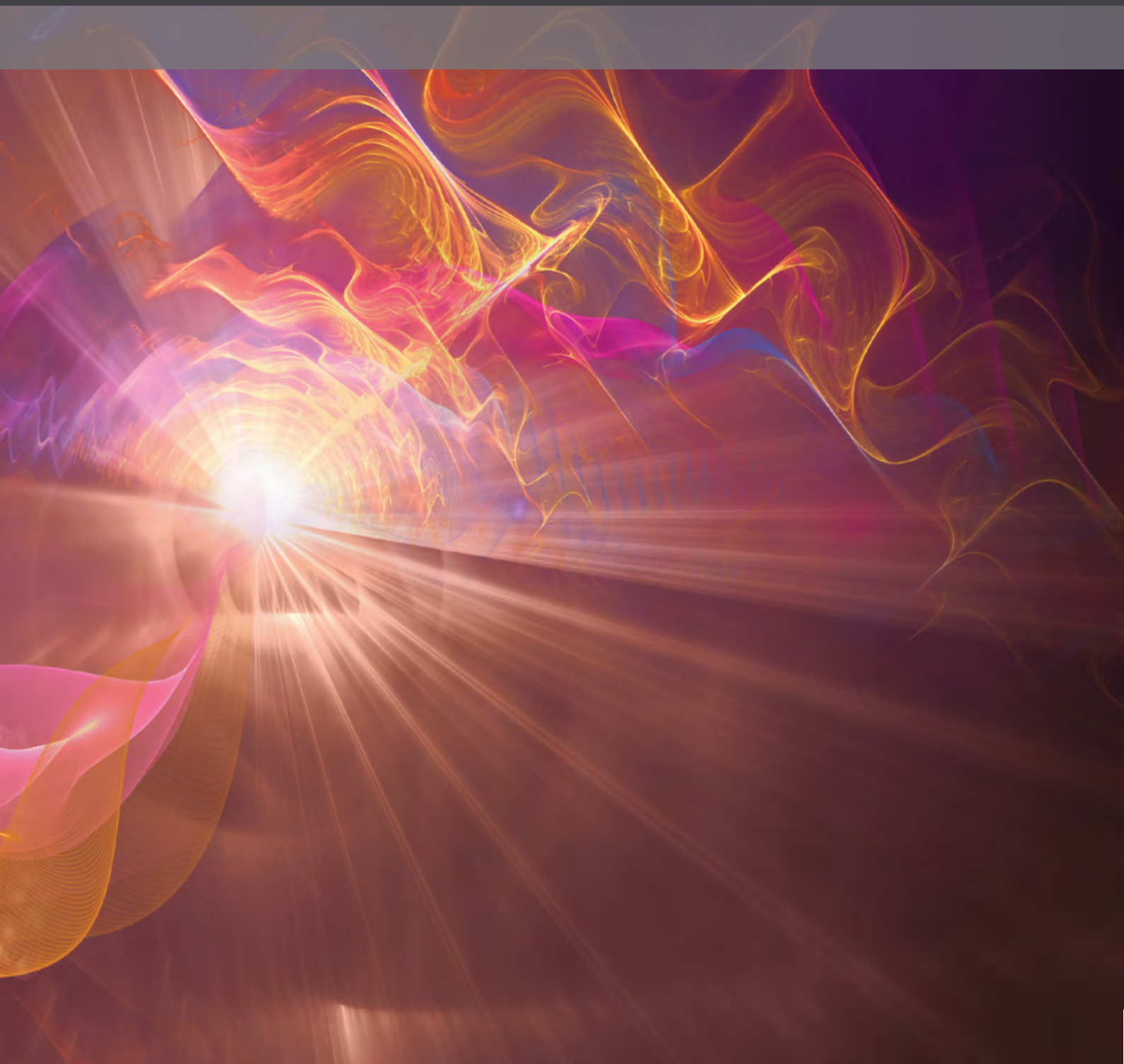
Lloyd's Register

Working together for a safer world

Lloyd's Register Technology Radar – Low Carbon



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Foreword

The drive towards sustainability has never been more urgent. While cultural and political diversity endures, every individual, community and organisation is part of the global challenge to create a productive and healthy today without compromising the needs of tomorrow.

This is the third year Lloyd's Register has conducted its award-winning Technology Radar research. While earlier editions have focused on the oil and gas sector, this time around the research concentrates on the low carbon sector, with particular attention to nuclear and renewable energy, energy storage and infrastructure. We recognise and welcome the building momentum around the global decarbonisation agenda – and the contribution Lloyd's Register can make.

As a digitally enabled global leader of technical solutions, we are uniquely placed to stimulate the growth of low carbon power on a worldwide scale. We do this by facilitating the development and deployment of innovative technologies and, on a day-to-day basis, helping our clients operate their nuclear and renewable energy assets safely and profitably.

For the Technology Radar – Low Carbon, we sought the insights and opinions of leaders across the sector, as well as the views of more than 500 professionals and experts. We are very encouraged by the findings, which highlight not only a growing optimism across the sector but also a vigorous and intelligent debate about the pathways to decarbonisation. Clearly, there are many uncertainties about exactly how the sector will evolve, but what is inarguable is that the conversation is no longer about "should we?" but "how should we do it?"

The research is presented as a set of two reports: the Lloyd's Register Technology Radar – Low Carbon, which provides a comprehensive review of the findings about renewables, nuclear, energy storage and infrastructure, and its sister report, the Lloyd's Register Technology Radar – The Nuclear Perspective, which offers a closer look at the findings as they relate specifically to nuclear power. We hope you find the research interesting, inspiring and valuable. As always, we welcome your feedback.

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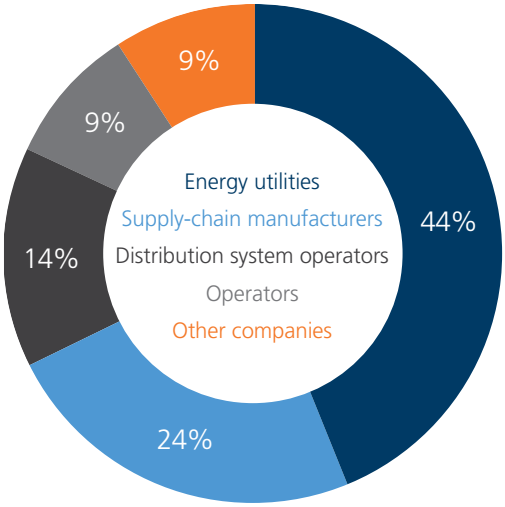
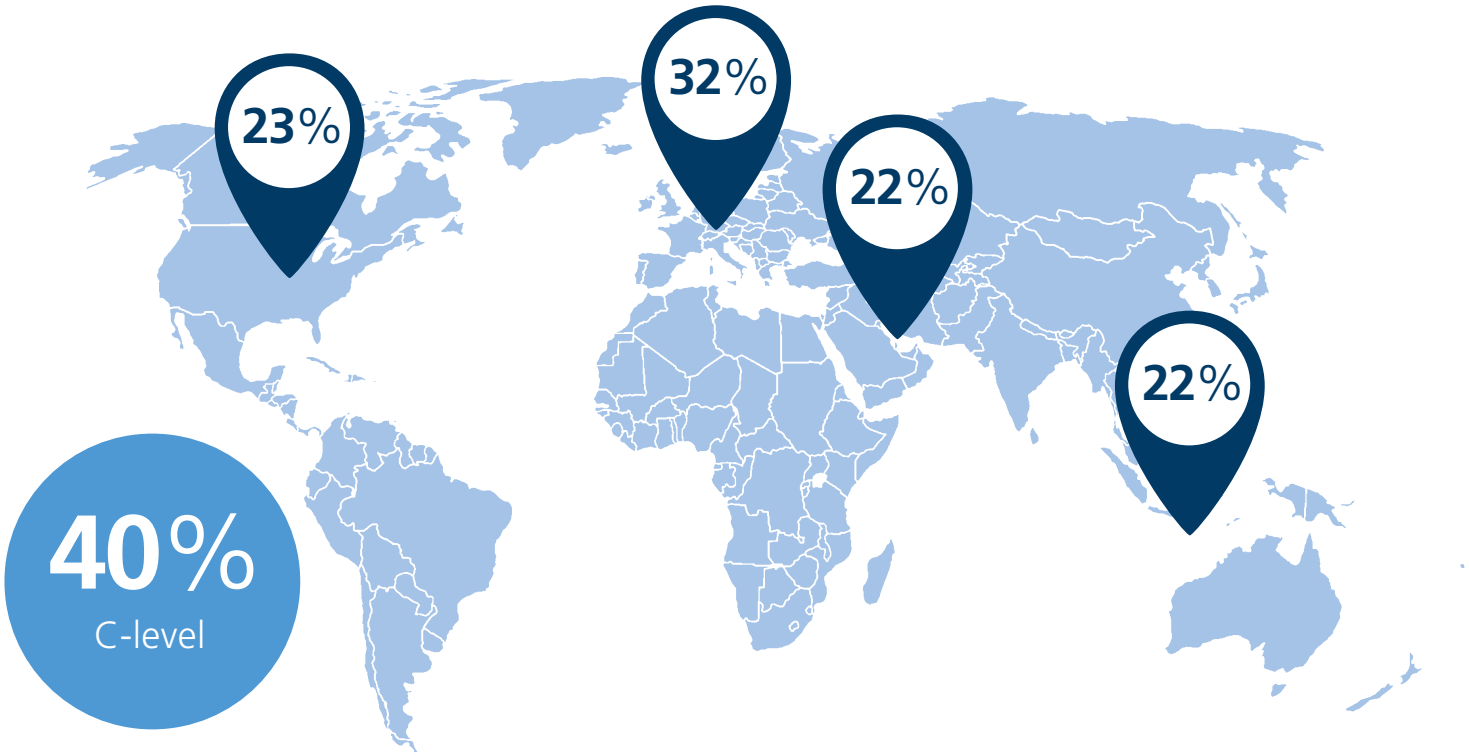
About the research

The results used in this report come from a Lloyd's Register survey conducted in November 2016 by Longitude Research. Of the 583 total respondents from across the low carbon sector, 154 identified themselves as operating in nuclear, and 323 as operating in renewables; in this report we refer to these groups as 'nuclear respondents' and 'renewables respondents'.

