Towards the tipping point.

Technology Radar - Renewable Energy

Lloyd's Register

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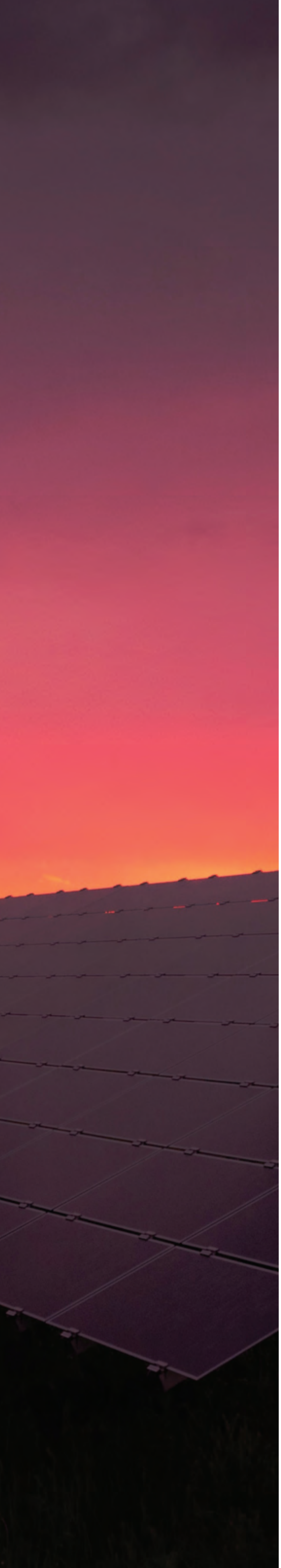

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Foreword

Welcome to the fourth edition of the Lloyd's Register Technology Radar, and the second in the series to be dedicated exclusively to low carbon power.

The 2017 edition of the Technology Radar found that renewable energy was largely felt to have achieved cost parity, although hydrocarbons retained their dominant position in the global energy mix.

This is a reflection of the energy transformation currently under way across the globe as communities, businesses and organisations increasingly recognise and act upon the urgent need to decarbonise economies.

But whilst this is a global challenge and the end goal is universal, the solutions are not uniform. In fact, the best energy ecosystem for any given country depends on a set of characteristics that are specific to that nation – including the natural resources available, geo-demographics, energy demand, market design, policy, technology, public appetite and social acceptance. It needs to take into account what resources are available, how they can be harnessed, how the population and industry needs and uses power (and will in the future) and therefore how the network needs to operate and adapt.

Taking this as its starting point, this research looks at the degree to which renewable energy has gained traction throughout the world – and what needs to happen to accelerate it. Based on a large survey of renewable energy professionals across the global sector and the insights of a number of industry leaders, the research illuminates the outlook for renewable energy – and highlights the technologies that are expected to deliver the greatest impact.

We are heartened by not only the optimistic outlook, but also the measured and realistic approach that is displayed throughout the results and insights in the research. Grid transformation must be based on sound understanding of each country's individual ecosystem, and it is clear that this is advancing alongside technology, policy and investment.

We hope you find the report valuable, and we welcome your feedback.

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About the research

The analysis in this report is based on a Lloyd's Register survey of 792 executives working in the renewable energy sector.

It was conducted by Longitude in November and December 2017. The survey respondents represent power and utility companies with renewable energy assets (58% of the sample), energy companies with renewable energy assets (excluding utilities and power generation) (21%), and oil and gas companies with renewable energy assets or activities (21%).

The sample is global, with 28% of respondents based in the Americas, 24% in Europe, 23% in Asia Pacific, and the remainder in the Middle East and Africa.

Companies of all sizes are represented: 25% of respondents work in firms with $50 million or less in annual revenue, 46% in firms earning between $51 million and $500 million a year, and the remaining 29% in firms with annual revenue above $500 million.

Please note that where graphs do not add up to 100%, this is due to rounding or questions where respondents were able to select multiple answers.

We would also like to thank the following individuals for the insights they provided in a series of in-depth interviews.

Stephen Church
Partner and energy market leader, EY

Bruce Douglas
Deputy CEO, SolarPower Europe and co-chairman, Global Solar Council

David Eyton
Group head of technology, BP

Deborah Greaves
Head, School of Engineering, University of Plymouth

Walburga Hemetsberger
Board member, energy transition solutions, Hydrogen Europe

Samuel Leupold
Executive VP and CEO of wind power, Ørsted

John Liljelund
Chief executive officer, AW-Energy

Stephanie McClellan
Director, special initiative on offshore wind, University of Delaware

Lyall McLachlan
Chairman, Solastor

Paul Stangroom
Head of renewables, Lloyd's Register, Asia Pacific

Rebecca Sykes
Technology innovation leader, Lloyd's Register

Introduction

If there were doubts that renewable energy sources can compete with oil, natural gas and coal in power generation, developments in the past two years should have dispelled them. According to the International Energy Agency (IEA), 2016 was a record year for renewable energy projects, which provided two-thirds of new global power capacity.[1]

By July 2017 China, the world's biggest generator of solar photovoltaic (PV) power, had already met its 2020 target for installed PV capacity. Earlier in the year, Germany's electricity regulator awarded bids for the country's first subsidy-free offshore wind farms;[2] in December, the Netherlands' government followed suit.[3] And September saw sharply reduced subsidies in auctions for similar projects in the UK, as well as the opening of the country's first subsidy-free solar PV farm.[4]

This continuing growth of solar and wind capacity in many parts of the world, and the increasing incidence of projects involving low or no subsidies, have led some observers to proclaim the arrival of a 'tipping point' for renewables. This is the point at which one or more renewable energy sources match fossil fuels used in the grid in terms of their cost competitiveness.

Basing this sort of assertion on individual projects is a risky move. After all, every project has its own circumstances and economics, and these can differ – sometimes considerably – even within the same country. Nonetheless, tipping-point predictions do provide an indicator of the progress made to date and what is still required to reach the point where renewables overtake fossil fuels in each country's energy balance.

This 2018 edition of the Lloyd's Register Technology Radar provides an industry perspective on the challenges that need to be overcome for renewables to become the primary form of energy consumed in countries. It is based on the views of 792 senior executives from around the world who are close to their companies' renewable energy activities or renewable technology development.

As a group, they are cautious about their expectations of when renewables will overtake fossil fuels. But they are also optimistic that technology innovation in different fields will have a sizeable impact in the next five years on the performance of renewable energy generation, transmission and storage. Many eyes are fixed, for example, on the development of storage technologies. But it is important not to underestimate the cumulative impact of a series of less dramatic process improvements – especially those powered by digital technologies.

1 https://www.iea.org/Textbase/npsum/renew2017MRSsum.pdf

2 https://www.bloomberg.com/news/articles/2017-04-13/germany-gets-bids-for-first-subsidy-free-offshore-wind-farms

3 https://www.ft.com/content/b4a4f0ae-e597-11e7-97e2-916d4fbac0da

4 https://www.ft.com/content/7401f5e0-96c0-11e7-a652-cde3f882dd7b and https://www.ft.com/content/8ea432e4-a1e9-11e7-9e4f-7f5e6a7c98a2

Key findings

- **The tipping point is still in the future.** Despite recent advances, grid parity for major renewable energy sources is still several years away for most countries. The industry expects parity for solar to be achieved earliest in China (2022/23), and for wind earliest in Germany (2024).

- **A decisive tilt in the energy balance will take longer.** Taken together, renewable sources are expected to surpass fossil fuels in countries' energy mixes first in Europe and North America (by 2025), in the Middle East by 2028, and in Asia Pacific and Africa in 2033 or later.

- **More than grid parity is needed to shift the energy balance.** Achievement of grid parity is not by itself enough in most countries to tilt the energy balance decisively in renewables' favour. Issues with grid connection, transmission and storage often combine to limit the impact of individual projects.

- **Technology advances can change the equation.** Continued technology innovation could accelerate progress towards achieving grid parity. Most of the attention is on advances in solar and storage technologies that could have a big impact on performance, but these may take time before having the desired impact on cost.

- **Technology innovation overshadows policy as a growth driver.** Most executives believe that technology advances will do more to improve the economic case for renewables than policy or regulatory factors. But policy change remains a potential inhibitor in both developed and developing markets.

- **Incremental advances will have an outsized impact.** In wind energy, boosts to scale and optimised processes will be more influential in improving performance and cost-efficiency than breakthrough technologies. Larger offshore turbines and rotors, for example, and streamlined installation and maintenance practices (with the help of analytics) are expected to improve wind-farm economics.

- **Digitisation will drive performance improvement.** Hopes are high for a favourable impact from digital technologies on renewable energy generation and transmission. For example, companies are looking to use predictive analytics, demand management and even machine learning to improve the operational performance and economics of energy transmission.

- **Cutting innovation costs is a top priority.** Uncertainty over returns constrains technology innovation in many firms, and this has much to do with the high costs of deployment. Better logistics and installation processes will help to ease deployment constraints.

