ARISAIG PARTNERS

Solar Energy Industry: Overview and Investment Opportunities

Contents

Executive Summary

In the coming decades, global electricity generation, and energy generation more broadly, is going to face a profound shift. Today about 60% of global electricity is supplied by fossil fuel sources, and the proportion of energy requirements from fossil fuels is even higher (over 80%), due to oil consumption for transport and gas for residential heating. If the world is to avert the worst effects of climate change, this contribution from fossil fuels will need to fall, and fall substantially, opening a huge growth opportunity in renewable energy sources.

In parts of the world the political backdrop is becoming more supportive to renewables, with the EU's EUR 1tn "European Green Deal" arguably the poster child for this. In China, investor expectations are rising that the government may accelerate renewable energy generation targets as part of the upcoming 14th Five Year Plan. The impact of COVID-19 will likely accelerate these trends, and the dynamics in financial markets have changed significantly in the past year. A concrete example of this is the shift in Orsted's (the large Danish offshore wind developer) market capitalisation from roughly 20% of oil major BP's market capitalisation at the end of 2018 to 85% in September 2020.

In our view the two backbone electricity generation technologies in this renewable transition will be wind and solar (predominantly photovoltaic, although perhaps with a contribution from concentrating solar as that technology improves).

In this report we will focus on the solar PV value chain and investment opportunity set. The cost of solar electricity (per kWh) has fallen materially in the past decade (an 80% reduction for solar PV); is already highly competitive in many regions on a pure cost basis; and we think the cost benefit trade-off will continue to improve.

The major outstanding issue is grid externalities (the cost that renewables pose on the grid due to intermittence and the lack of flexibility in supply). Here we are also cautiously optimistic, as we think cost declines for batteries, hydrogen storage and improvements in grid management techniques open significant opportunities.

In our opinion, all of this underwrites a material growth opportunity for solar electricity, likely in the order of at least a low double-digit CAGR over the next twenty years (in terms of growth in kWh of solar generated per year).

Regarding investment opportunities, most of the upstream market is in China, where we see one or two potentially attractive investments. The downstream market (solar farm developers and solar farm owners) offers a more geographically diversified opportunity set. However, it is worth noting that pure play downstream solar companies are increasingly diversifying into "solar plus wind plus storage" businesses, to enable them to offer a more attractive electricity profile to clients.

Solar Capacity Today and Potential Growth

Solar power has the potential to provide a significant portion of humanity's energy requirements. Every year 1.5bn TWh of solar energy hit the surface of the earth. To put that into perspective, the total energy (through electricity and other fuels) used by humans in a year is in the region of 160k TWh. Even with the 20% efficiency levels that current solar panels operate at, an area the size of Spain covered in solar panels could, in theory, provide the world's energy needs.

Of course, reality is more complicated than that. This thought experiment does not include costs, which would be roughly USD 25-30tn for the solar panels alone (around a third of global GDP – although the installer may receive a bulk buying discount!). In addition, solar power is an intermittent energy source since power changes over the course of the day and night as well as seasonally. Without massive improvements in energy storage there are limits to the role that solar can play in the electricity grid.

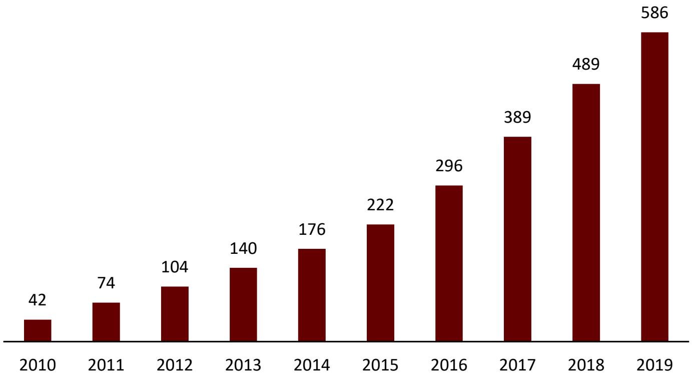
Nonetheless, the core point remains that as countries try to shift away from a carbon-based energy system, solar is likely to be an important part of that transition. Today, 2% of global electricity generation is produced through solar energy. It seems likely that this will increase significantly over the next couple of decades, meaning that solar energy could currently be at the bottom of a significant s-curve.

While there are a few different methods of capturing the sun's energy, such as concentrated solar power, in this report we will be focusing mainly on photovoltaics, and specifically silicon based photovoltaics. This is the technology that completely dominates the commercial market today, and accounts for the vast bulk of installed solar capacity.

The chart below shows global installed capacity of solar power. Over the past decade the industry has seen significant growth in installed capacity, driven particularly by China (which now accounts for 35% of global installed solar capacity). To put that chart into perspective, the total global installed capacity for all (renewable and non-renewable) electricity production globally is in the region of 7 Terawatts[1].

[1] A watt is a measure of power, which is energy per second (one watt is one joule per second). Installed capacity is measured in megawatts or gigawatts. Actual energy produced and used will be measured in kilowatt hours (one kilowatt for one hour) or the relevant scale factor (GWh, TWh). As a point of reference, an average UK home uses around 3,700 kWh per year.

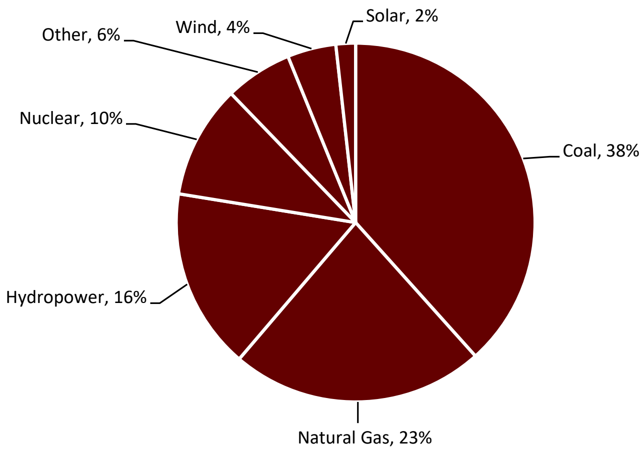
Solar Power Global Installed Capacity (GW)



Source: IRENA

Potential for Solar:
In order to understand the outlook for solar energy and renewable energy, it is helpful to start with an overview of total world energy consumption. The easiest place to start is with electricity generation by source, before taking a step back and looking at how to account for energy consumption more broadly.

Electricity Generation by Source (2018) Percent Breakdown (International Energy Agency)



Source: IEA

Renewables account for a quarter of global electricity generation, with most of that from hydropower. Meanwhile coal still produces almost 40% of electricity. With solar and wind at only 2% and 4% respectively of electricity generation, there would seem to be significant room for growth as these technologies become more cost competitive.

Of course, our energy needs are not entirely met through electricity. In fact, an often-quoted statistic states that electricity only accounts for about 20% of energy consumption (this is a very tricky figure, but the basic principle stands[2]).

The table below, from the International Energy Agency, sets out the global inputs into energy, how that is consumed and the breakdown by sector[3]. To give a sense of how to read this table, you can see that 44k TWh of coal are an input into the system, of which a portion is then converted to electricity, while 12k TWh is used directly by other sectors (most being industry).

Total World Energy Breakdown (TWh) From International Energy Agency

	Coal	Oil	Natural Gas	Nuclear	Hydro	Wind, Solar, Etc.	Biofuels and Waste	Electricity	Heat	Total
Total Primary Energy Supply	44,077	51,748	36,132	7,995	4,082	2,987	15,457	-4	22	162,497
Total Final Consumption	11,863	46,343	17,472	0	0	527	12,069	21,372	3,367	113,012
Total Final Consumption By Sector:										
Industry	9,509	3,731	6,601	0	0	11	2,409	8,945	1,601	32,807
Transport	1	30,104	1,218	0	0	0	972	364	0	32,659
Residential	879	2,498	5,124	0	0	381	8,173	5,775	1,179	24,008
Other	1,475	10,009	4,529	0	0	135	516	6,288	587	23,539

Source: IEA

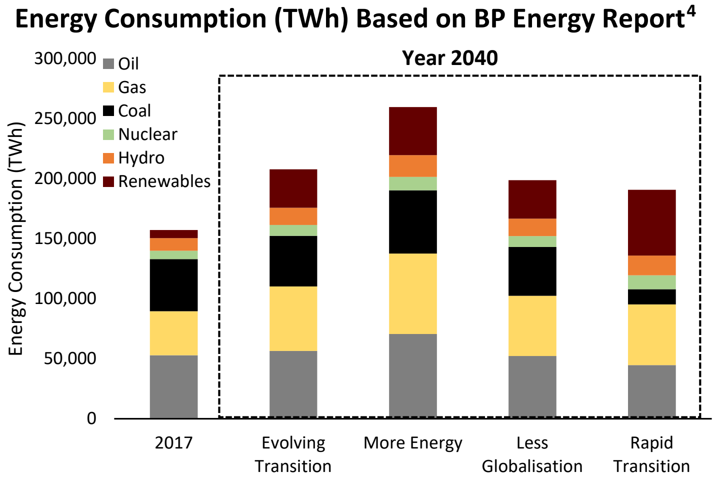
As you might expect, a major source of non-electricity energy demand is the use of oil in transport (30k TWh). However, residential use of oil and gas for heating is also material, as is the direct use of coal, oil and gas in industry.

This raises the importance of moving towards the "electrification" of our energy systems. By shifting towards the use of electric cars, but also improvements such as better insulated homes that can be kept warm with air source heat pumps, societies can make better use of renewable resources. In theory this could mean that not only will renewables share of electricity generation rise, but so will the demand for electricity.

Now, we will turn to forecasts. For a big picture look at global energy trends, a reasonable place to start is the BP Energy Outlook. You can take a view on the vested interests in this publication, but it is very comprehensive, and the team is headed up by Spencer Dale, the former Chief Economist of the Bank of England. They produce analysis and forecasts for total global energy consumption. This includes all forms of energy consumption, not just through electricity but also fuel for cars, heating houses as well as the embedded energy when fossil fuels are used for non-combustible purposes (such as plastics). They also produce the forecasts across a range of scenarios, as shown in the chart below.

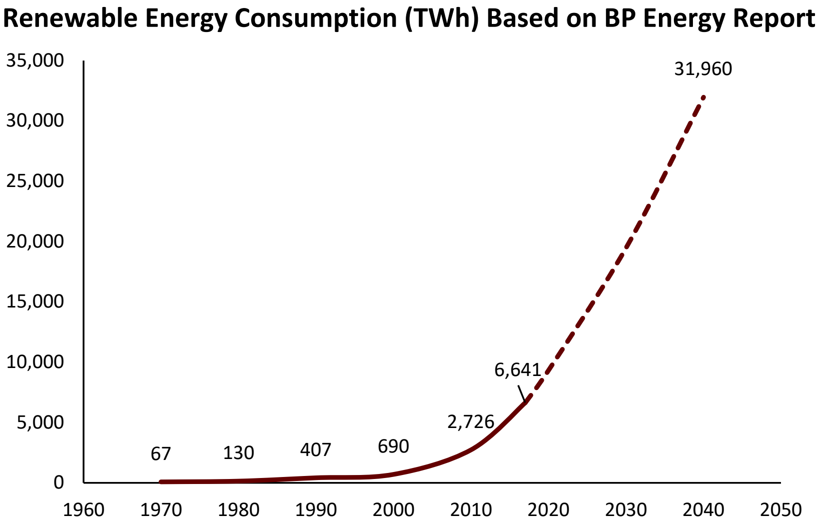
[2] In this energy accounting, it is the chemical potential of fossil fuels that are used – which is significantly higher than the actual energy we can extract from the fuel (for example in a car only about a fifth of petrol's chemical energy is converted into useful kinetic energy, while for an electric vehicle about 60% of the energy in a battery is converted into useful kinetic energy).

[3] It's worth noting that these data were initially given in terms of barrels of oil equivalents, but I have converted this to TWh to maintain comparability with the figures used elsewhere in the report.



Source: BP Energy Outlook

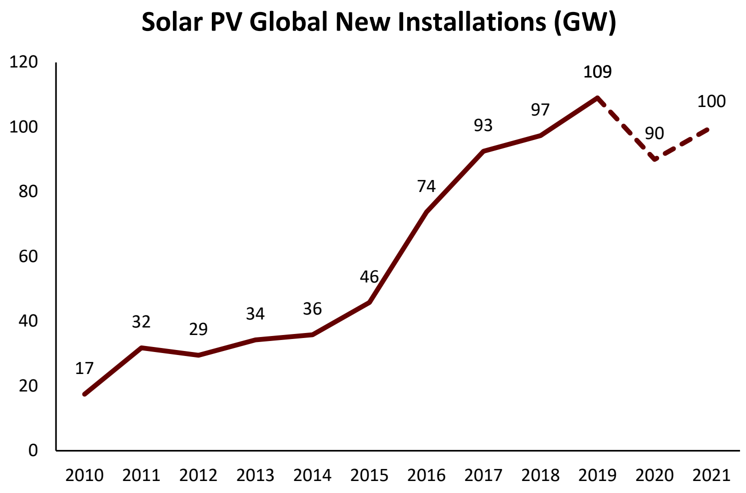
The core point here is that in all the scenarios above, renewable energy is going to substantially increase its contribution to global energy consumption. The chart below focuses specifically on renewable energy demand in the "evolving transition" central scenario. It suggests that there will be a 6% CAGR in renewable energy consumption over the next twenty years. This includes biofuel, and when we look at solar and wind specifically the CAGRs rise to 12% and 9% respectively.



[4] The scenarios are: evolving transition (which essentially assumes a gradual move in sustainable energy policies in line with history); more energy (a scenario where they test a higher trajectory of energy per unit of GDP); less globalisation and; rapid transition (which is in line with meeting the Paris climate goals).