The makeup of our 583 respondents is as follows: 44% are energy utilities; 24% are supply-chain manufacturers; 14% are distribution system operators; 9% are other companies in the supply chain, such as engineering or service providers; and 9% are operators. Meanwhile, 22% of respondents come from the Middle East; 23% from North America; 22% from Asia Pacific; and 32% from Europe. And 40% are C-level, with the remainder occupying other senior positions.

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





We would like to thank the following interviewees (listed in alphabetical order) for their contribution to this research:

Mark Barrett	**Professor of Energy and Environmental Systems Modelling** University College London (UCL)
Sandy Butterfield	**President** Boulder Wind Consulting
Brent Cheshire	**Country Chairman** DONG Energy UK
Thomas Choisnet	**Chief Technology Officer** Ideol
Professor Richard Clegg	**Foundation Chief Executive** Lloyd's Register Foundation
Serge Gorlin	**Head of Industry Cooperation** World Nuclear Association
Tom Greatrex	**Chief Executive** Nuclear Industry Association
Daniel Grosvenor	**Head of Energy, Advisory Corporate Finance** Deloitte UK
Johan Gullman-Strand	**Energy Innovation Leader** Lloyd's Register
Karl Ove Ingebrigtsen	**Director** Lloyd's Register Low Carbon Power Generation
Lady Barbara Judge CBE	**Chairman** Institute of Directors
Simon Reeve	**SVP Technology & Innovation** Lloyd's Register
David Scott	**Advisor to the Chairman** Abu Dhabi Executive Affairs Authority
David Senior	**Executive Director Assurance, Policy & International** Office for Nuclear Regulation
Rebecca Sykes	**Technology Innovation Leader** Lloyd's Register
Ross Wigg	**Vice President - Renewables** Lloyd's Register

Introduction

It wasn't so long ago that the viability of low carbon power was inextricably linked to the oil price: the lower the cost of fossil fuels, the less likely clean energy uptake seemed. In recent times, however, the low carbon sector has broken this link: despite the drop in the oil price, clean energy attracted $325 billion in investments in 2015 – a new record.[1] Also, for the first time, developing countries attracted a greater share of this capital, which suggests that environmental goals no longer have to be traded off for economic development.

Renewable energy sources, particularly solar and wind, have achieved vast efficiency improvements in recent years – enough to compete with fossil fuels and, in an increasing number of cases, reach grid parity. The races to capture new offshore energy capacity and to build the next generation of solar panels have inspired several new technological breakthroughs. However, increased innovation is still sorely needed around market structures, regulatory frameworks, transmission and distribution infrastructure, and energy storage systems to integrate the new supply that has been created.

Executives interviewed for this report are optimistic about the pace of innovation in the low carbon space, but a quicker deployment of clean energy technologies will be necessary to meet energy sustainability goals and cut costs. Lloyd's Register's Technology Radar – Low Carbon aims to provide insights into where and when these innovations may next emerge. It is based on the insights of the nearly 600 executives and experts surveyed across the low carbon industry – from energy utilities and distributors through to equipment manufacturers. Respondents were asked to rate a number of technologies in terms of their potential impact on the low carbon sector, the amount of time it will take for these technologies to hit the market, and how likely they are to be adopted once they do.

1 https://data.bloomberglp.com/bnef/sites/4/2016/01/BNEF-2015-Annual-Investment-Numbers-FINAL.pdf

The report's key findings

Low carbon generation technologies are cost competitive. Nuclear is now one of the cheapest options for power generation when lifecycle costs are taken into account, and 70% of renewables respondents say that renewables are reaching cost parity with fossil fuels.

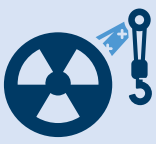
Solar cell technology is likely to have a major impact, and soon. Renewables respondents are most optimistic about the potential of advances in solar cell technology – and the likelihood of adoption.

The potential contribution of small modular reactors (SMRs) is unclear at this stage, although their impact will most likely apply to smaller grids and isolated markets. However, the underlying modularisation technology is expected to have a major impact on the sector.

Nuclear will continue be part of the solution to climate change long into the future. Although public acceptance is a major challenge in some countries, nuclear is likely to contribute to the energy mix for the foreseeable future.

Software advances will be instrumental in transmission and distribution. They are seen by respondents as the innovation that will be the quickest to arrive and the most likely to be adopted. Indeed, blockchain could reshape the way we think about the transmission and distribution of power by enabling a new era of peer-to-peer low carbon generation.

It is electrical technologies that will transform storage, rather than mechanical storage or chemical technology innovations. In particular, respondents expect supercapacitors, which will rapidly speed up charging times for large batteries, to have the greatest impact on storage.



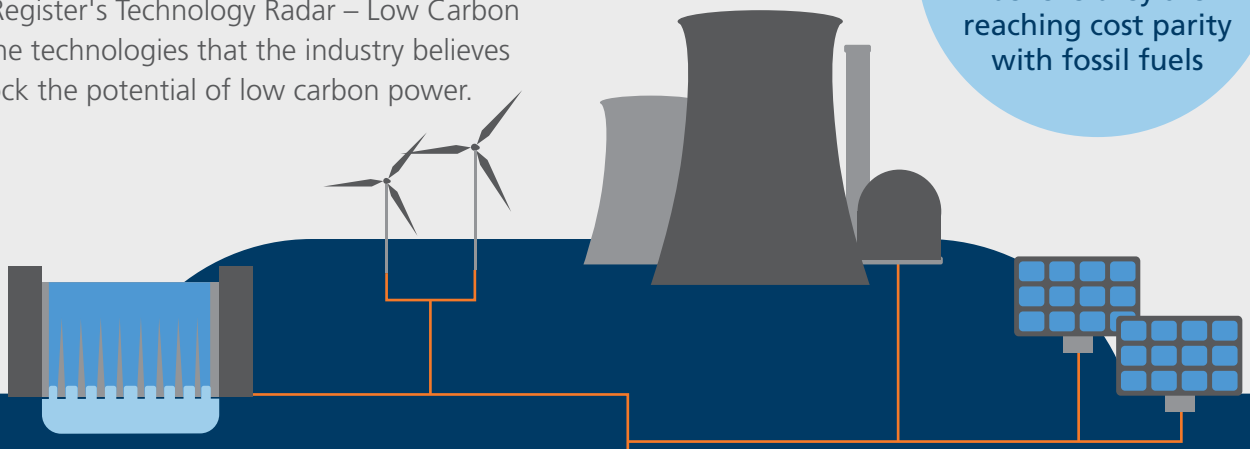
Deployment is a major barrier. Implementation of technology in both nuclear and renewables is hindered by deployment, and each sector faces its own distinct challenges here.

Standardisation is a much-needed development for the low carbon sector. Industry experts agree that regional and global consensus on regulations could speed up deployment and further reduce costs.

Technology's role in a low carbon future

70%
of respondents from the renewables sector believe they are reaching cost parity with fossil fuels

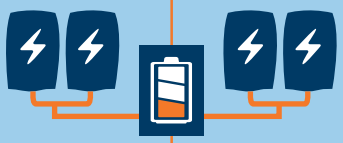
Lloyd's Register's Technology Radar – Low Carbon shows the technologies that the industry believes will unlock the potential of low carbon power.