- **More standardisation is needed.** In newer renewable energy technologies, such as wave and tidal, experts believe that significant improvements in economics await industry convergence around the design of key technologies.

Technology drives renewable energy growth, although policy change remains an investment inhibitor

Where executives predict grid parity will be reached first:

2022
Solar CSP
China

2023
Solar PV
China

2024
Offshore wind
Germany - UK
Onshore wind
Germany - US

Technology advances will do more to improve the economic case for renewables than policy or regulation

71%
of renewable energy executives agree

Gains in offshore wind performance will come from larger turbines as well as installation and process improvements, with opportunities for floating platforms and next-gen dynamic positioning vessels, for example

Electrochemical and other utility-scale storage technologies are advancing, but development costs remain high and capacity limited

Inhibitors of renewable energy growth (aside from cost):

- **37%** Slow development of storage technologies
- **32%** Government policies
- **28%** Insufficient investment

Digital technologies are ready to have impact:

1. Demand response management
2. Predictive analytics
3. Advanced metering infrastructure
4. Blockchain
5. Machine learning

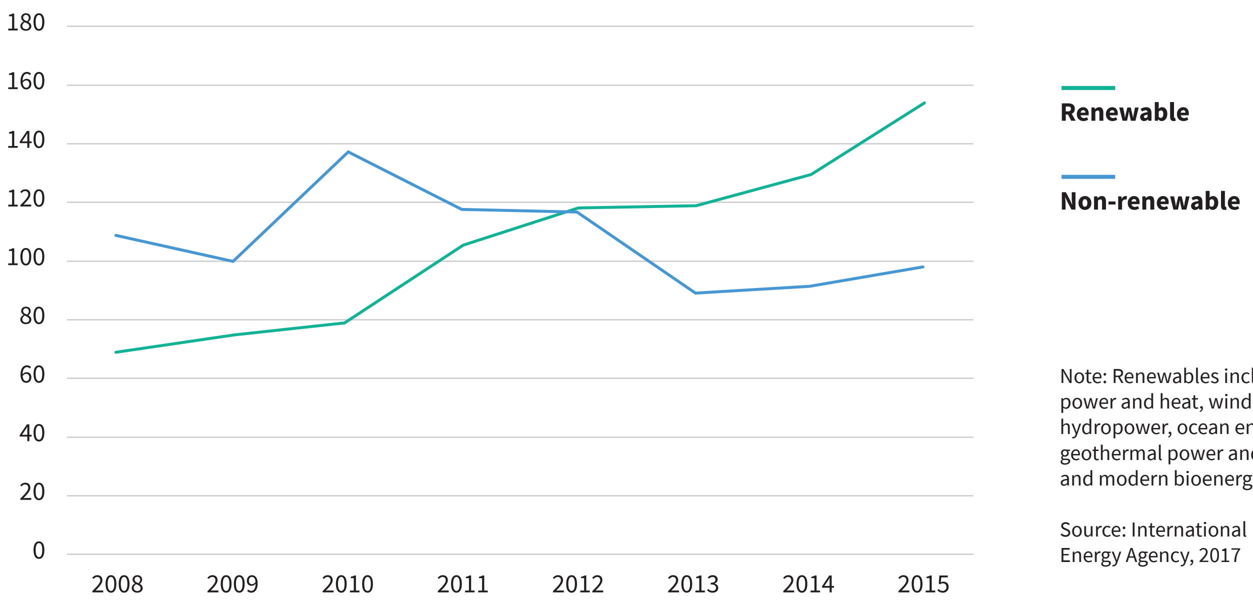
1. March of the renewables: a reality check

When will countries reach the 'tipping point' for renewable energy sources?

In other words, when will they become as economical as fossil fuels (or more so) for domestic power utilities? In our 2017 study, a majority of renewable sector executives stated the belief that parity was being reached. This year we've asked them to predict where it would be reached first and when.

Some of the experts we spoke to for this report choose to apply a broad perspective to the question. For Deborah Greaves, who heads the School of Engineering at the UK's University of Plymouth, the tipping point can be defined in terms of the degree of public acceptance of renewable energy sources, or of the contribution renewables are making to overall electricity usage. Stephen Church, a partner and energy market leader at EY, takes a similar view. He maintains that countries such as the UK have already passed an important milestone of public acceptance, given that "we as consumers are now used to non-fossil-fuel sources of energy". Paul Stangroom, head of renewables at Lloyd's Register, Asia Pacific, points out that while economics are critical, policy commitments to meeting carbon reduction targets have thus far been as important a factor in driving installation of renewable energy capacity, particularly in the developed world. In each of the past several years, he notes, additions of renewable energy generation capacity have far outstripped those of conventional sources, suggesting that some form of equivalence may already exist in some countries.

Global renewable and non-renewable power capacity additions, 2008–2015 (GW)



Note: Renewables include solar power and heat, wind power, hydropower, ocean energy, geothermal power and heat, and modern bioenergy.

Source: International Renewable Energy Agency, 2017

Another way to look at the tipping point is to define it in price terms, using a widely accepted definition of 'grid parity'. Grid parity is the point at which the levelised cost of electricity (LCOE) from a renewable energy source becomes equal to or less than the cost of power from conventional energy sources used in the grid. LCOE itself can be defined in different ways. One commonly used method excludes government subsidies and the costs of storage, backup generation and other measures needed to deal with intermittency and deliver generated power into the grid.

Parity first in China?

Using this LCOE formula, we asked our survey respondents to predict the country and year in which they think wind and solar will reach grid parity. Their consensus is that China will meet this milestone for solar PV first – in 2023 (the mean year of prediction), followed by the US a year later.

China is also expected to reach grid parity first in concentrated solar power (CSP) – in 2022 – followed by Spain and the United Arab Emirates in 2024, and by Australia and the US in 2025.

The survey group predicts that Germany and the UK will reach grid parity for offshore wind first – in 2024. In the same year, respondents say, Germany and the US will reach parity in onshore wind.

In which country do you think the following renewable energy sources will reach grid parity with fossil fuels first, and in which year?*

Offshore wind

Country	Year
Germany	2024
UK	2024
US	2025
Denmark	2025
Sweden	2033

Onshore wind

Country	Year
Germany	2024
US	2024
Denmark	2028
Sweden	2033
Finland	2038

Solar PV

Country	Year
China	2023
US	2024
Germany	2028
Denmark	2033
Sweden	2038

Solar CSP

Country	Year
China	2022
Spain	2024
UAE	2024
Australia	2025
US	2025

* The countries shown enjoyed the highest frequency of survey responses as the most likely to reach grid parity first. The years shown are the mean year of the prediction for each country.

The question of subsidies

Our exclusion of government subsidies is important, because very little wind or solar capacity has been built without subsidisation in some form. As we have seen, there are examples of solar and wind auctions with bids that assume sharply reduced or no subsidies in terms of guaranteed minimum prices for developers.

Subsidies take different forms, however. For example, the German and Dutch offshore wind auctions organised in 2017 involved no price subsidies, but exempted developers from paying the expensive grid-connection costs. Auctions in other countries including the UK, on the other hand, require bidders to cover these costs.[5]

In Europe, according to Samuel Leupold, executive vice president and chief executive of wind power at Ørsted (formerly DONG Energy, which secured three of the four projects involved in the German auction), no renewable or conventional energy developer is currently able to cover the cost of a new investment. “All technology, whatever type of power you want to add to the grid in whatever European market, has to come through a form of subsidy,” he says.

5 http://www.nera.com/content/dam/nera/publications/2017/PUB_Offshore_EMI_A4_0417.pdf

Roadblocks to parity

Renewable economics are unquestionably improving. According to Bruce Douglas, deputy CEO, SolarPower Europe and co-chairman, Global Solar Council, the cost of building solar capacity for utility-scale generation has fallen by more than 80% in the past 10 years, which has helped to fuel the rapid expansion of solar capacity worldwide since 2014.

Yet despite subsidies and technology advances, high costs remain a barrier to reaching parity and to faster renewables growth. A majority of survey respondents, 62%, say that high costs remain the primary argument against pursuing renewables in their country. Respondents involved in solar development are only slightly less emphatic on this point, with 59% agreeing.

