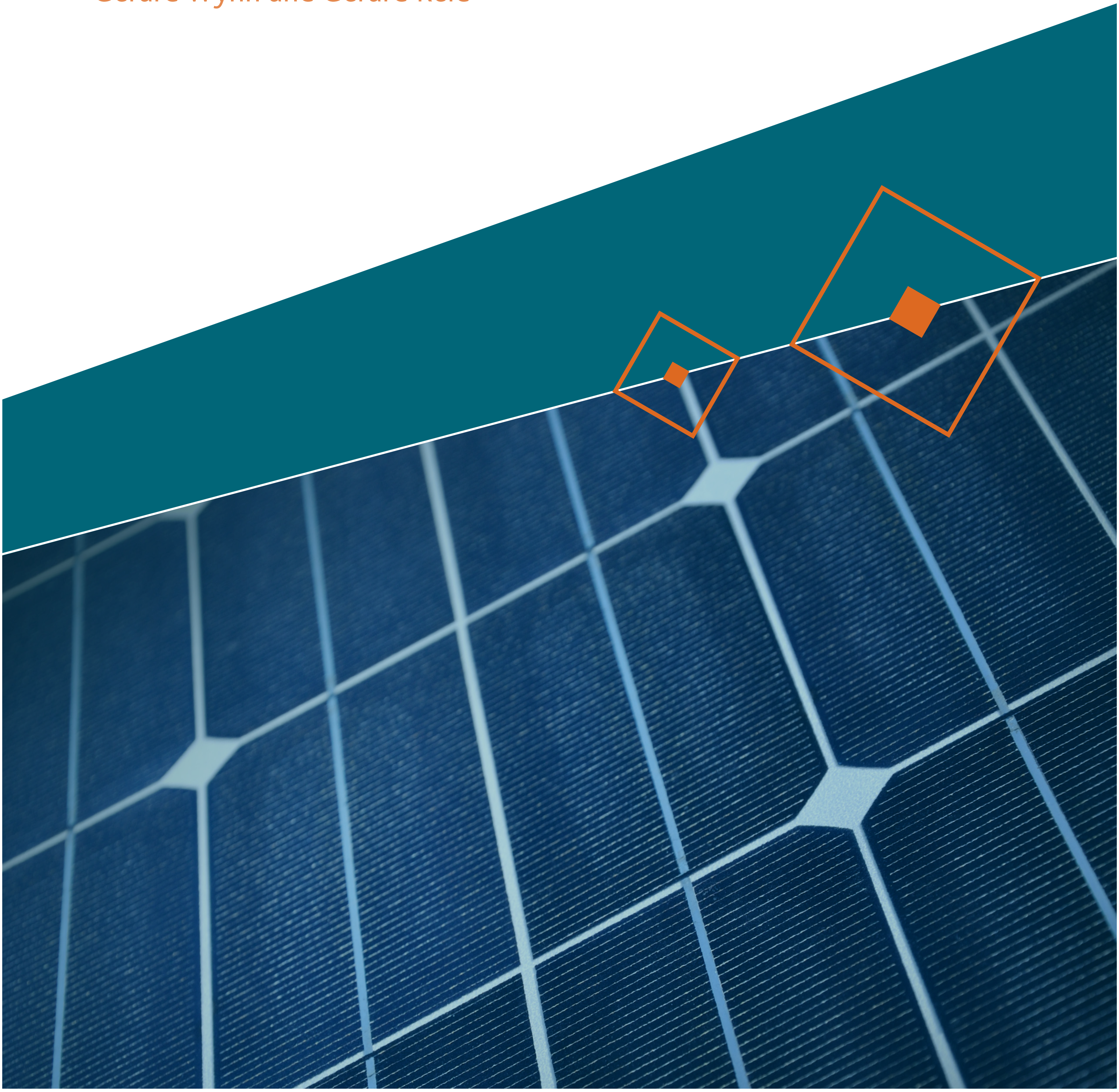
In Sight: Unsubsidised UK Solar

Gerard Wynn and Gerard Reid



Thema1

THEMA1 is an independent Berlin-based think-do-tank specialised in accelerating our transition to a low-carbon society.

Founded in 2006 by Guido Axmann, Jacob Bilabel and Rasmus Priess, THEMA1 initiates research and operates projects in the fields of sustainable consumption, renewable energy and mass mobilisation of the public towards a low-carbon future. Each of THEMA1's activities is defined by the strong belief of its founders that 'Talk without action means nothing'.

We are proud to support this report, which shows how solar power will have an increasingly important role in European power markets. Britain is already closing in on the economics of solar power in Germany, showing the benefits of a predictable regime of support to date. Britain is benefiting from solar cost reductions achieved through market growth and technical innovation over the past decade in Germany and globally.

Germany has shown the benefits of solar power, as an industrial strategy to generate jobs, and as a clean, flexible, secure source of energy. Solar is also extremely fast to build, a benefit Japan is reaping this year, installing multiple gigawatts in record time, and so protecting the grid from the continuing shut-down in the country's nuclear fleet.

Guido Axmann, THEMA1 co-founder

Foreword

Solar is leading new changes in the power market. In 2015, solar PV globally will overtake both gas and coal to become the number one power generation technology in terms of annual installations. This trend of continuing capacity increases coupled with cost reductions has caught out policymakers and analysts. Ignoring these trends would be like ignoring the displacement of fixed telephone lines by mobile phones. The reality is that the cost of solar power is on a downward trajectory.

We wrote this report against the backdrop of some negativity, for example regarding the German solar market. That may be unsurprising, given the impact that a solar revolution will have on power markets, and a resulting fight-back by some incumbents. However, the "genie is out of the bottle". There is now enough global support and manufacturing prowess in solar that costs will continue to fall. Solar can become a bedrock of the power system going forward. That said, the road going forward is unchartered and difficult. Our message to the UK government is to reduce support for solar, but to do so gradually.

To the writers, Gerard Wynn and Gerard Reid: we have known each other for many years from our times at the news agency Reuters and the investment bank Jefferies respectively. We have been writing and analysing the energy sector for many years, and decided to come together both to write this report, and launch a blog, http://energyandcarbon.com/ in which we discuss our ideas on energy markets, technology and climate change policy.

Gerard Wynn (GWG Energy) and
Gerard Reid (Alexa Capital)
December 4 2014

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Acknowledgements

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Executive Summary

This report assesses what role solar photovoltaic (PV) power can play in the British power system; what public support it needs; and for how long. The timescale of the analysis is the next 10 years. The context includes present government plans to cut public support for large-scale solar.[1] In addition, Britain is representative of similar solar markets in high-income countries which have placed a high priority on cutting carbon emissions and boosting renewable power; have been a mainstay for global growth in solar markets; but whose support is now coming under pressure.

The original goals for European support were to boost energy security; help meet national and European Union targets for carbon emissions and renewable power; and generate jobs in a long-term growth sector. But governments, and the European Union more broadly, have now made it clear that support for mature renewable power technologies including onshore wind and solar must now fall steadily, towards elimination this decade and in the early 2020s.[2]

This report uses detailed, bottom-up industry data to analyse the impacts of expected further cost reductions on the competitiveness of solar power in Britain, and assess whether the solar market can survive without support in the near future. In addition, it considers wider concerns about solar power, including its impact on farmland, landscapes and grid stability, as well as non-market benefits including lower air pollution and carbon emissions.

Main findings

- We investigate three markets in solar power: large-scale, ground-mounted "solar farms"; commercial roof-top; and residential rooftop. We estimate that all three will be economic without support in the next decade. Such an outcome assumes progressively falling support under a stable policy regime.

- Increasing cost-competitiveness and capacity growth of solar PV in Britain will impact the British power system, including falls in wholesale power prices, as already seen in Germany. The growth of solar power may threaten electric utilities which fail to transition away from solely supplying electricity, to providing residential energy services.

- Unsubsidised cost calculations are sensitive to various assumptions, some of which are more predictable than others. We believe that assumed cost reductions in solar hardware, batteries and installation are reliable. However, assumptions which are notoriously difficult to predict include: power prices; costs of capital; and the ability of households to use more solar power for themselves, rather than export it to the grid, through so-called load shifting and use of batteries.

- We find that unsubsidised residential solar power may be cheaper with battery storage. Unsupported domestic solar battery packs achieve payback periods of little more than 10 years by 2020. By 2025, solar battery packs are fully competitive without subsidies across Britain. That could create an inflexion point driving adoption of domestic solar systems.

- The variability of solar power will involve some grid integration costs at higher penetration levels, such as more frequent power market scheduling; more interconnector capacity; storage; and backup power. These costs and responses should be weighed against non-market benefits including the potential for grid balancing; lower carbon and particulate emissions; and energy security.