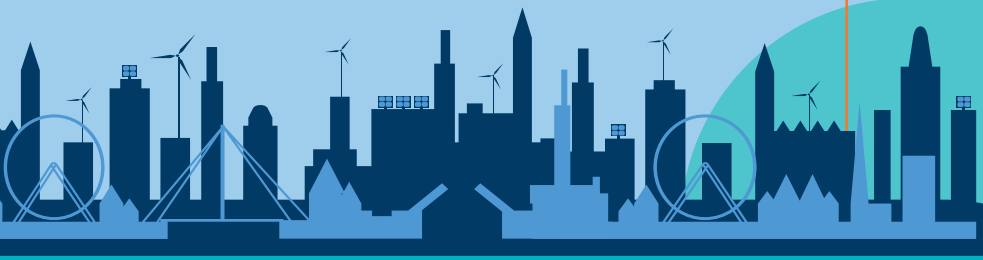


The next generation of solar cells will focus on improving energy conversion efficiency. Further off, new wind turbine technologies will lead to ever more powerful wind capacity

Energy trading will be boosted as high voltage direct current (HVDC) advances improve the distances that low carbon energy can travel between communities

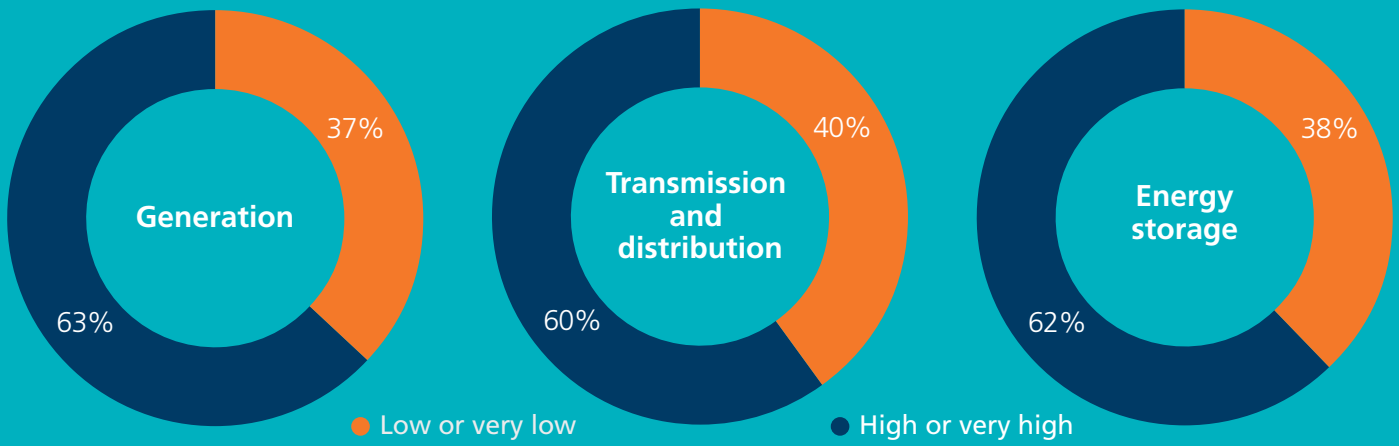
Software advances will soon improve the efficiency of existing battery storage – in the long-term, expect to see new types of supercapacitors to store even more energy, and for longer





Blockchain could play a major role in the way individuals trade energy between one another

What is the rate of technological innovation you are currently seeing in each of the following areas?

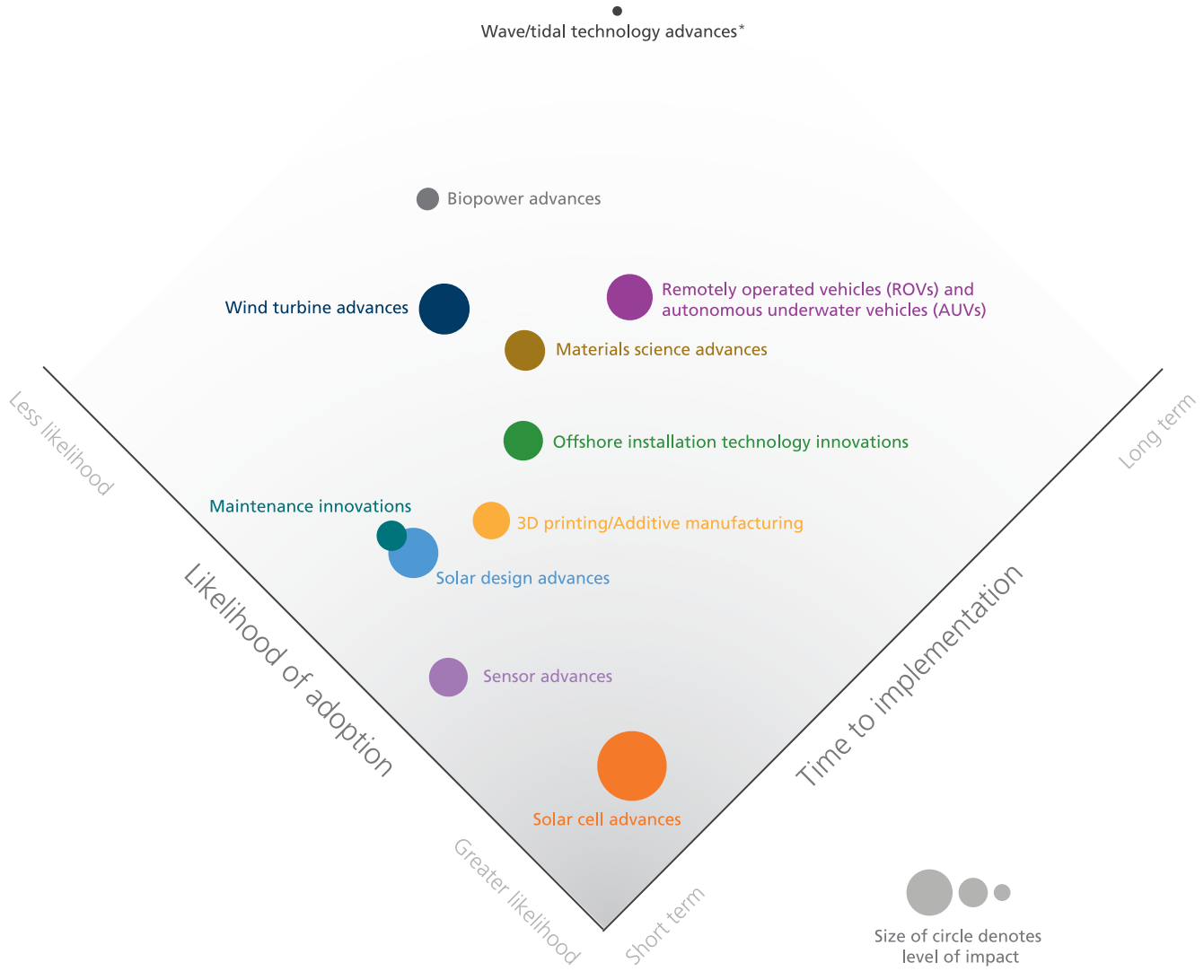


Section 1

The future of low carbon technology

The low carbon technologies assessed in this report span four areas: renewable technologies, nuclear technologies, transmission and distribution technologies, and energy storage technologies. This section reviews the outlook for each.

Renewables



*our survey was in the field before the Swansea Bay Tidal Lagoon development was announced in the UK

Solar

According to the results of our technology radar, solar cell advances are viewed as the innovation most likely to be adopted in the short term by the renewables sector, and they are expected to have a major impact. This chimes with current developments in solar power generation, as research teams around the world compete to improve photovoltaic (PV) design.

A major area of focus for researchers at the vanguard of solar cell development is extending the durability of perovskites. A compound of these new solar cells can be painted or sprayed on to surfaces, and is thinner and cheaper to manufacture than silicon crystals (which are widely used in the PV cells currently on the market). Meanwhile, a different technology, which uses a photothermal process – which enables not only light but also heat from the sun to be captured and converted into electricity – is also edging closer to commercialisation. MIT published a groundbreaking study in 2016 proving that solar thermophotovoltaics (STPVs) could beat the traditional maximum efficiency of solar cells (which is slightly over 30%).[2] This makes it theoretically possible for a given area of panels to supply twice as much power as they do currently. Clearly, innovation will reshape how we think about the effectiveness of solar in the years ahead.

Wind

Survey respondents also view advances in wind turbine technology favourably. However, despite respondents believing that these developments will have a high impact, they were less sure about how long they will take to get to market, and how likely they are to be adopted.

Many of the innovations currently being developed are incremental improvements on current technology – for example, better ways to anchor large offshore turbines, or larger turbines with more generation capacity. For Thomas Choisnet, Chief Technology Officer at Ideol, innovation is unlikely to be the cause of any radical change in the field in the near future. "With wind turbine innovations, I don't see many technologies in development that would transform the way we connect wind power and transform it into electricity except turbine size increases," he explains. "It took turbine manufacturers a few decades to reach the current level of reliability and quality."

Even though innovators in both offshore and onshore wind have some common development goals – lighter machines and bigger rotors are priorities for both – multiple factors such as 'NIMBY' (not in my backyard) syndrome and a constraint on available land use separates the two sources.

Some developed countries have already witnessed a withdrawal of government support for onshore wind, forcing generators to either scrap their projects or look for innovative financing methods – such as co-financing with local communities – to keep them afloat.

The falling cost of solar

It is efficiency that is now the determining factor for the next-generation solar panel, as cost-related challenges have now largely been overcome.

Swanson's Law[3] dictates that every time the global manufacturing capacity of PV cells doubles, their cost falls by approximately 20%. The real figure, according to Bloomberg New Energy Finance's solar PV experience curve, is in fact a little over 24%. These economics – costs have fallen by more than 80% in less than a decade – have made solar to become the cheapest form of renewable energy in the world.

2 http://news.mit.edu/2016/hot-new-solar-cell-0523
3 https://www.ft.com/content/d9f9f1b4-a3f0-11e5-873f-68411a84f346

Nuclear

A number of the experts we interviewed as part of this report are optimistic about the impact of small modular reactors (SMRs) on the nuclear sector, but Lloyd's Register's Technology Radar – Low Carbon results suggest otherwise.

Survey respondents say that SMRs will only be seen in the medium term, have a low likelihood of eventual take-up, and will have a low impact when they arrive. According to Tom Greatrex, Chief Executive of the Nuclear Industry Association and former shadow energy minister in the UK, however, this isn't stopping governments from investigating their potential. "SMR technology could potentially provide flexible low carbon generation, which would complement baseload from larger nuclear plants," he explains. "There is a very strong interest in the technology being shown right now and the UK government are running a competition which might have a quite significant impact in the medium term."

