Research Paper

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The Power of Flexibility
The Survival of Utilities During the Transformations of the Power Sector

Contents

Summary

- **The race for electricity system flexibility is unleashing a new phase of transformations in the power sector, for which existing companies are ill prepared. Due to the accelerating deployment of an array of 'flexibility enablers', the spectre of cost escalation – resulting from the expense of managing intermittent wind and solar power at huge volumes – may never materialize.** New technologies that enhance system flexibility include smart electric vehicle (EV) charging, battery storage, digitalization with intelligent control, and demand-side management. Companies providing these solutions may come to dominate the power sector in the coming decades.
  - EV uptake is gathering pace, with global deployment of new EVs exceeding 1 million units for the first time in 2017. Smart, staggered EV charging could enable significant advances in system flexibility. By 2030, smart EV charging in the UK could be equivalent to 18 per cent of the country's current generating capacity. Rapid cost reductions in battery manufacturing, driven by increased deployment of EVs, are enabling affordable static, grid-level storage, in turn enhancing power system flexibility.
  - Digitalization of the electricity sector will lead to significant advances in system efficiency and flexibility. Residential demand will become flexible and networks functionally 'smarter'. Machine-learning algorithms could be a game-changer, helping to manage the increasing complexity of electricity systems and identify new system-level efficiencies.
  - Enhanced system flexibility and a growing role for these technologies will provide new entry points for highly disruptive market actors, many of them not traditionally associated with the power sector. These actors include powerful technology companies and automotive manufacturers such as Google, Tesla and BMW. More widespread electrification of transport, and eventually of heating, will change the political and regulatory landscape of the electricity sector.
- **This 'second phase' of transformations in the electricity system comes as the sector is still reeling from a profound 'first phase' of disruptive shocks** – one most noticeably affecting Australia, the EU and parts of North America. In these markets, once-powerful utility companies are struggling or having to restructure to survive.
  - The 'first phase' of transformations has been marked by the emergence over the past decade of three interlocking pressures that have undermined the business models of traditional utilities: (1) unprecedented deployment of renewable energy; (2) slower than expected or stagnating demand growth as a result of higher energy efficiency standards; and (3), in many jurisdictions, market reform.
  - The transformations to date have undermined the business models of traditional power utilities. For example, the contribution of solar photovoltaic (PV) installations and wind power to electricity generation in the EU increased from 2.5 per cent to 13.0 per cent between the end of 2006 and the end of 2016. In the same period, the average share price of the major power utilities in Europe halved, while the FTSE 100 Index rose by 15 per cent.

  - Power utilities face the prospect that renewables will achieve ever higher penetrations within the electricity market, aided by greater system flexibility. This will continue to erode the role of large power stations in 'system balancing' – balancing supply and demand – and will put further pressure on existing business models.

- **The threats for today's utilities are considerable, but so too are the opportunities for those able to transform.** Whereas past market reforms have separated the operations of utilities into discrete functions, in the emerging 'second phase' of electricity system transformations energy services themselves are likely to be fragmented into smaller functions.

  - The growth in electricity demand from EVs presents an opportunity for power companies, but it is unlikely to compensate fully for slowing overall electricity demand in OECD countries. As EV adoption rates rise, utilities could offer smart-charging tariffs that encourage staggered EV charging at lower unit prices.

  - The modular nature of batteries enables their cost and size to be optimized for specialized system requirements. This, combined with their ease of deployment, is likely to result in storage competing with conventional power plants in supplying the electricity market. While first-mover advantages within the renewables market are already broadly out of the reach of power utilities, the battery storage market offers an opportunity to develop new businesses and maintain market influence. Residential flexible-demand markets also present new opportunities for utilities that have established retail relationships with household consumers.

  - Digitalization could support business models based around the administration of 'energy service platforms' for consumers who own distributed energy resources (DERs) – and who thus seek not only to purchase electricity but to sell it back into the market. This could result in a reduction in the amount of electricity paid for via traditional utilities' retail tariffs, threatening their revenues. Furthermore, digitally enabled peer-to-peer transactions could begin competing with retail tariffs.

- **New regulatory approaches are needed to encourage market actors to deliver flexibility.** Evidence is growing that highly flexible electricity systems could deliver lower whole-system costs, especially given the dramatic projected falls in solar and wind power costs by 2030. This outcome is contingent on policy and regulatory action to stimulate the diverse set of flexibility-enabling technologies discussed in this research paper. There is a need for new market mechanisms that appropriately value the emerging suite of ancillary flexibility services while ensuring adherence to core principles of energy security and environmental protection.

  - Government reforms of electricity markets can create efficient market signals for these new forms of flexibility. The focus of system operation is shifting, from transmission networks with capacity markets for large power generators towards distribution systems, DERs and energy service platforms.

  - Governments, regulators and utilities will need to work together to design the rules and protocols for energy service platforms. If implemented, this will enable the connection of DERs to the network, and allow new consumer-oriented services to emerge.

  - To avoid new cybersecurity threats, regulators will need to work with utilities and technology companies to develop protocols and standards for the burgeoning number of internet-connected appliances and DERs, as flexibility is provided in ever greater volumes from such sources.

1. Introduction

The electricity sector is undergoing a set of profound disruptive shocks, due to a confluence of technological innovation, tougher environmental policies and regulatory reform. This is most apparent in Australia, the EU and parts of North America, where once-powerful utility companies are struggling (many are restructuring in order to survive). Decision-makers elsewhere are asking whether these power markets are outliers, or whether they herald a global trend.

Within the regions most affected, the economics of the power market have undergone a structural shift. Renewable generators tend to have lower operating costs and priority access to the grid. As such, when renewable electricity is being produced, it is typically used in preference to electricity from fossil fuel generation – thus reducing the revenues of traditional utilities reliant on oil-, gas- or coal-fired generation. At the same time, improvements in the energy efficiency of household appliances have dampened the prospects for growth in electricity demand that might partially offset the impact of renewables.

These transformations have occurred, in many OECD countries, within the context of power sector liberalization that has allowed consumers to choose between a growing number of suppliers – thus threatening incumbents. While factors such as the extent of renewables deployment, the slowing of demand growth and the opening of markets to new players vary across regions, the transformation of the sector looks set to continue and extend into other markets. In countries such as China and South Korea, the operation, management and market structure of power systems remain similar to historical practice elsewhere: companies with large dispatchable[1] power plants sell electricity to consumers who continue to have the same, passive relationships with their suppliers. Yet few countries can ignore the wider sectoral transformations under way. Regardless of the market structure, renewables are being deployed at scale.

Meanwhile, technological innovation continues to redraw the prospects for the sector. Fast-rising sales of electric vehicles (EVs) could have a huge impact on future electricity demand. Households are increasingly installing batteries to store excess power generated by rooftop solar photovoltaic (PV) units. Multinational technology companies are vying with traditional utilities to capture the new opportunities from the growth of the 'Internet of Things' (IoT) or to optimize the grid. New payment systems such as blockchain protocols are enabling transactions that could bypass traditional intermediaries. Finally, investments in super-cooled power lines are increasing electricity flows across borders.

These transformations are often considered in isolation from each other, framed as changes either to the electricity sector or to the wider energy system (i.e., including transport, heating and cooling). Yet it is unclear how developments such as changes in network infrastructure, digitalization, optimization, smart appliances, EVs and battery storage will affect the electricity system as a whole. This paper explores several questions. To what extent is an emerging second phase of disruptive technologies, and the associated rise of new market players, poised to have further transformational

[1] Dispatchable power plants or generation are sources of electricity whose output can be used on demand, dispatched at the request of system operators.

impacts on the electricity sector? Might these technologies enable greater deployment of renewables while keeping the costs of integration into the system reasonable? Finally, what might be the impact and response of the traditional utilities to these shifts?

The paper is organized into four chapters, including this introduction. In the rest of Chapter 1, the paper explores the three elements of what can be called the 'first phase' of electricity sector transformations: renewables, energy efficiency and market reform. It goes on to survey the impacts of these transformations on traditional utilities, and utility firms' responses to these impacts. Chapter 2 investigates the 'second phase' of electricity sector transformations, which are being driven by technological innovation and the need for system flexibility. Emerging developments are examined within the context of falling barriers to further deployment of renewable energy, the outlook for future electricity demand, the emergence of new market actors, and the implications of the sector's structural changes for utilities. The chapter includes analysis of the main transformations that utilities will need to undergo. The analysis is segmented by the technologies driving increased flexibility, including: EVs, digital infrastructure, interconnectors, storage, and digital control of demand and the wider electricity system. Chapter 3 explores the emerging power landscape, the competition between the new market actors and incumbent utilities, as well as a potential new role for utilities that operate the grid – all within the context of the shift towards energy service platforms and new transactions methods. The chapter also looks at the regulatory shifts that will need to accompany the second phase of flexibility transformations. The conclusions in Chapter 4 draw together the main themes of the second phase of transformations.

Transformations driven by climate and air quality

Climate and air quality policies are responsible for some of the most profound changes to have occurred during the first phase of electricity sector transformations. By burning fossil fuels and releasing carbon dioxide (CO_2), energy production and use are responsible for around 60 per cent of global greenhouse gas (GHG) emissions.[2] Consequently, according to the Intergovernmental Panel on Climate Change (IPCC) and others, without a move away from a 'business as usual' approach in the energy sector, the rise in global temperature could exceed 4°C above pre-industrial levels by the end of the century.[3] The largest proportion of energy-related emissions originate from the heat and power sectors, which are responsible for approximately a quarter of all GHGs.