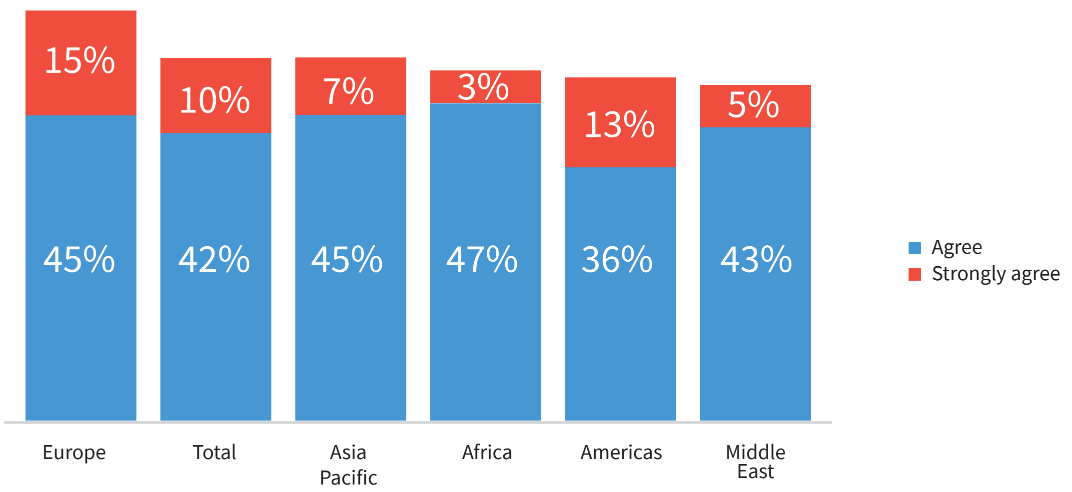
For many renewables companies – particularly in less advanced fields such as wave, tidal and biomass – it is scale that will bring projects closer to grid parity. This is the view of John Liljelund, chief executive of AW-Energy, a Finland-based developer of 'WaveRoller' wave technology. "Scale is what's lacking now in wave energy," he says. "And that's a more decisive factor than advances in technology, which is already well developed."

Another major inhibitor to the growth of renewables, and to their greater attractiveness to utilities, is a lack of storage at an affordable price. Excluding cost, the most frequently cited obstacle by survey respondents to the growth of renewables in their country's energy mix is the slow development of storage technologies.

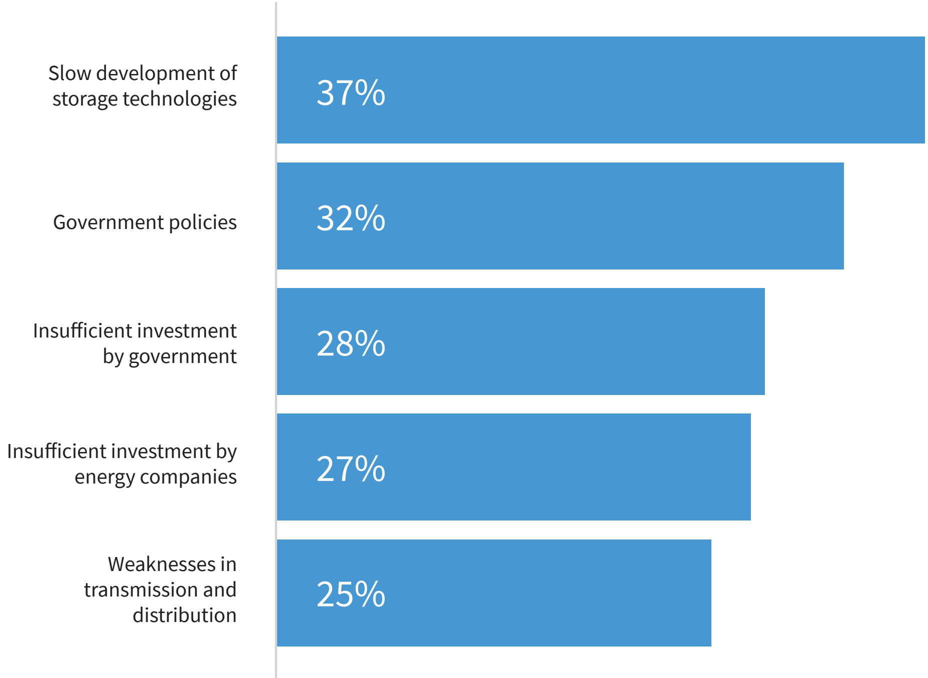
Energy storage systems are key to easing the intermittency problems of many forms of renewable energy. While advances in electrochemical technology and materials science have helped to increase short-term battery capacity and reduce costs for smaller-scale applications such as electric vehicles, progress has been slower with systems for utility-scale storage.

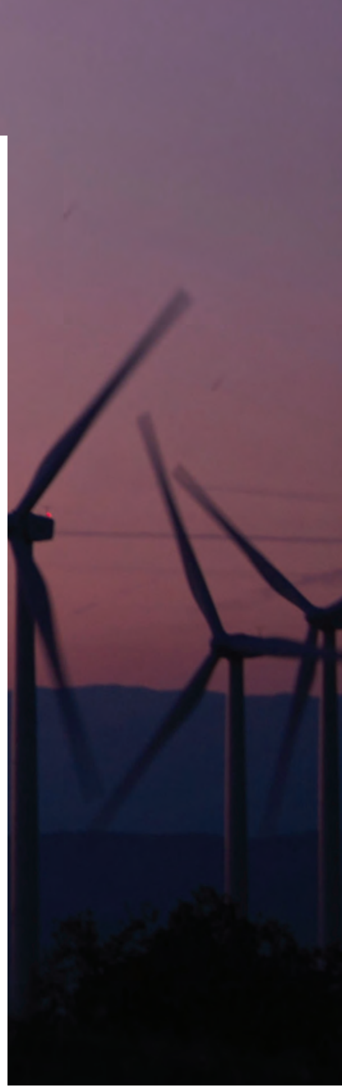
Partly for this reason, storage of renewable energy is costly. "High penetration of intermittent renewables involves a high cost of storage and transmission," says David Eyton, group head of technology at BP. "If you include the costs of storage that go with these more intermittent sources of power, such as batteries or hydro storage and demand management, then it can take considerably longer to get to what I would call true grid parity, taking into account the quality of power in systems."

"Reaching grid parity will not be enough to cause a sustained increase in investment in renewables in my country." Do you agree or disagree?



Aside from cost, what do you think is the most important factor inhibiting the growth of renewables in the energy mix? (Top responses)





Battery storage continues to rely, as it has since the early 1990s, largely on lithium ion technology, which can store only relatively small quantities of energy. Existing storage technologies are therefore not yet ready for grid-scale solutions. "The largest battery I know of could store the production of our Hornsea wind farm in the UK for no more than two minutes," says Ørsted's Samuel Leupold.

The absence of high-capacity storage gives rise to another weakness of renewable energy in the eyes of power utilities – limited dispatchability. Utilities need to be able to call on energy producers for additional power whenever it is required, whether for load balancing or meeting surges in demand. (The Lloyd's Register Foundation's recent review of energy storage examines this challenge in greater detail.[6])

Achieving full dispatchability of renewables is therefore a priority for some grid operators. Regional US operator ISO-NE, for example, aims to make all renewable energy generators in New England fully dispatchable. As of early 2017, 22 of the region's wind farms and 29 hydroelectric facilities had achieved full dispatchability.[7]

"Many countries are finding is that it's all very well achieving parity, but if the energy is not dispatchable, then grid operators have to cope with the subsequent problems," says Lyall McLachlan, chairman of Solastor, an Australian solar CSP developer.

6 www.lrfoundation.org.uk/publications/foresight-energy-storage-download.aspx
7 https://www.clf.org/blog/making-renewable-energy-dispatchable/

When will the energy balance shift?

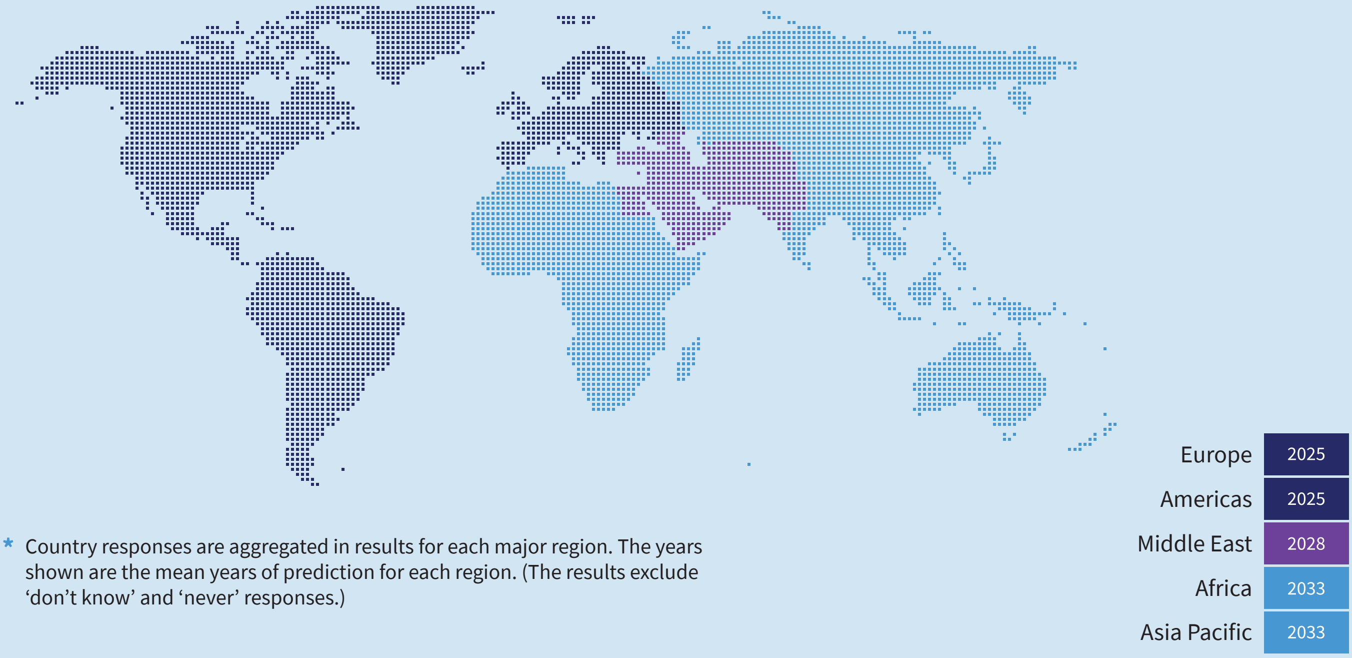
These obstacles mean that even if grid parity comes soon, a decisive shift in the energy balance towards renewables will take longer.