Nuclear is seen by many as a key source of low carbon power – hence the interest in new technologies that could potentially reshape the sector. "Nuclear should be working hand in hand with renewables," says Lady Barbara Judge CBE, Chairman of the Institute of Directors and Chairman Emeritus of the UK Atomic Energy Authority. "You

> "There is a very strong interest in the technology being shown right now and the UK government are running a competition which might have a quite significant impact in the medium term."

Tom Greatrex
Chief Executive of the
Nuclear Industry Association

can't have renewables alone – they don't provide baseline generation – but we could do them together, and that would be a good thing." Appetite among survey respondents for SMRs could be lower than expected because they anticipate that it is the technology driving them – which was also included in the poll – that will have the more significant impact. Modularisation technologies, our survey respondents predict, will hit the market sooner than fully fledged SMRs, are more likely to be implemented, and will have a much greater bearing on the sector. "There will be challenges for SMRs to deliver on all of their promise and be the radical change to the industry that people are hoping," says Daniel Grosvenor, Head of Energy, Advisory Corporate Finance at Deloitte UK. "However, the focus on modular and more efficient construction techniques and building the UK supply chain could make a real difference across the sector."

Technologies that respondents expect to have the greatest potential impact on the nuclear sector are waste storage innovations and resistant alloys to boost lifecycle, although respondents believe that the latter will take longer to reach the market.

The challenges around waste storage are also cited as a major impediment to introducing new nuclear power – ahead of concerns over safety. A more in-depth analysis of nuclear technologies can be found in the companion report: Lloyd's Register Technology Radar – The Nuclear Perspective.

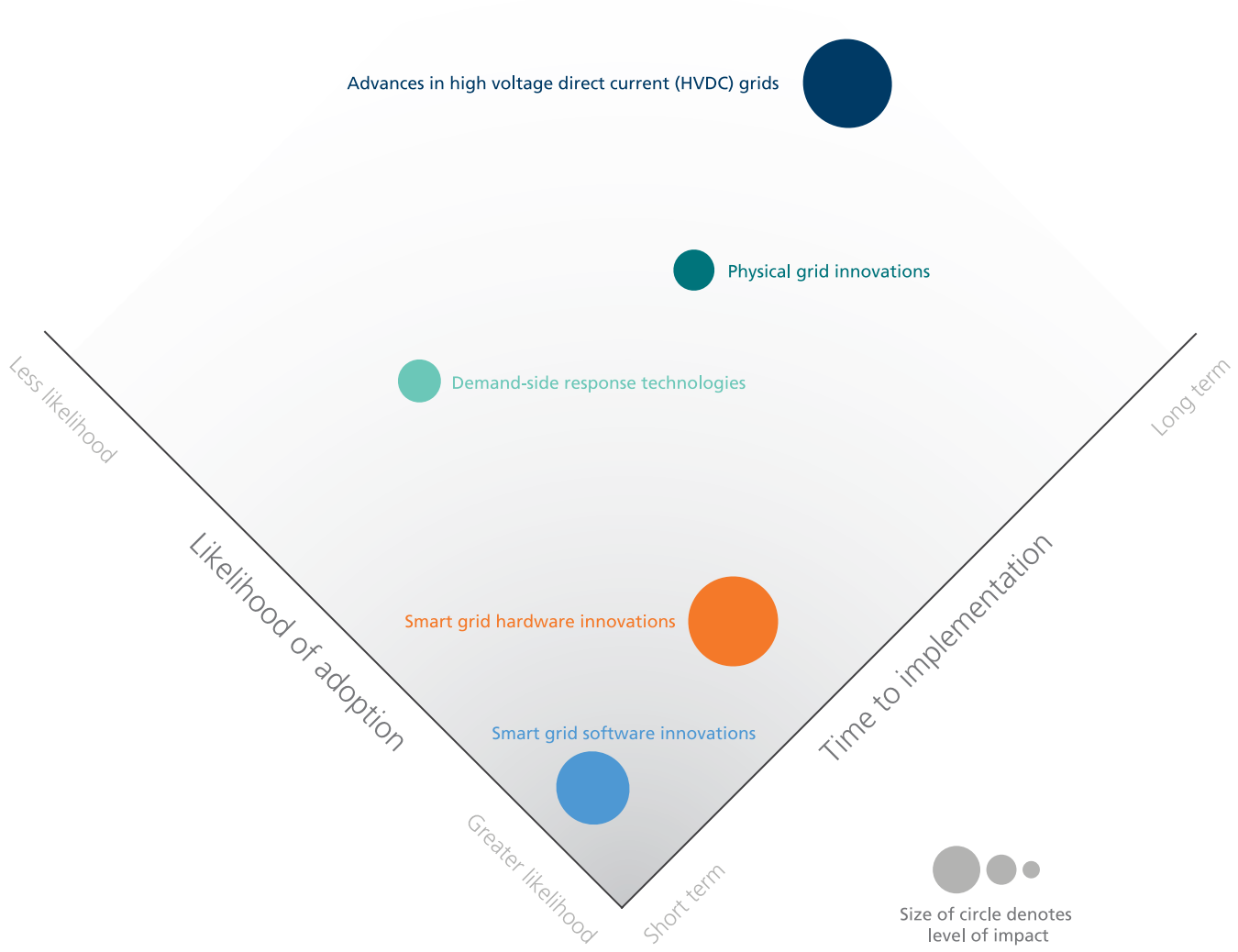
Transmission and distribution

Although respondents in the Lloyd's Register Technology Radar – Low Carbon predict that smart grid hardware will have a slightly greater impact, they say that software innovations will reach the market faster and are more likely to be adopted.

One of the biggest software innovations is blockchain, a distributed ledger technology that could prove hugely disruptive to current transmission and distribution hierarchies. The first ever blockchain energy transaction took place in the US early in 2016, when a pilot project by US start-up LO3 Energy enabled a New York City resident to generate their own solar power and sell it to a neighbour. Over the next decade, blockchain has the potential to tap into the sharing economy and unlock a vast, decentralised energy marketplace.

New market entrants

As the expertise involved in these projects is not specifically industry-related, it could provide an opportunity for new market entrants. "Some of the future innovators or disruptors in transmission and distribution may well be technology companies, rather than utilities or traditional



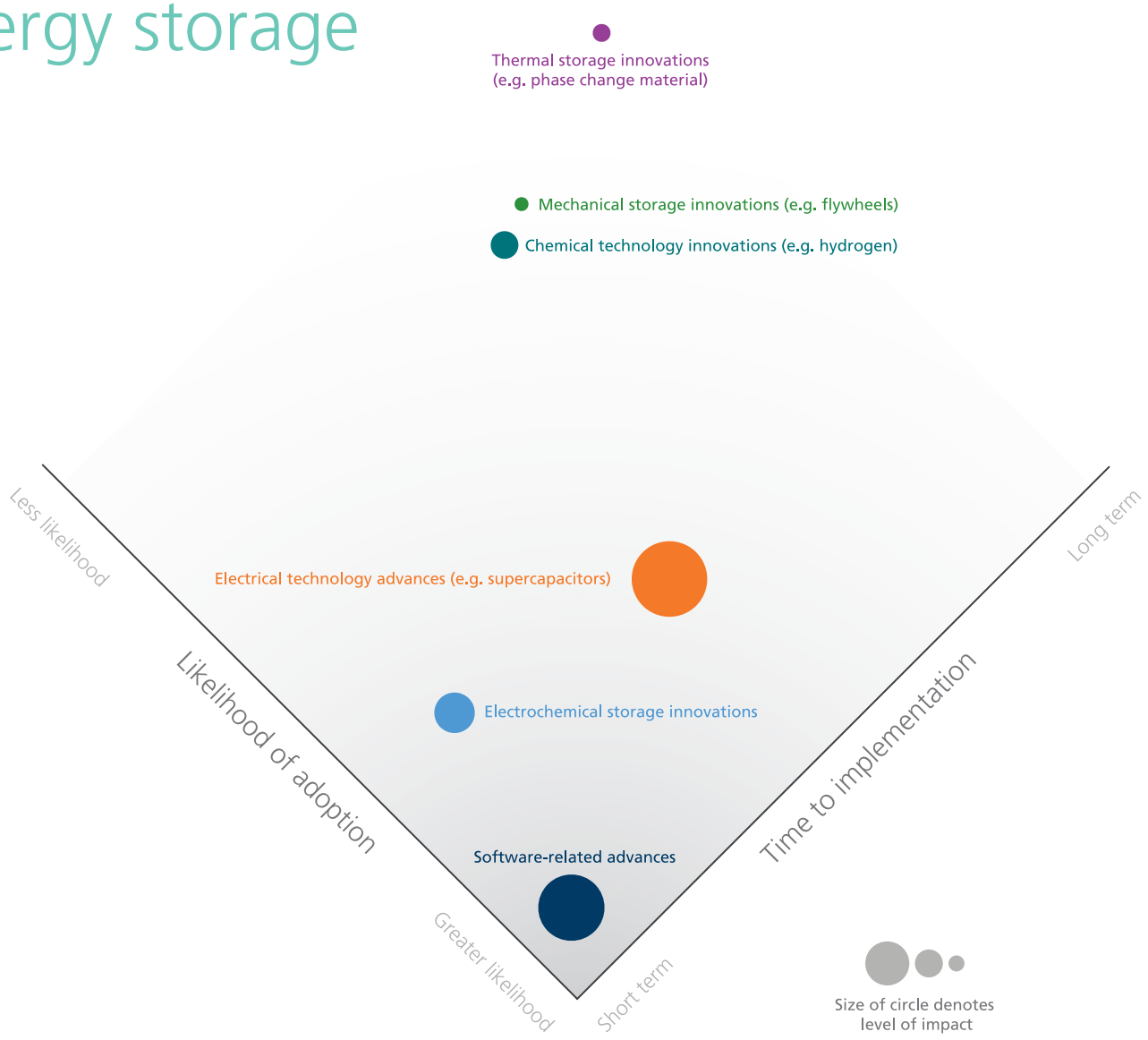
suppliers to the energy sector," predicts Deloitte's Daniel Grosvenor.