- Wholesale power prices may fall as grid penetration of renewable energy rises. In that case, all energy technologies may need some form of support, as is emerging for new, UK nuclear and gas-fired power. In this case, large-scale solar parity may be defined as cost-competitiveness with gas, rather than with wholesale power prices. We note that lower wholesale power prices will help mitigate the impact of rising retail power prices both for industry and households.

- Solar PV in Britain suffers a seasonal mismatch with peak power demand, which we believe can be balanced with a more intelligent grid and more electricity interconnection into Europe.

Main actions for policymakers

- Solar PV will be a critical technology in the 21st century, and the British government should continue to support the industry until it is fully economic without subsidies; we believe that this will be reached within the next decade across all solar markets in Britain.
- Support must be reduced progressively and predictably towards elimination over the next decade, to help build a more mature, low-cost supply chain, while maintaining value for money and preventing developers from inflating prices. Getting the right support level is critical to driving sustained cost reductions.
- Policymakers can reduce the impact of solar support on domestic power prices, by shifting some price-based support towards alternatives such as low interest rate credit, and subsidies for batteries. Britain's Green Investment Bank has so far excluded solar power from loans of £1.6 billion for renewables.
- The government should support measures to optimise the grid integration of renewables, including the rollout of smart meters, and an increasingly computerised grid which uses digital technologies for faster, deeper, more responsive network communication and control.
- Policymakers should consider near-term support for domestic solar battery packs, for example through grants or low-cost credit. We present evidence that batteries boost the value of unsubsidised residential solar systems, a trend which will continue as battery costs fall. As a result, batteries can accelerate the elimination of support for residential solar.
- The government's plan to force large-scale solar to compete with onshore wind for less support will seriously damage that market. Concern about amenity impacts of solar farms can be addressed through best practice guidelines, for example to avoid building on agricultural land where possible.

This report is presented in five sections. Section 1 describes the solar market both globally and in Britain. Section 2 examines the economics of solar and factors, and the increasing viability of solar over the next decade. Section 3 offers our analysis of the changing economics of solar in the UK until 2025, including when solar in Britain becomes as cheap as buying from the grid or from the utility (grid parity). Section 4 assesses wider, hard-to-quantify concerns and benefits about solar power. Section 5 looks at the impacts of solar on the utility industry. Section 6 offers our view of the way forward for policy.

Box 1 Six reasons why solar power will emerge as an important part of the UK energy mix over the next 10 years	
1 INCREASINGLY AFFORDABLE	Solar costs have fallen faster than rival technologies. Such cost reductions will continue, leading to ever greater grid penetration in the near and medium term.
2 LOWER WHOLESALE POWER PRICES	Assuming solar PV continues to have priority grid access, higher installed capacity will lead to falls in wholesale power prices, as seen in Germany.
3 FAST TO BUILD	Solar PV has the fastest installation rate in Britain among electricity generating technologies. It takes an average of 1.1 years to generate its first electricity from initial planning application, compared with 5.4 years for offshore wind. EDF Energy has forecast 12 years (from planning application in 2011) to commission the Hinkley Point C nuclear power plant in Britain.
4 PREDICTABLE	Solar power is variable, but reliable and predictable; day ahead forecasts are about 90% accurate.
5 SECURE	By relying on a web of thousands or millions of individual installations, solar power can become an important part of a highly resilient and intelligent power network.
6 CLEAN	Solar power emits next to zero carbon emissions, and also displaces particulate matter (PM) from coal combustion, which is harmful to human health.

1. Introduction

Global change

The global energy sector has seen huge change in the past five years. It would have been impossible to predict that the United States in 2014 could be on the brink of becoming a crude oil exporter, for example, with rising U.S. output leading to global over-supply and falling oil prices. Solar power may be on the brink of similarly significant changes in the global power sector.

To date, European countries have supported the growth of solar PV, with the goals of cutting carbon emissions, boosting energy security and nurturing a clean technology sector. As these countries cut support, the industry may appear at a cross-roads.

Evidence from rapid cost reductions and capacity growth suggests that solar power will prosper without support. The fastest capacity growth is now outside Europe, not only in other high-income countries such as the United States and Japan, but in low-margin markets in emerging economies and in particular China.

As a silicon, semiconductor-based form of power generation, solar PV contrasts with the traditional spinning turbine used in almost all other technologies, including coal, gas and biomass-fired power, hydropower and wind turbines. Solar PV may therefore reap faster, sustained cost reductions as seen in the semiconductor industry, through advances and innovation in light conversion, materials and production. The last few decades shows solar module costs have fallen by about 20% for every doubling in installed capacity (see Section 2).[3]

Recent cost reductions have reduced the share of solar modules in full system costs. Further reductions will increasingly depend on other, so-called balance of system costs. The rate of cost reductions may therefore fall. However, higher installation costs compared with Germany indicate continued scope for near-term reductions in Britain (see Section 2).

In addition to falling costs, solar power benefits from speed of construction, as the quickest power plant to install (see Section 4). It is also uniquely flexible, where the same solar cells are deployed at scales ranging from a pocket calculator, to rooftops and utility-scale systems. Scalability is important for driving continued cost reductions.

Recent market growth shows the emergence of solar power as a serious global energy player. In the last 10 years, cumulative installed capacity has grown at an average rate of 49% annually.[4] In 2013, about 37 gigawatts (GW) of new PV capacity were added globally (equivalent to about 37 nuclear power plants), bringing cumulative capacity to more than 135 GW.

Solar power is driving change on industrial and human scales. On the industrial scale, solar power could disrupt existing power systems, and generate new systems based on solar plus other technologies, for example using the grid network as backup. On the human scale, electricity is no longer generated exclusively by huge, centralised utilities, instead by hundreds of thousands or millions of households, with 1.5 million solar installations in Germany and more than 600,000 in Britain.[5]

The technology also has disadvantages and concerns which have slowed its expansion until now, which it must overcome. These include high up fronts cost compared with the cheapest alternative (usually gas or coal-fired power); variable output and grid integration costs; and in the case of large-scale solar, perceived landscape blight and consumption of farmland (see Section 4).

Grid parity

Large-scale solar is already cost-competitive with fossil fuel power plants, in sunny countries including Chile and parts of the Middle East and North Africa.[1] Rooftop solar power is already cheaper than residential power prices in several European countries, including Germany, Italy and Spain.

The three main configurations of solar PV are small-scale, residential rooftop; commercial rooftop; and large-scale, ground-mounted solar farms.

Large-scale solar delivers electricity into the medium-voltage, transmission network. Once large-scale solar is competitive with wholesale power prices, called grid parity, it will be economic without government support. In this report, we use British government projections for wholesale power prices.[6] It is noted, however, that wholesale power prices may fall faster than these projections, as a result of more wind and solar power, or rise, depending on fossil fuel prices and energy technologies going forward. The notion of "support-free" large-scale solar may be less relevant in an increasingly regulated power market where all technologies are supported, as we are seeing in Britain. In this event, parity with gas may be the target.

Rooftop solar delivers electricity into the home or business, at the low-voltage, distribution end of the electric grid, called distributed generation. It is sometimes assumed that once rooftop solar is cheaper than residential power prices, it is cost-competitive without support. In fact, competitiveness depends on the proportion of solar power that households use ("self-consumption"); retail power prices; and the proportion that they feed into the grid instead.

In Europe, households with rooftop solar presently consume about 30% of the solar power they generate, feeding the remainder back into the grid. That is partly because of a mismatch between peak power demand by many households in the early evening, and peak solar output at midday.

Self-consumption of solar power is profitable where it displaces more expensive mains power. Feeding solar power into the grid at much lower wholesale power market rates is still unprofitable in Britain. At present, the export price in Europe is normally a supported, "export tariff", which is well above the wholesale power price. If solar users had to export power at wholesale power prices, rooftop installations would be breaking even now in central and southern Europe.[7]

Maximising self-consumption is therefore critical for subsidy-free, rooftop solar. Going forward, we see this issue being resolved by continuing cost reductions, and trends which drive self-consumption rates to well above 50% (see Section 3). These trends include smart energy devices in our homes, which coordinate home appliances with solar power generation, plus cost reductions in battery storage.