The Paris Agreement of December 2015 increased and cemented global ambition on climate mitigation, calling for 'aggregate emission pathways consistent with holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels'.[4] At the same time, the agreement recognized that the cumulative effect of individual countries' climate mitigation plans, known as their Nationally Determined Contributions (NDCs), was insufficient to meet agreed targets and that additional action was therefore needed.

[2] Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M. , Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P. M. (eds) (2013), 'Summary for Policymakers', *Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change*, Cambridge, UK and New York, NY: Cambridge University Press.
[3] Ibid.
[4] UN Framework Convention on Climate Change (2015), *The Paris Agreement*, Bonn: United Nations Framework Convention on Climate Change, https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

Policy activity on climate change has undoubtedly broadened and deepened in recent decades. The number of climate change-related laws and policies adopted globally has doubled every four to five years since 1997, and now exceeds 1,250. However, the rate of growth in legislation and policy formation has slowed in recent years, suggesting a shift towards implementation and consolidation.[5]

Not only are concerns about CO_2 emissions driving change in the power sector. More immediate worries about air quality are also prompting the early closure of power stations and/or the cancellation of plans for the construction of new plants; although these changes chiefly affect coal-fired facilities, oil-fired plants are also under pressure. In the EU, 60 per cent of power stations, accounting for around 120 GW of capacity, do not comply with the EU's 2010 Industrial Emissions Directive. As a consequence, they will need to be retrofitted or closed. In China, older and less efficient power stations accounting for 10.8 GW of capacity were closed in 2016, and further action is being targeted to reduce pollution in major cities.[6] Beijing closed its last coal-fired power stations in 2017,[7] and cancelled plans to build an additional 100 coal-fired plants.[8] In South Korea, 10 of the country's oldest coal stations are due to close on account of pollution reduction efforts.[9]

Electricity is a vital societal resource, providing energy services for light, heat, cooking, transport, telecommunication, commerce and industry. Global annual electricity consumption stands at around 21,000 terawatt hours (TWh), yet 1.1 billion people still do not have access to electricity. Recognizing this, some traditional utilities in mature electricity markets are seeking to move into emerging markets. However, new technologies may be moving faster than the utilities.

The first phase of transformations

The rise of renewables

This section illustrates how the renewables sector has become central to the first phase of electricity system transformations. Three main technologies provide, or aim to provide, significantly lower-carbon and lower-pollution electricity: nuclear power, carbon capture and storage (CCS), and renewables. Of the latter, solar PV and onshore wind power are now significant contributors to new generating capacity. This is due partly to the failure to commercialize CCS, and also to the rising costs of building new nuclear plants compared to falling costs for renewable generators.

Nuclear power plants are operating in 31 countries. However, high costs and safety concerns, following major accidents at Chernobyl in Ukraine in 1986 and Fukushima in Japan in 2011, have dramatically affected the level of deployment. As a result, the contribution of nuclear power to global electricity supply is decreasing, from a peak of 17.6 per cent in 2006 to 10.3 per cent in 2017. New nuclear capacity is being added in 17 countries, with a total of 57 reactors in the pipeline. Eighty

[5] Grantham Research Institute on Climate Change and the Environment (2016), *The Global Climate Legislation Study*, London: Grantham Research Institute, London School of Economics and Political Science, http://www.lse.ac.uk/GranthamInstitute/publication/2015-global-climate-legislation-study/ (accessed 21 May 2018).
[6] Robinson, D. and Li, X. (2017), *Closing Coal in China: International experiences to inform power sector reform*, working paper, Sustainable Finance Programme, Smith School of Enterprise and the Environment, University of Oxford, http://www.smithschool.ox.ac.uk/research/sustainable-finance/publications/Closing-Coal-in-China-SFP-Working-Paper-English.pdf (accessed 27 Apr. 2018).
[7] Needham, K. (2017), 'Beijing closes last big coal-fired power station in push for clean energy', *Sydney Morning Herald*, 20 March 2017, http://www.smh.com.au/world/beijing-closes-last-big-coalfired-power-station-in-push-for-clean-energy-20170320-gv20hx.html (accessed 20 Sep. 2017).
[8] Forsythe, M. (2017), 'China Cancels 103 Coal Plants, Mindful of Smog and Wasted Capacity', *New York Times*, 18 January 2017, https://www.nytimes.com/2017/01/18/world/asia/china-coal-power-plants-pollution.html (accessed 20 Sep. 2017).
[9] Harris, B. (2017), 'South Korea's new president cracks down on air pollution', *Financial Times*, 15 May 2017, https://www.ft.com/content/c8a5da0a-3935-11e7-821a-6027b8a20f23 (accessed 20 Sep. 2017).

per cent of all new-build units (42) are in Asia and Eastern Europe, with 20 of these projects being in China.[10] Most reactors still operating in Western Europe and North America were built in the 1970s and 1980s. Despite the widespread practice of extending the operational lives of these plants, the amount of electricity produced by nuclear power is likely to continue to diminish in the coming decades. While the Chernobyl and Fukushima accidents undoubtedly raised public and political concerns over nuclear safety, the main obstacles to deployment in most markets are difficulty of financing and lack of economic competitiveness.

Of the 162 national pledges, 144 mention renewable energy; and of these, 111 refer to a target for, or planned expansion in, the use of renewables.

The electricity sector was expected to be a pioneer for the use of CCS. In March 2007, the European Council called for 12 CCS projects to be operational by 2015,[11] while in 2008 the G8 called for the creation of 20 large-scale CCS demonstration projects globally by 2010, with a view to beginning broad deployment of CCS by 2020.[12] The EU set aside considerable funding through the European Energy Recovery Programme (€1 billion) and the New Entrants Reserve 300 Scheme (NER) (more than €2 billion for CCS and renewables). However, to date no commercial-scale CCS systems are running at power plants, and leading proponents of the technology such as the UK have cancelled their programmes.[13] At a time of low electricity prices and low carbon prices, rapid and widespread deployment of CCS seems unlikely.

Given the lack of deployment of CCS and limited construction of new nuclear capacity, renewable energy is thus dominating the decarbonization of the power sector.[14] Between 1997, with the agreement of the Kyoto Protocol, and 2016, global electricity generation from nuclear power grew by 225 TWh.[15] Over the same period, the increase in generation from non-hydro renewables (primarily biomass, wind and solar PV) was seven times that of nuclear power. Hydropower generation recorded similar growth.[16] The trend is likely to continue, as renewables dominate NDCs. Of the 162 national pledges, 144 mention renewable energy; and of these, 111 refer to a target for, or planned expansion in, the use of renewables.[17]

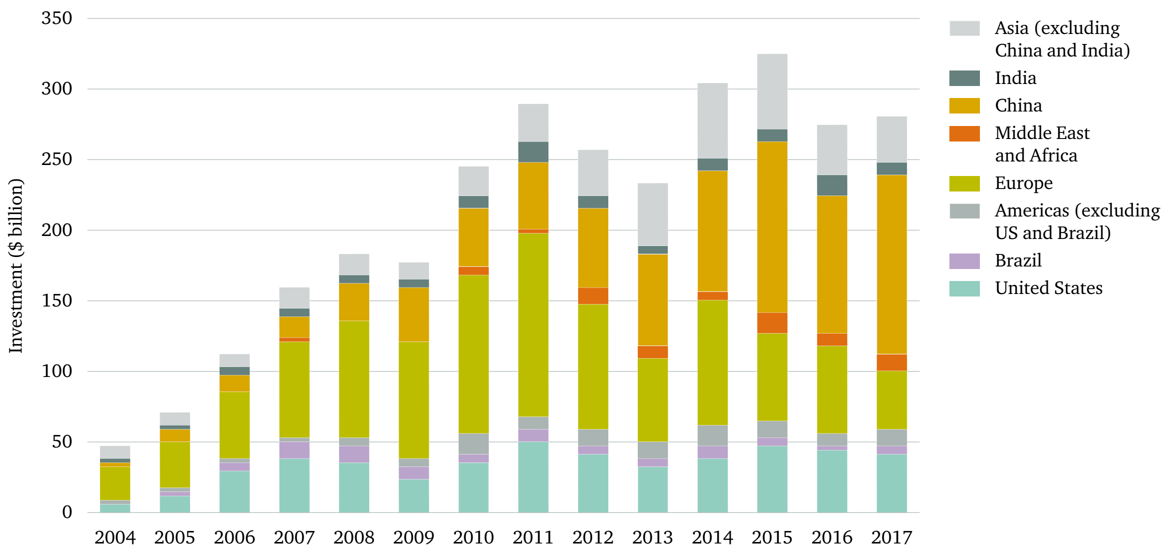
According to data published by Bloomberg New Energy Finance (BNEF) and the United Nations Environment Programme (UNEP), global investment in renewable energy – excluding large hydropower facilities – was just under $279 billion in 2017, a rise of 2 per cent on the previous year. Wind and solar PV dominate the growth in non-hydro renewables, accounting for around $107 billion and $161 billion in investment respectively.