A number of utilities have already taken measures to counter the threat posed by these new entrants. Vattenfall, one of Europe's largest power generators, has launched its own energy sharing marketplace called Powerpeers,[4] which takes the peer-to-peer feature a step further by connecting to the mobile communications platform WhatsApp. German utility firm EnBW, meanwhile, has invested in a start-up energy cooperative,[5] and Siemens has started collaborating with LO3 Energy to jointly develop blockchain-based microgrids.[6]

By improving long-distance transmission and grid infrastructure, high-voltage direct current (HVDC) – another innovation included in our technology radar – offers opportunities for communities that are unable to absorb all of their local energy supply. For regions struggling with renewable energy overcapacity, such as northwest China, these power superhighways and grids cannot come fast enough. While HVDC transmission lines are commercially available and are already supplying power over land and under sea, the technology radar shows that HVDC grid advances could have a major impact, but are a long way from market readiness.

4 http://news.vattenfall.com/en/article/vattenfall-launches-energy-sharing-marketplace-powerpeers
5 https://www.enbw.com/company/press/press-releases/press-release-details_10302.html
6 http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2016/energymanagement/pr2016110080emen.htm&content[]=EM

Energy storage



Respondents to our technology radar predict that the next innovation to shake up energy storage will be software-related. This makes sense: software improvements are an 'easy fix' to boost the efficiency of current storage technologies, and are easier to push out to market than new storage hardware.

Although our respondents also expect innovations in electrochemical storage to arrive in the short term, they predict that their impact will be relatively limited. Respondents perhaps feel that new innovations in this area will not have as much impact as improved economies of scale with existing batteries. Tesla's 'Gigafactory' in Nevada, which is due to start producing in-house-manufactured battery packs this year, aims to reduce production costs by 30%. This effort alone is projected to boost the North American electric vehicle market by around 60% in 2017,[7] and with Tesla also making forays into domestic energy storage through its Powerwall and Powerpack products, the potential is there for existing technology to have a huge impact on the energy sector. The storage technology that respondents believe will have the biggest impact is electrical technology such as supercapacitors, which will rapidly speed up charging times for large

7 http://www.navigantresearch.com/research/electric-vehicle-geographic-forecasts
8 http://www.electricvehiclesresearch.com/articles/6750/next-supercapacitor-advances-will-transform-electric-vehicles

batteries. The supercapacitor materials market is growing rapidly, and it is estimated that it will be worth $5 billion by 2025. Industry experts believe that best energy density within supercapacitors will be achieved before 2030.[8]

Section 2

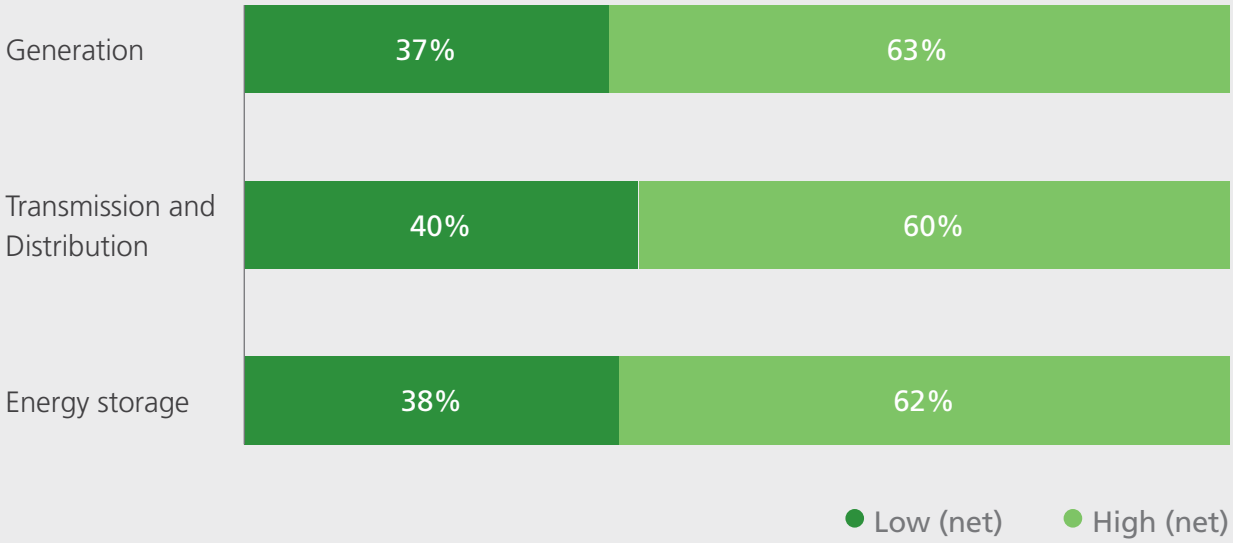
Assessing the pace of low carbon innovation

Across each of the three areas of generation, transmission and distribution, and energy storage, more than six in 10 of the executives polled believe that the pace of innovation is fast.

There is a large appetite for new and emerging technology in both nuclear and renewables, but it is nuclear respondents (67%) who say that the scale of their investment has increased most over the past couple of years.

As for the physical deployment of renewable energy sources, 71% of respondents agree that they have seen an overall increase over the past two years. The global installation of renewable power capacity did in fact surge in 2015, rising 30% from the previous year.[9]

Chart 1: In your view, what is the rate of technological innovation that you are seeing right now in each of the following areas?



9 https://www.iea.org/newsroom/news/2016/october/medium-term-renewable-energy-market-report-2016.html

The effect of COP21 and geopolitics

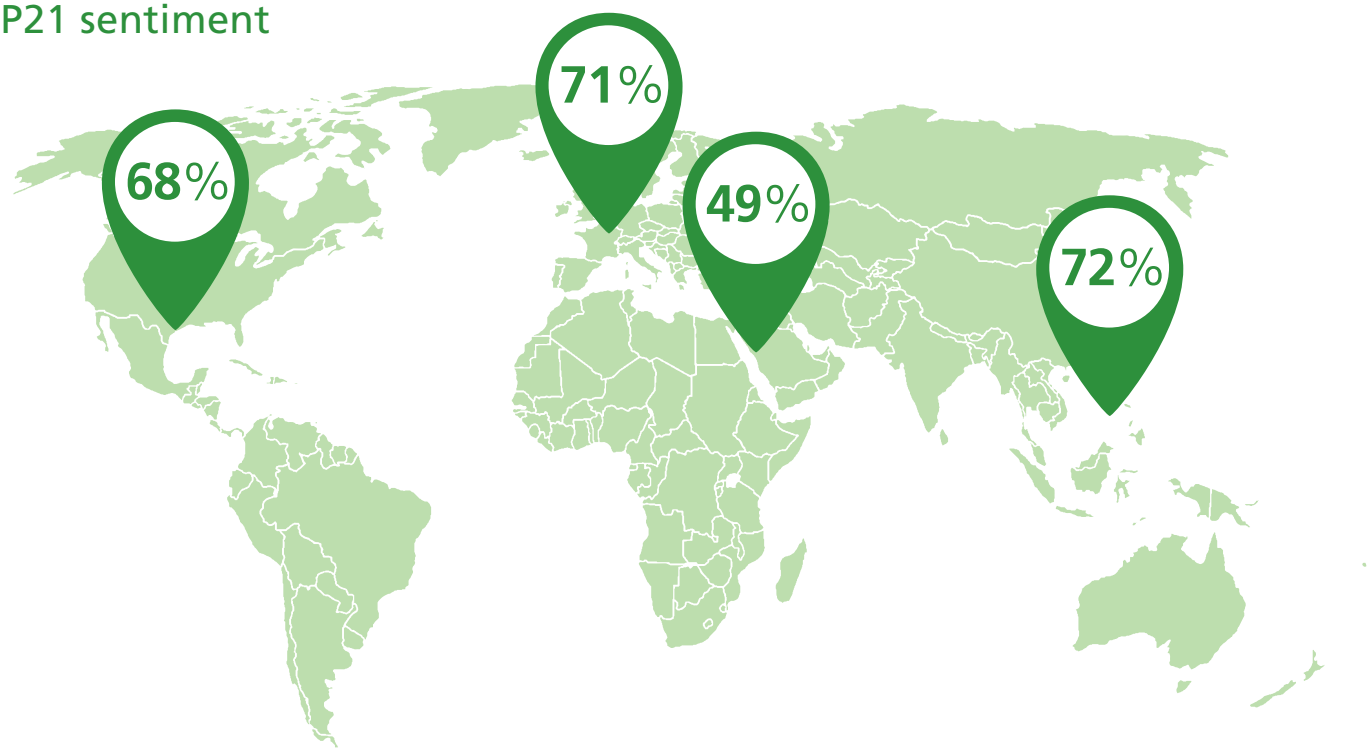
COP21 appears to have influenced the upward curve in deployment, and nearly two-thirds of respondents believe it has had a major impact on the global uptake of renewables. In addition to outlining carbon reduction objectives, the climate accord, which came into effect just before the COP22 meeting, is credited with highlighting the growing urgency around climate change.