Source: BP Energy Outlook

It's worth noting that while some parts of the value chain, such as the downstream energy producers, will have revenues linked to electricity produced, the upstream revenues are more related to the volume of new installations. To put that into perspective we have put the global solar PV new installations in the chart below, with a two year forecast from the International Energy Authority.

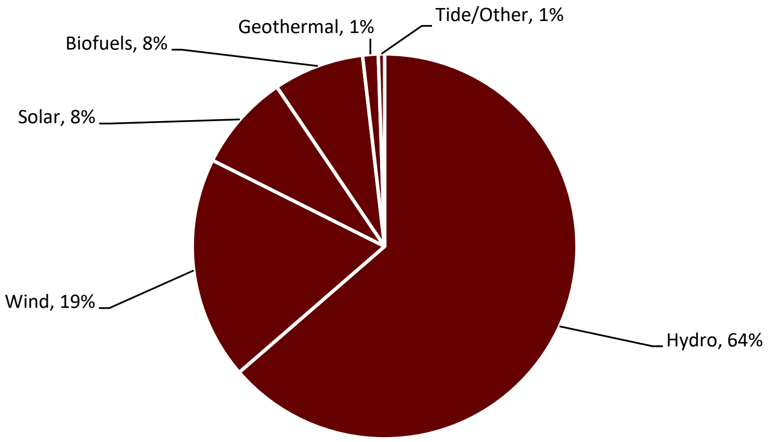


Source: IRENA and IEA

Solar Versus Other Renewables

It is helpful to compare solar energy to some of the alternative renewable energy sources. Currently renewable energy is nearly 30% of electricity generation on a global basis, the majority of which is from hydropower. The chart below shows the breakdown of electricity generation per type of renewable energy source. Note that the chart below refers to electricity only. If we were to look at total energy, then biofuels would be significantly larger (as this would include, for example, wood burning stoves).

Breakdown of 2018 Global Renewable Electricity Generation (%)



Source: IEA

Table Comparing Renewable Energy Sources

Source	Comment
Hydropower	**(i) Cost:** Very cost competitive; **(ii) Consistency:** Hydropower is a useful part of the grid as it can be turned on very quickly to meet energy demand; **(iii) Scalability:** The key problem is that LCOE can be kept relatively low when using natural water formations, but this is obviously highly location dependent (in Norway 95% of electricity comes from hydropower). In other areas flooding land to create dams has a negative environmental impact. **(iv) Technological trends:** Hydropower is a fairly mature technology.
Wind	**(i) Cost:** Wind is a cost competitive technology on an LCOE basis (onshore wind is about 20% cheaper than offshore in the UK, but there are space limitation issues). In fact, it is already a substantial part of electricity production in some regions. In 2019 onshore and offshore wind was 20% of total UK electricity generation. **(ii) Consistency:** Wind is often intermittent and this can cause limits to the ability of the grid to depend on wind power. **(iii) Scalability:** The ability to change the scale at which wind power operates is mixed. Of course, residential wind turbines are available, but wind turbines operate best when they are at a high elevation and have a clear path for the wind free from obstructions. The large wind turbines are highly efficient and generate significant amounts of power. However, they are noisy and need large amounts of space. For example, the Vestas V164, which is one of the most powerful wind turbines on the market today with a capacity of 10MW,

	has a total height of almost 190 meters and a blade diameter of 160 meters. They are not a good residential or suburban solution (or even in many areas of countryside). **(iv) Technological trends:** Wind turbines today can operate at around 50% efficiency. This is close to the theoretical limit (Betz's law) of 59.3%. A major area of potential growth is floating offshore wind – a relatively new technology that could significantly increase offshore wind opportunities (since it can be deployed in deeper waters).
Bioenergy	I'm somewhat sceptical about the long-run scalability of bioenergy, predominantly due to the efficiency of photosynthesis versus photovoltaics. photovoltaics are significantly more efficient than photosynthesis. This means that the efficiency of land use is also much higher for solar versus growing an equivalent amount of biofuel. There is some debate about this, and location matters significantly, but some data states that the usable energy per hectare can be 100 times greater for photovoltaics than biofuels.
Solar	**(i) Cost:** This is dependent on location, but has dropped very significantly in the past ten years (an 80% decline on a global average basis) and is now becoming very competitive in high irradiance areas; **(ii) Consistency:** Obviously power output reaches a maximum at midday and falls to essentially zero at night. Seasonality can be a major consideration in latitudes far from the equator; **(iii) Scalability:** This is a major advantage for solar, in the sense that it can be efficient at multiple different levels from residential rooftop solar to utility level solar. It is also less intrusive than other types of renewable energy like wind or hydropower; **(iv) Technological trends:** My view is that solar still has the capacity for significant areas of improvement in terms of cost and efficiency, as well as breakthroughs that could improve the usability of photovoltaics - such as flexible polymer solar cells that could be coated on the outsides of buildings.
Geothermal	**(i) Cost:** This is a very cost competitive energy source. It can have some externalities such as emissions of sulphur dioxide and hydrogen sulphide, as well as earth tremors. **(ii) Consistency:** Very consistent and reliable source of power. **(iii) Scalability:** Geothermal energy is limited to use in specific locations near tectonic plates. **(iv) Technological trends:** There is scope for improvement in areas such as drilling.
Marine	This is a very niche technology which is not a material part of the energy mix in most areas. In theory there could be room for development of areas like tidal power. However, this raises concerns about the environmental impact. In addition, operating in marine environments adds costs due the complexity and difficulty in reaching installations.

Cost of Solar Electricity

A major issue with any technology or product is accurately assessing that products' cost/benefits versus alternatives. With solar power this calculation can be quite challenging to generalise since it depends on: where you are (solar irradiation levels and seasonality); when you are using energy; the proportion of solar or renewables already used in the grid; and whether we are talking about utility level solar or rooftop solar. It also depends on whether there are subsidy or feed-in-tariff regimes in place.

Our key conclusions are set out below, and detailed further in the following pages:

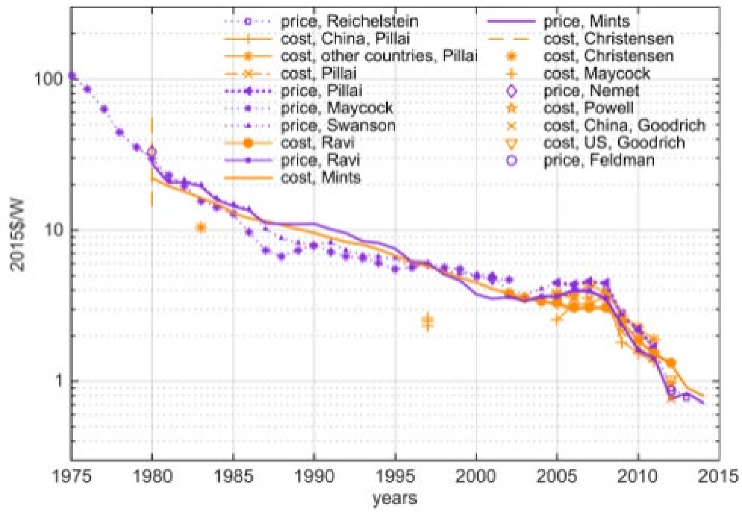
(1) The cost of solar energy (as measured by the Levelised Cost of Electricity) has fallen significantly in the past decade, and on a non-subsidized basis is becoming competitive with non-renewable technologies.

(2) LCOE does not represent the actual value of renewables to a grid (due to issues with consistency and reliability). However, we believe that solar can have a meaningful part to play in many grids around the world and that issues with "grid externalities" will decline significantly over time due to improvements in batteries, hydrogen storage and other grid management techniques.

(3) We will look at why the downward trend in solar energy has occurred. We believe that this is sustainable and not the product of artificial reduction in costs.

Solar Energy Cost Trends and the Levelised Cost of Electricity:
In the past few decades there is no doubt that the cost of solar energy has fallen significantly. A major part of this has been the drop in the cost of solar modules. In the 1970s, as shown in the chart below, solar modules cost USD 100 per watt. Today, at retail, you can buy solar modules for about USD 0.5 per watt. The broad properties of this cost curve are captured in "Swanson's Law" which says that for a doubling of cumulative module production the cost per watt falls by 20%.

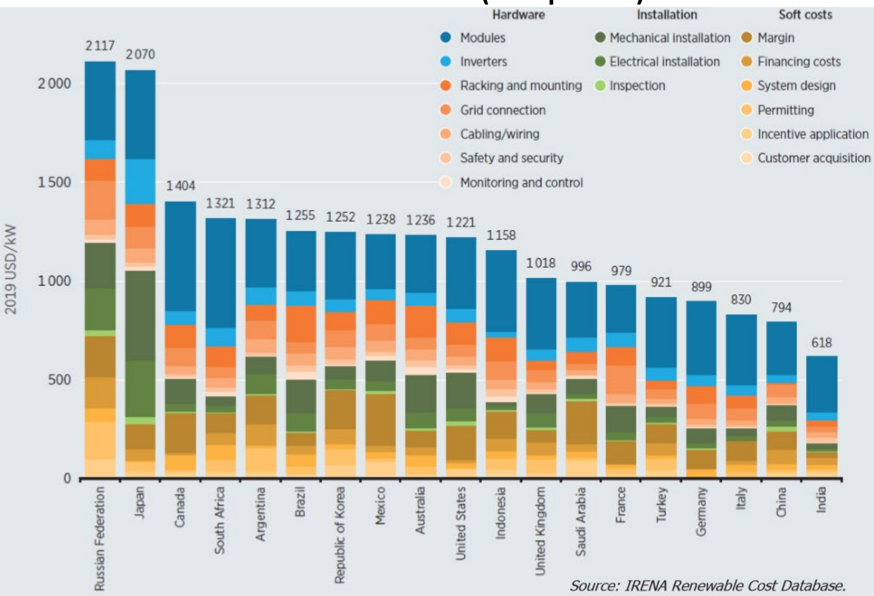
Module Price (Purple) and Cost (Orange) USD per Watt



Source: https://www.sciencedirect.com/science/article/pii/S0301421518305196?via%3Dihub

Of course, module costs are not the only component of costs for a new solar installation. In fact, at utility scale modules are now typically less than 40% of the entire capex cost, and for rooftop solar they may be less than a quarter of the total cost. Inverters account for a further 10%, with the remainder being related to more basic "construction" capex. The chart below (from IRENA) gives a very good sense of Total Installed Costs for Solar PV, and its components, around the world.

Total Installed Costs (USD per kW)



Source: IRENA

When considering costs per kWh, we also need to understand the large differences in cash flow profile between electricity generation processes. For example, solar has relatively high capex costs, but almost no running costs. Conversely, fossil fuels have higher relative running costs, since the fuel needs to be purchased.

The standard way to measure the cost of electricity for a source of electricity generation is the **Levelised Cost of Electricity (LCOE)**. This is the present value of costs divided by the present value of electricity that will be generated by the source. Another way to think of it is that if you get paid the LCOE for your energy output, the IRR of the project will be the discount rate. For example, if the LCOE for a solar farm is 10 US cents per kWh, with a 5% discount rate, and the solar farm can sell all their electricity output at USD 10 cents, their return on investment will be 5%.

While the LCOE is not a perfect measure for assessing the cost/benefit of a project, it is the "first port of call" when trying to get a general view of energy costs across production methods. One other point to note is that LCOEs for solar are quite sensitive to interest rate assumptions when compared to fossil fuel electricity. This is because the ratio of initial capex to operating costs is much higher for solar. This is an important point to consider when making cross country comparisons.

Before we start going into general data, a specific example may be helpful. In the table below I have run a basic LCOE calculation for utility level solar in the UK. The figures are based on this article[5]. In the second chart I have posted that LCOE price figure versus the time series of UK wholesale electricity prices since 2011, as well as the projected cost of solar in 2025.
The point here is not to give a pin-point accurate estimate for solar costs in the UK, but rather to give a sense of the figures and calculations that go into the LCOE number.