The UK market

Britain is not remote from the impact of solar power. Cumulative solar PV capacity is already above 5,000 megawatts (MW),[8] compared with total generating capacity in Britain of about 71,200 MW.[9] Solar capacity is divided between large-scale ground-mounted installations bigger than 5 MW; residential rooftop installations smaller than 10 kilowatts; and everything else, including large, commercial rooftop installations.[10]

The rooftop market is nearing cost-competitiveness with domestic power prices, as solar costs fall and residential power prices rise. Large-scale solar in Britain is already cheaper than offshore wind power; is in the same ballpark as nuclear; and could compete with onshore wind in the next few years, and gas, coal and wholesale power prices in the 2020s.[11]

Germany now provides a possible glimpse of Britain's electric power system in 2020. Solar photovoltaic (PV) power accounts for nearly 6% of the country's electricity demand. While that sounds rather little, solar accounts for most peak demand in summer, and as much as half of all electricity demand on summer weekends (see Section 5). It has up-ended power markets, pushing wholesale power prices lower. Having zero fuel costs and a guaranteed right to sell power into the grid, it has muscled out gas and coal-fired power, leading even to negative wholesale power prices, and vaporising utility margins (see Section 5).

In this report, we do not assess the addressable market in Britain, defined as the size of market opportunity such as the total area of south-facing roofs in the residential market. However, we see market penetration following the similar-sized German market, which would imply around 5% total power generation provided by solar in Britain in Britain in 2025.

2. UK solar economics: recent trends

Solar module selling costs and prices

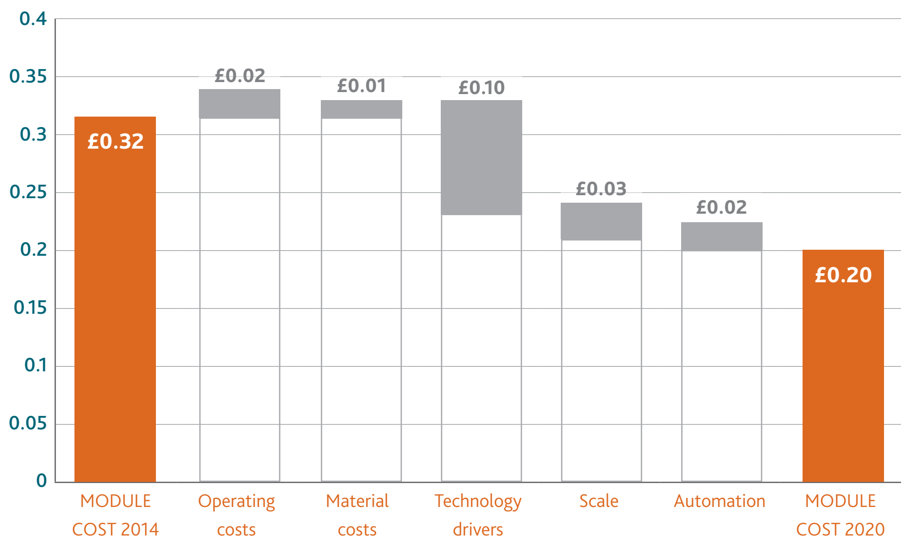
Solar module prices have fallen sharply over the past four decades. Such cost reductions recall Moore's Law, named after the Intel co-founder Gordon E. Moore. Moore's Law anticipated continued growth in density of semiconductor circuits in line with rising production. The core material used both for semiconductor chips and solar panels is silicon, one of the most abundant elements in the Earth's crust, driving expectations for a "Solar Moore's Law".

A decade ago, solar panel (module) prices were as high as £4.00/Watt and the global market for solar was 500 megawatts (MW) installed per year (equivalent to the peak production of one small gas power plant). Today modules prices are well below £0.40/Watt and the global market in 2014 is expected to be over 40 GW (equal to the peak capacity of 40 nuclear power stations).

Solar module cost reductions are driven by a combination of innovation in the efficiency of material use; light conversion; and production. Regarding light conversion efficiencies, for example, U.S.-based First Solar expects to reach efficiencies of 19.5% in 2017, from 13% in 2013.[12] Such numbers refer to the proportion of light energy striking a solar module that is converted to electricity.

Our own predictions, based on in-depth conversations with manufacturers, suggest best-in-class module costs falling from £0.32/Watt in 2014 to £0.20/Watt in 2020 (see Figure 1).

Figure 1. Module production cost reductions, 2014-2020

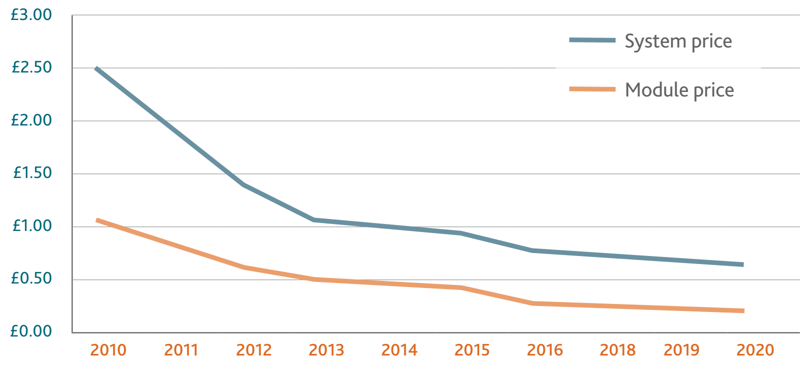


Source: First Solar and unpublished industry cost maps

Full solar system costs may not maintain the same pace of reductions as seen in the past five years. That is because the swiftest reductions have come from solar modules, which now account for a smaller share of the total. The remaining, so-called balance of system costs, include inverters, installation and financing. Inverters convert direct current electricity generated by solar modules into alternating current required by many machines and household appliances. Inverter costs are continuing to fall, and Britain will in addition benefit from continuing reductions in installation and financing, as the supply chain matures. However, these cost reductions may be more gradual.

We see the pace of full system cost reductions in Britain moderating for the rest of this decade, compared with the previous five years. Nevertheless, we still expect full installed costs to fall by about one third between now and 2020 (see Figure 2). This is slightly more ambitious than some estimates. For example, the International Energy Agency recently estimated that global average full installed solar costs (including equipment, labour and financing) would halve by 2040 or sooner.[13]

Figure 2. Full installed costs, UK ground-mounted systems, 2010-2020



Source: Our research, industry experts

Box 2 Factors which could drive faster solar power breakthrough and disruption

BUILDING-INTEGRATED, ROOFTOP SOLAR PANELS	Solar panels can replace roofing materials, conferring an additional cost advantage. Net of roofing savings, electricity generation costs from such panels dwindle to a few pence per kWh.
EVOLUTION OF SOLAR DEVELOPERS INTO NEXT GENERATION UTILITIES	In the United States, installers such as Solar City retain and lease back installed solar panels, selling the electricity that they generate under power purchase agreements (below retail power prices) for up to 20 years. By evolving into independent power producers, installers will drive efficiencies by acquiring a predictable revenue stream which can be aggregated and refinanced at lower cost costs of capital. The speed of growth of Solar City illustrates the power of this business model, although presently benefiting from federal and state-level solar support schemes. Solar City reported more than 128,000 contracts with U.S. customers as of mid-2014, compared with less than 30,000 in mid-2012.[14]
EXPANSION OF YIELDCO FINANCING	YieldCos, such as NRG Yield, are publicly traded renewable energy companies which own renewable assets. They are able to issue a regular and stable dividend based on long-term electricity sales contracts. Developers benefit from a lower cost of capital, which allows them to offer cheaper projects, while investors benefit from a highly predictable and superior yield compared with bonds and other assets in a low interest rate environment.
CHINA AND INDIA	China has already played a large part in the growth of solar power, by driving down module manufacturing costs. China, with India hot on its heels, is now turning to domestic demand through ambitious targets to increase renewable power, creating large, competitive, low-margin markets. China announced in mid-November energy targets in 2020, including a ramp-up in solar capacity to 100 gigawatts (GW),[15] from an estimated 18 GW at the end of 2013.[16]
ELECTRIC VEHICLE (EV) POWER STORAGE	Falling costs of EVs and solar power could drive faster adoption of both, by driving mutual economies in the cost of electricity and motoring, because households can use their solar panels and associated batteries to charge their EVs at night. The EV automotive sector may also drive faster reductions in the cost of batteries generally, where Tesla Motor's plans for a "gigafactory" is illustrative (see Section 3).[17]
FASTER ADOPTION OF SMART HOME ENERGY DEMAND SYSTEMS	Home energy systems are now on the market which can increase self-consumption rates to 45%, by motivating load shifting to peak solar hours.[18] If these were widely adopted, that would lead to faster falls in the cost of residential systems.
A RADICAL TECHNOLOGY IMPROVEMENT	Disruptive advances in material science, including graphene and nanotechnology, could result in unexpectedly large cuts in solar costs in coming years.

