules resulting in an 85 percent recycling rate of the silicon material.[xxxviii]

THIN-FILM BASED SOLAR PANEL RECYCLING TECHNIQUES

CIGS thin-film panels are composed of 89per cent glass, 7percent aluminium and 4percent polymers. The small percentages of semiconductors and other metals include copper, indium, gallium, and selenium. CdTe thin-film is made up of 97 percent glass and 3percent polymer. Other metals include nickel, zinc, and tin and cadmium telluride

Thin film based panels are placed in a shredder. A hammer mill reduces the particles to 5 mm to fracture the lamination and release the contents for removal. Unlike silicon-based solar panels, the remaining content consists of both solid and liquid material. These are separated with a rotating screw. The solid material rotates inside a tube leaving the liquid component to drip into a container. The liquids go through a precipitation and de-watering process to ensure purity before the next stage of metal processing in which semi-conductor materials are separated. On average, about 95 percent of the semiconductor materials are re-used, though this can vary depending on the design of the panels.

The solid contents, which are contaminated with so-called lighter interlayer materials, are removed through a vibrating surface. The remaining materials are actually pure glass, 90 percent of which after rising can be re-manufactured.[xxxix]

DEDICATED RECYCLING FACILITIES

IRENA estimates that global PV waste will grow from 250,000 tonnes in 2016 (just under 1% of installed capacity) to more than 5 million tonnes by 2050. In a 2016 study on solar panel recycling, IRENA advocated the establishment of dedicated PV recycling plants since, the recovered materials could be worth $450million in 2030. In summer this year, French water and waste group Veolia, opened Europe's first dedicated recycling plant for solar PV at Rousset in southern France. The plant is expected to recycle as much as 300 tonnes of solar panels this year rising to 4,000 tonnes by 2022.[xl] In southern Germany a pilot plant, is recycling silicon solar panels using the energy-efficient pyrolysis process to destroy unwanted polymer layers to allow the mechanical separation of multiple materials including aluminium, glass, and silver, copper, tin and silicon. The pilot plant could process up to 50,000 end- of-life modules per year with a recovery rate of 95 percent of re-cyclable materials.[xli]

CONCLUSIONS

Solar PV power can now compete with most fossil fuels as well as with nuclear energy, and has become a major player in the electricity sector of Germany, Italy, and the UK. With the cost of solar PV electricity going below 0.02USD/kWh in very sunny locations, PV will become the cheapest energy source of electricity for new plants.[xlii] Technological advances will bring greater efficiency to solar PV and the next doubling of production will initiate another virtuous circle of diffusion and market penetration.

The predominance of rooftop installations could be reinforced in the future by the advent of a mass market in electric cars and the development of smart cities. An emerging trend is the rise of the corporate segment of producers and energy-intensive customers. IT companies with big data processing centres, manufacturers of steel, brick and tiles as well as service enterprises such as Paris Airport and France's Railway Company SNCF are beginning to purchase renewable energy with private power purchase agreements.

Between 2015 and 2016, Germany added 10 percent more wind turbine capacity and 2.5 percent more solar capacity but generated less than 1 percent more electricity from wind and generated 1 percent **less** electricity from solar because sunshine and wind levels in 2016 were lower than in 2015.[xliii] And the extreme heat of the summer of 2018 severely curbed wind power. Therefore, energy sources dependent upon the weather require better weather forecasting and energy storage solutions. Battery storage and pump-storage hydro, ranging from small to large, are needed for different generating capacities and locations – from rooftop generation to local, regional and national markets - to overcome the vagaries of the weather.

The climate agenda makes it imperative for solar energy to expand beyond the power sector into buildings, transport and heating and cooling systems. However, the era of generous financial incentives for renewables has passed: solar and wind must be able to compete in these new market segments without government support.

This anticipated growth in solar and wind power will affect the traditional business model of centralised fossil fuel power generation. Today the need is for rapid responsiveness - i.e. one second, rather than ten, shorter cold start times, and operations at lower minimum stable levels, which requires better demand management and grid balancing, for which battery storage and peaking plants will play an increasingly important role.

In Europe, significant installations of solar PV began in 2001 and ageing panels are beginning to come off rooftops in Germany, Italy, and Spain. Around 60 MW of capacity will need to be decommissioned between 2020 and 2024; accelerating to over 700 MW in 2032.The subsequent surge in end-of-life panels will justify the establishment of dedicated recycling facilities across Europe.

APPENDIX 1 TECHNOLOGY OF SOLAR

The modern solar cell was invented in 1954 at the Bell Telephone Laboratories in the US.

"Photovoltaics (PV) also called solar cells are electronic devices that convert sunlight directly into electricity. "[xliv]

Three generations of PV technology:

1st Generation – the poly and mono crystalline silicon solar cell module, with an aluminium frame, sealing, glass, EVA cells and Tedlar film, which is an ideal back sheet material for bifacial modules that can generate greater power output..

2nd Generation – PV with thin film technology like cadmium telluride, amorphous and copper-indium selenide modules.