[10] Schneider, M. and Froggatt, A. (2017), *The World Nuclear Industry Status Report 2017*, https://www.worldnuclearreport.org/-2017-.html (accessed 27 Apr. 2018).
[11] European Council (2007), 'Presidency Conclusions – Brussels', 8–9 March 2007, http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf (accessed 20 Sep. 2017).
[12] International Energy Agency (IEA) (2009), *Carbon Capture and Storage: Full-scale demonstration progress update*, Paris: IEA, https://www.iea.org/publications/freepublications/publication/ccs_g8july09.pdf (accessed 21 May 2018).
[13] Carrington, D. (2015), 'UK cancels pioneering £1bn carbon capture and storage competition', *Guardian*, 25 November 2015, https://www.theguardian.com/environment/2015/nov/25/uk-cancels-pioneering-1bn-carbon-capture-and-storage-competition (accessed 20 Sep. 2017).
[14] IEA (2016), *Tracking Clean Energy Progress 2016*, Paris: IEA, https://www.iea.org/etp/tracking2016/ (accessed 27 Apr. 2018).
[15] BP plc (2017), *Statistical Review of World Energy 2017*, https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf (accessed 27 Apr. 2018).
[16] Ibid.
[17] Schneider and Froggatt (2017), *The World Nuclear Industry Status Report 2017*.

Due to lower technology and installation costs, the global capacity of small-scale non-hydro renewables[18] increased by 157 GW in 2017, compared with 2016.[19] This accounted for 61 per cent of net new installed capacity (including all fossil fuel, nuclear and hydro) in 2017. Solar PV added 98 GW and wind 52 GW. Globally, China is the single largest contributor of new renewables, with $126.6 billion in investment (45 per cent of the global total) in 2017, including $86 billion in solar PV and the deployment of 53 GW of new solar PV capacity. In contrast, investment in renewables in the US fell by 6 per cent to $40.5 billion, and in Europe by 36 per cent to $40.9 billion.[20]

Investment rates for renewables have varied around the world in recent years, reflecting regional differences in policy formation and in the availability of new technologies. A decade ago Europe dominated, with large-scale deployment of wind power and solar PV led by Germany, Italy and Spain. Over the past five years, however, the main growth in investment has been in Asia, led by China (see Figure 1).

Figure 1: Global investment in renewables by region ($ billion)



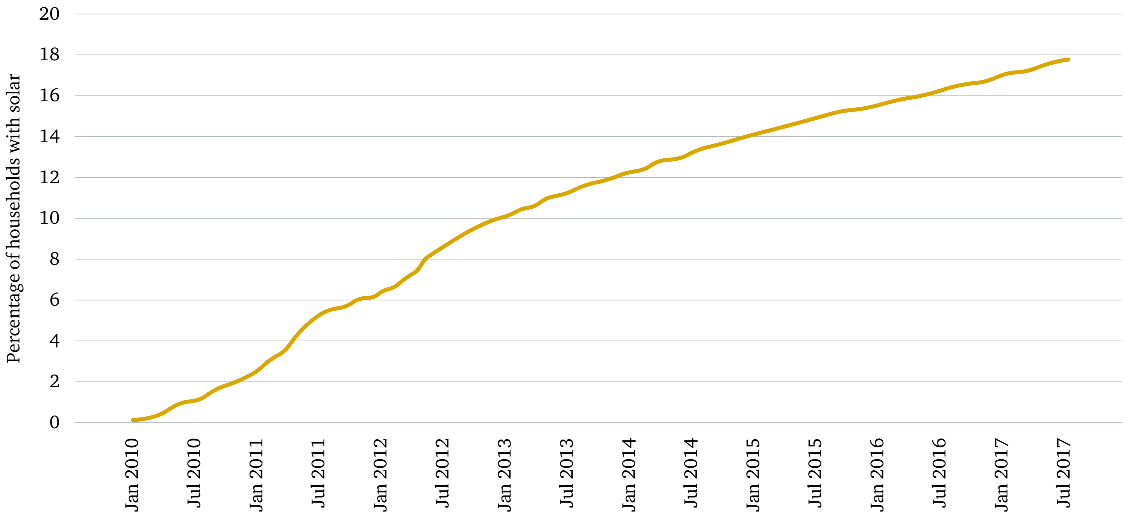
Source: FS-UNEP (2018), *Global Trends in Renewable Energy Investment 2018*.

A distinct advantage for renewables is that deployment is cost-effective on a relatively small scale. The factory-based manufacturing model for renewables is more flexible than the highly capital-intensive, complex, infrastructure-based models associated with nuclear power and CCS. For solar PV, between 2010 and 2016, more than 23 million units of less than 100 W in capacity (also known as pico-solar PV) were sold worldwide for off-grid purposes.[21] In the UK, more than 1 million homes now have solar PV panels, as do more than 1.4 million in Germany. Most recently, Australia has seen a huge uptake in the use of distributed solar PV installations. Since 2010 the share of Australian homes with a solar PV installation has risen from a negligible base to 17.7 per cent as of August 2017 (see Figure 2). Australia's domestic solar PV penetration is the highest worldwide, and three times

[18] Wind power, solar PV, biomass and waste-to-energy, geothermal, small hydro and marine sources.
[19] Frankfurt School-UNEP Centre/BNEF (FS-UNEP) (2018), *Global Trends in Renewable Energy Investment 2018*, http://fs-unep-centre.org/publications/global-trends-renewable-energy-investment-report-2018 (accessed 27 Apr. 2018).
[20] Ibid.
[21] REN21 (2017), *Renewables 2017 Global Status Report*, Paris: REN21 Secretariat, http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf (accessed 27 Apr. 2018).

that of Germany and the UK.[22] BNEF, in its *New Energy Outlook*,[23] expects that Australia will continue to dominate small-scale – that is, decentralized – solar PV deployment.

Figure 2: Proportion of households in Australia with solar PV



Note: Residential or household solar PV classified as under 9.5 KW.
Source: Chatham House analysis of data from Australian Photovoltaic Institute (2017), 'Australian PV market since April 2001', http://pv-map.apvi.org.au/analyses (accessed 9 Nov. 2017).

Renewables' domination of new capacity in the power sector is expected to continue. The International Energy Agency (IEA) forecasts that 'solar PV and onshore wind together [will] represent 75% of global renewable electricity capacity growth over the medium-term', with global renewable electricity capacity expected to grow by 42 per cent (or 825 GW) by 2021.[24] It should be noted that significantly more renewable capacity is required to replace a unit of installed capacity from a non-renewable source. In other words, replacing 1 GW of non-renewable generation capacity, for example, would require the installation of more than 1 GW of renewable capacity. This is because renewable installations are weather-dependent and thus generate less electricity per installed unit of capacity. Recent figures for the US demonstrate this disparity. In 2016, the country's nuclear facilities had a capacity factor – the ratio of actual to maximum possible generation – of 90 per cent. Coal and gas had capacity factors of 55 per cent and 56 per cent respectively. In contrast, the capacity factor for wind power was around 34 per cent.[25] BNEF estimates that nearly three-quarters of the expected $10.2 trillion in investment in new power-generating capacity through to 2040 will be renewable.[26]

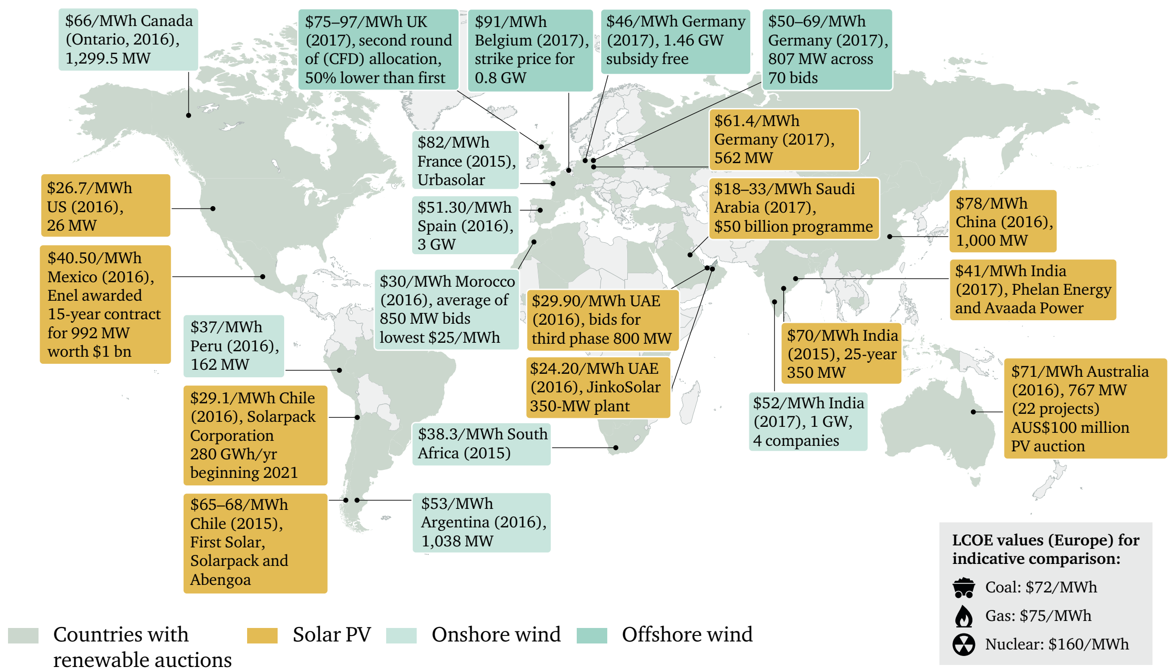
While decarbonization policies initially stimulated the deployment of renewables, economics are now driving accelerated rates of deployment. As renewable technologies continue to be deployed, their manufacturing and installation costs are decreasing, and their competitiveness is improving.