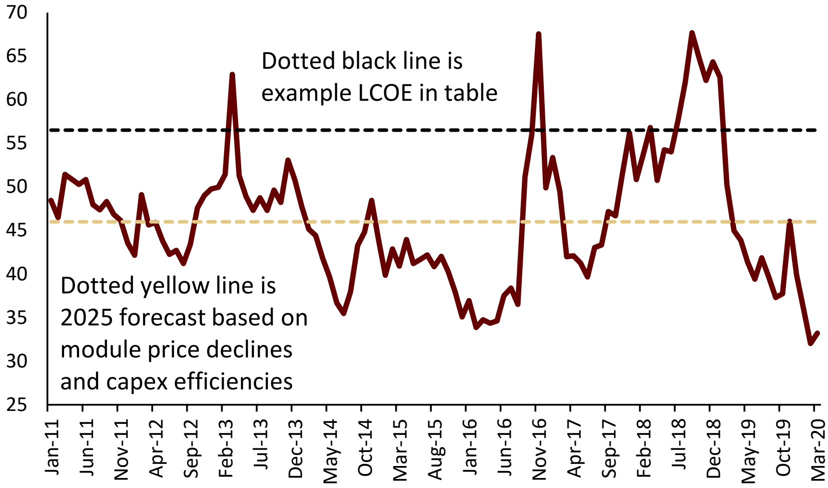
UK Example 1MW Utility Solar LCOE Calculations

	2019	2020	2021	...	2049
Energy Output:				...	
Annual Availability (Hours)	-	8,672	8,672	...	8,672
Load Factor	-	12%	12%	...	12%
Annual MWh Pre-Degradation	-	1,041	1,041	...	1,041
Degradation	-	1.00	1.00	...	0.89
Annual MWh Post-Degradation	**-**	**1,041**	**1,037**	**...**	**929**
Costs (GBP):				...	
Modules	200,000	0	0	...	0
Inverters	50,000	0	0	...	0
Grid Costs	50,000	0	0	...	0
Other Capex	220,000	0	0	...	0
Opex	0	13,000	13,260	...	23,086
Business Rates	0	3,180	3,244	...	5,647
Land rent	300	306	312	...	543
Total Costs	**520,300**	**16,486**	**16,816**	**...**	**29,277**
Discount Rate	**5.5%**				
PV Costs (GBP)	**820,138**				
PV Energy (MWh)	**14,515**				
LCOE (GBP / MWh)	**57**				
LCOE (USD / MWh)	**71**				

Source: Solarpowerportal.co.uk and Arisaig Partners calculations

UK Electricity Wholesale Price (GBP / MWh)

[5] https://www.solarpowerportal.co.uk/news/uk_solar_costs_plummeting_beyond_forecasts_as_cheap_as_40_mwh_by_2030

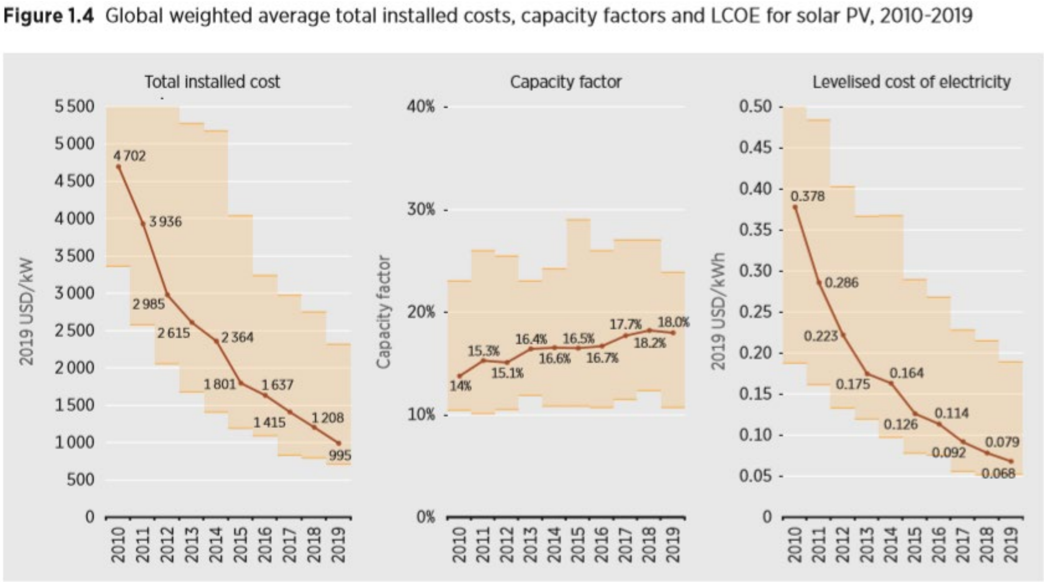


Source: OFGEM and Arisaig Partners calculations

With that example out of the way, let's take a more general look at LCOEs for solar and renewable energy sources. The charts below show the average costs for global solar panel projects, taken from the IRENA database. For the reasons discussed previously there can be quite a significant variation in LCOE between projects, which is shown with the bands in the charts below.

The key point in the chart below is that between 2010 and 2019, the average LCOE for solar fell from USD 380 to USD 70 per MWh.

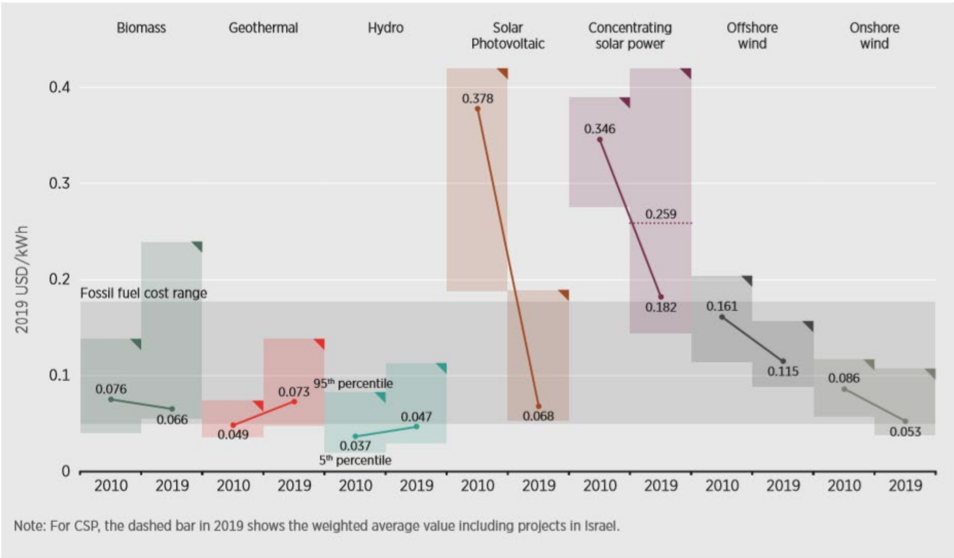
Global Solar Energy Costs (IRENA)



Source: IRENA Renewable Cost Database

Global Renewable Energy Costs (IRENA)

Figure ES.1 Global weighted average levelised cost of electricity from utility-scale renewable power generation technologies, 2010 and 2019



Note: This data is for the year of commissioning. The thick lines are the global weighted-average LCOE value derived from the individual plants commissioned in each year. The project-level LCOE is calculated with a real weighted average cost of capital (WACC) is 7.5% for OECD countries and China and 10% for the rest of the world. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

Source: IRENA

Cost Comparison With Non-Renewable Alternatives:

The chart above from IRENA has the LCOE cost for fossil fuels in a wide range in beige. This requires some more context[6].

There are three main non-renewable electricity generation sources:

(i) **Coal:** Coal fired power stations are currently the single most common source of electricity generation in the world. There have historically been sound reasons for this: coal was reliable and relatively low cost. However, coal generates significant CO_2 emissions (about twice that of gas) as well as pollutants such as sulphur dioxide and nitrogen oxides (much less prevalent with gas). According to Lazard, coal fired power stations have an LCOE of between USD 66 – 152 per MWh. It's worth noting though that the marginal cost of a coal fired power station (running it once it has already been built) is much lower, at about USD 30 per MWh.

(ii) **Gas:** This can be split into peaking gas power stations and combined cycle gas power stations. A peaking power station is designed specifically to ramp up and down very quickly to provide power at peak demand times (combined cycle plants aren't as suitable for this). The benefit of combined cycle plants is efficiency since they use two processes to extract energy where first the gas turns a gas turbine, and then the extra heat is used to generate electricity through a steam turbine.

[6] Here I will reference figures from the Lazard LCOE analysis for 2019 which are US focused and unsubsidized https://www.lazard.com/perspective/lcoe2019

These two power plants serve different purposes and therefore do have very different LCOEs. According to Lazard analysis a gas peaking power plant has an LCOE of between USD 150 – USD 199 per MWh, while a gas combined cycle power plant has an LCOE that ranges from USD 44 – USD 68 per MWh.

(iii) **Nuclear:** The LCOE for nuclear power plants is USD 118 – USD 192 per MWh, while the marginal cost (running it once it has been built and is operational) is about USD 30 per MWh.

When we look at the numbers above we need to think about them in the context of the USD 68 per MWh LCOE for solar power from IRENA, and the roughly USD 40 per MWh from Lazard (the latter are US focused numbers while IRENA is global).

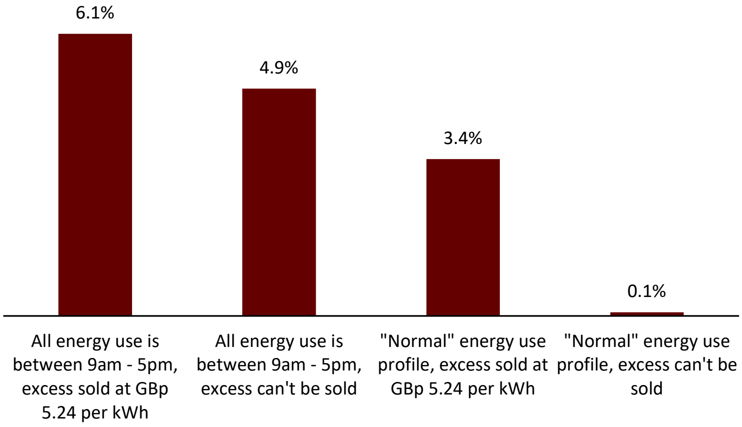
We think the fair conclusion here is that, while fossil fuels have many benefits as an energy source (that's why we have used them for so long!) in recent years the cost of solar has fallen impressively, and is also becoming highly cost competitive in its own right. One example of this is the recent signing by Scatec Solar of a PPA in Tunisia at a price of only USD 25 per MWh.

Renewables - Cost Versus Value:
It is very important to note that LCOE is a part of the picture for electricity cost/benefit equation, but it is not the whole picture. As important as LCOE are factors such as consistency and flexibility, and this is one of the reasons that multiple different energy sources have a place in the grid. It is also worth noting from the examples above, that even though a gas peaking power station may have an LCOE multiple times that of a gas combined cycle power station, that cost is offset by the value derived from being able to quickly ramp up and down electricity production. The major problem with renewable energy sources is that they are intermittent, not particularly flexible, and may not match the timing of energy supply with demand. Therefore, you cannot simply view the LCOE for solar in direct comparison with, say gas.

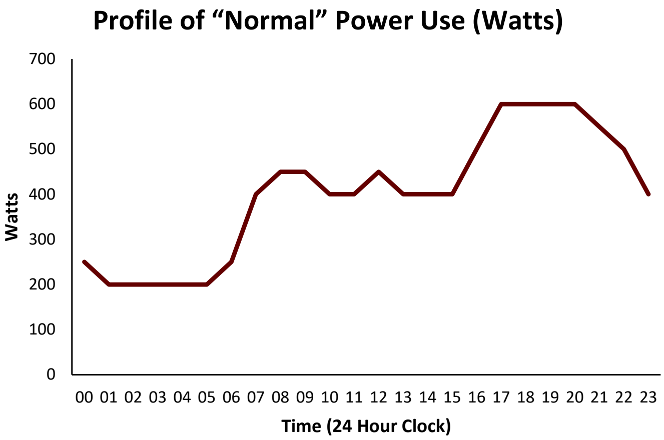
As a thought experiment/example, we ran numbers for the IRR on a residential rooftop solar installation in Dorset (UK), using average daily solar irradiation levels from online tools available for these purposes. We used a retail cost of electricity of 14 British pence (so the IRR is based on the costs saved by not paying that if you install the panels). We then ran scenarios based on the time of day that energy is being used, as well as whether you are receiving an export price for delivering excess energy to the grid (there is some flux in the UK at the moment due to the ending of the feed-in-tariff regime for new solar installations).

The chart shows that there is a huge variation in returns based on the timing of energy use. If you use your energy entirely between 9am – 5pm, solar has an attractive return, even in the UK. However, if your habits change that return can decline rapidly.

IRR for UK Dorset 3KW Rooftop Solar, Based on Time Profile of Energy Use and Energy Export Price Assumptions



Source: Arisaig Partners calculations



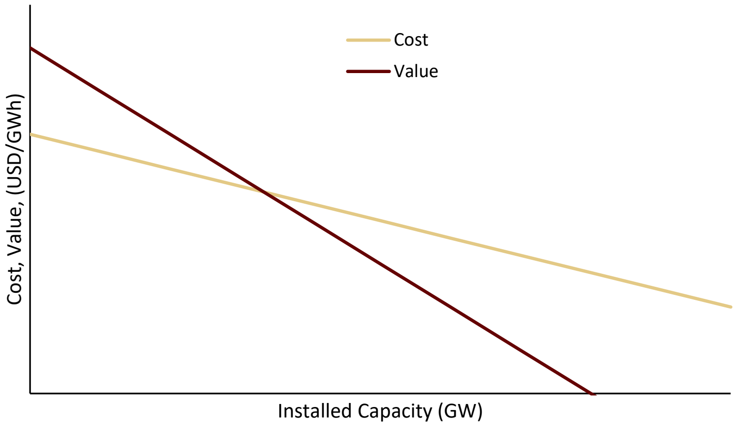
Source: Arisaig Partners calculations

The other problem is that this is a static analysis, while reality is dynamic. If solar installations were to increase continuously, the supply of energy during the day relative to other times would also increase, leading to a decline in the value of that energy. As a result, there is a natural move towards an equilibrium where the value of solar energy decline with installed capacity.

The chart below (sourced from "Taming the Sun" by Varun Sivaram) highlights this point. As installed capacity rises, costs decline due to economies of scale. However, the value of the solar electricity to the grid also declines. In order to then increase solar installed capacity further you need either a downward shift in the cost curve (a new efficiency breakthrough or production technology) or you need a change in slope of the value curve (better energy storage).

Of course, the slopes and nature of these curves also differs by country, which is part of the difficulty with making big picture generalisation about solar energy.

Example Cost and Value Contribution From Solar Power



Source: "Taming the Sun" by Varun Sivaram

A More Holistic LCOE – UK Example:

In August 2020 the UK Department for Business, Energy and Industrial Strategy published an updated report on electricity generation costs[7]. This covered the current and the expected trajectory for LCOE of renewables in the UK, as well as an "enhanced LCOE" metric. Although this is a UK focused example, it is quite helpful to get an overview of the issues involved. By the BEIS's own definition the enhanced LCOE metric attempts to "capture some of the wider system impacts of adding a marginal unit of a technology to a range of generation mixes".
These wider system impacts are:

1) **Impacts on the wholesale market:** Measures how timely or valuable a MWh from the technology is.

2) **Impacts on the capacity market:** Captures the reliability of the technology at peak demand.