A handful of respondents (7%) say that renewables have already overtaken conventional fuels as the primary sources of energy in their countries, and 3% expect it to happen in the next two years. Nearly six in 10 (58%), however, believe that this milestone will not be reached until after 2025.

Europeans and North Americans are confident that this tilt towards renewables will happen in their countries by 2025. UK executives, for example, expect the shift to come in 2024 (the mean year of respondent predictions), and the consensus view of those in the US and Canada is that it will happen in their countries in 2025. Further south, Brazil respondents also believe 2025 will be the year.

Respondents expect the shift to occur latest in Asia Pacific and Africa: 46% and 45%, respectively, of respondents from those regions say thatrenewables will overtake fossil fuels after 2040. Executives from China and India buck the trend slightly, expecting this milestone to be reached in 2033.

When, if ever, do you think the contribution of low carbon energy sources will exceed that of fossil fuels to your country's total primary energy supply?*



* Country responses are aggregated in results for each major region. The years shown are the mean years of prediction for each region. (The results exclude 'don't know' and 'never' responses.)

A wildcard in any energy-mix projection is the potential for policy and regulatory change. For example, while onshore wind has progressed as a renewable energy source, its growth is constrained in many countries by community resistance to turbines near residential areas. More than four in 10 (45%) of the surveyed executives (including 55% in Europe) say that resistance to onshore wind turbines in their countries is too strong to enable significant growth from this source.

Any sharp change in government commitment to supporting renewables growth can naturally dampen investor and market sentiment. Bruce Douglas of SolarPower Europe believes that policy change is a constant risk to solar growth in Europe: "The on-again, off-again national policies that we've seen in some European markets result in an on-again, off-again industry, which is unsustainable. Clear, ambitious targets and stable long-term policy frameworks are essential for the sustained and predictable growth of renewables."

Yet, such uncertainty has not dented renewables' broader progress in establishing themselves as competitive sources of energy in countries. Most of the credit for this, as we will see in section 2, is due to continuing technology innovation.

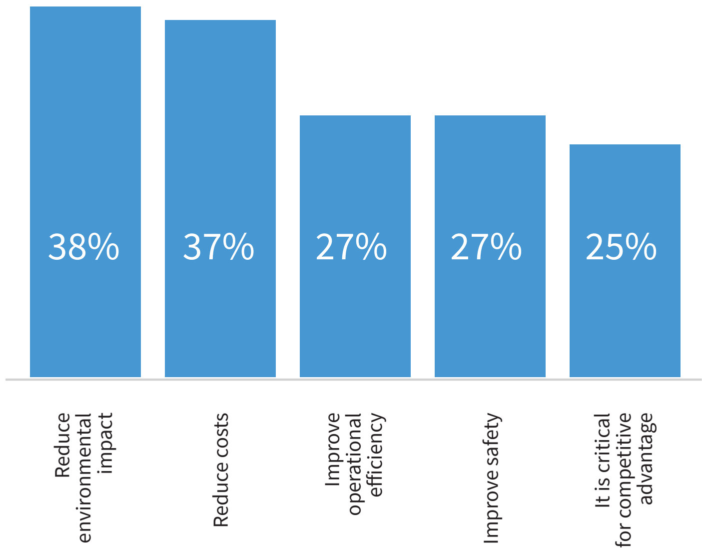
2. Technology catalysts

Recognising that the worldwide march of renewable energy is slower than popularly assumed should not lessen appreciation of its progress, or of the role that technology innovation has played in propelling it forward.

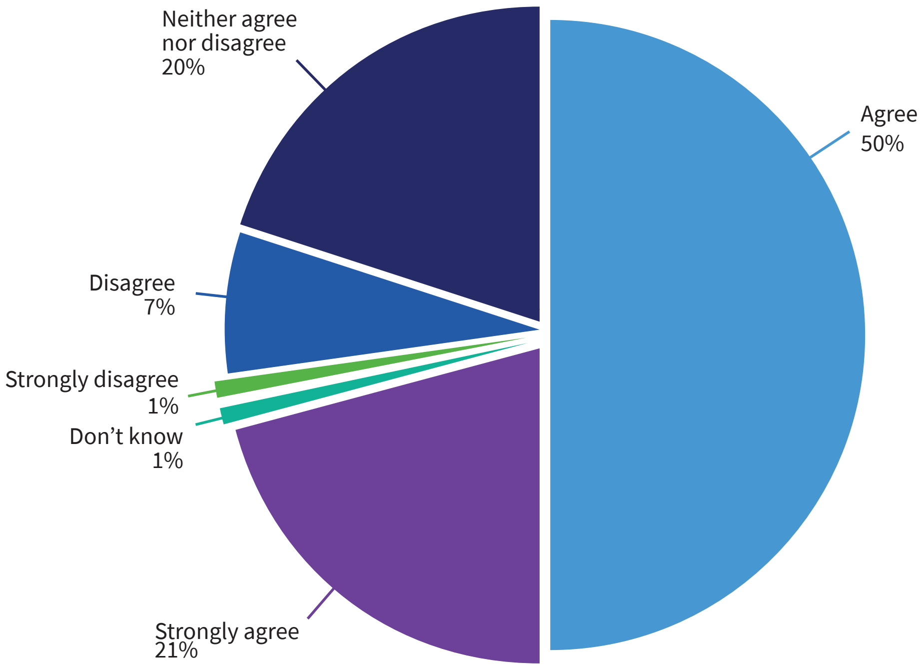
A series of improvements in solar-panel design, for example, have made considerable contributions in recent years to the cost-competitiveness of solar PV. And expansion of electrochemical battery capacity – in both grid and residential systems – has also helped solar PV's growth. In offshore wind, advances in materials such as composites have increased the efficiency of turbine blades, which has in turn helped to improve wind's economics.

In the next five years, continued technology advances will be instrumental in improving the economic case for renewables. Indeed, reducing costs is the second reason given by our respondents for their investment in technology innovation – only just behind the objective of reducing the environmental impact of their operations. And more than seven in 10 survey respondents believe that such innovation will do more to improve the case for renewables than policy or regulatory changes.

What are your firm's primary drivers for investing in renewable technology innovation? (Top responses)



"Technology advances will do more in the next five years to improve the economic case for renewables than policy or regulatory changes." Do you agree or disagree?



Innovations to come: a five-year radar

What will such innovation look like? Consistent with the findings of this study, in the next five years industry experts expect innovation mainly to take the form of incremental improvements to existing technologies and processes, rather than radical breakthroughs.

These incremental improvements add up to a bigger picture of progress, and it is becoming easier to discern the shape of major longer-term advances in wind, solar, wave and tidal, and storage.

Wind

In offshore wind, industry executives tell us that the most positive advances in the next five years are likely to take the form of process improvements and gains in size.

"Near-term innovation in wind is less about fundamental advances in turbine technology and more about increases in blade size and generators, along with work on the control and management of projects to get the most out of them," says Paul Stangroom of Lloyd's Register. "Improvements in materials, control in monitoring performance and fatigue loading will help wind developers get the most out of the equipment that they have."

Meanwhile, bigger will continue to mean better. "The most important advance we will see in offshore wind is in the size of turbines," says Samuel Leupold. The limit for upgrades of current technologies is about 10MW, he explains, "but a new platform is in development in the range of 12-14MW with rotor sizes that may reach 200 metres or more."