[22] Australian Energy Council (2016), *Renewable Energy in Australia – How do we really compare?*, June 2016, https://www.energycouncil.com.au/media/1318/2016-06-23_aec-renewables-fact-sheet.pdf (accessed 21 May 2018).
[23] Bloomberg New Energy Finance (2017), *New Energy Outlook 2017*, https://about.bnef.com/new-energy-outlook/ (accessed 21 May 2018).
[24] IEA (2016), *Renewable Energy Medium Term Market Report 2015*, Paris: IEA, https://www.iea.org/newsroom/news/2016/october/medium-term-renewable-energy-market-report-2016.html (accessed 27 Apr. 2018).
[25] Dell, J. and Klippenstein, M. (2017), 'Wind Power Could Blow Past Hydro's Capacity Factor by 2020', Greentech Media, 8 February 2017, https://www.greentechmedia.com/articles/read/wind-power-could-blow-past-hydros-capacity-factor-by-2020#gs.8GQHC1o (accessed 7 Nov. 2017).
[26] Bloomberg New Energy Finance (2017), *New Energy Outlook 2017* (accessed 6 Feb. 2018).

Solar PV is already at least as cheap as coal in Germany, Australia, the US, Spain and Italy. By 2021, it is expected to be cheaper than coal in China, India, Mexico, the UK and Brazil, according to BNEF.[27]

BNEF estimates that the cost of onshore wind power has fallen dramatically in the past 30 years, from more than $500 per megawatt hour (MWh) in 1985 to around $70/MWh in 2015, including a 50 per cent fall since 2009. BNEF anticipates a further 41 per cent drop by 2040, largely because of efficiency improvements. The price of installing solar PV has fallen by 99 per cent since 1976 and by 80 per cent since 2008; it is expected to drop by another 66 per cent by 2040.[28] Yet BNEF's price decline forecasts may even turn out to be conservative, as production, installation and authorization costs (particularly given more competitive auctions) further drive down the costs of renewable energy, as can be seen in Figure 3.

Figure 3: Renewable-power contracts agreed in 2015–17, with comparison of levelized cost of electricity (LCOE)[29] values for coal, gas and nuclear generators



Note: For sources, see Appendix 1.

Globally, electricity generation increased by 29.2 per cent between 2006 and 2015, while renewables' share of generation increased from 19.7 per cent to 24.2 per cent over the same period. The large-scale deployment of renewables, particularly solar PV and wind power, has already changed the electricity mix in Europe and other parts of the world. In the EU, renewables provided 12 per cent of electricity in 1990, 15 per cent in 2000, 21 per cent in 2010 and 29.6 per cent in 2016 according to Eurostat; unofficially, the share in 2017 was 30 per cent.[30] That said, across the EU there have been considerable

[27] Ibid.
[28] Ibid.
[29] For a power plant developer, the LCOE is equivalent to the wholesale price required at commissioning to cover costs (excluding grid connection) while achieving a required rate of return, excluding subsidies.
[30] Sandbag and Agora Energiewende (2018), *The Power Sector in 2017: State of Affairs and Review of Current Developments*, https://sandbag.org.uk/wp-content/uploads/2018/01/EU-power-sector-report-2017.pdf (accessed 13 Aug. 2018).

differences in uptake of renewables between countries. For example, in Austria 70.3 per cent of electricity is generated by renewables; in Sweden the figure is 65.8 per cent; in Portugal 52.6 per cent; in Latvia 52.2 per cent; and in Denmark 51.3 per cent.[31] In 2016, Denmark managed a peak production level for renewable electricity of 140 per cent of demand, while Germany achieved 86.3 per cent.[32] The contribution of solar PV and wind power to electricity generation in the EU increased from 2.5 per cent to 13.0 per cent between the end of 2006 and end of 2016. Traditional utilities have been slow to deploy and invest in renewables, and this has affected investor confidence. Between December 2007 and December 2017, European utilities lost around 45 per cent of their share price value, as measured by the 29 utilities comprising the Stoxx eurozone utilities index.[33] The accelerated deployment of renewables has significantly contributed to this decline,[34] and has been accompanied by write-downs of power station valuations.[35]

Box 1: The next wave of renewables

Combined with the falling costs of solar PV and wind power, new technologies for floating generation facilities could soon allow renewable power to be implemented in locations that are impractical for conventional installations. In addition to the implications for generation capacity, floating wind turbines and floating solar PV arrays offer potential land-use and political benefits: they reduce competition over land for food production and housing, and help to circumvent local opposition to new power projects. Although moving generation offshore currently carries additional costs compared to land-based facilities, these costs could be expected to fall over time, as has been seen in the UK, where guaranteed prices for offshore wind power in September 2017 were more than 50 per cent lower than those at similar auctions two years earlier.[36]

Growth in the use of floating solar PV facilities is likely to be led by their installation in the reservoirs of hydropower dams, which benefit from still water and established grid connections. In 2017, China turned on the world's largest floating solar PV farm, with capacity to power 15,000 homes. The plant takes up no land space, and the cooling effect of the water improves efficiency by 3–5 per cent.[37] The potential market for power generated in this way is expected to grow to 2.5 GW by 2024.[38]

The world's first commercialized floating wind plant has been built in Scotland, supplying 30 MW of electricity 25 km offshore.[39] Floating wind turbines can operate in water up to 220 metres deep. Their fixed-bottom counterparts can only be installed where water depths are 50 metres or less. As a result, floating turbines potentially open up steep continental shelf coastlines, such as around Japan, the Mediterranean and the US west coast, to wind power. Further away from the coast, floating turbines can also capture higher wind speeds, potentially boosting generation.[40]

[31] Eurostat (2017), 'Renewable energy statistics', http://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics (accessed 3 Oct. 2017).
[32] REN21 (2017), 'Another Record Breaking Year for Renewable Energy: More renewable energy capacity for less money', press release, 7 June 2017, http://www.ren21.net/wp-content/uploads/2017/06/Press-Release_ENGLISH.pdf (accessed 27 Apr. 2018).
[33] STOXX Digital (2017), 'STOXX® Europe 600 Utilities', https://www.stoxx.com/index-details?symbol=SX6p (accessed 11 Dec. 2017).
[34] Coren, M. (2017), 'Utilities need to plan for a 100% renewable energy future, even if it never happens', Quartz, 22 June 2017, https://qz.com/1011798/utilities-need-to-plan-for-a-100-renewable-energy-future-even-if-it-never-happens/ (accessed 14 Sep. 2017).
[35] Stacey, K. (2016), 'European utilities slash asset valuations', *Financial Times*, 22 May 2016, https://www.ft.com/content/5b2dd030-1e93-11e6-b286-cddde55ca122 (accessed 11 Dec. 2017); Ward, A., Thomas, N. and Chazan, G. (2017), 'European utilities primed for consolidation in shift to renewables', *Financial Times*, 27 June 2017, https://www.ft.com/content/90003746-57f7-11e7-9fed-c19e2700005f (accessed 11 Dec. 2017).
[36] Thomas, N. (2017), 'Renewable energy case boosted by sharp subsidy fall', *Financial Times*, 11 September 2017, https://www.ft.com/content/7401f5e0-96c0-11e7-a652-cde3f882dd7b (accessed 27 Sep. 2017).
[37] Daley, J. (2017), 'China Turns On the World's Largest Floating Solar Farm', Smithsonian.com, 7 June 2017, http://www.smithsonianmag.com/smart-news/china-launches-largest-floating-solar-farm-180963587/ (accessed 14 Sep. 2017).
[38] Power Engineering (2017), 'Floating Solar Market Expected to Reach 2.5 GW by 2024', 17 May 2017, http://www.power-eng.com/articles/2017/05/floating-solar-market-expected-to-reach-2-5-gw-by-2024.html (accessed 13 Sep. 2017).
[39] Vaughan, A (2017), 'World's first floating windfarm to take shape off coast of Scotland', *Guardian*, 27 June 2017, https://www.theguardian.com/business/2017/jun/27/hywind-project-scotland-worlds-first-floating-windfarm-norway (accessed 13 Sep. 2017).
[40] Ibid.

Although Europe's wind resource is vast, much of it is inaccessible to fixed-bottom turbines. If floating wind becomes competitive and deployed at scale, existing EU targets – including the 2030 target of 150 GW – could be delivered earlier, aided by new capacity in deepwater sites.[41]

The European Commission has been supporting research and development (R&D) programmes into floating wind power, via funding initiatives such as Framework Programme (FP)7 and NER300. In the US, the Department of Energy has invested more than $55 million to develop WindFloat technology on the east and west coasts. Japan has also strongly pushed for floating wind technology since the Fukushima nuclear accident in 2011.[42]

Energy efficiency and low demand growth

The introduction of new energy efficiency standards, alongside the accelerated deployment of renewables, has contributed to stagnating growth in electricity demand. This trend, which has compounded the negative pressure on the share prices of traditional utilities, forms the second major component of the transformations under way within the electricity sector.