Box 3 Factors which could slow solar adoption

NETWORK CHARGES FOR SELF-CONSUMERS	Grid operators at present charge grid connection costs on a usage basis: the more power you use, the more you pay. That contrasts with a flat fee for a telephone landline connection. Self consumers of solar power therefore avoid paying part of the network fee, depending on how much mains electricity they displace. Charging for grid connection as a flat fee would erode the economics of rooftop solar in the near term. Governments are moving in this direction: Spain recently imposed a charge on self-consumption ("peaje de respaldo"), and Germany has introduced a self-consumption levy, although this does not apply to small, rooftop installations.[19] There may be a sting in the tail for utilities, however, if higher grid access fees plus lower battery storage costs in the medium term cause customers to leave the grid.
INCREASES IN THE COST OF CAPITAL	Interest rates are at historic lows. Rising interest rates will raise financing costs, and may favour technologies biased towards fuel rather than capital costs, such as gas.
INCUMBENT RESISTANCE	Solar technology is a threat to the business models of not only utilities but also their traditional suppliers, such as Siemens and Alstom, none of which have any real exposure to solar. We are already seeing resistance from utilities in Spain and Germany, and the beginnings of this in Britain.
SLOWER FALLS IN BALANCE OF SYSTEM COSTS	Solar modules account for a declining share of full solar system costs. As a result, continuing gains in cost-competitiveness will depend increasingly on shaving balance-of-system costs, including remaining hardware, labour and financing, which is less predicable and may prove hard to achieve.
SOLAR MODULE TRADE DISPUTES	The pace of European solar cost reductions has slowed since the European Union imposed a minimum price on imports of Chinese modules. The price has helped wipe out the benefit of continuing manufacturing cost reductions in China.
FALLING POWER PRICES	Solar benefits from rising utility bills and increasing wholesale power prices. A so-called "cost of living crisis" in the wake of an extended British austerity programme has led political parties to offer to freeze domestic energy prices in the near term. But British government projections still anticipate rising power prices through 2030.[20]

Levelised cost of energy (LCOE)

One common measure of the cost of generating solar power is the levelised cost of energy (LCOE), which divides the lifetime cost of a solar installation by lifetime power generation, measured in pence per kilowatt hour (kWh). For the sake of simplicity, LCOE excludes important costs, such as grid integration; waste disposal; and pollution. We return to these later in this report. LCOE is a useful way to account for important factors such as financing cost and load factor, two critical variables. . It can be used to assess the impact of modifying other variables, such as the self-consumption rate.

Load factor: This is the actual output of a power plant as a percentage of its theoretical maximum. In the case of solar, it will take into account local solar irradiance and day length. In very sunny countries, such as Australia, solar panel load factors can reach 30% or more. Britain's Department of Energy and Climate Change (DECC) calculated an average load factor for solar PV in Britain of 10.3% in 2013.[21]

Weighted cost of capital (WACC): WACC reflects the average cost of financing for a project. WACC will be higher for less mature technologies, because investors require a higher return on equity to compensate for the higher risk. The WACC is used to discount future cash flows, and so critically affects the cost calculation. British government estimates for large-scale solar LCOE illustrate the point. Using a 10% WACC across all energy technologies, DECC ranks solar costs higher than wind, nuclear and gas. However, using a lower WACC of 6.2%, which reflects the maturity of the technology and speed of construction, DECC ranked large-scale solar as the cheapest form of UK power generation before 2025.[22]

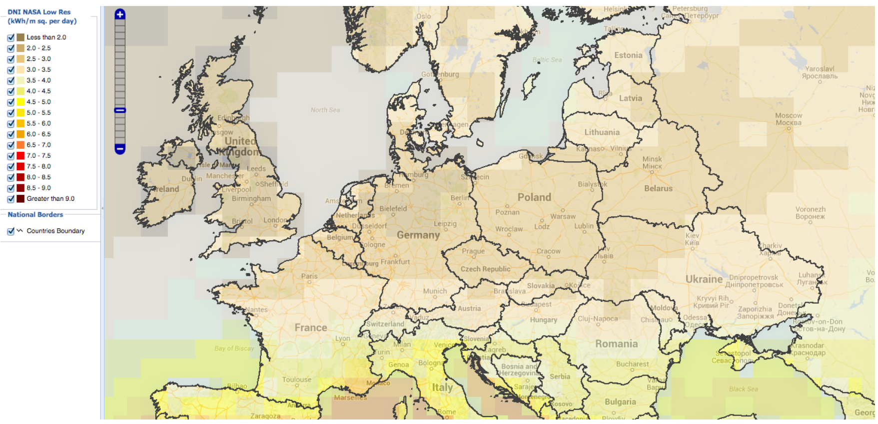
Self-consumption rate: Increasing the self-consumption rate is critical for the economics of unsubsidised residential systems in countries with high domestic power prices, like Britain. With higher self-consumption, households avoid selling surpluses at a very low wholesale power price (presently about 5 pence per kWh in Britain), and buying mains electricity at much higher retail power prices (about 16 pence). Exports presently receive a supported feed-in tariff. Self-consumption rates are about 30%, but home management systems are emerging which can boost these to 45%. As support is withdrawn, the incentive for self-consumption will rise. We assume steadily rising self-consumption rates (see Appendix). Critically, battery storage increases self-consumption above 50%, and may therefore be the cornerstone of unsubsidised residential systems.

Payback periods

Most rooftop solar consumers assess solar investments in terms of payback periods, rather than LCOE. As a result, we use LCOE as a measure for the economics of large-scale, ground-mounted solar, and payback periods for the economics of commercial and residential rooftop systems.

The payback period is defined as the length of time it takes to recoup the upfront investment, based on annual savings as a result of reduced utility bills. We assumed steadily rising domestic power prices, using the latest DECC projections (see Appendix). We expect that most customers would require payback periods around 10 years or below before considering an investment. Payback periods were calculated using the same bottom-up analysis as for LCOE, including estimates for cost reductions in solar hardware and balance of systems over the next decade.

Figure 3. Solar energy resources, Northern Europe



Source: SWERA[29]

Comparisons between Britain and Germany

Germany is a good benchmark for Britain, given its similar energy mix (fossil fuels, nuclear and renewables); standard of living; level of power demand; and solar irradiance (see Figure 3).[28]

The big difference at present is that Germany is the world's biggest market for solar, with an installed capacity of some 37.2 gigawatts across about 1.5 million installations.[30] Britain, in contrast, has about 5 GW installed across 0.6 million installations.[31] In 2013, solar power accounted for nearly 6% of total final electricity consumption in Germany,[32] compared with 0.6% in Britain.[33]

As the British solar market develops we expect it to go through many of the changes seen in Germany, including growing competitiveness across the solar value chain. Solar installation costs are lower in Germany than the UK because of greater efficiency, particularly in financing but also in development and installation. We believe that German and UK full installed solar prices will converge over the next years.

Lower German costs are reflected in differences in feed-in tariffs and installation costs for rooftop solar. In Britain, the support for solar power generation by 0-4 kW systems is 14.38 pence per kWh for 20 years, plus inflation, plus an export tariff of 4.77 pence.[34] The German feed-in tariff for small systems is 10.1 pence (12.69 euro cents) per kWh, over the same period. The differences can also be seen in the installation costs, which were £1,580 per kW in Q1 2014 in Britain, compared with £1,310 (€1,640) per kW in Germany. [35 36]

Germany's Fraunhofer Institute calculated the most cost-efficient solar farms were now competitive with onshore wind and well ahead of offshore wind. Cost reductions in the German rooftop market have levelled off recently,[37] perhaps reflecting the impact of a minimum price for European Union solar module imports from China. Nevertheless, the Fraunhofer Institute projects continuing cost reductions, where solar would be broadly competitive with gas-fired power from 2015, with hard coal in the 2020s, and with brown coal by 2030.[38] The International Energy Agency cited estimates that rooftop solar power in Germany would be competitive with all forms of generation, including gas, wind and coal, by 2020, assuming low costs of capital which may be representative of households.[39]

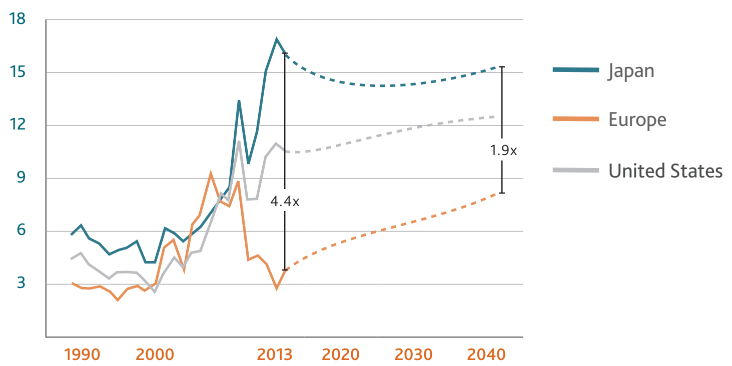
Cost trajectories: fossil fuels

Gas is what is called the "marginal provider" in Britain, meaning that power prices are determined most of the time by gas plants, as opposed to much of the continent where it is determined by coal and power prices in neighbouring countries.