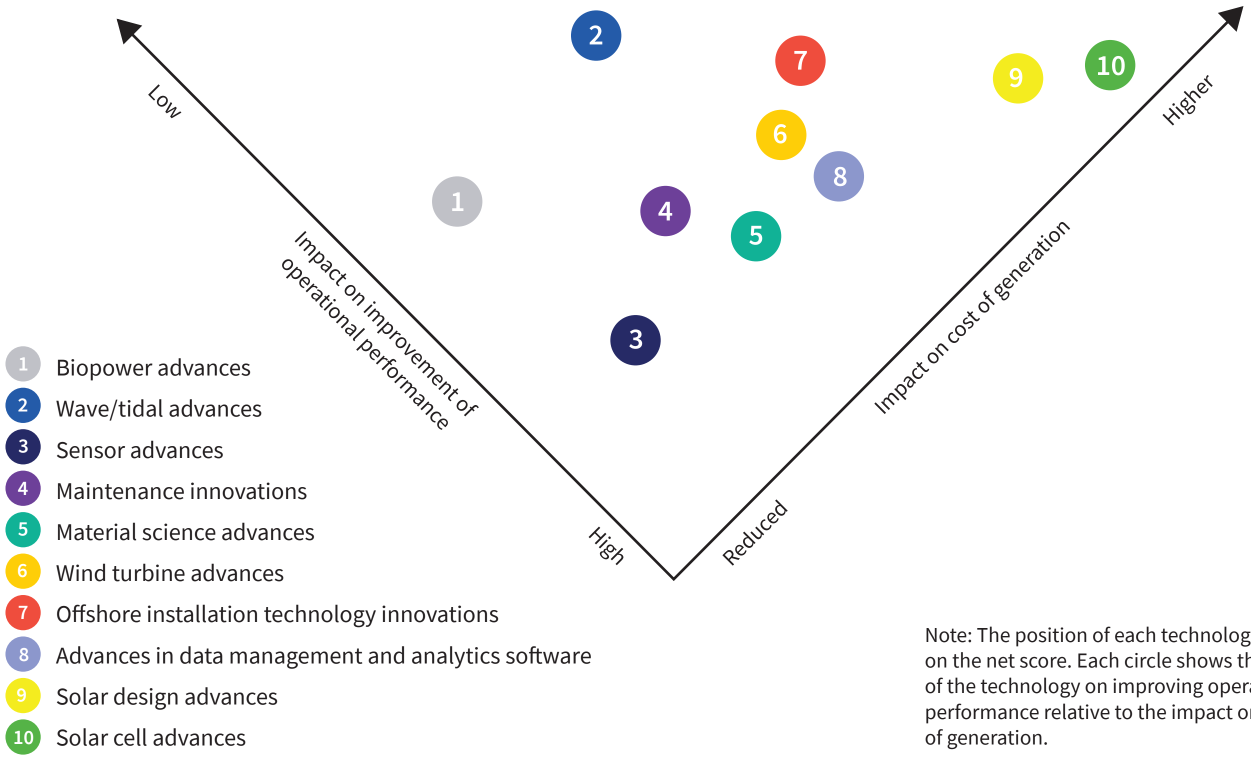
As turbines and their blades get bigger, improvements in platform design are likely to follow. For example, floating platforms constructed with advanced materials should offer better structural support for larger turbines – particularly in deeper water and further offshore.

According to US Department of Energy projections, floating foundations are expected to be cost-competitive with fixed-bottom platforms in the US by the mid 2020s.[8] "The maturing of floating platforms could radically improve the economics of floating offshore wind," says Stephanie McClellan, director of the special initiative on offshore wind at the University of Delaware. "They could have a big impact in California, for example, where the waters are deep even near to shore."

Advances are also expected in offshore installation technologies. An example is the use of dynamic positioning vessels (DPVs) in installing offshore turbines. Existing jack-up vessels often take several hours to gain stability, according to Leupold, but newer generations of DPVs can attain similar levels of stability more quickly and maintain them.

8 https://www.nrel.gov/docs/fy17osti/67675.pdf

Impact of technology advances on renewable energy generation: next five years



Note: The position of each technology is based on the net score. Each circle shows the impact of the technology on improving operational performance relative to the impact on the cost of generation.

Solar

In solar power, too, it is improvements in existing technologies rather than new breakthroughs that will have the greatest impact on performance in the short and medium terms.

SolarPower Europe's Bruce Douglas expects continued incremental improvements in the panels and components used in solar PV, as well as significant gains from digitisation of the energy sector. "These developments will continue to reduce costs and increase efficiency, contributing to wider solar deployment," he says.

As in our 2017 study, survey respondents are also optimistic about the impact of advances in solar cell technology. Developments that could have a positive near-term impact on cell efficiency include improvements in polycrystalline cells and wider use of thin-film modules. Another area of innovation involves improvements in amorphous silicon cells, which require substantially less silicon to produce than crystalline cells.

In the longer term, perovskite cell technology offers the opportunity to move away entirely from silicon in the production of PV cells, which promises greater efficiency. However, there are concerns, magnified by the existence of lead in the cells' structure, about the stability of perovskite cells.

The sun shines on CSP

Concentrated solar power (CSP) is among the oldest renewable energy systems: its main technology, the parabolic trough, was developed in the 1860s, and solar thermal technology was developed in the 1880s.

Yet CSP is the least commercially developed of the four major renewable energy sources covered in this study. Installed global capacity of all CSP forms was 4.8GW at end-2016, which pales in comparison with solar PV's 303GW and the combined 487GW of onshore and offshore wind.[9]

The growth of CSP capacity has stalled in its largest existing markets of Spain and the US in recent years, but it is on an upward curve in less developed markets such as China, South Africa, India and Morocco. These countries have high levels of direct normal irradiance, which is the amount of sun that hits the earth's surface. This makes them attractive markets for CSP technology producers such as Australia's Solastor, which has developed a solar thermal technology based on graphite. It currently operates demonstration plants in China and Australia, and is establishing commercial projects in South Australia, Cyprus and Egypt.

Among solar thermal's chief advantages, according to Solastor chairman Lyall McLachlan, are 24-hour operation and dispatchability. He says that thermal storage based on graphite or molten salt should be regarded as an alternative to traditional electrochemical storage.

"There are only two ways to store energy," says McLachlan. "As electrical energy in a chemical battery, or as thermal energy in a graphite battery or other heat retention system." He adds that, because graphite has such high heat retention properties, it can store energy for long periods effectively and dispatch it on-demand and inexpensively, using a steam turbine. This means that thermal batteries can be an add-on to PV and wind farms, particularly for transfer of bulk quantities of energy.

"It also gives them dispatchability," he says. "Which is exactly what governments demand if these developers want to install systems in their countries."

9 http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf

Wave and tidal

Renewable energy generated from wave and tidal technologies is considerably further from reaching grid parity than wind or solar, according to experts we spoke to for this report.

One reason for this is the small scale of most existing projects. As is the case for most relatively nascent energy technologies, costs will decline as more projects come on line and generation capacity increases.

Another factor inhibiting progress, particularly in wave technologies, is a lack of standardisation. The University of Plymouth's Deborah Greaves says that this manifests itself in a multiplicity of competing designs for energy converters. For example, oscillating surge converters co-exist with oscillating water columns, attenuators, point absorbers and several other converter types. "For newer renewable technologies such as wave, there needs to be some convergence of design before they can approach grid parity," she says. "We haven't seen that for wave energy, although it is closer for tidal."

Cost reductions should also come with the development of materials and components that help improve substructure reliability, which is a particular challenge in seabed tidal. For example, according to Rebecca Sykes, technology innovation leader at Lloyd's Register, the more reliable the substructure, the less often teams need to visit the site, which is a particularly costly exercise in the case of structures fixed to the seabed.

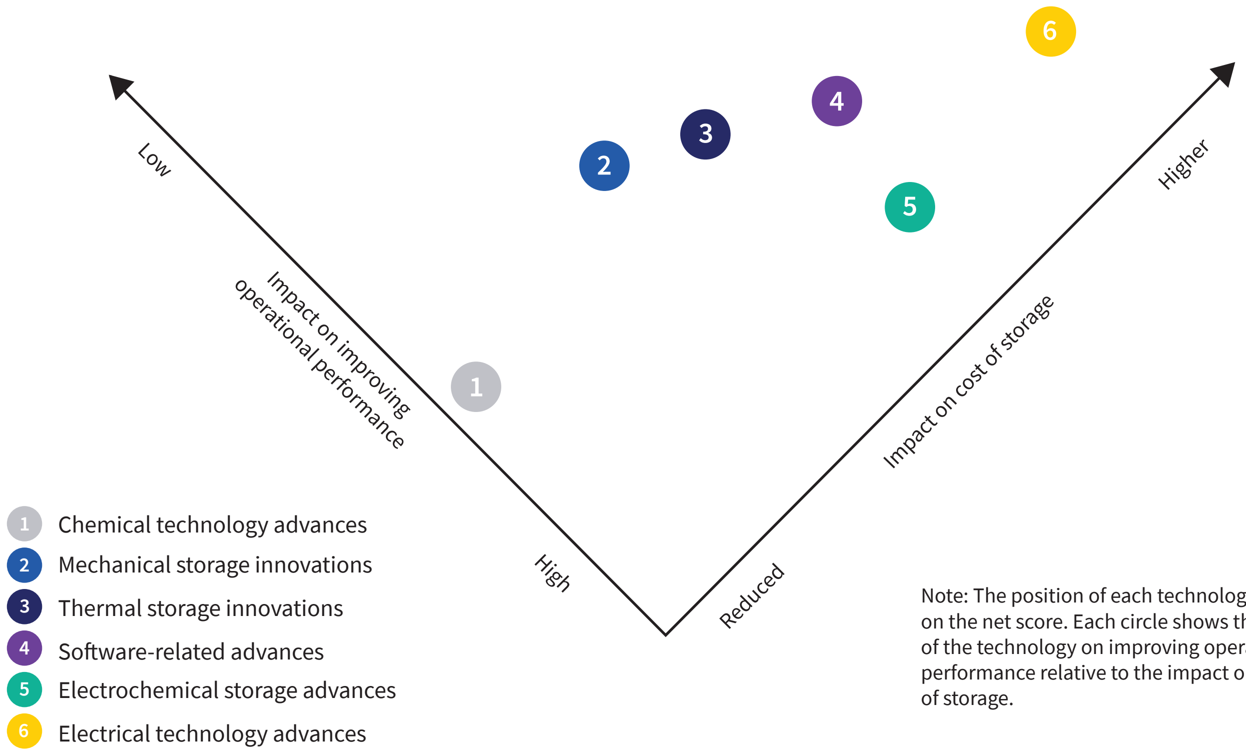
Storage

The outlook for large-scale solar power systems (and wind and wave power to some extent) is closely tied to developments in energy storage.