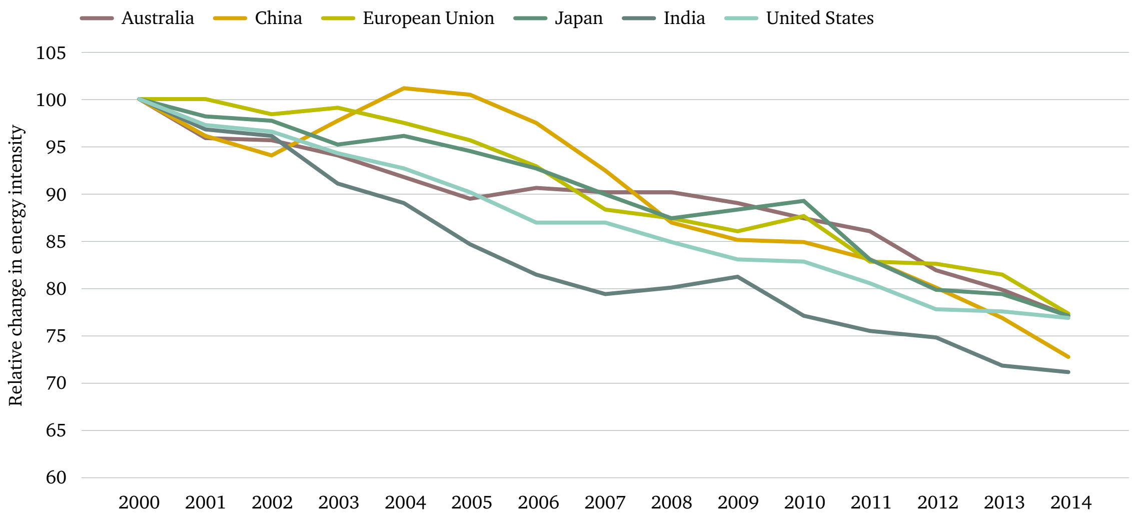
Energy efficiency is generally regarded as the most cost-effective, economically prudent means to cut CO_2 emissions and enhance energy security. As such, 90 per cent of the Paris Agreement's NDCs rely on energy efficiency to deliver their commitments. Although end-users of energy may not see the attractiveness of efficiency measures while prices are low, governments certainly do.

However, the impact of energy efficiency on the future of electricity demand is complex. Efficiency in the wider energy system can stimulate electrification, for example through the more stringent vehicle petrol standards that are partly driving the shift to EVs. Yet it can also inhibit electrification – for instance, in the buildings sector thermal insulation lowers the heating load, reducing the economic incentive to use heat pumps. Further, efficiency within the electricity sector reduces the cost of powering appliances. This results in some consumers buying larger appliances or running appliances for longer than they otherwise would, a phenomenon known as the 'rebound effect'.[43]

Forecasters and scenario-builders all too often assume that growth in energy consumption will be much higher than it turns out to be.[44] The energy intensity of the global economy – defined as the amount of energy used per unit of gross national product – has actually declined from 6.49 megajoules per dollar at the turn of this century to 5.36 megajoules per dollar in 2014, according to the World Bank.[45] As Figure 4 shows, energy intensity has improved (i.e. fallen) across major economies, but the extent of the change varies considerably. Clear improvements have occurred in the emerging economies, which have deployed energy efficiency measures, accelerated growth of service sectors and slowed infrastructure development.

[41] James, R. and Costa Ros, M. (2015), *Floating Offshore Wind: Market and Technology Review*, Carbon Trust for the Scottish Government, https://www.carbontrust.com/media/670664/floating-offshore-wind-market-technology-review.pdf (accessed 27 Apr. 2018).
[42] Ibid.
[43] Sorrell, S., Dimitropoulos, J. and Sommerville, M. (2009), 'Empirical estimates of the direct rebound effect: A review', *Energy Policy*, 37(4), doi:10.1016/j.enpol.2008.11.026 (accessed 28 Apr. 2018).
[44] McKibbin, J. and Langham, E. (2015), 'Inaccurate energy forecasts are costing us the Earth: here's why', *The Conversation*, 14 June 2015, https://theconversation.com/inaccurate-energy-forecasts-are-costing-us-the-earth-heres-why-42808 (accessed 5 Oct. 2017).
[45] World Bank (2017), 'Energy intensity level of primary energy', https://data.worldbank.org/indicator/EG.EGY.PRIM.PP.KD (accessed 20 Sep. 2017).

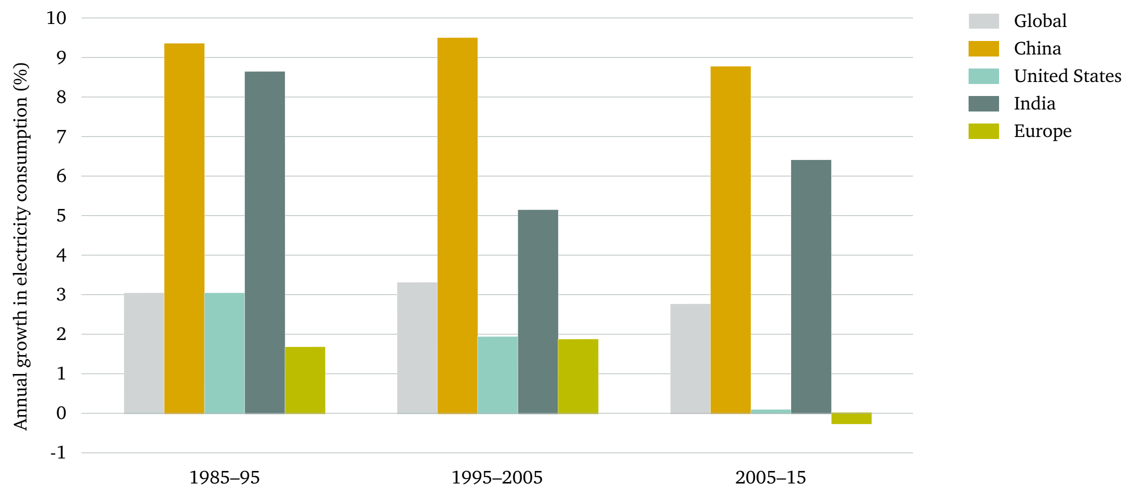
Figure 4: Energy intensity since 2000 in selected economies



Source: Chatham House analysis of World Bank (2017), 'Energy intensity level of primary energy'.

Improvements in energy intensity and economic competitiveness have resulted in slower electricity demand growth. The average annual demand growth per decade is shown in Figure 5, highlighting that peak demand growth straddled the turn of the century at the global level. Even in China, power demand growth has slowed in the past decade. In OECD countries in Europe and North America, demand is now flat or falling.

Figure 5: Change in electricity consumption, 1985–2015



Source: Chatham House analysis of BP (2017), *Statistical Review of World Energy 2017.*

Efforts to improve energy efficiency in the electricity sector have traditionally focused on lighting and appliances in buildings. In the wider energy system, such efforts have focused on thermal insulation in buildings and fuel efficiency standards in transport.[46] Efficiency drives have been extremely successful in areas such as lighting, which accounts for around 15 per cent of global electricity demand. To date, nearly 200 million LEDs have been installed,[47] saving around 100 TWh per annum. Mandatory Minimum Energy Performance Standards (MEPS) now cover around 30 per cent of global final energy use,[48] and have played a key role in lowering energy demand. For instance, 90 per cent of electric motors sold globally are subject to MEPS[49] (see Box 2).

Significant energy efficiency measures are yet to be implemented across buildings, transport and industry. Huge price reductions in LEDs have stimulated pledges from companies and governments to install in excess of 14 billion LEDs under the Clean Energy Ministerial's Global Lighting Challenge.[50] The use of MEPS is also likely to expand, and motor systems should become increasingly efficient. Two major areas for policy development in electricity efficiency are small appliances and electric motors. Small electrical appliances represent almost half of electricity consumption by appliances, but are generally not subject to MEPS, while motor systems represent more than half of global electricity consumption (see Box 2).

Box 2: Efficiency of motors

Within industry, electric motor systems in the form of pumps, fans, compressed air systems, material handling systems and processing systems account for around 70 per cent of electricity demand, equivalent to 30 per cent of global electricity consumption. Within buildings, around 33 per cent of electricity consumption is used to drive motors in everyday appliances such as hair dryers, vacuum cleaners, washing machines, tumble dryers, dishwashers, pumps, air conditioning units, fans, juicers and food blenders.

Electric motors have been subject to efficiency improvements and MEPS, but the nature of such motors means there is still room for large savings in the wider system in which they operate. As a motor is generally designed to work at one speed, much of its rotational motion is wasted prior to driving the end-use device. More widespread use of variable-speed drives and the introduction of wider system efficiency measures, combined with continued tightening of efficiency measures for motors themselves, could save around 40 per cent of electricity consumption within industry.[51] Installing variable-speed drives alone can increase the efficiency of motors by 15–35 per cent.[52] Due to rapid growth in the applications for which motor systems are used, the IEA anticipates that electricity demand from motors will grow by 80–100 per cent by 2040 relative to 2014, depending on the extent to which system-wide efficiency measures are applied. By 2040, efficiency measures could save around 1,600 TWh per annum.

[46] Gynther, L., Lapillonne, B. and Pollier, K. (2015), *Energy efficiency trends and policies in the household and tertiary sectors*, Odyssee-Mure Project, http://www.odyssee-mure.eu/publications/br/energy-efficiency-trends-policies-buildings.pdf (accessed 27 Apr. 2018); Sorrell, S., Mallett, A. and Nye, S. (2011), *Barriers to industrial energy efficiency: a literature review*, United Nations Industrial Development Organization, Working paper 10/2011, http://sro.sussex.ac.uk/53957/1/WP102011_Barriers_to_Industrial_Energy_Efficiency_-_A_Literature_Review.pdf (accessed 21 May 2018).
[47] Clean Energy Ministerial (2017), 'CEM's Global Lighting Challenge Announces 14 Billion Efficient Lighting Products Committed in Two Years', 6 June 2017, http://www.cleanenergyministerial.org/News/cems-global-lighting-challenge-announces-14-billion-efficient-lighting-products-committed-in-two-years-83976 (accessed 11 Aug. 2017).
[48] IEA (2016), *World Energy Outlook 2016*, Paris: IEA, https://www.iea.org/newsroom/news/2016/november/world-energy-outlook-2016.html (accessed 27 Apr. 2018).
[49] Ibid.
[50] Clean Energy Ministerial (2017), 'CEM's Global Lighting Challenge Announces 14 Billion Efficient Lighting Products Committed in Two Years'.
[51] IEA (2016), *World Energy Outlook 2016*.
[52] European Commission (2000), 'Improving the Penetration of Energy-Efficient Motors and Drives', Project ID: XVII/4.1031/Z/96-044 Project webpage, https://cordis.europa.eu/project/rcn/36277_en.html (accessed 27 Apr. 2018).