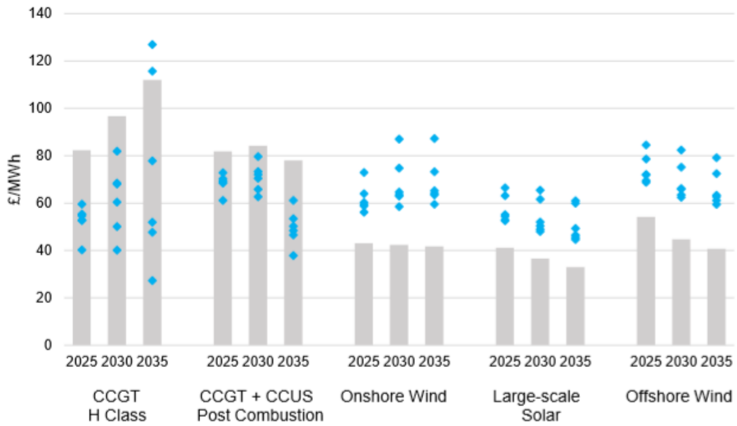
3) **Impacts in balancing and ancillary service markets:** Captures whether the technology is helpful in balancing the supply and demand for the energy system. – essentially how flexible it is.

4) **Impacts on networks:** This is a very subjective category that attempts to capture how near the technology is to demand centres.

The first chart below is taken from the report and gives an overview of the results, while the second chart looks at averages, and how the Enhanced LCOE differs from the standard LCOE in percentage terms by technology. The fact that there are different scenarios in the first chart captures how the costs and benefits of different technologies differ depending on the electricity supply mix and electricity demand.

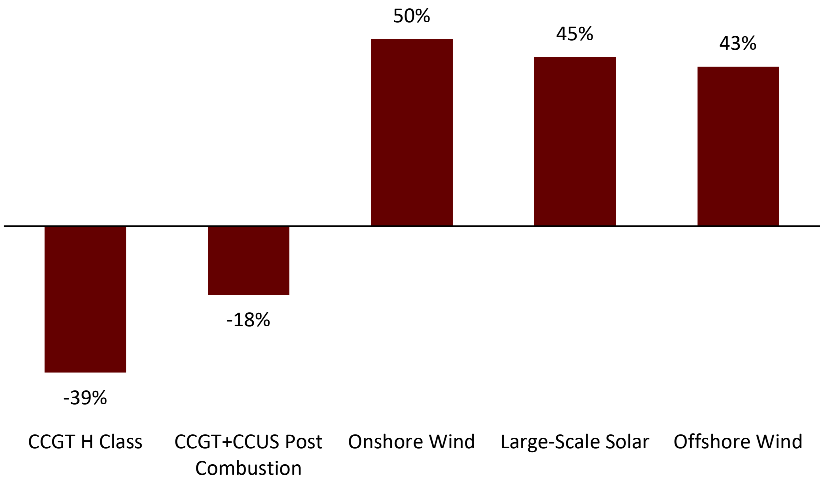
LCOE (Grey) and "Enhanced LCOE" (Blue Dots For Scenario Analysis) For UK Electricity Generation By Type

[7] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911817/electricity-generation-cost-report-2020.pdf



**CCGT = "Combined Cycle Gas Turbine", CCUS = Carbon Capture Usage and Storage*
Source: BEIS

Percentage Deviation of Enhanced LCOE From Original LCOE (2025 Scenario)



Source: BEIS

We think there are a couple of meaningful observations here. First, even in the "enhanced LCOE" 2025 scenarios, wind and solar are fairly competitive (GBP 65 per MWh for onshore wind, GBP 60 per MWH for solar, GBP 50 per MWh for CCGT and GBP 67 per MWh for CCGT+CCUS). Remember, this is in the UK where capacity factors for solar are relatively low.

Second, it does show that the broader calculation for energy supply is much more detailed than simply LCOE, and can have a difference in the order of 50% to the real underlying value of the technology.

The Importance of Energy Storage:
Fundamentally, the only way to overcome the problems with the intermittence and unreliability of renewable energy sources (the "grid externalities") is with better energy storage (most likely either with utility scale batteries or better hydrogen storage technology). This leads to one final obvious question – where are we today in terms of the cost benefits of energy storage?

Clearly it depends on geography, and for simplicity we'll assume that we are talking about areas with quite high capacity factors (20% plus). For a residential or off grid application, we are already at the stage where a solar plus battery arrangement is competitive, and even cheaper, than running a diesel generator. The problem is financing, since the upfront costs for a diesel generator will be lower.

At a utility level, we did some rough calculations assuming a 100MW solar installation with a 60 MW battery that can last for 4 hours (so 240 MWh). This gives an LCOE[8] of USD 120 per MWh, which is still materially higher than the range (Lazard calculations) for a gas combined cycle power plant of USD 44 – USD 68 per MWh (although marginally lower than peaking gas power plants).

In our view, there are reasons for optimism. Solar PV has two types of costs: (1) The Total Installed Costs that are captured in LCOE; (2) The "grid externality" costs due to intermittence and lack of flexibility. The fact is that LCOE (type 1 costs) have declined faster in the past ten years than many people thought possible. Why should we not expect type 2 costs to decline in an equally favourable manner – especially since the political and commercial focus on renewables is arguably greater now than it has ever been?

Why Have Solar Costs Fallen?

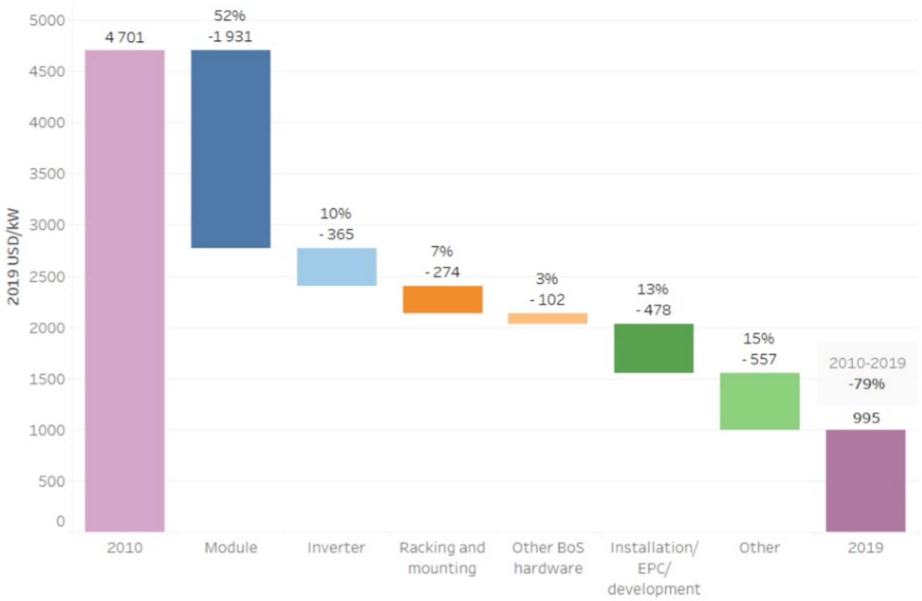
It is an observable fact that the cost of solar electricity has fallen dramatically in the past few decades. This does, however, raise a couple of questions. Why have costs fallen so much? Are the falls sustainable or has the concentration of solar panel construction in China been driven by other incentives that are artificially holding down costs?

First, we need to split the LCOE into two components, "hard tech costs" and "soft costs". The former are the modules and inverters, and account for roughly 40% - 50% of utility level capex and about a quarter for rooftop residential. We will focus specifically on module costs in this section. However, it's worth noting that non-module costs and other general improvements in efficiency are a major part of the set of marginal improvements that are relentlessly driving down solar costs. As an example, reductions in panel weight and improvements in the standardisation and efficiency of the mounting process mean that a decade ago it took 16 hours to complete a standard solar panel rooftop installation, but now it takes 4 hours[9].

There are also a host of other areas of improvement. For example, for rooftop panels microinverters have driven a significant change in capacity factors for partially shaded areas. At the utility level the improving cost of single axis tilt mounts (two axis are still not cost effective but are improving) can drive a significant increase in capacity factors, as can bifacial modules. The chart below (from IRENA) shows how the Total Installed Cost (global average) for solar PV has changed in the past decade. About 60% of the decline has been related to "tech" (modules and inverters) but about 40% is due to old fashioned building and construction techniques.

Total Installed Cost (Global) Change 2010 - 2019

[8] This calculation assumes a discount rate of 5.5% and a capacity factor of 22%.
[9] https://www.ohmconnect.com/blog/blog-post/why-did-solar-get-so-cheap-in-the-last-20-years



Source: IRENA

Here we will focus on module costs. This paper[10] from 2018 helps to break down the drivers of solar module cost declines. The paper only runs its analysis to 2012, but I would suggest that there have been three main phases in the solar PV market.

(1) **Research and development (1954 – 2000):** The practical history of the solar cell really started with a breakthrough at Bell Labs in 1954. At that time, a silicon solar cell with a 6% conversion efficiency (from sunlight to electricity) was created. By 1980 the efficiency for deployable modules was around 8% (note that there is a difference between efficiency for a single cell in a lab setting, and of a full module, so this improvement is more significant than it first appears). In 2001 module efficiencies were around 13% and they now are in the low 20%s for the better silicon modules. In 1980 the cost per watt for solar PV was an incredible USD 29, but that had fallen to USD 4 by 2001.

(2) **Early commercialisation (2000 – 2010):** By this stage the basic R&D had been done, and relatively efficient products were available. However, the industry was still at a small scale, and dependent on government subsidies, which meant that costs remained high. To give a sense of this, in 1980 a plant might produce 1MW of solar PV modules in a year. By 2001 that had reached 13MW, by 2012 1GW and today LONGI has a module capacity of more than 20GW.

(3) China and Economies of Scale (2010 – Present): Since 2010 the solar PV market has scaled massively. In 2010 the entire installed capacity of solar in the world was 42GW, while today new installations each year are more than twice that level. China has played a large part in moving solar down the cost curve, whether it be in polysilicon production or wafers. It's probable that government support played a role here initially, but in our research we have heard nothing to suggest that a rapid spike in module costs is probable.

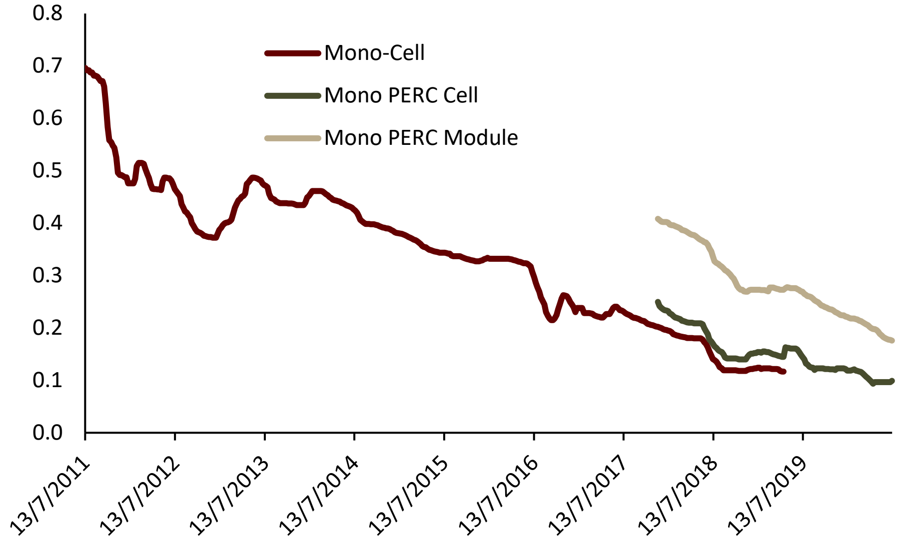
[10] https://www.sciencedirect.com/science/article/pii/S0301421518305196?via%3Dihub

In fact, the consensus seems to be that there will be further pressure on module costs for at least the next few years.

It's helpful to give some concrete examples of what can actually drive cost declines. Issues can include making thinner wafers (so using less polysilicon); increasing wafer area; using thinner diamond saws so that losses are less when the ingot is cut and; reductions in wastage from wafers or cells rejected due to quality issues, or broken during handling (automation has been a major improvement here).

The chart below shows the more recent trajectory for cells and modules from average Chinese manufacturers.

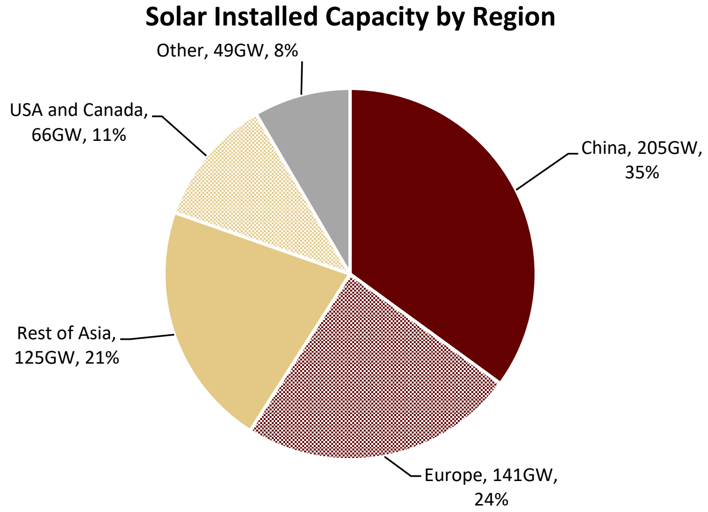
Cost Per Watt (USD) Source Chinese Manufacturer Data Collected By UBS



Source: UBS Solar High Frequency Database

Key Regional Issues

Solar panels are a developing technology globally, but of course its importance varies by country and region. China, in part as a measure to reduce its reliance on coal, has been very active in developing solar power and now has the largest amount of installed solar capacity in the world. When it comes to the supply chain it should be noted that China is also very dominant. Approximately 60% of solar panels are produced in China[11]. Processes such as the production of polysilicon, ingots and wafers are driven by economies of scale and China has played an important part in bringing down prices here over time.
In the US, while there are listed solar panel businesses, they tend to focus on specific technologies such as cadmium telluride (First Solar); specific cell arrangements (SunPower/Maxeon) or installation and financing.