Paul Stangroom observes that developers of solar and wind farms are cautiously optimistic about new storage solutions becoming available in the foreseeable future, and are planning space for battery storage to be built alongside projects or added to them later.

Tesla's 100MW Powerpack system, meanwhile, which was turned on in December 2017 at the Hornsdale wind farm in South Australia, is the focus of considerable attention. The largest electrochemical battery system in existence, it serves as a back-up power supply to the facility's 30,000

Impact of technology advances on renewable energy storage: next five years



Note: The position of each technology is based on the net score. Each circle shows the impact of the technology on improving operational performance relative to the impact on the cost of storage.

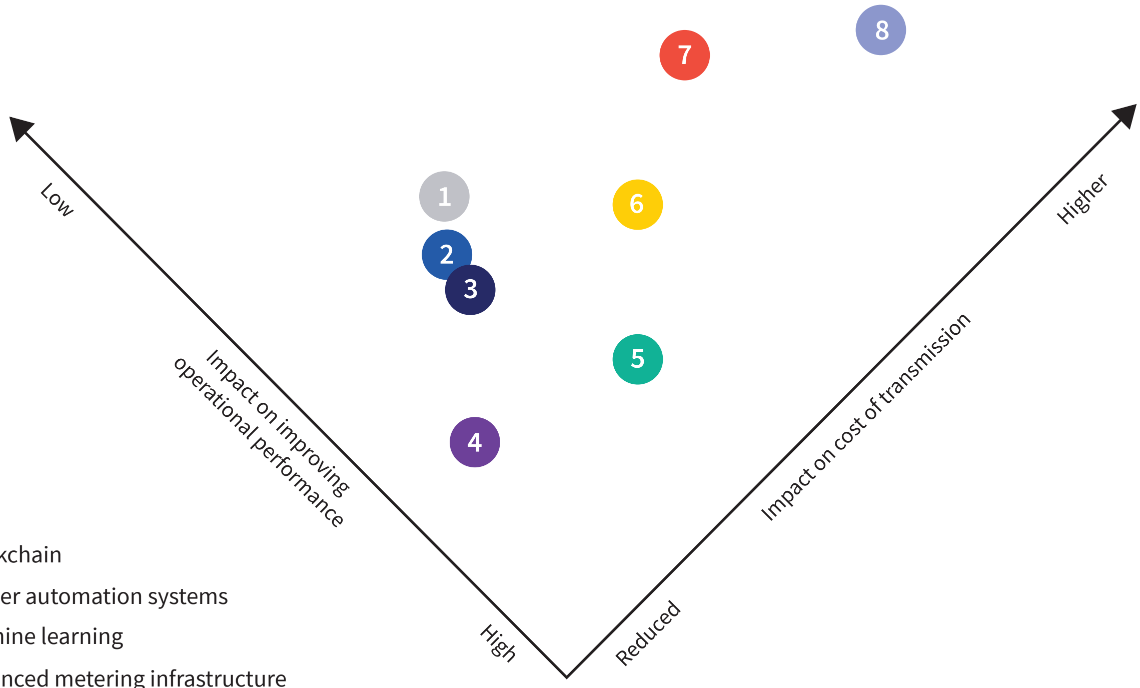
residential customers at times of low wind generation. The chief technical question about its performance is how long the system will be able to store power. Its current capacity is one hour, which is reportedly three times longer than other grid-scale electrochemical batteries in existence.[10]

Other technologies are being proposed as complementary or alternative storage systems to mainstream electrochemical technologies, but are currently in much more limited use. (See, for example, 'The sun shines on CSP' on page 16.)

The survey respondents also anticipate that chemical storage technologies will be more widely used in the next few years. An example is hydrogen storage, where electricity can be converted via electrolysis into hydrogen. The latter can then be stored for long periods and used for a multitude of applications. Conventional hydrogen (produced from natural gas via a chemical process) is currently used mainly in large industrial sites, such as oil refineries or chemical plants. According to Walburga Hemetsberger, board member for energy transition solutions at industry body Hydrogen Europe: "By applying electrolysis we can achieve 'green hydrogen', which, unlike standard forms of hydrogen, minimises carbon emissions." The technology's advocates also hold it up as an alternative form of storage to electrochemical batteries, as hydrogen can store energy for considerably longer and in far larger quantities.

10 https://www.ft.com/content/2ca27ee6-d634-11e7-8c9a-d9c0a5c8d5c9

Impact of technology advances on renewable energy transmission: next five years



1 Blockchain
2 Feeder automation systems
3 Machine learning
4 Advanced metering infrastructure
5 Demand response management systems
6 Advances in high-voltage direct current (HVDC) grids
7 Supervisory control and data acquisition (SCADA)
8 Smart power inverters

Note: The position of each technology is based on the net score. Each circle shows the impact of the technology on improving operational performance relative to the impact on the cost of transmission.

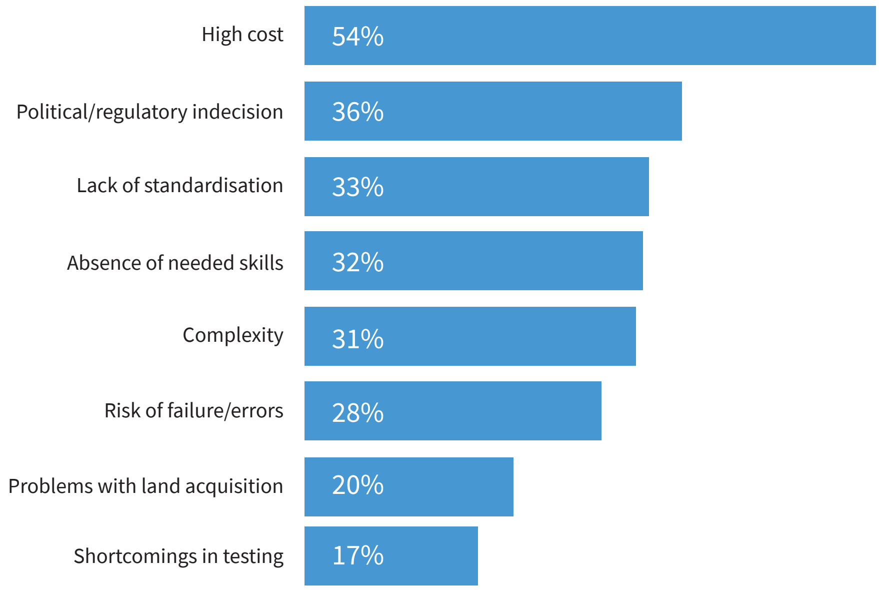
Innovation remains costly

Respondents' optimism about these technologies is tempered by concerns that they may not bring short-term improvements in economics.

Some hoped-for advances, such as in solar cell technology and electrical and electrochemical storage systems, still have considerable development costs. And testing and deploying new offshore platform designs, for example, involve enormous transport and logistics costs. This is one reason why industry executives cite uncertainty of returns as a major barrier to introducing renewable technologies.

Deployment challenges are a close second, and the dominant issue here is high costs – more so than policy uncertainty or lack of standardisation.

What do you believe are the main factors inhibiting the deployment of low carbon technologies?



Fortunately, ongoing digitisation will give developers and utilities unique opportunities to improve the cost efficiency of renewable technology deployment and maintenance, and renewable energy transmission and distribution.

An oil major's perspective on renewables

In December 2017, BP announced it was taking a $200 million stake in Lightsource, Europe's largest solar PV developer,[11] a clear sign that renewables growth is bringing fundamental change to energy markets. It is not BP's first foray into the renewables sector (it also owns onshore wind and biofuel assets), and is unlikely to be its last. The company's technology research and development team, led by David Eyton, group head of technology, is optimistic about advances to come in a few areas of renewable energy generation.

Wind energy, for example, is a mature technology but, says Eyton, further incremental gains in performance can still be achieved through the digitally optimised positioning of turbines, improvements in maintenance, and increasing the size of blades. Step changes in performance can also still be realised from advances in technologies such as floating platforms and kites, which could provide access to larger volumes of high-quality wind without the need for large towers.