In contrast to falling costs of solar power, gas-fired power has limited scope for reductions, given that turbines are a mature technology, and because the largest cost element in terms of its LCOE is fuel cost (the natural gas price), which is both difficult to predict and hedge. There are huge differences in global gas prices, with Japan (in 2013) paying on average $17 per Mbtu as opposed to $10 in Europe and $3 in the US. The major reason for this is the difficulty and high cost of transporting gas (see Figure 4). In Britain, domestic resources are dwindling, with little hope of UK shale gas coming online for another decade, meaning that other, more expensive sources need to be found.

Partly, as a result of expected rises in gas prices, as well as the growing cost of support for environmental policies and grid network upgrades, the Department of Energy and Climate Change (DECC) projects rising British residential power prices for the rest of this decade and beyond.[41] If British gas and power prices rise, it will become easier for solar PV to compete, and market penetration will continue to grow.

Figure 4. Natural gas price by region in the New Policies Scenario, World Energy Outlook 2014, IEA/OECD



Source: International Energy Agency (2014) [40] ; Based on IEA data from IEA WEO 2014 © OECD/IEA, IEA Publishing; modified by GWG Energy and Alexa Capital. Licence: http://www.iea.org/t&c/termsandconditions/

3. UK solar economics, projected 2015-2025

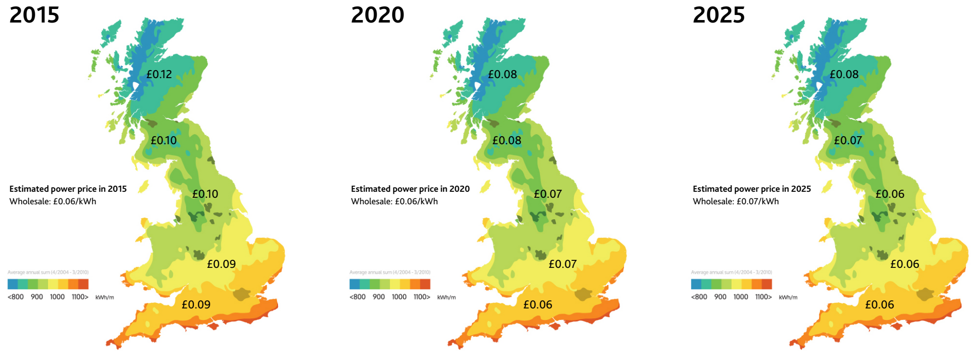
Solar cost estimates, without government support: our findings

We have conducted an extensive bottom-up analysis of the likely costs of solar hardware and balance of systems costs, based on interviews with multiple installers, developers and manufacturers in the industry. The analysis enabled us to make estimates for cost, assuming no government support, across different parts of the UK over the next years (see Appendix). Below we present the findings for the LCOEs of large-scale ground-mounted solar, and payback periods for commercial and residential rooftop solar.

Large-scale ground-mounted solar LCOEs

In the southern half of England, we estimate that large-scale solar farms will reach parity with onshore wind power in 2015, and full parity with fossil fuels and wholesale prices by 2025 at the latest (see Figure 5). See Section 1 for a discussion of the possible impact of much lower than projected wholesale power prices on the economics of all centralised power plants, including large-scale solar, fossil fuel, nuclear and wind.

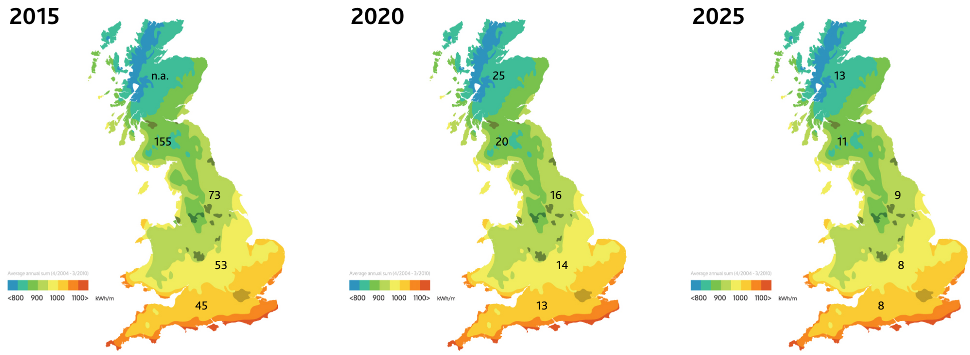
Figure 5. UK large-scale solar farm LCOEs, £/kWh, 2015-2025



Commercial rooftop payback periods

We estimate that commercial rooftop solar power will be economic without support in England by 2020, provided the commercial business can use 70% of the power produced (see Figure 6). Across Britain more generally, using government assumptions for irradiation and power prices, commercial rooftop solar would break even by 2025, with payback periods well below 10 years, which could be a substantial driver of this market.

Figure 6. UK commercial rooftop payback periods, number of years, 2015-2025



Residential rooftop payback periods

At present, unsupported rooftop solar does generate net savings but is not yet economic. This changes over the coming decade. By 2020, paybacks of 16 years are reached in southern England, under our various assumptions. By 2025, payback periods are as low as eight years in southern England, and even in northern Scotland only 14 years. At these levels, residential solar is viable without government help.

These findings assume steadily rising consumption rates of home-generated solar power, and therefore bigger savings on avoided utility bills. If self-consumption remained at present rates of about 25-30%, unsubsidised residential solar may struggle even in 2025 (see Table 1). On the other hand, a lower cost of capital would bring forward parity without support. We assumed much higher residential financing costs, for example, than the bottom end of the 1-12% range used by Britain's National Audit Office[42].

Figure 7. Residential rooftop payback periods, number of years, 2015-2025

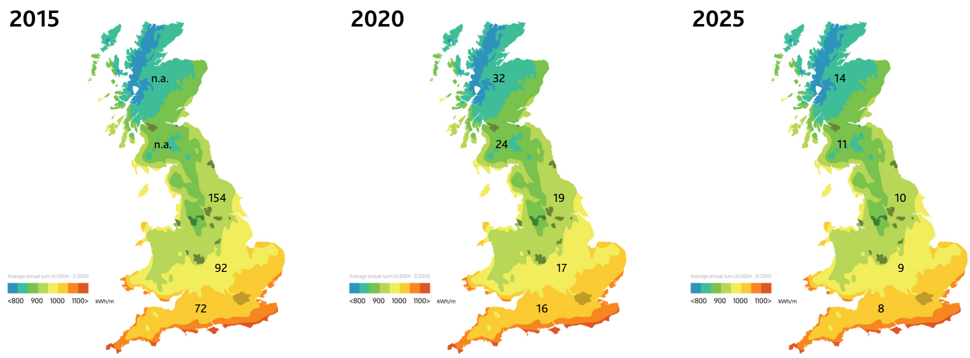


Table 1 UK average payback period for unsupported residential solar, according to self-consumption ratio, 2015-2025

2015	SELF CONSUMPTION RATIO	100%	75%	50%	25%	0%
	Payback period, years	19	29	69	(190)	(40)
2020	SELF CONSUMPTION RATIO	100%	75%	50%	25%	0%
	Payback period, years	8	11	17	40	(106)
2025	SELF CONSUMPTION RATIO	100%	75%	50%	25%	0%
	Payback period, years	6	7	10	18	70

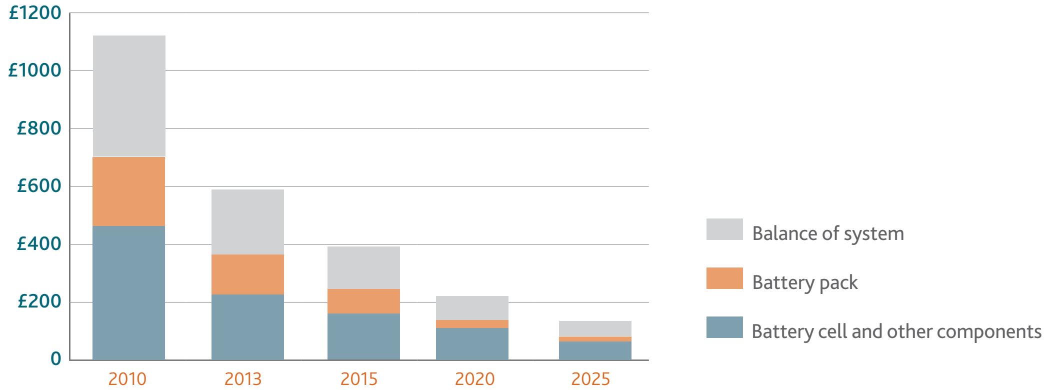
Battery storage of solar power

Solar battery pack solutions

Various potential remedies exist for the variability of solar power (see Box 4). Battery storage is one of these, where solar battery pack products are now emerging. Storage solutions available today are expensive. Electricity must be converted into another form of energy and then converted back into electrical energy. Lithium-ion is one promising battery storage technology currently under development. Lithium ion battery packs are still costly, at around £320/kWh.[42]