Professor Richard Clegg, Foundation Chief Executive of the Lloyd's Register Foundation, believes that the agreement that came out of COP21 served as a catalyst for evaluating awareness of decarbonisation and energy security – and is leading to more countries contemplating nuclear as a viable low-carbon power source. "People are essentially looking over the edge of the cliff and thinking, 'I don't want to go there,' and so they begin to think differently about all the options, including nuclear," he says.

Regionally, the Middle East is the least likely to share the COP21 sentiment: only 49% of respondents there agree or strongly agree that it played a major role; compare this with respondents in Asia Pacific (72%), Europe (71%), and North America (68%).

It is difficult to say with certainty whether geopolitical factors affected these regional differences. For example, our survey was in the field during the US presidential election, so the results reflect Donald Trump's victory. Although in the immediate aftermath of the election the value of stocks of notable renewable energy companies Vestas and SolarCity fell, growing global confidence in low carbon generation may balance this out in the medium to long term. In the US, it remains to be seen whether federal policy can override the powerful market-driving forces behind renewables within individual states – California in particular.

COP21 sentiment



> People are essentially looking over the edge of the cliff and thinking, 'I don't want to go there,' and so they begin to think differently about all the options, including nuclear.

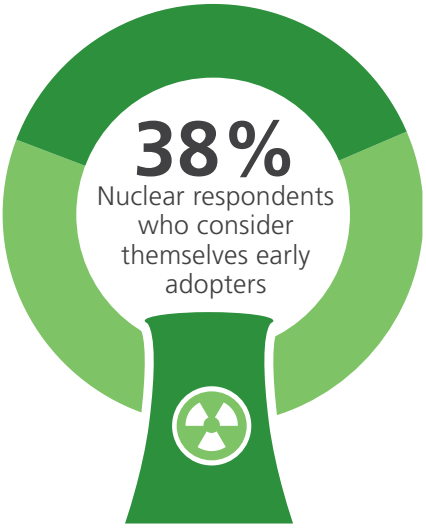
Professor Richard Clegg
Foundation Chief Executive of the Lloyd's Register Foundation

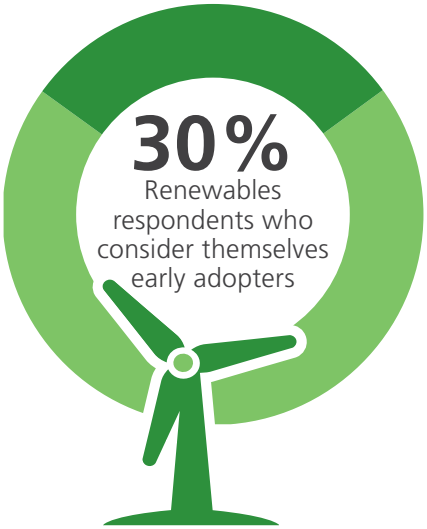
What does it take to be an early adopter?

Most of our respondents identify themselves as 'fast followers' rather than 'early adopters', which can be partially explained by low carbon project economics: only certain players can afford to take on the risks that come with testing new and emerging technologies, while securing sufficiently low borrowing rates.

Our survey also reveals that there are more early adopters in nuclear (38%) than in renewables (30%), although respondents in both sectors see themselves predominantly as fast followers. Nuclear respondents in Asia Pacific account for the most significant regional variation – only 16% consider themselves to be early adopters, and 60% fast followers.

The disparity between innovation ecosystems for renewables and nuclear, particularly in regard to their investor bases, is starting to narrow. Historically, the bulk of international funding for advanced nuclear R&D has been government-led, with most work contained in national laboratories. However, the private sector has begun to close this gap, with public-private partnerships seen as one solution to the lengthy gestation times that hamper nuclear development.





In the US and Canada, tech firms involved in nuclear innovation have attracted over $1.3 billion in private capital.[10] Private investors such as Bill Gates and Li Ka-shing have been investing in nuclear technologies for some time now; one of the companies that Gates has invested in, TerraPower, has been working on a generation IV (the next generation of nuclear reactor technology) travelling wave reactor that generates power from depleted uranium.

Our survey reveals that equipment manufacturers are unanimously viewed as the greatest innovators in the supply chain. Brent Cheshire, Country Chairman of DONG Energy in the UK, shares this sentiment, and credits DONG's relationship with OEMs as a key success factor. "If you're a first implementer, you have to work closely with OEMs because the technology investment is not yours, but theirs," he says. "So we have many iterative conversations with them around costs, and market and pipeline size, in order to drive that investment."

Last year, DONG secured development consent for the world's largest offshore wind farm, Hornsea Project Two. It's a cyclical process: "You've got the volume and purchasing power," explains Cheshire. "Which allow the cost curve to be driven down, which then allows governments to be more comfortable about offering more wind-farm licences or offshore licences."

10 http://www.thirdway.org/report/the-advanced-nuclear-industry

Chart 2: Which of the following best describes your company's speed at adopting new renewable technologies and innovation?

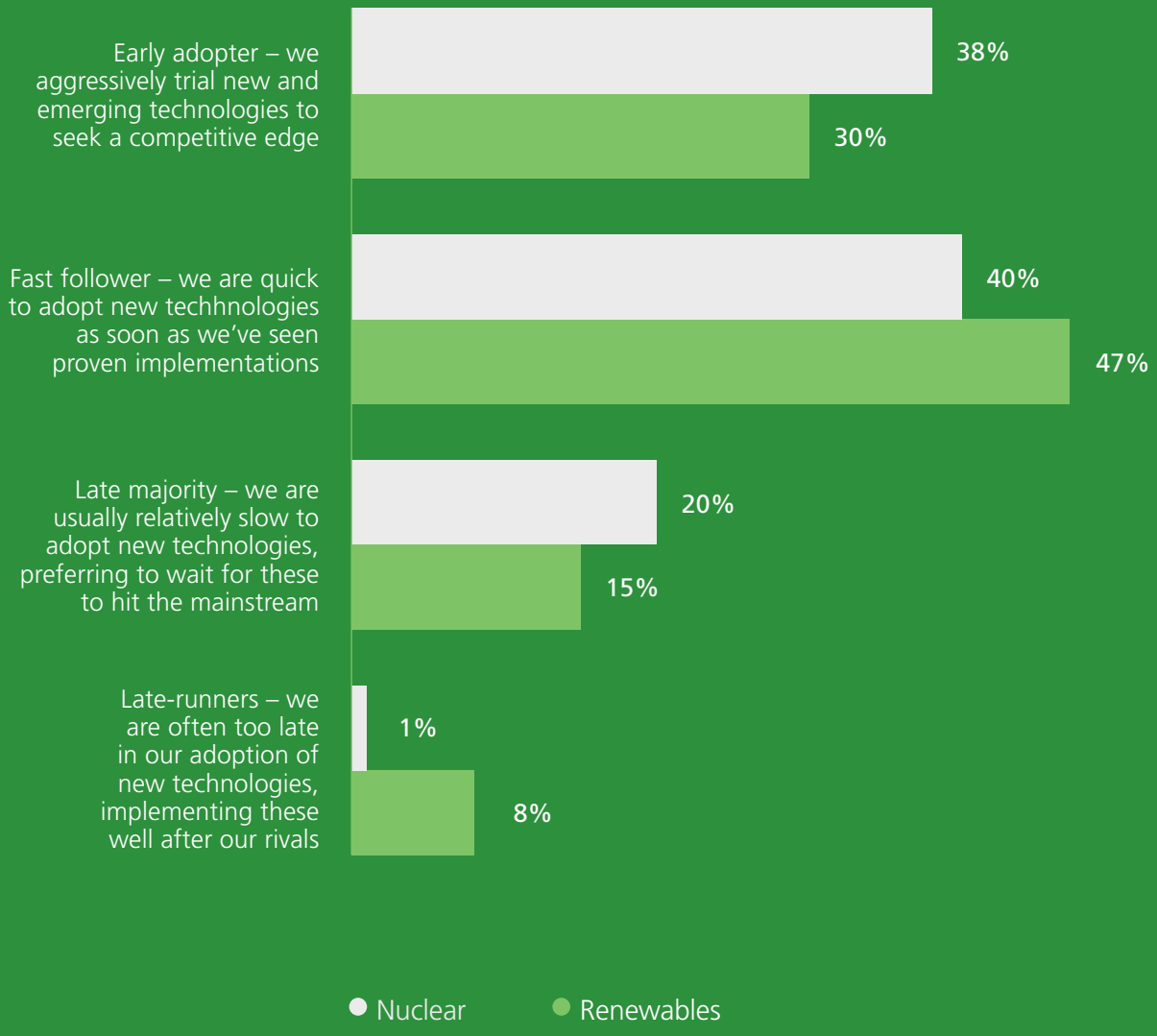
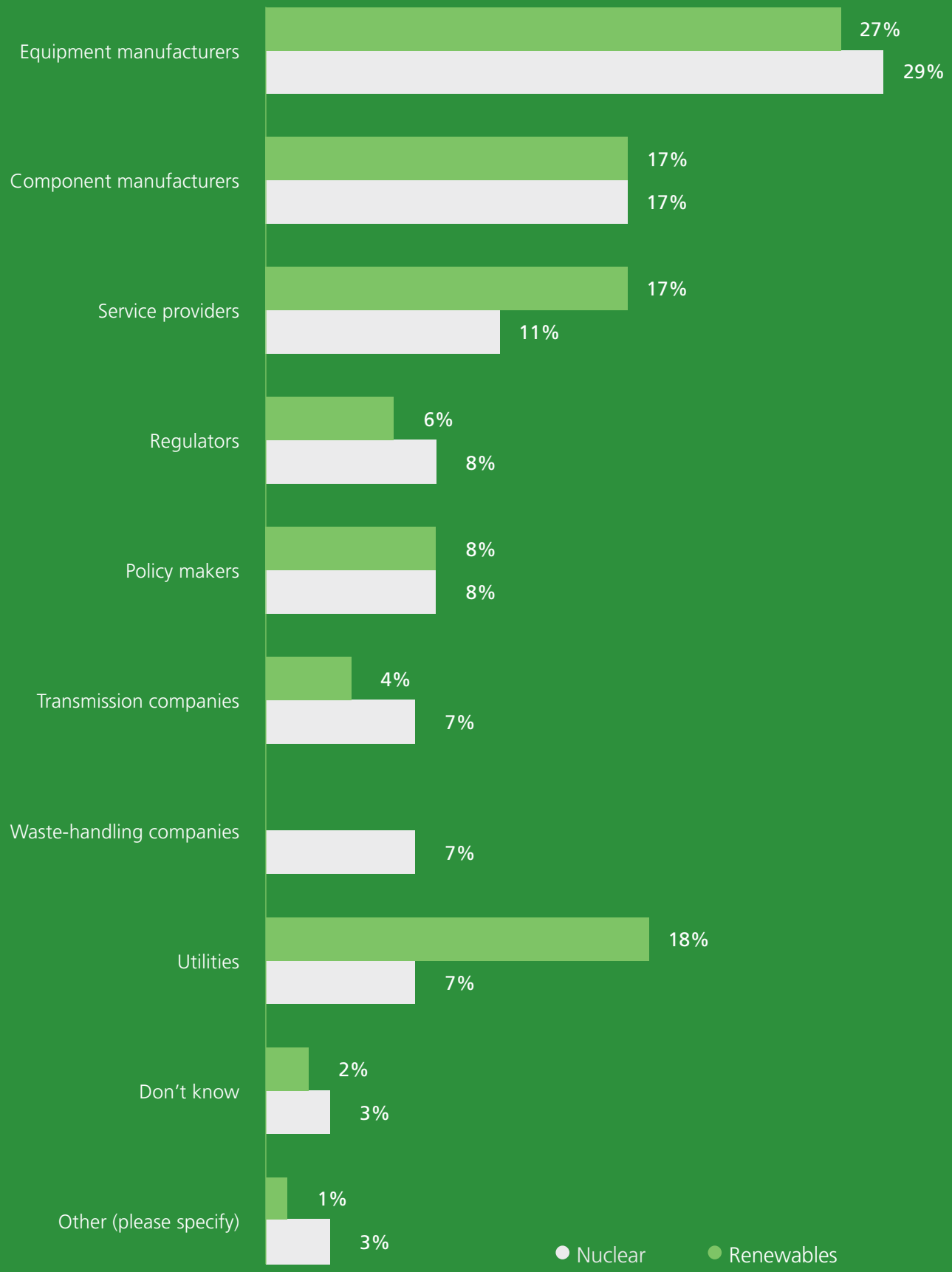