The big challenge in solar power, according to Eyton, is to boost the percentage of the bandwidth of light that panels capture. He expects silicon-crystalline cells to remain the leading technology for now in cost terms, but notes that considerable innovation is taking place with alternative chemistries and nano-structuring, together with in-built options for residential use including windows and roof tiles, that are able to capture more of the available sunlight.

What about storage, the high costs of which, in Eyton's view, represent renewables' single biggest obstacle to reaching grid parity? Although there is always the potential for breakthroughs, he expects lithium ion batteries to remain the dominant battery technology for most of the next decade. This could be a problem: "Batteries are still only useful for storing energy for short periods of time. They need to progress significantly if they're going to fulfil the potential that they offer for grid-scale energy storage."

Eyton and his team reserve their greatest optimism for the impact of digital technologies. "Digital platforms have extraordinary potential to optimise energy systems, which can and should be more efficient," he says, adding that BP is investing in artificial intelligence, blockchain and quantum computing to help drive improvements across the entire value chain. "I expect advances in digital technology to have an enormous impact on the world's energy systems," he says, whether renewable or conventional. "This is particularly important when balancing increasingly variable sources and uses of power."

11 https://www.ft.com/content/f2ca752e-e0d9-11e7-8f9f-de1c2175f5ce

3. Digital dividends

In each of our technology impact charts in section 2, the prominence of digital technologies is clearly visible.

Among transmission technologies, for example (see chart on page 19), survey respondents clearly expect advanced metering infrastructure (AMI) and demand response management (DRM) systems to have a beneficial impact on operational performance in the next five years. They also expect AMI and DRM to help bring down the transmission costs of renewable energy.

Advanced data management and analytics tools are integral to these technologies, and they are also useful in renewable energy generation. Predictive analytics that crunch data generated by sensors, for example, are used to guide dynamic positioning vessels and their cranes at work in deep waters.

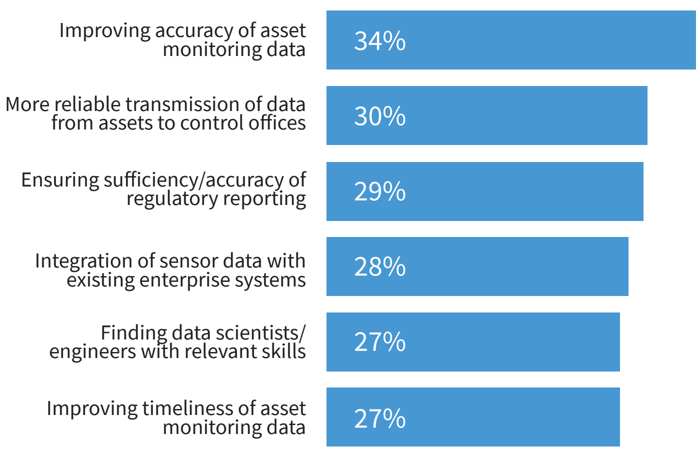
Predictive analytics and algorithms will help wind farm operators to plan and optimise asset maintenance with much greater efficiency, says Lloyd's Register's Rebecca Sykes. Developers are already using them to predict how quickly turbine or other platform components will erode and when they will fail.

Sykes also believes that more developers will use drones to inspect remote assets and perform repairs once existing battery capacity expands significantly. Offshore service companies that currently use airborne drones say they can inspect a turbine in a fraction of the time it takes with conventional forms of inspection.[12] And underwater drones are now being developed to inspect submerged platform components and cables.[13]

Unsurprisingly, networked sensors loom large in our survey respondents' hopes for continued improvement in physical asset installation and maintenance (see chart on page 15). But to capitalise on the data their sensors generate, operators need the tools and capacity to extract insights from it. Like their counterparts in oil and gas, renewable energy companies continue to struggle with data integrity and accuracy, as well as the integration of newer sources of data with existing databases and systems.

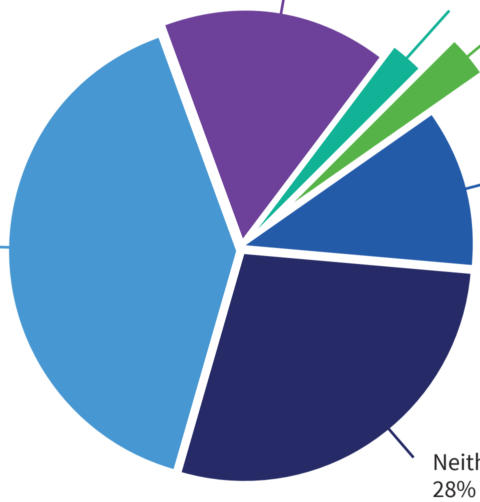
Digital technologies are of course software driven, and most industry executives (56% of respondents) expect software development to be at the heart of many of the sector's advances in the next five years.

What do you believe are the toughest challenges involved in managing and analysing data related to renewable energy assets and operations?



12 http://www.windpowerengineering.com/offshore-wind/drone-inspects-offshore-wind-farm/
13 https://www.windpoweroffshore.com/article/1434069/new-underwater-drone-cable-inspection-launched

“Software advances will have a greater impact than hardware advances in the next five years to improve the economic case for renewables.” Do you agree or disagree?



Our 2017 study identified blockchain, the distributed ledger technology that underpins cryptocurrencies such as bitcoin, as a potential disruptor of energy transmission and distribution. This latest survey finds respondents expecting the blockchain impact on transmission to be felt within the next five years.

Among blockchain’s potential applications is in enabling microgrids through the regulation of peer-to-peer consumer transactions.

Siemens and US start-up LO3 Energy, for example, are currently conducting a pilot microgrid project in Brooklyn, New York, in which consumers trade excess solar power that they generate.[14] Smart microgrids like this could eventually begin to address what Paul Stangroom describes as the problem of the overloaded grid. “The challenge we face in Australia is that soon, the existing electricity grid and the type of projects that can connect to it will be full,” he explains. “We will then be left wondering how we can find space to connect a lot more renewable energy projects without building a whole new set of transmission lines.” Soon, the question will be whether such large-scale grids are fit for future purpose, he says.

Next-generation impact

To many involved in the renewable energy sector, it is too early to say that machine learning techniques will have a significant impact. And our survey respondents broadly agree: while half expect the impact of machine learning on the likes of power transmission to be moderate at best in the next five years, a large minority (40%) anticipate that it will play a more significant role in transmission, both in terms of operational performance and in reducing transmission costs (see chart on page 19).

Rebecca Sykes expects to see utilities using machine learning techniques to predict alarm signals from supervisory control and data acquisition (SCADA) systems. They can analyse the large volumes of sensor data from turbines, for instance, to predict trends in anomalies and communicate them to control rooms in real time.

EY’s Stephen Church believes that widescale use of machine learning in demand management is not far off. And it may come into early use in load balancing: in Germany, the Fraunhofer Institute for Wind Energy and Energy System Technology, the German Meteorological Service, and three transmission system operators are researching the use of machine learning to predict wind and solar power generation needs over a 48-hour period based on expected weather conditions. The operators will use the power forecasts to guide the requests they regularly issue to utilities to dispatch or reduce the flow of different types of energy into the grid.[15]

In wave energy, meanwhile, developers are exploring machine learning’s potential to help them harness more power from the ocean (see ‘A role for machine learning in wave energy?’).

14 http://www.power-technology.com/features/featurethe-brooklyn-microgrid-blockchain-enabled-community-power-5783564/
15 https://www.nature.com/news/germany-enlists-machine-learning-to-boost-renewables-revolution-1.20251

A role for machine learning in wave energy?

Getting the most out of wave energy converters demands a great amount of number crunching. Companies have traditionally used statistical modelling based on device, wave, wind and other dynamics to control converters, but experts say that this is limited by the high computational costs involved, and point to inaccuracies that can lead to low energy absorption or even damage to the converters.[16] Now, companies are exploring how they can use machine learning techniques to optimise converter performance by predicting wave conditions.

IBM, the US technology giant and pioneer in applying machine learning in health and other fields, is pursuing a 'deep learning' approach that uses available historical and forecasted data on boundary wave conditions, ocean currents and winds. It says that this approach generates predictions 12,000% more quickly than conventional models – with no loss of accuracy.[17]

AW-Energy is taking a different approach. It aims to use machine learning in conjunction with neuroscience techniques to predict the frequency of incoming waves. Working with scientists from the Leibniz Institute for Neurobiology in Magdeburg, Germany, it is developing an algorithm based on historical wave data and guided by auditory response mechanisms of the types used by the brain – because ocean wave data is similar to soundwave data that is processed by the human brain. The algorithm will predict the height and power of each incoming wave, and enable fully submerged panels anchored to the seabed to respond to them.

According to the firm's chief executive John Liljelund, the panels already react to most incoming waves effectively, but the new capability will give them an extra few tenths of a second to prepare, which means capturing the maximum energy from each wave. He expects this machine learning capability to be operational at AW-Energy's WaveRoller installations within the next five years.