Battery costs are falling, however, partly as a result of production and innovation in the automotive sector. With its planned "gigafactory", Tesla Motors believe that their battery packs could reach £100-130/kW in 2020.[43]

Figure 8. Battery pack production cost reductions, 2010-2020 (£/kWh)



Sources: Published Tesla cost data; conversations with industry experts including Younicos

At present in Germany, the problem for unsubsidised solar is the very low wholesale power price at which solar surpluses must be sold into the grid. The Swiss investment bank, UBS, last year calculated that unsupported rooftop solar in southern Germany already breaks even (defined as total annual electricity costs with and without solar panels), assuming a grid export price of 3 cents, and 30% self-consumption.[45] The regulated, "subsidised" export price at present is up to 12.69 euro cents per kilowatt hour, in Germany, compared with domestic power prices of about 29 cents, and spot wholesale power prices of about 3 cents.

Without supported grid export prices, it becomes critical to maximise self-consumption. Households can first change their behaviour by using more self-generated electricity in the daytime, called load shifting. Leading global inverter manufacturer SMA Solar has developed software which matches the operation of household appliances and heating systems with forecast home solar output, through radio-controlled switches. This can increase self-consumption to 45%, the company estimates.[45]

Batteries can make a bigger difference. Households can use deliberately small battery packs, minimising extra costs, and extend home-generated solar power past sunset, and increase self-consumption beyond 50%. We note that use of solar battery packs will further undermine mains power consumption, with threats to utilities and gas-fired backup power plants (see Section 5).

Unsupported residential battery-pack solar PV systems are already becoming a cost-effective option in Germany, Italy and Spain, according to UBS. UBS sees a particular benefit from combining solar PV with a static battery, plus an electric vehicle (EV). That is because of a natural fit, where the static (non-EV) battery would mop up surplus daytime solar supply, and use this to charge the EV battery at night. In Germany, unsubsidised solar battery/ EV packages would deliver a return on investment of more than 7% by 2020, compared with a conventional car and no solar panels, according to UBS.[46]

Box 4 The problem of dispatch

At present, almost all electricity is supplied to the grid and consumed at the instant that it is generated. For solar power, that has created a problem because of mismatches between supply and demand. Solar power is not available at night, and in rooftop applications may generate surpluses at midday when a family is not at home. Unlike conventional fossil fuel and nuclear power, solar is not always available on demand. In electricity markets jargon, it is not dispatchable.

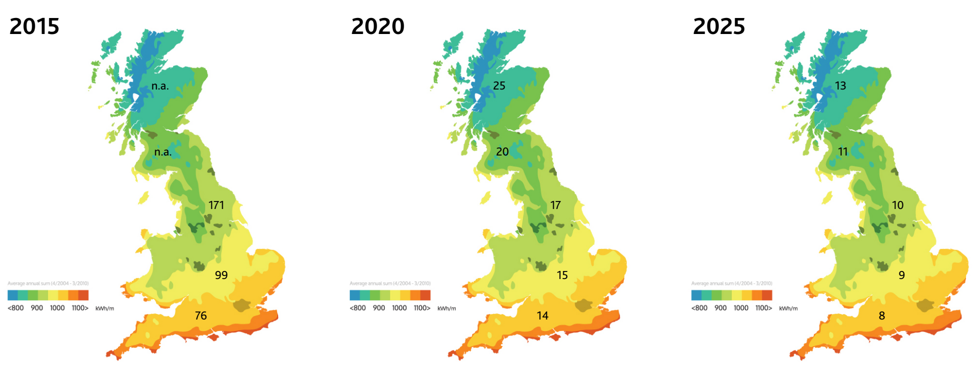
There are different ways to deal with this problem.

1 RAMP UP AND DOWN POWER PLANTS	Modern coal and gas plants can be ramped up and down quickly to respond to changing weather patterns and swings in demand. Older power stations can also be ramped up and down, but they are less flexible and response times are slow.
2 GAS-FIRED "PEAKING" POWER PLANTS	Because they can ramp up and down very quickly, peaker gas power plants have long served the role of balancing swings in demand and supply. However, they normally run only for a few hundred hours per year, and if the UK went down the same route of Germany, with widespread renewable power and modern fossil fuel power plants, they may be rarely used.
3 LOAD SHIFTING	Households and commercial installations with solar panels can shift consumption to match their solar output. Other consumers can be encouraged to use electricity at off peak times, through time-of-use-pricing enabled by smart meters.
4 INCREASE INTERCONNECTION WITH NEIGHBOURING COUNTRIES	Interconnectors can act as a buffer for more variable renewable power. Germany, for instance, has become the largest international trader of power in the world, exporting and importing power on a shifting basis across the course of a day.
5 MORE FREQUENT POWER MARKET SCHEDULING	If grid operators invite power plants to offer electricity into the market at shorter intervals, forecasting errors will be less, reducing the possibility of having to make more sudden, expensive adjustments such as using gas peakers.
6 USE STORAGE TECHNOLOGIES	Battery storage is likely to become more important over time, because of the inefficiency of capacity payments, and the limited potential for interconnectors. As total renewable energy generation plus "must-run" nuclear nears total demand, storage will be a critical solution.

Solar battery pack payback periods

We estimate that a solar battery pack could be competitive without any support in southern England by 2020, and more generally by 2025 (see Figure 9). We note that unsubsidised rooftop solar systems are more economic with batteries than without, reflecting higher self-consumption rates. Batteries represent an under-appreciated potential disruptor which could boost domestic solar adoption and reduce utility electricity sales.

Figure 9. Projected solar battery pack payback periods, number of years, 2015-2025



4. Wider concerns and benefits of solar power

The trouble with LCOE is that it excludes important costs which are hard to monetise, such as environmental, waste disposal and grid integration costs, and energy security and climate benefits. Some of these are critical factors which can sway political support. The major non-market concerns and benefits for solar power are summarised below.

Concerns

Support

All energy receives some form of subsidy. Support for renewable power is transparent, through a regulated power price, and is collectively capped under the government's Levy Control Framework at £4.3 billion in 2014/15.[47] Fossil fuels and nuclear are also supported. Taxpayers fund the Nuclear Decommissioning Authority, whose expenditure in managing civil nuclear waste in 2013/14 was £2.6 billion.[48] Gas-fired power and heating benefits from reduced VAT on domestic energy consumption, worth an estimated £3.5 billion in 2011.[49]

Grid integration

The variability of solar power will impose extra grid integration costs. On a daily basis, grid operators must manage the ramp down in solar power supply towards sunset, which will overlap with peak evening demand depending on the season. However, the short-term variability of solar PV is lower than wind, because of a predictable daily cycle and lower forecasting errors. On a seasonal basis, variability of solar power will also require compensating action, given lower output in winter (see Box 4).