Chart 3: Thinking specifically about the segment in which you operate, where do you think the most innovation is happening in nuclear/renewable energy?



Section 3

Barriers to implementing a low carbon agenda

Driving down the cost curve

The World Economic Forum estimates that in more than 30 countries renewables have already reached cost parity without subsidies, and that two-thirds of the world should get there in the next few years.[11]

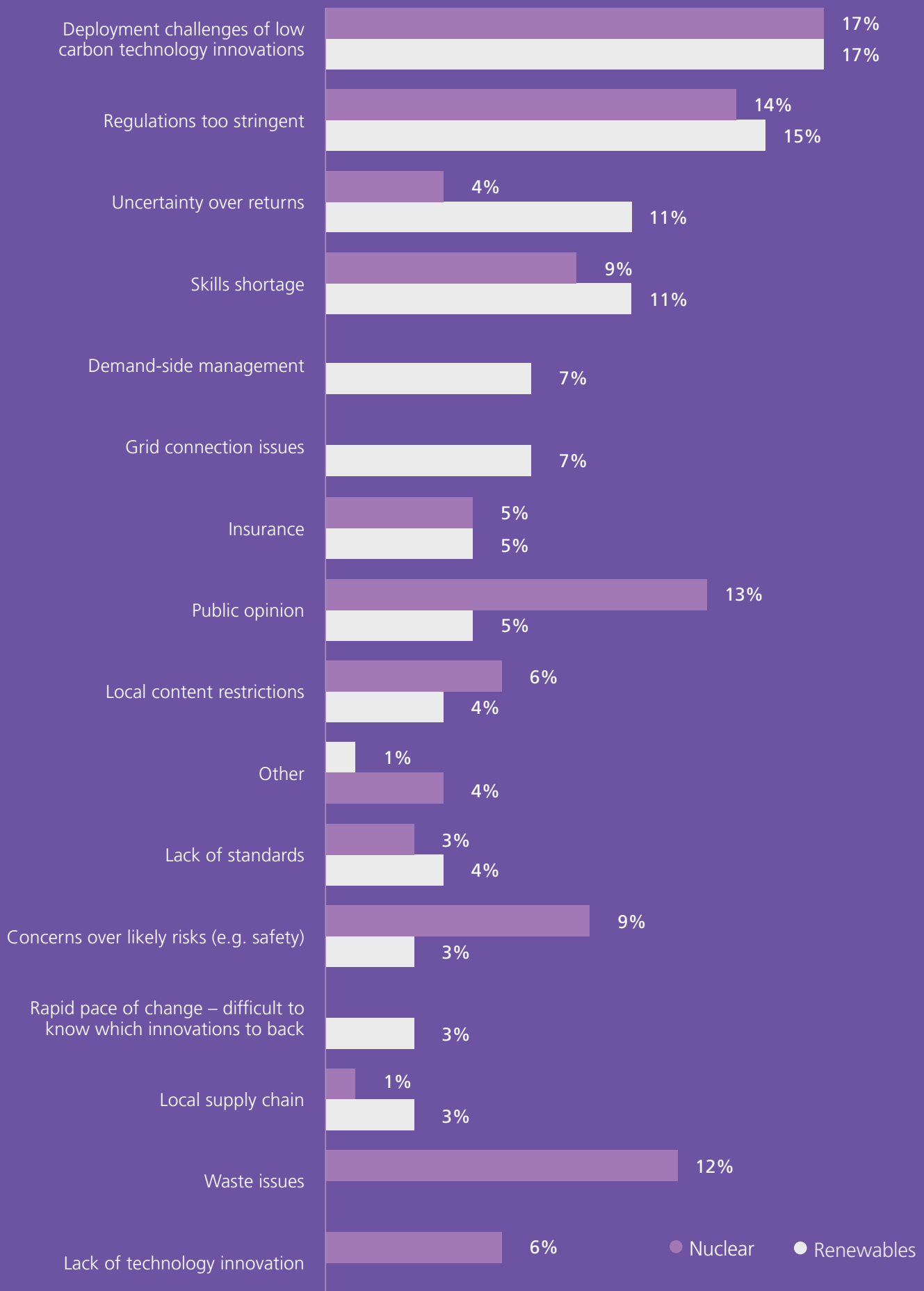
Our survey results largely reflect this, with 70% of renewables respondents agreeing that renewables are reaching cost parity with fossil fuels. At the same time, 64% of nuclear respondents envision nuclear as a necessary source of energy supply – despite its cost premium over fossil fuels.

Development costs, however, are still seen as the main barrier to low carbon generation: 74% of renewables respondents and 61% of nuclear respondents are of this opinion. On the renewables side, this is more strongly felt in Asia Pacific (85%) and North America (84%) than in Europe (61%). The Middle East is the region least likely to consider cost a significant barrier; instead, respondents cite stringent regulations as the leading obstacle.

In Europe, cost is much less of an issue for implementing nuclear technology than in North America – this may be because of investments like Hinkley Point in the UK which show an appetite for new nuclear development in some European countries. Only 47% of respondents in Europe consider cost to be the main barrier, compared with 80% in North America, 69% in the Middle East, and 58% in Asia Pacific. Our European respondents instead say that their biggest barriers to progress are public opinion (17%), too-stringent regulations (17%), and deployment challenges (16%).

11 http://www3.weforum.org/docs/WEF_Renewable_Infrastructure_Investment_Handbook.pdf

Chart 4: In your opinion, aside from cost, what do you think is the most important barrier to progress in introducing renewable/nuclear technologies?



Tackling deployment issues

Just 47% of European nuclear respondents believe that cost is the biggest challenge they currently face, so there are clearly other barriers to progress in the sector. This is also true for renewables: aside from cost, deployment is highlighted as the main challenge for both nuclear and renewables respondents (see Chart 4 on page 29).