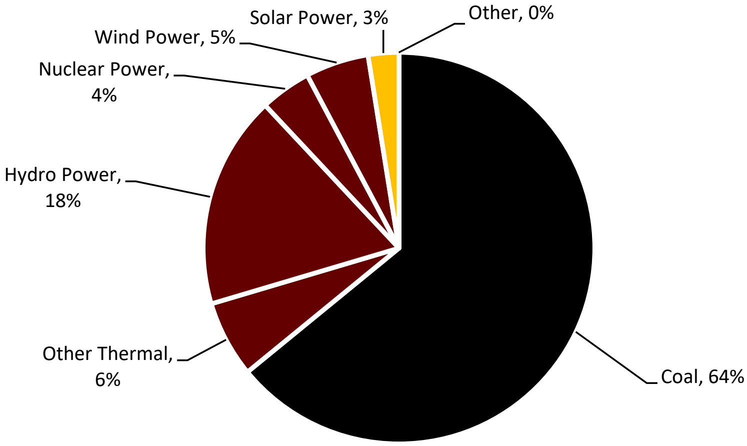


Source: IRENA

Solar Power In China:
Given the importance of China both for photovoltaic demand and production, it's worth a slightly deeper dive into some of the factors driving the industry here.

The chart below sets out the mix of Chinese energy production in 2018. The country is currently highly dependent on coal as a fuel source. However, the government has realised that this is not desirable, in part due to increasing concerns about air pollution. As a result, the government made a significant push towards renewables, including solar power. The rough trajectory for the decline in coal is that we should see it begin to accelerate from 2025 onwards when large swathes of aging coal power stations begin to be decommissioned.

[11] https://www.bbc.com/future/article/20180822-why-china-is-transforming-the-worlds-solar-energy



Source: Chinaenergyportal.org

Probably the most significant recent issue for the Chinese solar industry was the significant change in solar policy - the "531 policy" - announced in May 2018. This essentially ended the highly accommodative previous solar policy. The government did this for several reasons. They were spending CNY 46bn per year on subsidies for solar, often incentivising inefficient production rather than best in class operators. In addition, there were some problems with curtailment rates (renewable energy that wasn't being used) and a mismatch between production in the West and demand in the East. Lastly, the government expected solar power to reach grid parity in 2020 so there was no economic rationale for continuing subsidies past that point.

In reaction to this the government dropped targets for solar and encouraged local governments to stop subsidising non-economic projects. They also significantly cut feed in tariff rates by an average of around 30%.

Another important point to make has been the expansion of Ultra High Voltage transmission lines in China. As mentioned above there is a geographic mismatch in China between the location of renewable energy production and demand. This led to curtailment rates (energy produced but not used) of 20% for renewables in 2015. Following the significant expansion of UHV cables that curtailment ratio has dropped to 5%.

While the "531 policy" caused significant volatility for Chinese solar stocks in 2018, the policy backdrop remains accommodative and, indeed, solar stocks have rallied significantly in 2020.

How Solar Panels Work

In order to understand the solar value chain, we need to have a broad sense of how solar panels work.

In very general terms, silicon can generate an electric current when it is placed under sunlight because, due to its property as a semiconductor, photons can "knock" electrons out of the crystalline silicon structure causing an electric current to flow. Silicon has 14 electrons of which four are in its outer (valence) layer, and it is these electrons that can be "knocked" out of the silicon atom into the crystal structure.

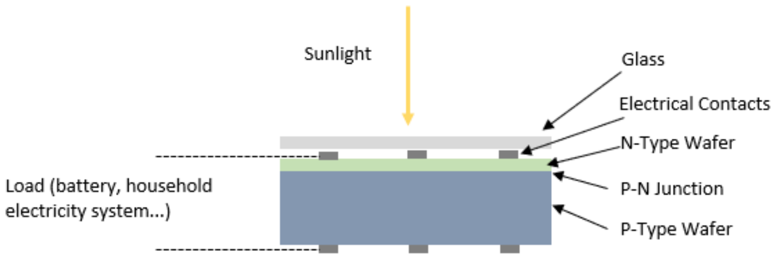
There are a few other building blocks here. The first key point to understand is the concept of "doping" silicon. This involves adding another element into the crystalline silicon. In a p-type wafer boron is added, which has three electrons in its valence layer. In an n-type wafer phosphorus is added, which has five electrons in its valence layer.

While these wafers don't have any charge in and of themselves, an interesting thing happens when the n-type and p-type wafers are brought together. The "extra" electrons from the n-type wafer flow across into the p-type wafer causing an area called a "depletion zone" in which an electric field occurs. On the n-type side there ends up being a positive charge (because the electrons have moved into the p-type wafer).

This sets up an electric field, meaning that when photons hit a silicon atom and dislodge an electron from the valence layer, that electron will tend to move across into the n-type layer. Electrical contacts can be added and you end up with an electric current.

The image below shows a very simple set-up of a p-type silicon solar cell. The two key things to note here are that the p-type wafer is on the bottom (the most common arrangement today, although n-type cells in the base do have some advantages) and the p-type wafer is much thicker than the n-type wafer. In fact, the n-type wafer is so thin that it is often not a distinct wafer, but is in fact just a treatment put on the top of the silicon wafer.

Basic P-Type Silicon Solar Cell Arrangement



Source: Arisaig Partners

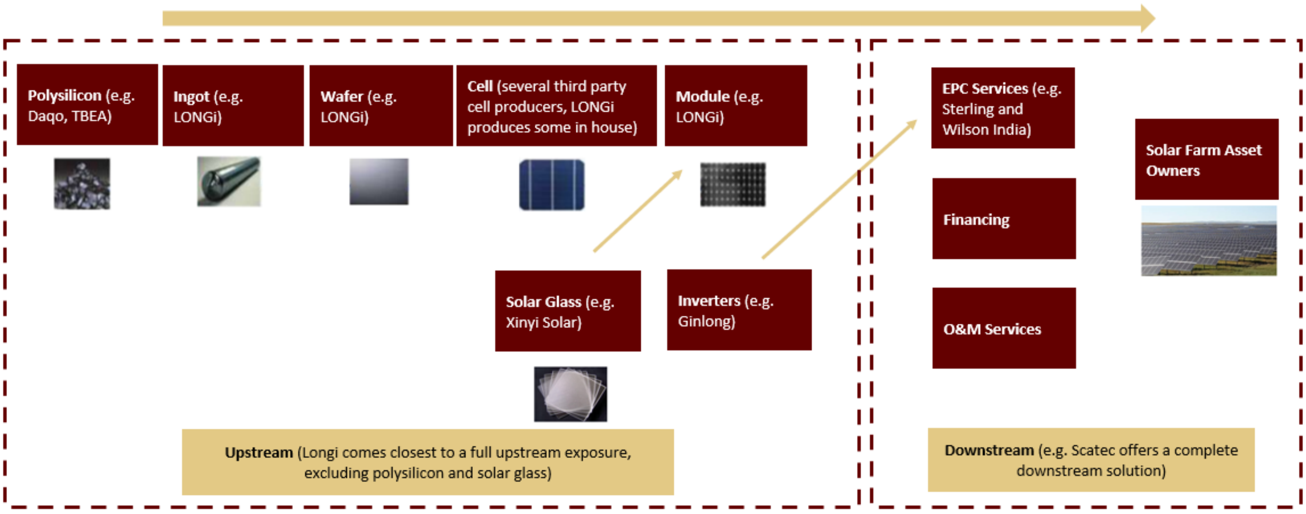
Types of Solar Cell:
At this point it is worth noting that there are other types of photovoltaic solar cell beyond silicon, although silicon cells do account for 90% of the solar cell market. We deal with this more in the "technology trends" section. However, the key point to make is that silicon solar cells are a relatively mature technology, operating at a commercial scale, and with the potential to still

significantly lower costs. As a result, it seems likely that silicon cells are likely to be a material part of the photovoltaic market for the foreseeable future.

Solar Value Chain

The chart below shows a general overview of the solar value chain. In the sections below we outline each of these stages in more detail. In broad terms, the industry can be split into an upstream component (mainly China) and a downstream component. It's worth noting that some companies will cover all or most of the value chain while others will focus on specific segments.

Solar Value Chain Overview



Source: Arisaig Partners

Polysilicon:

Polysilicon is made by combining quartzite (silicon dioxide) and carbon (coal) in an arc furnace, which produces silicon and carbon monoxide. Quartzite can be found in sand but mined quartzite is also used in this process. This gives 98% purity metallurgical grade silicon. After this first stage there is a second stage reaction to increase the purity of the polysilicon (to 99.999%)[12].

The polysilicon price has varied significantly over the past ten to fifteen years. In 2008 the price for a kg of polysilicon reached USD 400 but has now fallen to USD 10. In part this has been driven by a significant increase in low cost production capacity in China. The low-cost producers here are Tongwei, DAQO and TBEA.

Chunks of Polysilicon

[12] This is lower than the purity needed in silicon computer chips.

Source: Wacker Chemie website

Ingot:

The step above produces chunks of polysilicon. However, these can't be used directly in solar panels. As the photo above shows, the polysilicon is essentially lumps of "metal"[13]. These lumps need to be melted to create flat sheets that can be put into solar panels. In addition, the crystalline structure in polysilicon is far too inconsistent and unstructured to allow electrons to flow and generate an efficient amount of electricity.

At this point we can produce either monocrystalline or polycrystalline silicon. In the monocrystalline process there is a tub of molten silicon out of which a single crystal is drawn in a long cylindrical ingot shape (a comparison could be made to making cotton candy). This is called the Czochralski process.

In polycrystalline silicon the process starts with a tub of molten silicon, but it is gradually cooled from the bottom, leading to the gradual formation of multiple columns of crystals.

The polycrystalline process is simpler, and for a long time was significantly cheaper. However, it also produces lower quality wafers because it has relatively more grain boundaries than a monocrystalline wafer. In recent years monocrystalline wafers have scaled up significantly, bringing down costs. Given the better solar energy conversion efficiency of monocrystalline they now account for over 60% of the wafer market (from 28% in 2017).

Wafer:

The wafer stage essentially involves cutting the silicon ingot into very thin pieces. A silicon p-wafer will be a few hundred micrometers thick (one thirtieth of a centimeter).

So, at the end of this stage you would have many thin sheets of silicon, somewhat large than the size of a human hand (the standard that is now being pushed for is 182mm square wafers).

Cell:

The cell stage generally involves: (i) Texturing the surface of the wafer to improve photon absorption; (ii) Addition of anti-reflective coating; (iv) Addition of the electrodes that will allow a current to flow. Silver is often used on the front and aluminium on the back; (v) This is heated

[13] I put metal in quotation marks because silicon is technically a metalloid – but for our purposes it looks like a lump of metal!

up so that the metals meld into the wafers.

It is important to note that there are different types of cell architecture, and the details of this stage of the process can change significantly. That is why some solar companies, such as LONGi, used to outsource the cell stage of the process, although they are now bringing this back in-house.

Probably the only other point to mention is that the “standard” cell used to be a Back Surface Field Cell – which had an aluminium back surface. Now, Passivated Emitter Rear Contact (PERC) cells are becoming more popular. Essentially, PERC cells add some more layers at the back of the cell which help to reflect light back into the cell and reduce electron hole pair recombination.

Solar Glass:

This is an interesting sub-stage of the process. Solar glass is required on the front (and potentially back) of a solar panel to provide protection to the cells, while still allowing the optimal amount of light to get through and minimising reflection. In order to do this the glass is textured to minimise reflection and is often covered in an antireflective coating.

This is a business that is quite niche, but with significant economies of scale (the dominant player has a gross margin 20 percentage points higher than the tail end of producers). The dominant global solar glass company is Xinyi Solar, while Flat Glass is second place.

Panel (Module):

The solar panel is the end output that most people would immediately identify from either residential rooftops or pictures of solar farms. A typical solar panel could be around 1.5m long and 1m wide with a thickness of 40mm or so (although obviously these dimensions vary).

The actual panel construction process is highly commoditised (at least for standard silicon panels). It essentially involves connecting the cells together, placing them into a metal frame, adding an EVA plastic filling and placing the glass in place. As a result, apart from with highly specialised cell or panel architectures (which could pose their own risks) a standalone panel manufacturer is unlikely to be an appealing investment.

Inverters and Panel Management:

Once a solar panel is installed there are still important pieces of equipment that are needed to get the energy output into an optimal and usable form. The first point to note is that solar panels produce a direct current (DC) output while the electricity grid and most home appliances use alternating current (AC). This requires a product called an inverter to convert the DC to AC.

Another important point to note (more detail in Appendix B) is that optimising the power output from a solar panel requires periodic adjustments - usually an inverter can perform these functions.

Downstream:

The downstream end of the market is comprised of several parts: (i) Origination of deals; (ii) Building the solar farms (Engineering, Procurement and Construction, EPC, services); (iii) Maintaining the solar farms (Operations and Maintenance, O&M, services); (iv) Financing solar farms; (v) Owning and managing the equity exposure to the solar farms.

Generally, the upstream side of the market is concentrated in China, so downstream investment offer a more geographically diversified opportunity set.

There are a few points to note about the downstream end of the market. First, O&M services are very limited for solar farms (compared to, say, wind) because solar panels simply don't need that much servicing. Therefore, this is a potentially lucrative source of recurring revenue that is limited in the solar market. In addition, EPC services are quite commoditised. Installing a solar farm is simply not that difficult (compared to, for example, an offshore wind farm).