16 See, for example, http://ieeexplore.ieee.org/document/8045920/ and https://www.etp-scotland.ac.uk/Default.aspx?TabID=8400
17 https://phys.org/news/2017-09-deep-ocean.html

CCS: playing the long game

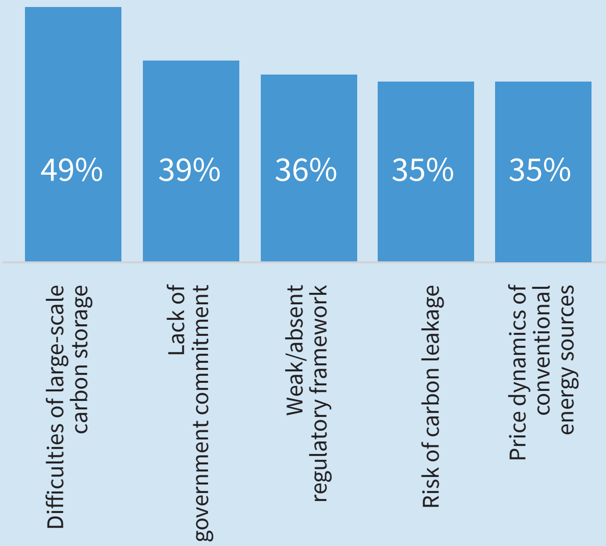
It has been a mixed couple of years for advocates of carbon capture and storage (CCS) technology.

In late 2015 and early 2016, the UK government signalled a broad retreat from financial support of CCS projects, citing doubts about their commercial viability. In June 2017, two European utilities withdrew from a large-scale project that planned to capture and store CO_2 generated by coal-fired power plants in the Dutch port of Rotterdam. According to one source, these developments have left Europe with no prospect of a major coal or gas power CCS project in the foreseeable future. [18]

CCS supporters will have been buoyed, however, by project launches elsewhere, including in the UAE and the US. Most encouraging of all is the Chinese government's commitment to deploying the technology. In March 2017, construction started on the Yanchang Integrated Carbon Capture and Storage Project – Asia's first commercial CCS venture – which aims to capture more than 400,000 tonnes of carbon a year from two gasification plants in Shaanxi province. And the government reportedly has several other CCS projects in the pipeline.[19]

Survey respondents' views on the outlook for CCS are similarly mixed. As many as 40% believe that the technology will have a big impact on reducing carbon emissions in the next five years. Over half (55%), however, think its impact will be moderate at best. Such scepticism probably comes from the majority belief (held by 53% of respondents) that CCS technology is unlikely to be deployed widely.

Aside from cost, what do you think are the most important factors inhibiting the adoption of carbon capture and storage technologies in electricity generation?



Despite this mixed picture in terms of policy support for CCS, the field is rich with start-ups and university-based researchers looking for innovative new approaches to capturing carbon, such as in the combination of CCS with biomass technology.

There is also no shortage of projects ongoing in many countries, but the vast majority are small in scale. The ability to achieve scale, according to half of our survey respondents, is the biggest challenge of CCS after high costs. Some of the Chinese projects may grow, but the question will remain of how replicable such projects are elsewhere.

18 http://ieefa.org/ieefa-europe-carbon-capture-dream-dying/
19 https://www.ft.com/content/d6ee4558-36d7-11e7-bce4-9023f8c0fd2e

Conclusion

Traditionally, the elephant in the room in discussions of renewable energy has been policy change. However, the industry executives involved in this study believe that the improving economics of solar and wind are reducing the scope for policy changes to obstruct renewables growth.

Recent evidence may be found in the US. Renewable energy capacity there continues to grow in spite of the current administration's retreat from COP21 and domestic commitments to combating climate change. Indeed, in large parts of the world policy appears to be diminishing as a decisive driver or inhibitor of renewable energy growth.

The sector's continuing investments in technology innovation help to explain this. In Europe, North America and parts of Asia, it is continued technology innovation that is doing the most to build the case for renewable energy – a view that is supported by most of our survey respondents. "In renewable energy, it's cost-lowering innovation that drives the economics," says the University of Delaware's Stephanie McClellan. "And the changing economics drive enthusiasm and therefore the policy."

This is not entirely the case in developing countries, where government support for renewables is often weak. In the survey, for example, many more Middle East respondents than those from other regions cite government policy as a renewables growth inhibitor in their countries. (Governments in some Gulf countries, such as the UAE and Saudi Arabia, are now actively looking to change this.) Conversely, it is also important to recognise the instrumental role that government support has played in renewables growth in both developed and developing markets.

As oil and gas majors increase their spending on research into renewable energy technologies, the tailwinds behind innovation are likely to strengthen. Other encouraging signs are coming from sovereign wealth funds – Norway's, for example, has signalled a divestment of its stakes in oil and gas assets.[20] China's, meanwhile, is actively increasing its investment in wind and solar projects.[21]

Government policy, of course, affects energy markets in many different ways, not least through decisions on subsidies for different energy sources. In most countries, few investors will look at a major renewable energy project without considering the financial support that the government may or may not be providing for it.

This study makes clear that there is some distance to go before the economic case for renewable energy becomes unassailable. The costs of technology innovation, for example, remain high, both in the development phase, as in the case of energy storage, and the asset construction phase, particularly when it comes to deployment. In some cases, the costs of innovation can act to limit operational cost reduction. At the same time, the digital technologies highlighted here should make a significant contribution to reducing operational costs for renewable energy developers as well as for utilities.

As technology innovation brings grid parity closer for renewable energy sources, then, it is also bringing closer the day when renewable projects can be judged purely on their commercial merits. When that happens regularly, the tipping point will almost surely have been passed.

20 https://www.reuters.com/article/us-norway-swf/norways-1-trillion-wealth-fund-proposes-todrop-oil-gas-stocks-from-index-idUSKBN1DG1TK
21 https://www.ft.com/content/9bb4b6bf-b1f0-35ca-a4e4-8131d8296729

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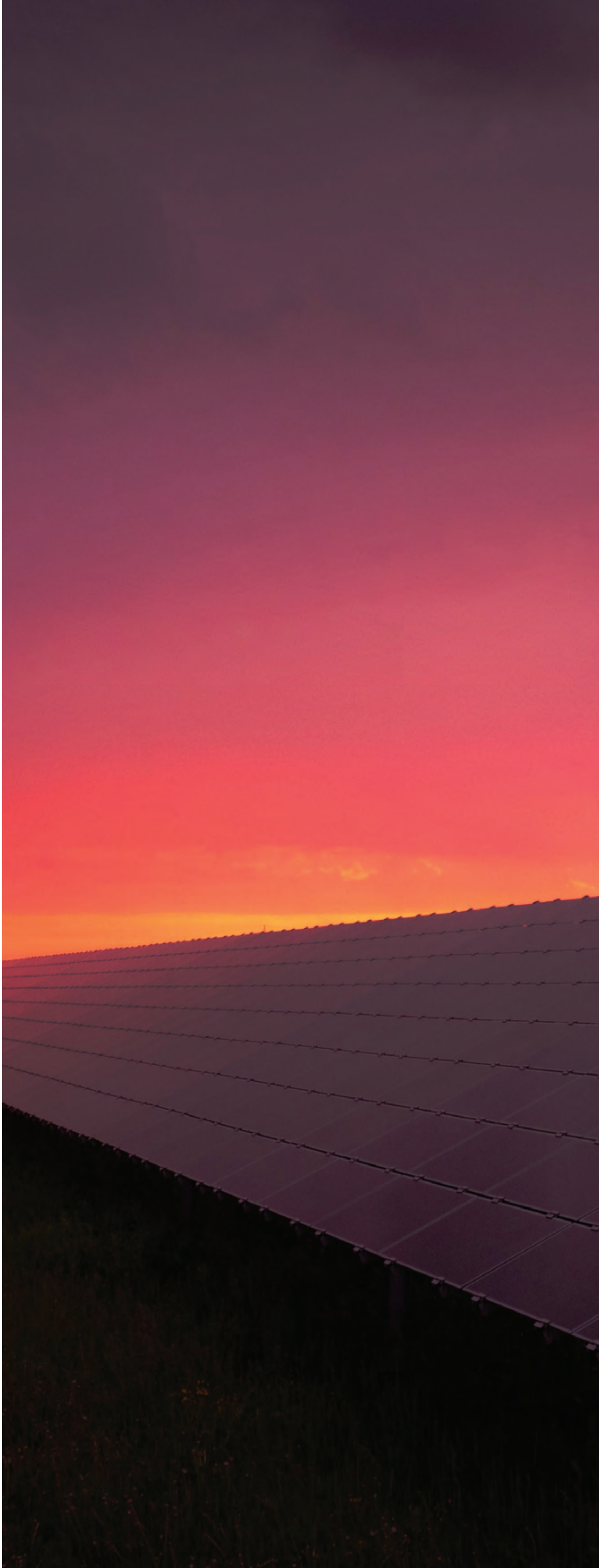

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