Globally, investment in energy efficiency averaged around $220 billion per annum from 2010 to 2015. However, merely to fulfil NDC pledges and comply with recent policy measures, such investment will need to more than quadruple to an average of $920 billion per annum by 2040. In addition, climate projections suggest that it will need to rise to $1.4 trillion per annum to keep global warming below 2°C. If NDC pledges and recent policy developments successfully drive efficiency improvements across the energy system, final energy consumption could be 27 per cent lower than it would otherwise be in OECD countries, and 20 per cent lower in non-OECD countries. This would cause world energy intensity to fall by more than 60 per cent by 2040, approximately doubling the average rate of improvement over the past three decades.[53]

Market reform

For many decades large, centralized fossil fuel power stations and, in some countries, nuclear power stations dominated the electricity sector. These were usually owned and run by the same state-owned entities that operated the grids and supplied electricity to the final customers. Through a process of market liberalization, state-owned electricity companies in many countries were unbundled to separate the operation of the grid from power generation and retail operations, often leading to the privatization of assets. This process allowed new companies to enter the market all along the value chain, though primarily in the generation and retail segments.

> As the power sector responds to environmental, economic and security-of-supply concerns, the pace of change will be determined in part by the current market structure and the vision of policymakers.

In the US retail market, Inspire Energy was formed in 2010, offering a tariff in northeastern states with 100 per cent of supply generated by wind. Demand for such tariffs has grown: there are now at least 13 green tariffs in operation across 10 states, including one offered by a public power company.[54] In Japan, liberalization has enabled established energy companies such as Tokyo Gas to enter the electricity retail market; 300,000 customers switched from their previous supplier to Tokyo Gas's competitive tariff in the first months of liberalization in 2016.[55] In the UK, new local authority-run suppliers such as Bristol Energy and, in Nottingham, Robin Hood Energy are joining the traditional utilities. Even international oil companies such as Shell are beginning to signal a move into electricity markets.[56] As the power sector responds to environmental, economic and security-of-supply concerns, the pace of change will be determined in part by the current market structure and the vision of policymakers.

There is no global standard for market structure or ownership of electricity sector assets, and consequently structure and ownership vary across and within countries.

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[53] Ibid.
[54] Tawney, L., Bonugli, C. and Melling, D. (2017), '6 Graphics Show How U.S. Utilities Are Turning Corporate Demand into Renewables Growth', World Resources Institute, 17 May 2017, http://www.wri.org/blog/2017/05/6-graphics-show-how-us-utilities-are-turning-corporate-demand-renewables-growth (accessed 7 Jan. 2018).
[55] Reuters (2017), 'Japan reaches million mark on electricity switching', 6 June 2016, https://www.reuters.com/article/japan-power-trading/japan-reaches-million-mark-on-electricity-switching-idUSL4N18Y1FF (accessed 14 Nov. 2017).
[56] Butler, N. (2017), 'Shell's strategic move into electricity', *Financial Times*, 14 August 2017, https://www.ft.com/content/6c9a9626-ad82-3ca5-854c-424ddd187be2 (accessed 14 Nov. 2017).

In March 2015, the government of **China** published its strategy document, *Deepening Reform of the Power Sector*, which recognized the need to reorient power sector reform around environmental goals while meeting growing demand for power. The top five state-owned companies still control 50 per cent of generation assets, and two state-owned grid companies control 100 per cent of transmission, distribution and retail. The reform's founding principles include the increased use of market mechanisms and the protection of residential and agricultural consumers. Key elements of the strategy also include reform of the grid companies responsible for both wholesale and retail sales of electricity. In addition, the wholesale market will be liberalized, allowing non-state-owned wholesale electricity companies to enter the market. Industrial-scale consumers will be able to bypass the grid companies and negotiate directly with suppliers.[57]

The **EU** introduced three sets of legislation to liberalize electricity and gas, in 1996, 2003 and 2009. These reforms progressively unbundled previously vertically integrated electricity and gas companies, enabling greater consumer choice and moving regulatory control away from governments towards independent national and EU bodies. In 2016, the EU introduced further liberalization legislation, including proposals on a new market structure and regional cooperation.[58] The legislative proposals seek to adjust the rules of the market (such as on infrastructure, investment and effective renewables integration), and also feature internal energy security elements (covering capacity markets and security standards, among other things). Other areas being discussed are greater involvement of household consumers in the market; the introduction of smart grids; data protection; and opportunities to save energy.

In the **US**, the electricity industry is governed by a complex set of regulatory rules set at municipal, state and federal levels. Most rules are set at state level, although the Federal Energy Regulatory Commission (FERC) has exclusive jurisdiction over the interstate sale of electricity. Federal regulations are also set for the licensing of infrastructure such as nuclear and hydropower facilities. Market liberalization policies have been introduced at state level, leading to very different models from one state to another. Potentially significant developments include the New York Reforming the Energy Vision (REV), and more gradual reform in California and Hawaii – in both states, renewables are a significant source of power, much of it from rooftop PV. In many states, however, power sectors remain vertically integrated.

Japan has also been reforming its power sector. The first reform, introduced in 1995, enabled independent power producers to enter the market. Three additional reform packages were subsequently introduced, in 2000, 2004 and 2008. For many years, the 10 electricity companies effectively remained regional monopolies, and opposed large-scale market reform. However, their political power and support within government diminished in the wake of the Fukushima nuclear accident and subsequent economic turmoil, enabling the reformers to push through their agenda.[59] Following Fukushima, reforms established the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) and the Electricity Market Surveillance Commission in April 2015. Full liberalization of the retail market, from April 2016, included the legal unbundling of transmission and distribution activities from generation, and the planned abolition (by 2020) of retail rate regulation.

[57] Pollitt, M. G., Yang, C.-H. and Chen, H. (2017), *Reforming the Chinese Electricity Supply Sector: Lessons from International Experience*, EPRG Working Paper, Cambridge: Energy Policy Research Group, University of Cambridge, http://www.eprg.group.cam.ac.uk/wp-content/uploads/2017/03/1704-Text.pdf (accessed 27 Apr. 2018).
[58] European Commission (2016), 'Clean Energy for All Europeans', 30 November 2016, https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans (accessed 15 Jan. 2018).
[59] Steffensen, J. (2013), 'Reforming Japan's Electricity Sector: Abe's Push for Deregulation, An Interview with Koichiro Ito', The National Bureau of Asian Research, 23 October 2013, http://www.nbr.org/research/activity.aspx?id=368 (accessed 1 Nov. 2017).

Reform of the power sector in **South Korea** started in 2001, but national-level reforms largely stalled from 2004 onwards. The Korea Electric Power Corporation (KEPCO) is currently responsible for all transmission, distribution and retail of electricity. It fully owns five generation companies – four thermal and one nuclear. However, about 10 per cent of generation is provided by privately owned independent power producers. All power is traded through the Korean Power Exchange, which is also responsible for grid balancing, management of the market, and enacting and revising market rules.

Despite the changes in these markets, most of the power systems have continued to be largely operated and managed in similar ways, by companies with large dispatchable power plants,[60] selling to consumers who continue to have the same, passive relationships with their energy suppliers. Many of the large traditional generating companies have also remained, and still dominate the market.

In many jurisdictions, the first government-owned electricity providers were deemed to be 'utilities' on the basis that they maintained the infrastructure that provided a public service. Liberalization brought a fragmentation of the market and infrastructure, which were to be operated and owned by many private companies. Generators, distribution network operators, transmission network operators and retail suppliers were subsequently created as potentially distinct companies, but the role of each entity is now significantly removed from that of a pure 'utility'. In the coming sections, the term 'utility' is often used to describe an established or traditional utility, unless a specific segment of the electricity system is being referred to.