The grid operator in England and Wales, National Grid, noted that once installed solar capacity rose above 10 gigawatts (GW) in Britain (compared with about 5 GW now), some compensating action would be required to balance the grid, such as increased interconnector or electricity storage capacity or demand response (see Box 4).[50]

The National Grid also observed that grid management would be less of an issue, however, where grid operators could control solar output remotely through smart metering and other internet-based switches. The European Network of Transmission System Operators for Electricity (ENTSOE) introduced a network code in 2013, requiring remote control of all electricity generation, which all EU member states including Britain must apply in the next two years.[51]

Farmland consumption

Some members of Britain's Coalition Government have stated that large-scale solar farms consume too much farmland.[52] The average solar park needs about 1.7 hectares per megawatt (MW).[53] Planning data show that England and Wales has about 7,000 MW of large-scale solar above 1 MW capacity either operating, approved or likely to be approved.[54] Under the most conservative assumption that these were all ground-mounted on farmland, they would consume up to 11,900 ha, or 0.1% of the total agricultural area.[55] In reality, some would be built on paved, brownfield, amenity or unused land. In addition, solar farms do not exclude other, complementary land uses, including continued agricultural use and biodiversity management.[56] Application of best practice may help, such as avoidance of agricultural land where possible.[57] British planning rules state that solar farms are temporary structures, to be dismantled after 25 years.[58]

Landscape amenity

In November, British Under-Secretary of State for Energy and Climate Change, Amber Rudd, said: “Solar farms are not particularly welcome because we believe that solar should be on the roofs of buildings and homes, not in the beautiful green countryside.” [59] Anecdotal evidence from individual projects confirms that local people can object to solar farms on landscape grounds. That said, the technology generates less local resistance than onshore wind. The UK industry has defined good practice including visual screening.[60]

Benefits

Lower carbon emissions

Solar power emits zero carbon dioxide during power generation, and has lifecycle carbon emissions (including manufacture) of about 50 grams per kWh.[61] That compares with UK power grid average emissions of 490 grams per kWh, implying net savings of about 440 grams of CO2 per kWh of solar electricity generated.[62] In 2013, British solar PV generated some 2,036 gigawatt hours of electricity,[63] implying that it displaced about 0.9 million tonnes of CO2 from the grid. That compared with total British CO2 emissions in 2013 of 464 million tonnes.[64]

Carbon emissions add two types of cost: the priced carbon cost imposed by climate regulations; and the un-priced cost of climate change. Regarding the avoided regulatory cost, Britain has imposed a carbon price floor of £18 per tonne of CO2 going forward.[65] That implies net cost savings for solar of about 0.8 pence per kWh, compared with the UK grid average. Regarding avoided environmental cost, the United States Government estimates the full, "social cost" of climate change at £24 ($37) per tonne of emitted CO2,[66] implying net cost savings for solar power of 1.1 pence per kWh, compared with the UK grid average.

Cleaner air

Burning fossil fuels, and in particular coal, generates local air pollution which has an immediate, local health impact. The most dangerous air pollution is particulate matter (PM), defined according to its size. The smallest, PM2.5, is the most dangerous, and increases the prevalence of lung cancer, chronic obstructive pulmonary disease, ischemic heart disease and stroke.[67] A recent report estimated the health benefit from lower PM2.5 emissions as a result of burning fewer fossil fuels at $73 (£47) per tonne of CO2 avoided.[68] Applying that value in full implies cost implies savings from solar power of 2.2 pence per kWh, compared with the UK grid average.

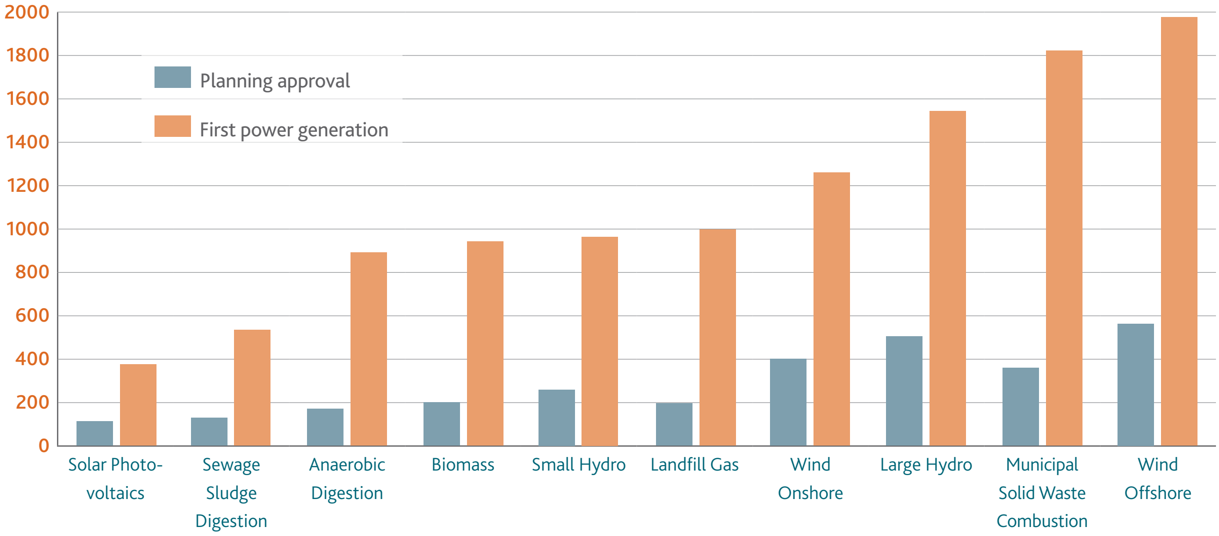
Improved energy security

Solar power can contribute to energy security in three ways: a greater diversity of distributed generation sources; reduced energy price volatility; and avoided cost of fossil fuel imports. Regarding a diversity of energy sources, this report has already referred to the value of a million or more individual solar power installations in Britain and Germany, compared with relying on a handful of large, centralised fossil fuel power plants. Regarding reduced price volatility, solar power has zero fuel costs and predictable operating and maintenance costs, leading to very low fuel price risk. Regarding avoided fossil fuel imports, the European Commission estimated the total value of avoided fossil fuel imports as a result of all European Union (EU) renewable energy, including electricity, heating and transport, at 30.4 billion euros in 2010.[69] That compared with the total cost of EU renewable energy support schemes of 18.6 billion euros in the same year.[70]

Flexibility

Solar PV proceeds faster than any other renewable energy technology through the UK planning process, from initial application to commissioning and generation of first electricity (see Figure 4), reflecting low rates of planning refusals and straightforward, rapid construction.[71] For solar PV, it takes an average of 13 months between submission of a planning application and the first power generation (1.1 years). The longest average renewable energy processing time was for offshore wind, at 5.4 years. By contrast, EDF Energy submitted its licence and site applications for its 3.2 gigawatt Hinkley Point C nuclear power plant in July 2011,[72] and expects to commission the first unit in 2023, 12 years later.[73] EDF has over-run by several years the commissioning dates for its present nuclear new build projects. EDF announced in November that it was extending by an additional year a four-year delay at Flamanville, in France.[74]

Figure 10. Processing time of UK renewable energy projects, from first planning application (days)



Source: DECC (2014)[75]

Grid balancing

Solar power has certain advantages in helping grid operators to fine-tune supply and demand. As digital electronic devices, they can be controlled more precisely and quickly than fast-spinning turbines, including almost instant shut-down and start-up. Modern electronics allow PV systems, via their inverters, to perform tasks autonomously, including riding through wide ranges of voltage and frequency fluctuations; actively counteracting voltage changes in providing reactive power; and reconnecting softly to avoid sharp spikes when disconnecting during power outages.[76]
In practical terms, solar power can provide grid balancing services through virtual power plants (VPPs), which are a growing feature in Germany. Existing smart grid technology allows owners to operate several, distributed renewable energy installations, including biomass, wind and solar, as well as loads and batteries, from a single platform as if they were one power plant.

The next step for VPPs is to use renewable energy for assisting grid stability in so-called balancing markets.

5. Demand destruction for electric utilities

Solar power can provide a valuable addition to the network as a result of its falling costs and non-market benefits. In this section, we review the implications for a significant scaling up of solar power on incumbent energy technologies, and in particular on electric utilities.

Lower wholesale power prices and load factors

Solar power generates electricity at near-zero operating cost, because it has zero fuel costs. In addition, at present it has to be taken by the grid operator, through so-called priority access as required under the EU Renewable Energy Directive,[79] or is traded under emerging rules which require renewables to compete on a market basis with other forms of power. The result, either way, is that at any moment solar PV can offer electricity at a lower cost than fossil fuel power plants. Utilities therefore have to optimize their power generation portfolios based on weather predictions, and the prices they receive by ramping up and down their fleet depending on expected volumes of solar. They do this by predicting the weather (especially on the day ahead market) and making a decision on how much power they will deliver to the grid. If they do not do this they run the risk of an excess of power in the system, and receiving prices below their marginal cost, or as sometimes happens, negative prices.

The impact of solar can be seen in continental Europe where peak power needs (generally the most profitable power sales of a utility) are being met by solar. In Europe on sunny days, utilities already have to react to over 80 gigawatts (GW) of solar by switching down and then up their traditional generators. The issue is that utilities are not as able to "control" the power price as they once did due to the massive competition from renewable generators who are incentivised through mechanisms such as feed in tariffs to produce as much power as possible. This is not the case with a utility which is often better off to not produce, thereby curtailing supply and supporting a higher power price. In Germany, solar power already supplies most peak power demand in summer (see Figure 11).[80] Because it takes time to switch off coal and nuclear power plants, these may offer to pay to remain on the grid when there is a surplus of renewable power, leading to negative power prices.