In the nuclear sector, the varying appetite for nuclear power around the world has created boom-and-bust cycles. In the down cycles, a lot of valuable deployment expertise is lost, along with project execution capabilities and sustainable supply chains. For more information on the deployment challenges faced by the nuclear sector, see our companion report: Lloyd's Register Technology Radar – The Nuclear Perspective.

As a relatively young sector, renewables faces a different set of deployment challenges relating to a lack of available skills (particularly in developing markets[12]), land acquisition and regulatory approval challenges. In the US, for example, which in 2016 was the world's fifth biggest generator of solar power, officials are still undecided about the viability of offshore wind power, with demonstration projects such as that of Fishermen's Energy in New Jersey already failing this year to receive approval from the US Department of Energy.[13] The sector must find better approaches to dealing with stakeholder and regulatory communities – especially given the expansive geographical footprint demanded by large-scale solar and wind projects.

13%

Nuclear respondents who say that public opinion is the most important barrier to progress after cost

12 https://www.irena.org/documentdownloads/OkinawaMay2012/18_Robert%20Guild_ADB.pdf
13 http://www.powermag.com/doe-ditches-another-offshore-wind-demonstration-project/

The role of government in innovation

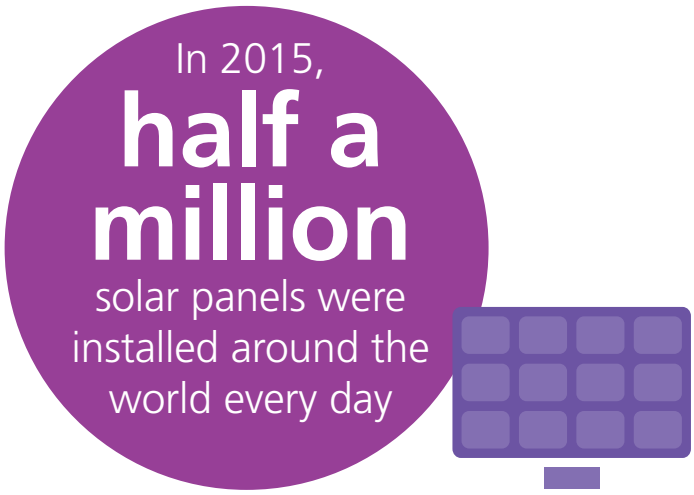
Survey respondents across the board are sceptical about government's role in innovation. Just 8% of both nuclear and renewables respondents say that policy makers are leading innovation efforts, with almost identical figures for regulators (see Chart 3 on page 26).

These two stakeholder groups are mandated with creating environments conducive to innovation, and this lack of confidence shows that there is room for improvement.

Regulators, however, are also responsible for creating standards, and in renewables these have driven the cost curve down and contributed to the rapid growth of the solar and wind industries – in 2015, half a million solar panels were installed around the world every day.[14]

The nuclear sector, however, has been unable to achieve anywhere near the same deployment rate. "There's been a cry for a long time from people saying, 'If we could just standardise, we could drive down cost per unit,'" explains David Scott, Advisor to the Chairman at the Abu Dhabi Executive Affairs Authority and a director on the boards of several firms operating in the nuclear industry. "And the challenge is that you have opposing regulatory regimes in different parts of the world that operate against standardisation. In that environment, perhaps the most promising path to 'scale effects' is larger individual projects, such as the UAE's four-unit project at Barakah, which has demonstrated significant efficiency gains from Unit 1 to Unit 4. This may suggest that the future could see more utilities aggregating demand and pursuing larger, geographically concentrated projects to hedge against first unit risks."

And while just 3% of nuclear respondents cite 'lack of standards' as the main challenge associated with introducing nuclear, industry opinion leaders believe that the complexity of the nuclear regulatory system has prevented it from reaching economies of scale. As Serge Gorlin, Head of Industry Cooperation at the World Nuclear Association, puts



14 https://www.ft.com/content/09a1f984-9a1d-11e6-8f9b-70e3cabccfae

it, "For almost a decade now, the industry has advocated a more harmonised regulatory system, so that the whole process of reactor design evaluation, for example, in one country does not have to be repeated in another."

Government support

Subsidies and other incentives programmes set by policy makers have undoubtedly contributed to the move towards grid parity with fossil fuels. There are multiple reasons for designing subsidy schemes: supporting new sources of energy supply, ensuring energy security, social welfare protection, and job creation. And in the right circumstances the eventual elimination of support programmes should increase competition and foster supplementary innovation in renewables. Pulling out too soon, however, is risky and can damage investor confidence. Policy makers are also responsible for green-lighting major infrastructure projects that set precedents for future utility-scale deployment.

Transmission and distribution are decidedly in need of additional government innovation, according to both renewables and nuclear respondents. As the power markets continue to undergo their shift towards a more decentralised generation system, a sure-fire path to market has to be designed for alternative suppliers.

"One of the challenges that we get quite regularly as the UK independent regulator is 'Why can't nuclear technologies be regulated internationally, and save these designs from having to be independently assessed by each individual country as they're proposed for deployment?' While recognising that regulatory bodies have to respect their sovereign regulatory decision-making duties, there is a challenge for the regulatory community to maximise its cooperation arrangements and sharing of assessment experience, building on the well-established Multinational Design Evaluation Programme."

David Senior
Executive Director Assurance, Policy & International, Office for Nuclear Regulation

Case study

The UK low carbon market

The UK, a global leader in offshore wind, has sent a strong message about its low carbon agenda by approving two significant projects: the world's largest offshore wind farm and its first nuclear power station in more than 20 years. Nevertheless, industry sentiment has been shaky following the Brexit vote and the new administration's total overhaul of the energy department.

Effective renewables integration depends on regulation, and the UK has already experienced certain downsides of wholesale power markets, such as negative pricing.

The executives we interviewed, however, are not worried. "The UK regulatory regime is designed in a much more adaptable way than some other markets internationally, and is quite well placed to be able to take account of and respond to and be flexible to new technological developments," says the Nuclear Industry Association's Tom Greatrex.

Sandy Butterfield, President of Boulder Wind Consulting, believes that many European countries, the UK included, are better placed than the US, where "certain utility 'area control' regulations inadvertently penalise renewable energy by constraining generation areas and restricting trading power across certain boundaries."

Trouble ahead

But the UK electricity system's elasticity could be threatened in coming years by an energy tariff that could be placed on power imports from and exports to the EU as a result of Brexit. Since shutting down many of its coal-fired power plants, the UK has bet on interconnectors to meet its energy needs sustainably – 10.5GW of new interconnector capacity is planned to go online by 2025, from a current level of 4GW.[15] This new tariff scenario could call into question the economic viability of the UK's large amounts of gas storage in the EU.

This scenario of fewer storage assets and the erosion of market coupling could have a negative effect on security of supply, grid flexibility, and ultimately slow the uptake in renewables in the short to medium term. This is not the only challenge that remains for the low carbon agenda in the UK: current energy efficiency and renewable energy policies only take the country half way towards meeting its 2030 Carbon Budget targets.[16]

Nuclear may be the answer here, and indeed, the UK has the most active nuclear build programme in the western world, with six nuclear power plants planned and investment from French, Chinese, Japanese and American companies. The UK government is also actively investigating the potential of SMR technology through a competition to identify the best-value SMR design.

15 https://www.ofgem.gov.uk/electricity/transmission-networks/electricity-interconnectors
16 The 2016 UK Energy Productivity Audit

> “I think from a decarbonisation point of view, the UK is pushing quite hard on the power sector through a combination of nuclear and renewables.”

Daniel Grosvenor
Head of Energy, Advisory
Corporate Finance
Deloitte UK

Time to tackle innovation, deployment and investment

The Lloyd's Register Technology Radar – Low Carbon shows that innovation will be critical to addressing the challenges of decarbonisation. And since energy markets must operate within policy and regulatory frameworks, governments should play a larger role in innovation and send out the signals that enable a smooth transition from a centralised, fossil fuel-driven model to a more flexible, decentralised, and steadily decarbonising one.

The Lloyd's Register Technology Radar – Low Carbon also shows that deployment of technology is the key constraining factor: while the renewables sector has benefited from standardisation, nuclear power generators struggle to achieve economies of scale and face prevailing issues surrounding public opinion. Advances in waste storage, more effective communication strategies, and a more market-driven model of development for nuclear reactors would invigorate the nuclear sector. This is critical: without new nuclear generation (representing a 17% share by 2050, according to the IEA), it will be impossible to transition to a low carbon economy while maintaining affordability and supply.

Global spending will also need to rapidly increase to meet carbon targets and curtail adverse climate change effects. In 2015, asset finance of utility-scale projects represented 60% of the record-level clean energy investment flows, but one class of investors was mostly absent: less than half a percent of clean energy investment came from institutional investors,[18] despite the risk-return profile approaching that of utilities when compared with high-risk emerging technologies.

Impact funds are increasingly demonstrating market-rate returns, and some investors are divesting from hydrocarbon-related businesses, so capital is increasingly being freed up. Private equity, pension funds and sovereign wealth funds could be brought into the fold of potential investors – and help to close the low carbon gap.

18 http://www3.weforum.org/docs/WEF_Renewable_Infrastructure_Investment_Handbook.pdf

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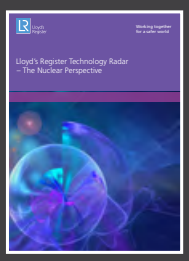

For more insight, please visit info.lr.org/techradarlowcarbon where you can also download Lloyd's Register Technology Radar – The Nuclear Perspective.