Impact on traditional utilities

Slower than expected demand growth (or in some cases decreasing consumption), coupled with greater deployment of renewables, is affecting the volume and price of electricity sales by incumbent generators. This can be seen in the intra-day price of electricity in countries with high volumes of solar PV. Historically, the price of electricity was high during the day, when demand increases; however, in countries with large amounts of solar PV, the peak intra-day price has disappeared for large parts of the year. This trend has been described as the solar PV 'duck curve'.[61] As renewable generators enter the market, even if they do not have priority access to the grid, their low production costs mean that they can underbid fossil fuel generators, which drives down the wholesale price. This is known as the 'merit order effect', and is now widely documented and observed in Spain, Germany, Denmark, Australia and the US.[62] For example, in Germany, a study of the day-ahead spot market found that prices fell by €1.23 per MWh for each additional gigawatt hour (GWh) of wind power.[63]

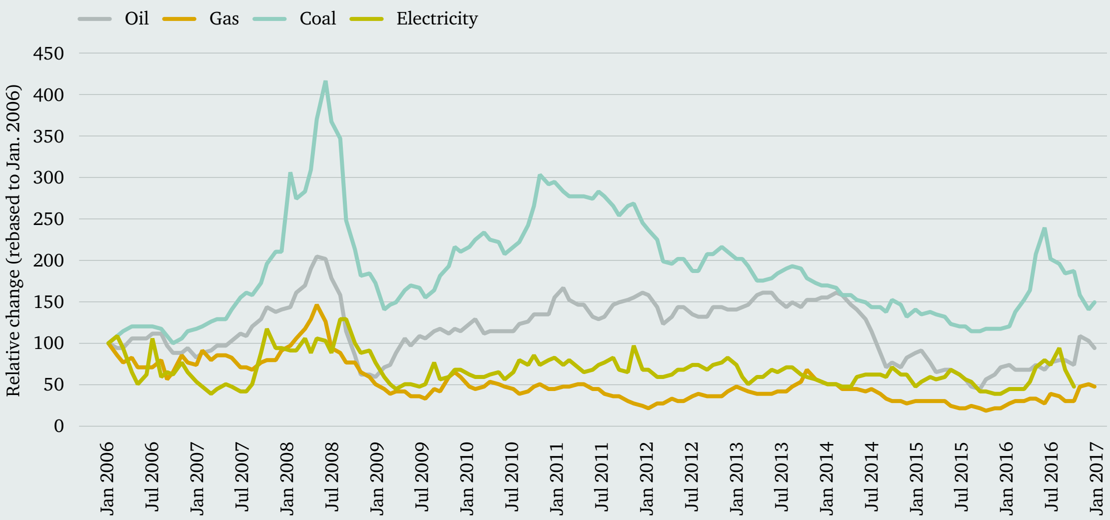
Major traditional power utilities see current low prices not as a cyclical trend but as a permanent structural change. 'The price of electricity has no reason to rise. It will never be like it was before,' said Isabelle Kocher, chief executive of the French-headquartered company ENGIE, the world's largest non-state-owned producer of electricity.[64]

[60] A dispatchable power plant is one that can be turned on and off, or that can adjust the power output depending on the demand.
[61] St. John, J. (2016), 'The California Duck Curve Is Real, and Bigger Than Expected', Greentech Media, 3 November 2016, https://www.greentechmedia.com/articles/read/the-california-duck-curve-is-real-and-bigger-than-expected#gs.__ukgY8 (accessed 3 Oct. 2017).
[62] Woo, C. K., Moore, J., Schneiderman, B. and Zarnikau, J. (2016), 'Merit-order effects of renewable energy and price divergence in California's day-ahead and real-time electricity markets', *Energy Policy*, 92 doi:10.1016/j.enpol.2016.02.023 (accessed 28 Apr. 2018).
[63] Benhmad, F. and Percebois, J. (2016), 'Wind power feed-in impact on electricity prices in Germany 2009-2013', *The European Journal of Comparative Economics*, 13(1).
[64] Stothard, M. (2016), 'Low European power prices here to stay, says utility CEO', *Financial Times*, 15 May 2016, https://www.ft.com/content/4bdf5a4e-1a84-11e6-8fa5-44094f6d9c46 (accessed 20 Sep. 2017).

Box 3: Changing fossil fuel prices

Power prices have always fluctuated. They are directly affected by fuel costs, which in turn are affected by regional or global prices. In 2008, the cost of coal was approximately $200/tonne in Europe and about $175/tonne in Asia; in both regions it fell to less than $75/tonne in 2015, and as of mid-2017 was between $40/tonne and $85/tonne. Globally gas prices have also fallen. In the US, prices have slid from $5 per million British Thermal Units (MBTU) in 2013 to around $3/MBTU in 2017. In Asia and Europe, over the same period, prices have fallen from $20/MBTU and $11/MBTU respectively to around $8/MBTU. Although traditional power utilities are experienced in adjusting their prices to compensate for cyclical fluctuations in fuel costs, volatile markets can affect the profits and outlook of companies in various ways, depending on their different fuel mixes.

Figure 6: European fossil fuel and electricity prices (rebased to January 2006)



Source: Chatham House analysis of Thomson Reuters data (2018).

Unsurprisingly, given falling power prices and flat or falling electricity production, earnings before interest, taxes, depreciation and amortization (EBITDA) have fallen over recent years for most traditional power companies. German utilities, along with ENGIE in France, have suffered significant declines in EBITDA. Electricité de France (EDF) has bucked this trend, despite its increasingly precarious financial position. However, even here, it is anticipated that the changes in market rules in 2016 will reduce its income. As credit ratings agency Moody's notes: 'A prolonged period of low power prices will further affect EDF given its exposure to market-exposed generation activities. Moody's estimates that approximately 50% of EDF's EBITDA is derived from market-exposed generation following the end of certain regulated tariffs in France.'[65] Other traditional power utilities in Europe, such as Enel of Italy, are protected from fluctuations in the market price for electricity, as they operate in more regulated markets where retail prices are fixed.

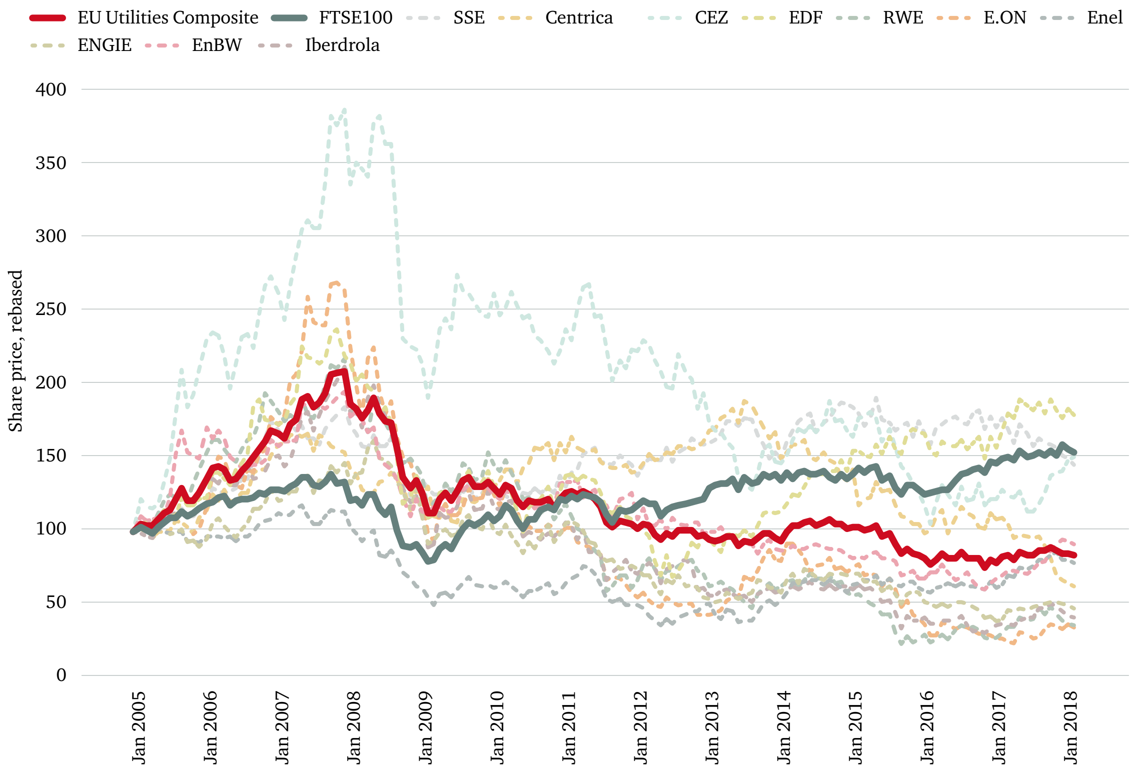
There have been significant changes in the operating income of many companies in Asia. Japanese companies that operated nuclear power plants have suffered significant impacts from the closure of their

[65] Moody's (2016), 'Moody's places EDF's A1/P-1 ratings on review for downgrade', 13 February 2016, https://www.moodys.com/research/Moodys-places-EDFs-A1P-1-ratings-on-review-for-downgrade--PR_343757 (accessed 20 Sep. 2017).

reactors: for example, the income of Tokyo Electric Power Company (TEPCO) fell from nearly $5 billion in 2010 to a loss of more than $3 billion in 2011. Higher retail prices subsequently enabled TEPCO's income to recover, even though the company had not restarted its reactors. In 2015, TEPCO's income topped $4 billion, although this fell to $1.2 billion in 2016.[66] The company has also benefited from a government bail-out thought to have cost up to $137 billion.[67] By contrast, KEPCO in South Korea experienced remarkable growth, with income rising from a loss of $2 billion in 2012 to a profit of $6.7 billion in 2016. This was largely because prices for fossil fuels – one of KEPCO's chief costs – have fallen while the tariffs it charges have remained fixed, boosting profitability.

Share prices offer a clear indication of how the perceived value of the power sector in Europe has changed (see Figure 7). Shares of traditional utilities, like those of other companies, rose in the second half of the last decade until the 2008 financial crisis, when they fell sharply. Although utilities' share prices briefly picked up after that point, they then declined again even as shares in other sectors rallied. The composite share price in Figure 7 is an average of the largest listed power utilities in Europe.[68] RWE and E.ON of Germany and EDF of France experienced the greatest losses. SSE of the UK and CEZ (Czech Republic) outperformed the FTSE 100 Index until the end of 2015. Between the end of 2006 and end of 2016, the average share price of the major power utilities in Europe halved, while the FTSE 100 Index rose by 15 per cent.