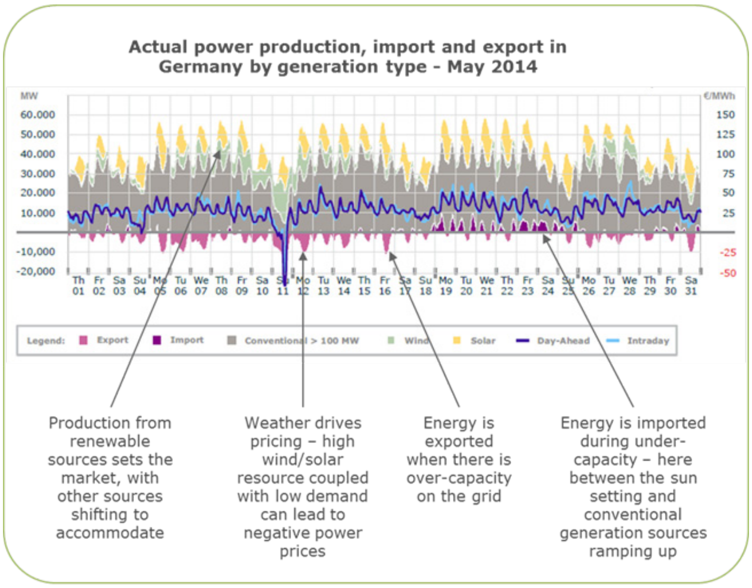
The heavy investment in renewable energy across the continent is producing record-low wholesale spot prices, especially for those countries which have embraced regionally-connected energy markets. It is not a coincidence that the countries with the least interconnector capabilities (UK and Ireland) have the highest power prices. For interconnected Europe (France, Germany, Benelux, the Nordics, Poland and the Czech Republic) wholesale prices hit seven-year lows below €36/MWh in 2014 compared to 2008 levels of nearly €90/MWh (see Figure 12). This trend is even more remarkable considering the closure of significant nuclear generation capacity in Germany during this period. The upside is that lower wholesale pricing are providing opportunities for intensive power users within Europe, such as chemical companies, to lower their production costs.

Fewer customers

By paving the way for a decentralised power revolution, solar PV may have an even bigger impact on utilities than wholesale power prices, which is by stealing customers as more households install solar panels. Removal of solar support could undermine utilities further, since households would be motivated to maximise self-consumption.

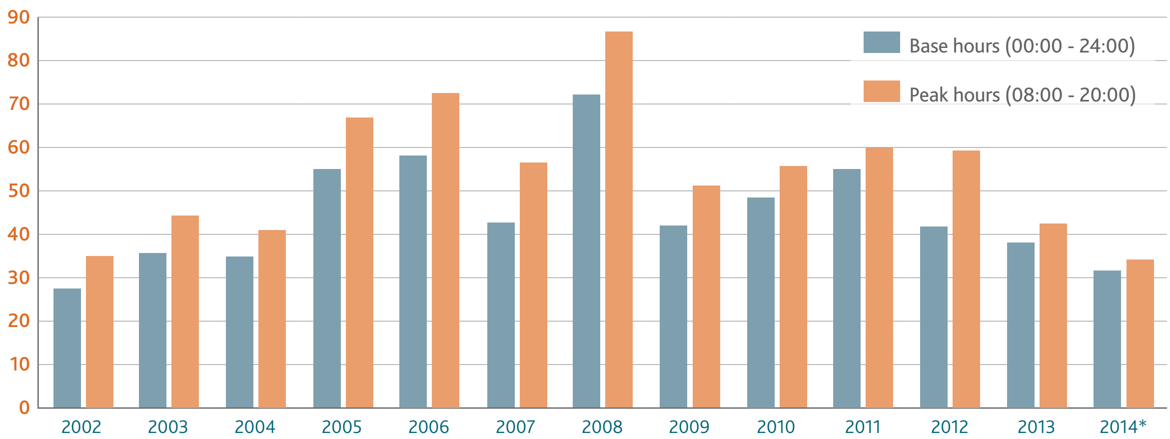
The utilities are crying foul, but the reality is that solar will continue to be built. Solar has broken the age old utility principle of using economies of scale at the point of generation to bring costs down. Utilities can survive a trend towards decentralised power, however, by moving into high value added energy services, leveraging their customer-facing business to sell energy services, including deploying solar panels, as well as smart meters and related energy efficiency advice and equipment.[82]

Figure 11. Actual power production, prices and cross-border flows, Germany, May 2014



Source: Fraunhofer (2014)[82]

Figure 13. Central Western Europe peak and baseload wholesale power prices, 2002-2014 (€/MWh)



Source: Fraunhofer (2014)[83]

6. A way forward: a successful solar industry in Britain

Solar is leading new changes in the power market. In 2015, solar PV globally will overtake both gas and coal to become the number one power generation technology in terms of annual installations. This trend of continuing capacity increases coupled with cost reductions has caught out policymakers and analysts. Ignoring these trends would be like ignoring the displacement of fixed telephone lines by mobile phones. The reality is that the cost of solar power is on a downward trajectory.

In the aftermath of the global financial crisis, however, households and governments are concerned about the cost of living, including energy prices. We wrote this report against the backdrop of increasing pressure on the UK government to reduce support for renewables. The leader of the opposition Labour Party, Ed Miliband, has pledged to freeze power and gas prices until 2017, if elected Prime Minister. This has led to "energy" becoming a major issue ahead of a general election in 2015. Support for solar power presently is passed on to consumer electricity prices, and is therefore vulnerable. In addition, rising support for renewable energy is nearing the cap for such support, under the Levy Control Framework.[83]

We agree that support for solar power should be cut progressively to zero over the next five to 10 years. The trick is finding the right balance, between driving efficiencies which create a new, low-margin business model, and killing a fledgling British solar industry which has huge export potential, particularly in finance and project development. Support for solar power to date has led to capacity increases which have cut costs as supply chains matured.[84] The International Energy Agency showed that Britain now has one of the most cost-effective markets for solar systems, with lower costs than major markets including the United States, Japan and France.[85] There is consensus among public policy advisers such as the New Climate Economy, the European Commission and the International Energy Agency that governments should reduce support for renewable energy progressively, but in a predictable way.[86]

This report finds that both large-scale and rooftop solar can survive without direct support from 2025 at the latest. That definition of support excludes wider policy measures which would indirectly benefit solar power, such as carbon pricing, or capacity payments for gas-fired power plants which would support the grid integration of variable renewables. Such less visible support may be justified in the context of clear, un-priced and under-priced non-market benefits of solar power, as discussed in Section 4.

Accordingly, we make the following policy recommendations:

- Solar PV will be a critical technology in the 21st century, and the British government should continue to support the industry until it is fully economic without subsidies; we believe that this will be reached within the next decade across all solar markets in Britain.
- Support must be reduced progressively and predictably towards elimination over the next decade, to help build a more mature, low-cost supply chain, while maintaining value for money and preventing developers from inflating prices. Getting the right support level is critical to driving sustained cost reductions.
- Policymakers can reduce the impact of solar support on domestic power prices, by shifting some price-based support towards alternatives such as low interest rate credit, and subsidies for batteries. Britain's Green Investment Bank has so far excluded solar power from loans of £1.6 billion for renewables.
- The government should support measures to optimise the grid integration of renewables, including the rollout of smart meters, and an increasingly computerised grid which uses digital technologies for faster, deeper, more responsive network communication and control.
- Policymakers should consider near-term support for domestic solar battery packs, for example through grants or low-cost credit. We present evidence that batteries boost the value of unsubsidised residential solar systems, a trend which will continue as battery costs fall. As a result, batteries can accelerate the elimination of support for residential solar.
- The government's plan to force large-scale solar to compete with onshore wind for less support will seriously damage that market. Concern about amenity impacts of solar farms can be addressed through best practice guidelines, for example to avoid building on agricultural land where possible.

Appendix

In our LCOE and Payback Period calculations we have assumed:

- Module prices for large scale systems of £0.46 pence today falling to £0.24 in 2020 and then £0.22 in 2025
- Zero support for solar power generation; export tariff at the level of the wholesale power price
- Load factors of 9.3% to 12.5%, depending on latitude
- Increased efficiency across the whole solar value chain
- Cost of debt: 4% and cost of equity 6% (German levels)
- Debt to equity ratios of 60:40 for large-scale and commercial solar, and 80:20 for residential
- The latest (October 2014) UK projections for residential, commercial and wholesale power prices, from the Department of Energy and Climate Change (DECC)
- For roof-top systems, self-consumption rates for commercial users of 70%; for residential systems, 32% in 2015 rising to 45% in 2025; and 55% for residential systems with batteries
- Depreciation: 10 years for batteries, 25 years for solar panels

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