However, we do see an interesting opportunity in downstream solar companies that cover the full downstream value chain from deal origination through solar farm construction and owning equity in the solar farms. The prime example here is Scatec, who (while listed in Norway) invest only in emerging markets.

The final point to note is that pure-play downstream solar companies appear to be gradually disappearing. The highest quality businesses (such as Scatec) are diversifying into solar plus wind plus battery solutions. This is to match client demand for more consistent and stable power supplies (for which a higher price can be commanded). In some respects we view this trend positively, because we believe it builds a more comprehensive and complicated product, with more of a moat.

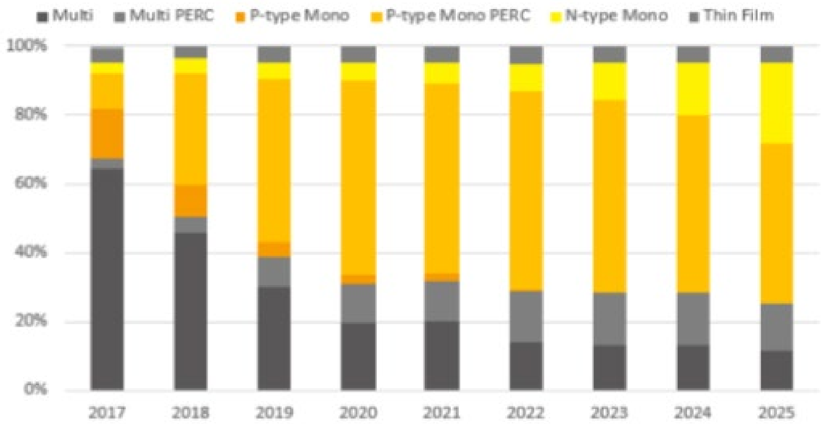
A final point to note is the end client (in this case we are referring to utility scale solar). The solar farm asset owner (e.g. Scatec) will sign a long-term Power Purchase Agreement (PPA) with either a electricity utility or, in some cases, a corporate customer.

Technology Trends

As with any sector, we need to be aware of the potential for disruptive trends. We should first make a distinction between two types of potential technological change: (1) A cell format change. This is a cell that still uses silicon but with a tweak in how the cell is formatted, for example a p-type versus n-type cell or a PERC cell. (2) A fundamental shift in technology, such as from silicon to polymer cells.

With regards to point (1) the chart below from the LONGi annual report shows some of the significant changes in the past few years. The market has changed from a multicrystalline (polycrystalline) market to a monocrystalline one, with a PERC cell architecture. The market is likely to remain monocrystalline, but n-type cells seem likely to gain share in the future.

Global Solar Wafer Market Shares (%)



Source: PV InfoLink taken from LONGi annual report

What could be more significant is the potential for a fundamental shift away from silicon. As mentioned earlier, silicon currently accounts for the vast majority of the photovoltaics market, and I doubt this will change in the medium term. Still, it is important to understand the different technologies and I have outlined these in the section below.

Other Types of Photovoltaic Materials:

There are three generations of solar cell: the first is silicon, the second is thin film and the third is a broader collection including polymer cells, multi junction, perovskite and quantum dot cells. In the paragraphs below I have set out some of the second and third generation technologies to be aware of.

(i) **Thin film solar:** Thin film panels have a global market share of under 10%. While they have some advantages to silicon cells (cheaper to produce with a less energy intensive production process), the main thin film technologies today use rare and/or toxic, chemicals which limits scalability. The common materials used for thin film solar cells are copper indium gallium selenide (CIGS), cadmium telluride and amorphous silicon (the first two are the main technologies, amorphous silicon has lower efficiency and less stability).

(ii) **Organic (polymer) solar cells:** These are essentially “plastic” solar cells that could have major advantages over silicon cells. They can be produced by printing (in a process almost as simple as printing out text on a sheet of paper), and therefore require significantly less energy to produce, with a much simpler production process. They can be made very quickly, and are flexible, which could open up more versatile applications. However, the problems are that: (1) Efficiency for polymer solar cells is significantly below that of crystalline silicon solar cells and; (2) The lifecycle for polymer cells is much shorter.

(iii) **Perovskite and other new technologies:** Perovskite solar cells are currently a major area of interest in solar energy research. The core idea is that perovskite cells could be much cheaper to make, as well as being significantly thinner (and semi-transparent) compared to silicon cells. This would make them suitable for tandem solar cells, which could increase cell efficiencies into the 40% range. Having said that, while there is clear promise in this new technology, there are concerns about durability (remember that traditional silicon panels can last more than 25 years) as well as the fact that many perovskites contain lead.

ESG Opportunity and Risk Analysis

In this section we will discuss how we frame and monitor the ESG risks associated with companies in the solar industry.

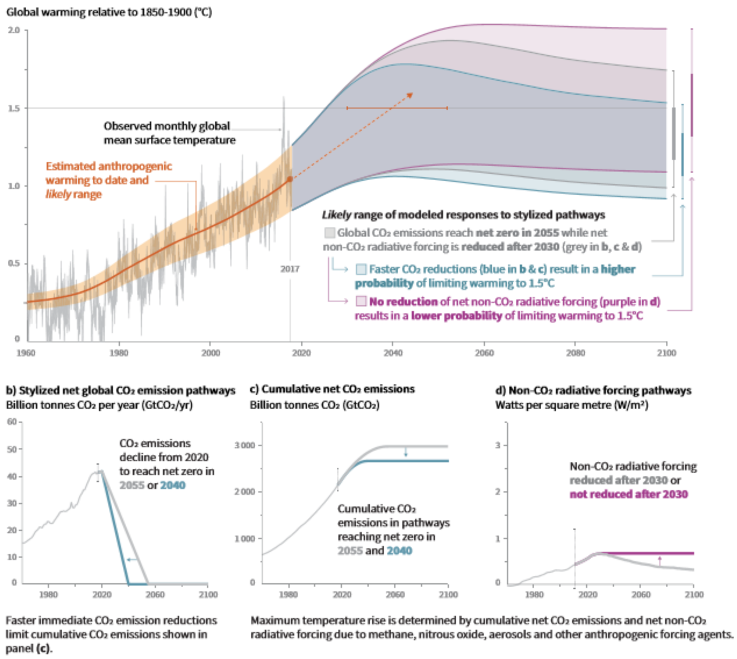
However, first, it is worth recapping the "ESG opportunity" that the solar industry faces (contributing to the reduction in global GHG emissions). In most of this report we have taken this opportunity as given and focused instead on the economic and technical aspects of solar power. Below we will briefly highlight the key issues here.

The Opportunity:

Through this report we have implicitly been focused on the GHG emission reduction opportunities embedded in solar power. Data on greenhouse gas emissions (GHG)[14] suggests that 73% of GHG emissions are related to energy use (the remainder is in areas such as agriculture, land use change and some industrial processes). Breaking down energy further, roughly 30% of total GHG emissions are related to electricity and heat generation directly, with another 16% related to transportation (which could, of course, be electrified over time). The key point is that while electricity generation is far from the only GHG emitter, it will be a major component of reducing GHG emissions over time.

As the IPCC has noted, limiting global warming to 1.5°C (which will help to mitigate the worst effects of climate change) implies achieving net zero carbon emissions globally by the 2050s. The electricity generation sector will need to be a major component of this.

IPCC[15] Temperature Change Projections and Carbon Emissions Pathways

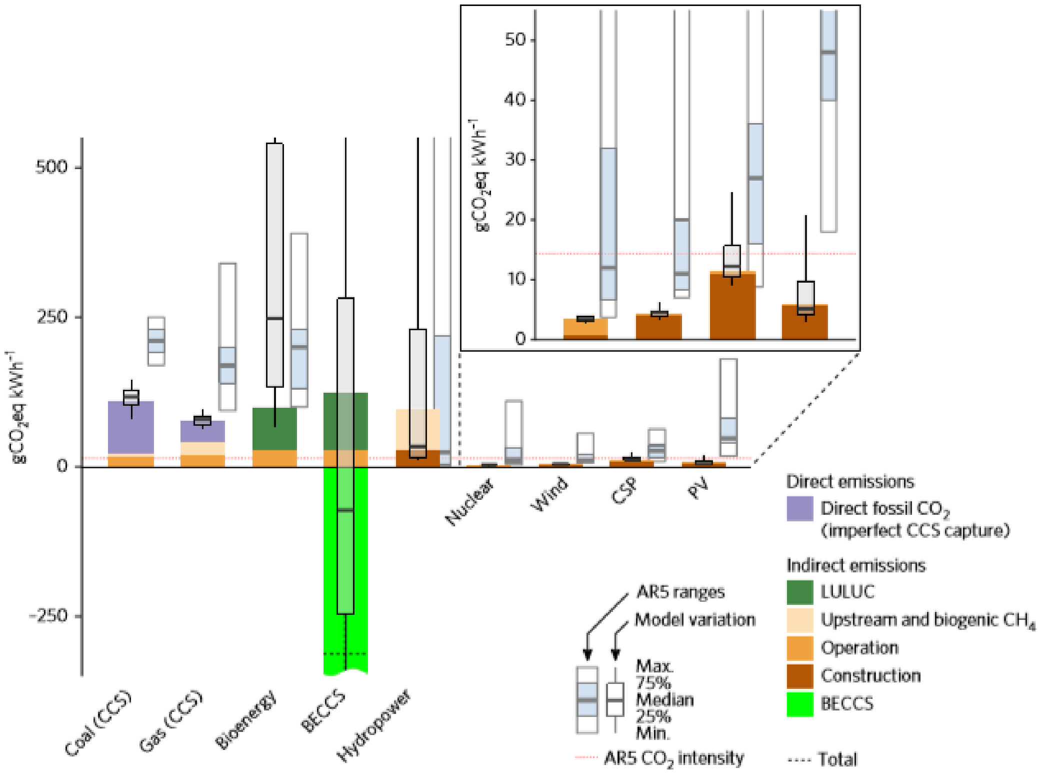


Source: IPCC

[14] See www.climatewatchdata.org
[15] https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

Solar PV can be a major contributor to this net zero effort. While solar panels do have embedded carbon due to their energy intensive production process, when this is amortised over the lifetime of a solar panel the gCO2eq per kWh is significantly lower than fossil fuel sources (even with carbon capture and storage). This is shown in the chart below. What is interesting about this chart is that the coloured bars are forecasts, based on assumptions that renewable energy will increasingly become part of the input to construct additional renewables (e.g. a solar PV factory powered by solar PV) which will significantly reduce embedded carbon relative to a solar factory powered by coal. On this point, it is worth noting that it is an interesting quirk that the upstream solar industry scaled in China, a country which is highly dependent on coal power, with commensurately higher embedded GHG emissions. The situation may have looked different if the industry had developed in a country with a more favourable energy mix – and indeed will improve as China transitions towards a greater use of renewable energy sources.

Direct and Indirect GHG Emissions (gCO2eq Per kWh) Coloured Bars Are 2050 Forecasts, Pale Blue and White Bars Are From IPCC Fifth Assessment Report[16]



Source: [*https://www.terrestrialenergy.com/wp-content/uploads/2020/07/Pehl_et_al-2017-Nature_Energy.pdf*](https://www.terrestrialenergy.com/wp-content/uploads/2020/07/Pehl_et_al-2017-Nature_Energy.pdf)

Helpfully the IPCC also set out electricity generation pathways that are consistent with a 1.5°C warming scenario[17]. In their models, coal falls from the 30% plus of electricity generation that it is today, to essentially zero by 2050. This requires a significant increase in electricity generation from other sources. They estimate that wind and solar electricity generation will need to increase

[16] From: "Understanding Future Emissions From Low-Carbon Power Systems By Integration of Life-Cycle Assessment and Integrated Energy Modelling".
[17] https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter2_Low_Res.pdf

by 26x between 2020 and 2050 in their 1.5°C consistent scenarios.

The point of these few paragraphs is merely to re-iterate that the renewable energy industry is significantly exposed to the positive opportunities that may well be "ESG risks" for other businesses. Nonetheless, companies operating within the solar energy industry are also exposed to their own risks, which we discuss in more detail below.

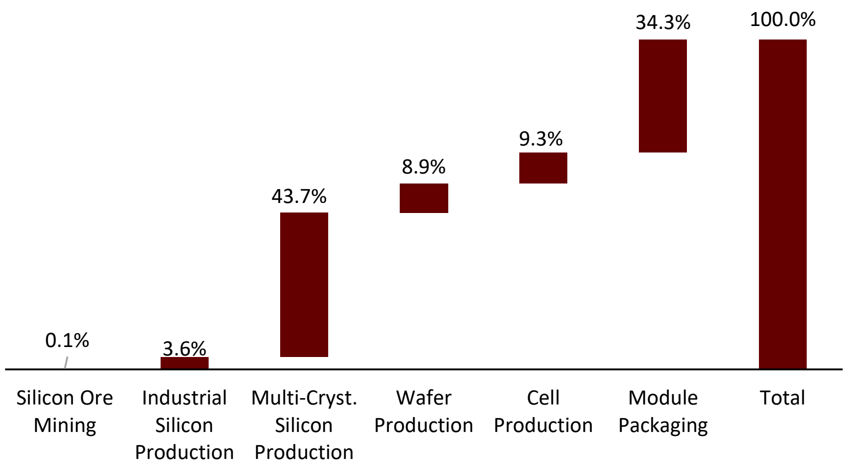
The Risks:
The profile of ESG related risks in the solar industry differs quite materially depending on where a company is located in the supply chain, as well as by geographic exposure. We think it makes sense to divide the discussion here between the upstream (manufacturing focused component of the industry) and the downstream market.