3rd Generation – concentrator photovoltaic or organic solar cells.

Market Shares: the crystalline silicon cell has a 90% share of the market; thin film has 10 %. NB Monocrystalline wafers could supersede the multi-crystalline variant in 2018.

Bifacial module -This technology allows the panel to generate power on both sides and promises 10-30 % higher yields depending on the solar cell technology and location. A niche product at just 5 percent of the market in 2017 it could grow to 40 % by 2028 according to the International Roadmap of Photovoltaic.

Central Inverters- the "brain," handle the output of all the panels and are going digital. Inverters convert the DC power from the panel to AC for export to the grid. With an average warranty ranging between five and 10 years, rather than a gradual fall off in performance, inverters simply stop functioning. They can be replaced at a cost of around £5,000.

'Micro-inverters', included with each solar panel have a potential lifespan of up to 25 years[xlv]

Tracking – ground mounted solar panels, which can follow the sun as it moves across the sky. A single axis tracking system is standard for utility-scale PV plants in the south.

Austrian Energetic is to begin production of high efficiency solar PV modules using a fully automatic production line. Panels will have a 15% higher power rating than current standard modules. Its gigawatt solar module factory will be competitive with Asian manufactured imports.

PERC technology - A typical 12v panel will house about 36 cells. The front face receives direct sunlight while the rear absorbs scattered and reflected light. Each cell contributes to the panels' overall energy generation. This compares with conventional mono crystalline cells, which simply have an emitter layer on the front side and a standard back surface field. PERC cells employ two different features not found in conventional cells. One, a dielectric passivation film on the rear surface of the cell and two tiny pockets in the film, which absorb more light.[xlvi] PERC cells have a three-part advantage over conventional cells:

1. A significant reduction in electron recombination
2. Greater absorption of light
3. Higher internal reflectivity

Which combined boosts energy generation in solar PERC cells above conventional ones.

PERC cells in a bi-facial module such as Trina Solar's DUOMAX Twin, delivers as much as 25 percent more generating capacity than a single-sided module. [xlvii]

CSP technology - Concentrating Solar Power (CSP) technologies use mirrors to concentrate (focus) the sun's light energy and convert it into heat to create steam to drive a turbine that generates electrical power. The plants consist of two parts: one that collects solar energy and converts it to heat, and another that converts the heat energy to electricity. [xlviii]

APPENDIX 2

TABLE 3 SAMPLE OF SOLAR FARMS IN EUROPE INCLUDING OPERATORS

Project	Came on line	Generating Capacity	Original operator	Current
Pellworm, Germany	1983	Was 300 KW, now 600 KW	E.ON Hanse AG	**E.ON Hanse AG**
Toledo-PV, Spain	1994	1 MW	ENF solar	**ENF solar**
Pocking Solar Park, Germany	2006.	10 MW	Shell	**Shell**
Serpa solar power plant, Portugal	2007	11 MW	GE Energy Financial Services, Powerlight Corporation, Catavento	**GE Energy Financial Services, Powerlight Corporation, Catavento**
Florina Solar Power Plant, Greece	2009	4 MW	AES Corporation	**AES Corporation**
Ralsko Solar Park, Czech Republic	2010	14 MW	CEZ Group	**CEZ Group**
Casale solar park, Italy	2010	3.3 MW	Statkraft	**Eurowood s.p.a. and Blue Stream Resources s.r.l.**
Rhosygilwen Solar Farm, Wales	2011	1 MW	Western Solar	**Western Solar**
Curbans Solar Park, France	2011	33 MW	Engie	**Engie**
Westmill Solar Co-operative, UK	2012	5 MW.	Westmill Solar Co-operative	**Westmill Solar Co-operative**
Trumau Solar Park, Austria	2013	300 kW	Wien Energie	**Wien Energie**
Guntramsdorf photovoltaic plant, Austria	2015	2 MW	Wien Energie	**Wien Energie**
Cestas Solar Farm,France	2015	300 MW	Neon	**Neon**
Onnens Solar Farm, Switzerland	2016	8.3 MW	Soleol	**Aventron, UBS Clean Energy Infrastructure Switzerland and Swiss Solar City**
Bann Road Solar Farm, Northern Ireland, UK	2017	14 MW	ENGIE	**ENGIE**

Solar park "Lange Runde", Holland	2017	14 MW	Statkraft	**Statkraft**
Sources: Various Sources				

LIST OF ABBREVIATIONS

CCGT - Combined-Cycle Power Plant

CO_2 – Carbon dioxide

CSP - Concentrated solar power

DSOs-Distribution System Operators

FITs - Feed-in-Tariff

GW -Gigawatt

IEA – International Energy Agency

IRENA -International Renewable Energy Agency

KW – Kilo Watts

KWh - Kilowatt-hour

KWp - Kilowatt peak

MW - Megawatt

MwH –Megawatt hour

PERC - Passivated emitter and rear cell.

PPA - power purchase agreement

PV – Photovoltaic

TSOs-Transmission system Operators

TWh – Terawatt hour

FOOTNOTES

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