Upstream Risks:
On the upstream side the main risks are the environmental externalities related to the development of solar equipment. These are heavy industrial processes and the main issues are: **(i) Energy consumption:** This is significant in some parts of the production process (involving embedded CO2 emissions), particularly at the ingot production and module packaging stage of the process; **(ii) Hazardous chemicals:** Disposal and management of hazardous waste is an important risk factor, particularly silicon tetrachloride during the polysilicon production process and hydrofluoric acid used to clean wafers (although sodium hydroxide can be used instead). Please note that in this discussion we are not considering thin film technologies (which have a relatively minor market share) since they involve their own set of hazardous material challenges. Poor management of hazardous waste has been an issue for Chinese manufacturers in the past. In 2011 Jinko Solar's share price dropped 40% when media reported that hydrofluoric acid from the company's factory had spilled into a nearby river killing hundreds of fish and dozens of pigs[18]; **(iii) Water use:** This can be quite high in the module packaging process, which is a particular issue in China due to limited water recycling.

As mentioned above, even within the upstream part of the solar industry, different stages of the manufacturing process face different challenges. The chart below (from a life-cycle assessment for Chinese solar panels) gives a sense of GHG emissions per stage of production – with the ingot and module packaging stage accounting for about 80% of emissions. This data is from 2014, so is somewhat dated, but still gives a good sense of the core energy consumption areas in the value chain.

[18] https://spectrum.ieee.org/green-tech/solar/solar-energy-isnt-always-as-green-as-you-think

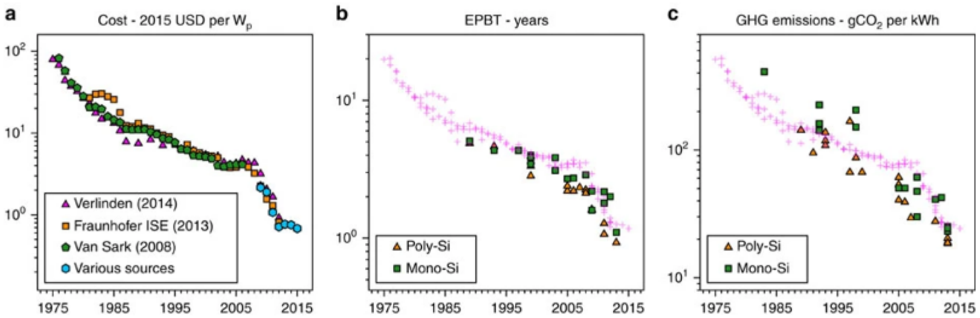
Percent of Aggregate Kg CO2eq Emitted Per kWp Multi-Crystalline Silicon PV Modules[19]



Source: https://core.ac.uk/download/pdf/191745578.pdf

It is worth noting that embedded CO2 will fall over time, partly because of efficiencies in the production process, but also because as China itself switches more towards renewable energy, the energy used in producing new solar panels involves emitting less CO2. We have already seen major upstream companies, such as LONGi, commit to having 100% of their energy from renewables by 2028 (up from 47% currently). The next chart highlights this point about improvements in environmental impact. Much as the financial cost of solar has declined over time, so have improvements in the production process reduced GHG emissions in the production process, as well as Energy Pay Back Times.

Financial and Non-Financial Costs For Solar Energy[20]



(**a**) Development of average module selling price over time, in 2015 USD per W_p. Data from[16,25,26,34,35]. (**b**) Development of energy payback time over time. (**c**) Development of greenhouse gas emissions from PV electricity over time. The magenta crosses in (**b**,**c**) are an overlay of the cost data from (**a**).

Source: https://www.nature.com/articles/ncomms13728

In fact, data from the Fraunhofer Institute for Solar Energy Systems suggests that energy payback times for silicon PV systems are now less than 1.5 years, and that the payback time for a rooftop

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[19] From "Life-Cycle Assessment of China's Multi-Crystalline Silicon Photovoltaic Modules Considering International Trade".

[20] From "Re-Assessment of Net Energy Production and Greenhouse Gas Emissions Avoidance After 40 Years of Photovoltaics Development" https://www.nature.com/articles/ncomms13728

system in Southern Europe has dropped from 3 years in 1990 to 1 year in 2020[21]

Embedded carbon in solar panels is likely to continue to be a major focus for utilities, developers and upstream manufacturers. France introduced controversial (some may say protectionist) regulations which required that solar PV projects in France must use modules that comply with certain embedded carbon restrictions[22]. We are also seeing best-in-class EPC/IPP businesses such as Scatec looking to publish more detailed scope three emissions, which will include estimates of embedded carbon in the solar panels that they purchase. As a result of this we would expect to see upstream manufacturers who are able to both limit and disclose embedded carbon emissions to gain market share in coming years.

Downstream Risks:

Downstream solar companies also face some risks, though they are of a slightly different nature to the upstream. Generally, energy consumption and hazardous waste are relatively less important, since downstream companies are not involved in industrial production processes. The main downstream risks relate to: **(i) Corruption:** Solar farms can be large projects, often negotiated with state or quasi-state entities. This opens up the potential risk of corruption at some stage of the process, particularly in certain emerging markets; **(ii) Environment and land use issues:** Solar developers need to be sure that any negative immediate environmental impact from solar farms is mitigated, and that if any displacement of local communities is necessary that it is managed appropriately; **(iii) Labour rights and safety:** Solar farms are not the most complicated and dangerous EPC projects, but ensuring worker safety remains key. In addition, where sub-contractors are used it is imperative that labour rights are respected; **(iv) Water:** Water is used for cleaning solar panels. This is an important resource to conserve, especially in water stressed areas.

The magnitude and relative importance of these risks will vary by company. In the case of Scatec Solar, management have been very clear that incidents of corruption are their single biggest ESG risk. Given that they are heavily reliant on development finance institution funding, any material incident of corruption could have a major detrimental effect on their funding model. In addition, they are exposed to high corruption risk countries.

To help mitigate this risk they have an Anti-Corruption Program; conduct corruption risk assessments on a country, project and contract basis; all employees are required to undergo anti-corruption training and; they have a whistleblowing channel.

The Arisaig ESG Risk Framework:

In the table below we have set out key ESG risks for companies operating in the solar industry, based on SASB guidelines. While there is clearly some overlap between the risk exposure of upstream and downstream companies, we think it makes more sense to have separate benchmark weightings for each. We would also note that these are guidelines for analysts. Companies may differ in their relative risk exposure even if they are within the same upstream or downstream segment.

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[21] https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

[22] https://www.pv-magazine.com/2019/04/27/the-weekend-read-playing-by-the-carbon-footprint-rules/

Key Issue	Policy Best Practice Checklist	Upstream Weighting	Downstream Weighting	Arisaig Metrics
Energy Management	- Stated policy for energy reduction, including targets - Carbon footprint analysis and progress towards reduction - Energy intensity (i.e. on a per unit of output) in line or lower than peers - Stated policy for the identification and adoption of renewable energy sources, including targets - Renewable energy mix in line or higher than peers	*30%*	*10%*	(1) Total energy consumed and by source (split by grid and renewable); (2) Energy usage per unit of output (i.e. intensity) (3) Gross global Scope 1 and 2 emissions; (4) Estimates of scope 3 emissions (through supply chain)
Water management	- Water use measured across all major facilities - Targets for water reduction (absolute and intensity) in direct operations (and progress towards them) - Water usage intensity at or below level of peers - Water treatment targets to return clean water to environment - Company involved in public policy dialogue	*20%*	*10%*	(1) Total water withdrawn (2) Total water consumed (i.e. Not returned to same catchment area from which it was withdrawn); (3) % withdrawn and % sourced in high water stress areas; (4) Discussion of risks associated with water withdrawal and description of practices to mitigate them (5) Targets for water reduction and reuse
Hazardous materials and product end-of-life management	- Hazardous materials management plan covers entire project lifecycle - Track record of compliance with all applicable legal and regulatory requirements - Use of innovative technologies to maximise recycling / reuse of end-of-life materials	*25%*	*10%*	(1) Amount of hazardous waste generated (2) % of hazardous waste recycled (3) Number and quantity of reportable spills and % recovered (4) Quantity of end-of-life material recovered, % recycled
E&S impacts of project development	- Compliance with all relevant legal requirements and international standards, such as IFC Performance Standards - Maintains comprehensive and effective Environmental and Social Management System (ESMS) for each asset - Conducts stakeholder engagement and develop engagement plans for all	*0%*	*20%*	(1) Number and duration of project delays related to environmental or social impacts (2) Publication of environmental & social impact assessments (ESIA) (3) Description and evidence of stakeholder engagement activities

	projects - Publicly available grievance mechanism available and evidence of use			
Supply chain sourcing	- Publicly accessible responsible sourcing policy - Auditing and engagement of key suppliers - Consideration of suppliers' performance in relation to material environmental and social issues e.g. energy & waste management, compliance with environmental regulatory requirements and with health & safety standards	*15%*	*10%*	(1) Description of how risks associated with the use of critical materials (including physical, price, regulatory and reputational risks) are managed (2) Description of supplier due diligence practices and outcomes
Employee Management (Labour Practices and Health and Safety)	-Clearly defined health and safety policy and standards (e.g. ISO 45001) -Information on how sub-contractors are managed and audited -Details on the use of local versus non-local and skilled versus unskilled labour	*10%*	*15%*	(1) Publication of a health and safety policy and ISO certification; (2) Data on fatalities, Total Recordable Injury Frequency and Lost Time Incident Frequency; (3) Information on the frequency of sub-contractor audits
Corruption	- Clearly worded and easily accessible policy on corruption and bribery, which also applies to joint venture partners - Board-level responsibility for regularly reviewing appropriateness of corruption and bribery policy - Track record of compliance with applicable anti-corruption laws - Code of Conduct governing employees' interactions with stakeholders, including public officials - Anti-corruption training for all employees - Anonymous whistle-blowing system	*0%*	*25%*	(1) Number/frequency of whistle blowing incidents; (2) Publicly available anti-corruption policy and Code of Conduct; (3) Fines and other penalties resulting from legal proceedings relating to corruption and bribery

The Public Market Opportunity Set

In the table below we have set out the public market opportunity set for solar in emerging markets, as well as some developed market comparable companies.

Overview of Listed Stocks in the Solar Energy Sector (Updated September 2020)

Code	Company Name	Country	Description	Market Cap (USD mn)	ADTV (USD mn)	Sales (USD mn)	ROA (3 Year Average)	ROE (3 Year Average)	PER NTM	EV/EBITDA NTM
Emerging Market Business										
Upstream:										
601012 CH Equity	LONGi Green Energy Technology	China	Global leader in monocrystalline wafers	39,458	1,065.2	4,763	10.5%	23.3%	32.2	23.8
600438 CH Equity	Tongwei	China	Producer of polysilicon and cell manufacturer. Legacy agriculture business is 1/2 of sales.	15,437	664.6	5,438	7.0%	15.6%	24.4	15.4
002129 CH Equity	Tianjin Zhonghuan Semiconductor	China	Major monocrystalline wafer producer, second to LONGi	10,264	787.2	2,445	1.9%	5.9%	38.9	18.4
968 HK Equity	Xinyi Solar	China	The global leader in solar glass manufacturing	11,096	92.1	1,161	9.7%	22.1%	21.5	16.2
601877 CH Equity	Zhejiang Chint Electrics	China	Low voltage power equipment, solar farms and distributed solar	9,895	132.6	4,376	7.4%	16.9%	14.1	11.6
6865 HK Equity	Flat Glass Group	China	Second place solar glass producer	6,554	34.7	696	7.8%	14.3%	19.5	20.4
300724 CH Equity	Shenzhen S.C New Energy Technology	China	Makes manufacturing equipment (for wafer texturing, doping, wafer cleaning)	4,980	115.0	366	8.8%	22.0%	46.8	41.8
600089 CH Equity	TBEA	China	Low cost polysilicon producer, other segments include transformers and cables	4,830	278.6	5,361	2.4%	7.0%	15.0	11.8
002506 CH Equity	GCL System Integration Technology	China	Solar cell and module manufacturer	2,756	411.3	1,257	0.2%	1.0%	-	30.2
300763 CS Equity	Ginlong Technology	China	Manufacturer of solar inverters	2,376	31.6	165	21.8%	41.9%	41.5	31.8
601222 CH Equity	Jiangsu Linyang Energy	China	A leader in distributed solar in China and increasing focus on N-type mono cells	1,884	78.0	486	4.4%	7.5%	10.9	7.9
DQ US Equity	Daqo New Energy Corp	China	Low cost polysilicon producer	1,567	23.5	350	6.9%	13.9%	8.3	5.8
JKS US Equity	JinkoSolar	China	Vertically integrated (polysilicon to module) module manufacturer.	1,220	25.9	4,307	1.3%	6.1%	9.4	9.7
300393 CH Equity	Jolywood	China	Manufactures back sheets as well as n-type bifacial panels.	977	52.1	504	3.6%	9.5%	13.6	-
3800 HK Equity	GCL-Poly	China	Largest polysilicon and polycrystalline wafer producer.	791	17.4	2,787	0.4%	1.7%	-	7.6
Downstream:										
541450 IN Equity	Adani Green Energy	India	Large publicly listed renewable (wind and solar) energy producer in India	13,853	10.0	294	-1.9%	-15.5%	-	-
300274 CH Equity	Sungrow	China	EPC is 60% of revenues. Also produces inverters and panel management systems.	5,692	246.8	1,883	5.4%	12.6%	30.9	24.5
3868 HK Equity	Xinyi Energy	China	Solar farm subsidiary of Xinyi Solar	2,805	7.4	203	8.0%	11.9%	20.4	13.0
SSO NO Equity	Scatec Solar	EM	Diversified EM solar farm operator/EPC (listed in Norway)	2,652	18.1	203	1.6%	13.7%	61.2	13.8
SPK SM Equity	Solarpack	Spain (LATAM)	Solar assets, in Spain, Chile, India and Peru, now mainly a "build to own" model	648	0.5	93	2.1%	6.2%	28.0	12.6
SPCG TB Equity	SPCG Public	Thailand	EPC and O&M as well as solar roof installation	547	0.8	169	11.3%	24.1%	7.4	6.3
GRE SM Equity	Grenergy Renewables	Spain (LATAM)	Mix of wind and solar assets across Spain and Latin America, now mainly a "build to own" model	522	0.4	81	11.2%	35.8%	12.0	8.3
542760 IN Equity	Sterling and Wilson Solar	India	Diversified EPC business (India, MENA, SSA and SEA). Issues with related party lending.	453	1.2	1,179	-	-	-	-
Developed Market References										
SEDG US Equity	SolarEdge Technologies	US	Produces inverters, transformers, power management systems	9,543	175.5	1,426	14.6%	24.2%	39.9	27.5
ENPH US Equity	Enphase Energy	US	Produces inverters, transformers, power management systems	8,911	303.0	624	-	-	47.2	35.0
RUN US Equity	Sunrun	US	Installation of residential solar and financing plans	7,639	132.8	859	1.5%	7.3%	94.8	270.3
FSLR US Equity	First Solar	US	Focus is thin film cadmium telluride modules	6,535	91.2	3,063	-0.6%	-0.9%	17.6	8.4
WCH GY Equity	Wacker Chemie	Germany	Diversified business, produces polysilicon	4,654	29.5	5,516	2.1%	4.7%	22.8	6.7
SPWR US Equity	SunPower	US	Following 2019 Maxeon spin-off this is a downstream North America business	1,706	40.4	1,864	-15.4%	-	-	30.1
S92 GY Equity	SMA Solar Technology	Germany	Produces inverters, transformers, power management systems	1,526	7.0	1,024	-4.8%	-10.3%	67.9	15.0
NESF LN Equity	NextEnergy Solar Fund	UK	Operator of solar farms in the UK and Italy	751	1.1	-	-	-	-	-
MAXN US Equity	Maxeon Solar Technologies	US	Solar panel manufacturer, spun out of SunPower in 2019, makes n-type higher efficiency panels	398	15.1	1,198	-	-	-	14.2

Source: Arisaig Partners, Bloomberg

Conclusion

From our research we can conclude two key points. First, the electricity output from solar energy sources is set to grow significantly in coming decades, most likely at least at a low double-digit rate over the next twenty years. Second, while there are many rapidly evolving areas of technology, it does seem that silicon solar cells are set to dominate for at least the next five years.

In terms of investment opportunities, we believe that while there are promising investments upstream, the moats here typically involve economies of scale, and so we should focus on the largest upstream businesses.

On the downstream side, we think pure EPC businesses offer a fairly commoditised product, with volatile revenues, and so do not offer serious investment opportunities. However, we think that full downstream offerings that work on the value chain through origination, to EPC, to arranging financing and then (ultimately) managing equity stakes in solar farms could present attractive returns. We would note that these businesses will probably evolve away from being pure solar energy providers to solar plus wind plus storage businesses. However, we view this as a positive move that offers more value to clients, and a larger moat to the company.

We have identified a “short-list” of three key potential investments, and we provide a brief summary of each below. Further details are available on request.

Scatec Solar:
Scatec Solar is Norwegian listed solar farm developer, but operates only in emerging markets, with a diversified geographic footprint across Africa, Latin America and increasing exposure to Asia. It currently has 1.9 GW of solar projects in operation and under construction (as of end Q2 2020), with a goal for that to reach 4.5 GW by the end of 2021. Scatec is involved in the entire downstream value chain for solar projects, from the project design and origination, to financing, construction and then the ownership and management of solar farms. The company has recently broadened its articles of association to allow it to expand beyond solar into other renewable energy sources (wind and batteries).

LONGi Green Energy Technology:
LONGi is a behemoth in the upstream solar industry, and is (by far) the largest producer of monocrystalline silicon wafers in the world, with a market share in monocrystalline products of roughly 60%. It operates through most of the upstream solar market, from ingot stage through to the end finished module product. However, a significant portion of its wafer production is sold externally to other companies who manufacture monocrystalline modules. LONGi was instrumental in shifting the global silicon PV market away from polycrystalline to monocrystalline modules, which I think is a positive sign regarding the company’s management team and founder, Li Zhongguo.

Xinyi Solar:
Xinyi Solar is the market leader in manufacturing glass for solar panels, with a market share of 30% in ultra-clear PV glass. It also owns 53% of Xinyi Energy, which is a solar farm company in China. The opportunity here is, in theory, quite clear. The solar glass business has significant economies of scale, which grant the larger businesses a material (10% plus) advantage over tail

producers in terms of gross margin. Xinyi Solar and second place player Flat Glass combined have about 50% of the solar glass market. Over time we would expect the long tail of producers to gradually go out of business, leading to market share gains for Xinyi Solar and Flat Glass. In addition, the increasing importance of bifacial panels could lead to demand for solar glass growing ahead of the overall solar market. However, our main concern here (and what may be a barrier to investing) is capital allocation. The rationale behind the decision to move into the downstream market with Xinyi Energy was unclear, and we worry that future free cash flow (of which we think there will be plenty) will be diverted to growing the business in size, rather than optimising returns on capital.

Appendix A – I-V Curve and Cell Efficiency

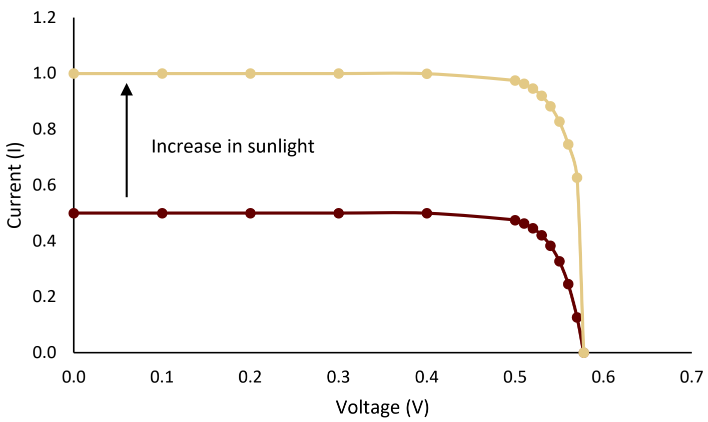
There are a few points here that were not important enough for the main text, but may be of interest.

The I-V Curve:

The I-V curve is an important part of optimising the power output from solar panels. At a given level of sunlight and temperature, you can vary the resistance in a circuit where a solar panel is attached. Changing this resistance will lead you to plot a curve like the ones below. Power output is voltage multiplied by current, so somewhere in the bend of the curve is the amount of resistance that will optimise power output.

However, if the amount of sunlight changes, or the temperature changes, the curve shifts, in turn changing the maximum power point. There are solar panel management systems which monitor the solar panels and ensure that the panel is operating as close to the maximum power point as is possible.

Example I-V Curve



Source: Arisaig Partners

It is also worth noting that one way of judging the quality of a solar panel is by looking at the "fill factor". The fill factor is the ratio of the maximum power output to the multiple of the short circuit current and the open circuit voltage.

Theoretical Maximum Solar Cell Efficiency:

There is a maximum efficiency for a solar cell with a single P-N junction. It is called the Shockley-Queisser Limit and is 33.7%. It occurs because of two reasons: (i) The "bandgap" which is the amount of energy required to move an electron from the silicon valence layer into the silicon crystal structure; (ii) Different wavelengths of light have more photons but less energy per photon (higher wavelength) compared to fewer photons but more energy per photon for lower wavelength light.

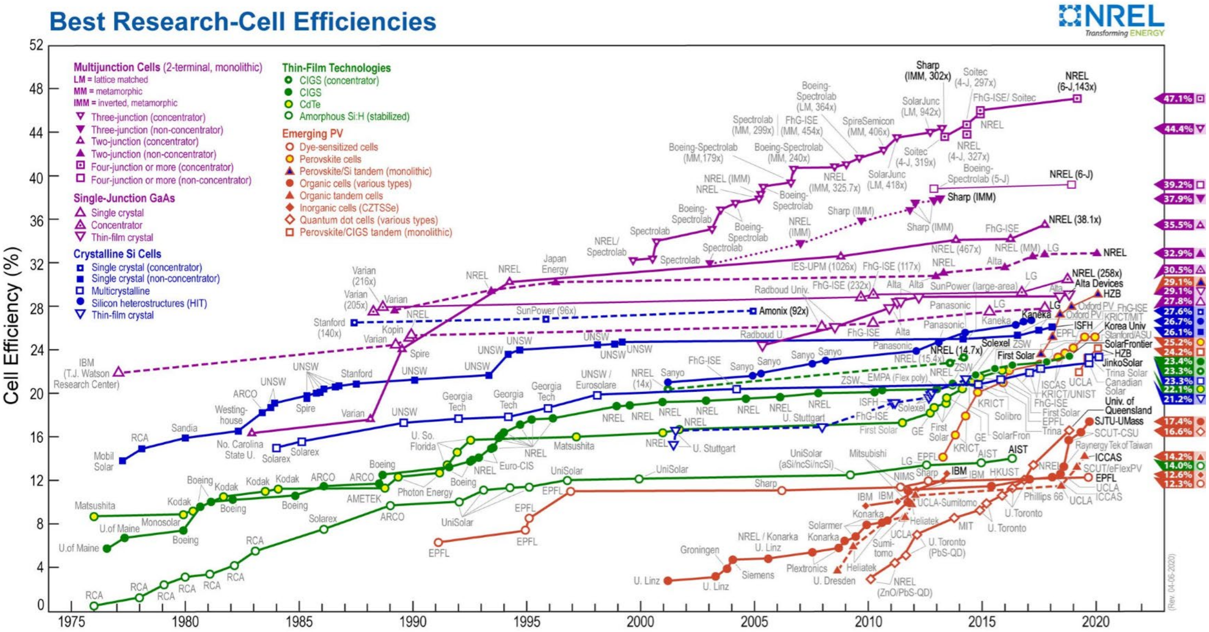
If you take the light spectrum on the earth's surface and lower the bandgap in the silicon (which you can do by changing the amount of doping) more photons will dislodge electrons, but the extra energy from the higher energy photons will be lost to heat. On the other hand if you increase the bandgap you will have fewer thermal losses but also fewer electrons dislodged since the lower energy photons will simply not be able to dislodge the electrons. This trade-off is at the heart of the efficiency limit.

Efficiencies of greater than 34% can be achieved by tandem solar cells which have different layers that absorb different parts of the light spectrum.

Current Levels of Solar Cell Efficiency:

The chart below shows the current levels of solar cell efficiency. It's worth noting that some of these are higher than the Shockley-Queisser limit because they use tandem cells. It's also worth noting that some of these cells are using concentrated light.

Best Research-Cell Efficiencies



Source: *https://www.nrel.gov/pv/assets/pdfs/best-research-cell-efficiencies.20200406.pdf*

Appendix B – Key Terminology

Term	Description
Efficiency	Efficiency refers to the power output of a cell versus the power input from the sun. In round numbers, the power of the sun per square meter at the equator during the middle of the day is 1,000 Watts. Therefore, if a solar module of one meter squared produced a power output of 200 Watts it would have an efficiency of 20%. In general terms, a good efficiency for a solar panel would be 20% or so.
Mono Wafer Versus Poly Wafer	Both "mono" and "poly" here refer to monocrystalline or polycrystalline silicon. In the case of monocrystalline a single polysilicon crystal is drawn from a vat of molten polysilicon (forming an ingot). This ingot is then chopped into wafers. You can tell a mono wafer from its smooth surface. The benefit of mono wafers is that they are more efficient than poly wafers (typically by roughly 2%). They used to be more expensive but as production efficiency has improved the cost has come down, leading to gains in market share. In the case of polycrystalline, chunks of polysilicon crystals are put in a tray, melted and then allowed to cool. This forms multiple crystals during the cooling process, and you can see that on the surface of a polysilicon wafer. The intuitive rationale for the greater efficiency of mono cells is that they have a much cleaner crystalline structure, which improves electron flow.
P-Type Versus N-Type Cells	A p-type or n-type wafer refers to whether the silicon is "doped" (has a small impurity added) of boron or phosphorus. It's worth noting that this "doping" is relatively very minor. Typically, it would be in the region of one atom of boron or phosphorus per hundred thousand silicon atoms. A p-type wafer is doped with boron which has one fewer electron than silicon, while a n-type wafer is doped with phosphorus which has one more electron than silicon. At this point it becomes slightly confusing – because standard silicon solar cells have both p-type and n-type sides. The key difference is that in a normal p-type cell the p-type wafer is on the "bottom" and is thicker, while the n-type portion is on the top. In an n-type cell this arrangement is reversed. While p-type cells have been the dominant technology with the most scale, this may change over time. The n-type cells typically have slightly higher efficiency (the p-type can suffer from something called the "boron-oxygen defect"). The problem with n-type cells is that they are slightly more complicated to manufacture and are currently produced

	in lower volume so are higher cost. However, this cost will likely improve, and the consensus in the market seems to be that n-type cells will become more popular over time.
PERC Cells	PERC stands for “Passivated Emitter and Rear Contact”. All this does is add another layer at the back of a solar cell that can help to reflect light back into the cell and reduce electron recombination.
Bifacial Panels	These are panels that can absorb solar energy both on the front and the back. While somewhat more expensive they can make up for this from gains in power output.
Energy Payback Time	It is worth noting that there are many stages in making a solar panel, and these stages require a lot of energy. How long does it take to get more energy cumulatively out of a solar panel than was used in creating it? A sensible rule of thumb is roughly 2 years – although this does vary depending on where in the world the solar panel is being used. Nonetheless, since solar cells have life expectancies in the order of several decades, the production of solar cells is worth it from a pure energy-in / energy – out perspective.