Figure 7: Share prices of the 10 largest listed European power utilities, and the composite (average) share price compared to the FTSE 100, rebased to 2005

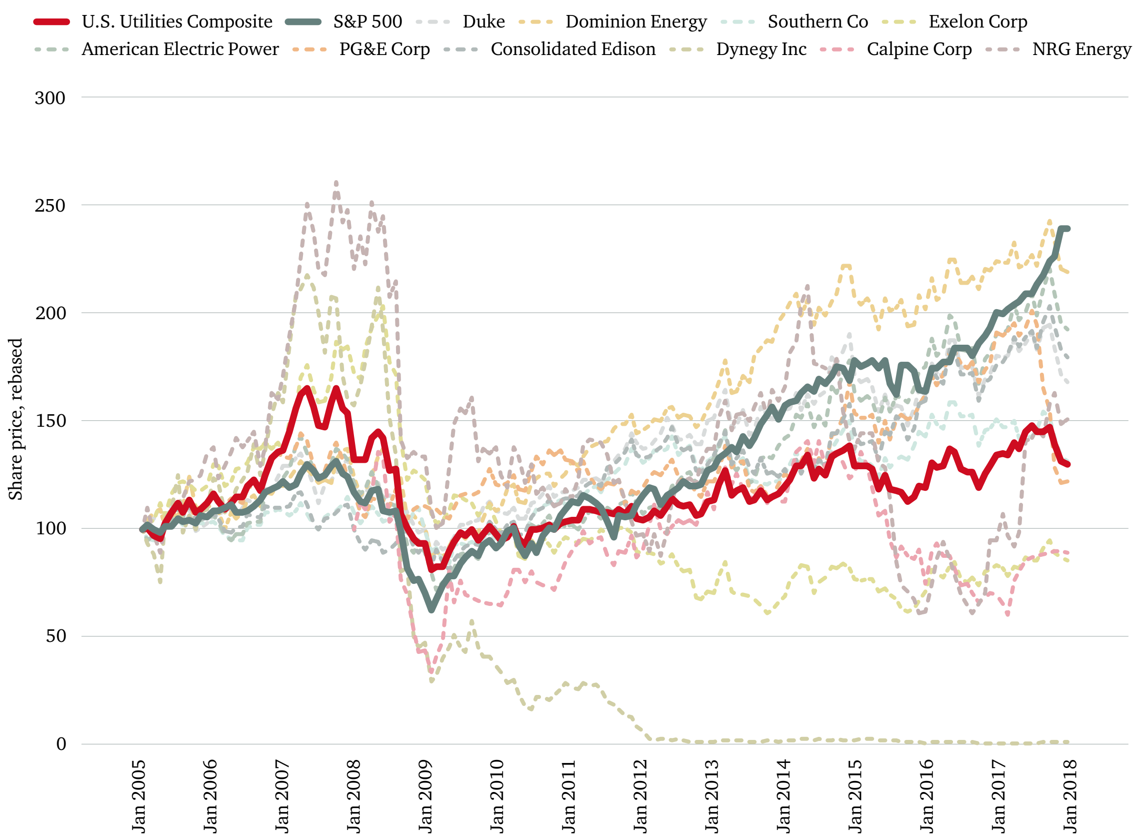


Source: Chatham House analysis of Thomson Reuters data (2018).

[66] TEPCO (2016), *Annual Report 2016*, http://www.tepco.co.jp/en/corpinfo/ir/tool/annual/pdf/ar2016-e.pdf (accessed 27 Apr. 2018).
[67] Inajima, T. (2012), 'Tepco Bailout Largest in Japan Since Rescue of Banks', Bloomberg, 24 February 2012, https://www.bloomberg.com/news/articles/2012-02-24/tepco-bailout-largest-in-japan-since-rescue-of-banking-industry (accessed 20 Sep. 2017).
[68] EDF, RWE, E.ON, Enel, ENGIE, EnBW, Iberdrola, PGE, SSE, Centrica, EDP and CEZ.

The situation is slightly different in the US, depending on the type of market in which a given utility is operating. Traditional utilities in regulated markets with guaranteed electricity prices are either surviving or, in some cases, flourishing. Those in markets without fixed prices are suffering. The 2018 Moody's outlook for the unregulated power and utility sector has remained negative, due to 'anemic demand, an oversupplied market and low wholesale power prices'. Power utilities primarily operating coal and nuclear plants are particularly affected. However, the credit ratings agency notes that 'for regulated utilities, the stable outlook affirms Moody's expectation that regulators will continue enabling utilities to recover costs and maintain steady cash flows'.[69]

Figure 8: Share prices of major power utilities in the US and the composite (average) share price compared to the S&P 500 Index, rebased to 2005



Source: Chatham House analysis of Thomson Reuters data (2018).

In the Asia-Pacific region, changes in share prices show clear differences between power utilities (see Figure 9). The immediate impact of the Fukushima disaster on Japanese companies is clear and expected, with a massive fall in value. Surprisingly, their share prices had not recovered even five

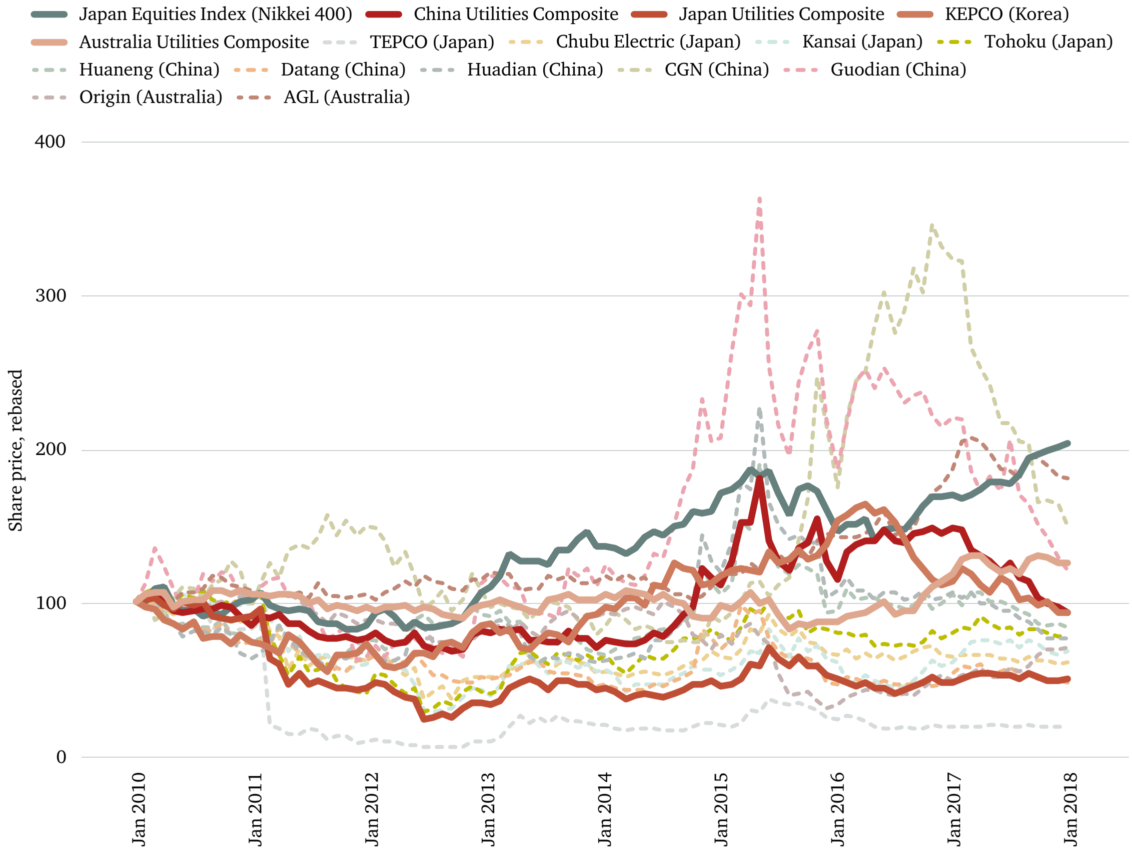
[69] Moody's (2017), 'Moody's: US unregulated power sector outlook remains negative on weak credit fundamentals', 2 November 2017, https://www.moodys.com/research/Moodys-US-unregulated-power-sector-outlook-remains-negative-on-weak--PR_374885 (accessed 29 May 2018).

years after the tsunami. This could be because nuclear power plants were not restarted. As of mid-2018, only nine reactors were operating. Legal battles are ongoing,[70] as are actions by shareholders to prevent any further use of nuclear power.[71]

In Australia, the share prices of power companies have shown divergent trends, averaging each other out. Overall, power companies' share prices have remained stable over the past five years. Although demand for power has been flat, the European trend of equity valuations falling in tandem with power prices and market share is not yet evident in Australia.

In South Korea, as mentioned, lower fossil fuel prices combined with fixed retail prices have boosted the earnings of KEPCO, which until 2016 was reflected in its higher share price. In China, the fall in share prices in mid-2015 likely reflected the turbulence of the stock market during that period, rather than the fundamentals of the companies *per se*. However, the fact that power demand in 2015 recorded its smallest increase for decades possibly undermined the outlook for Chinese power companies.

Figure 9: Share prices of major power utilities in Asia and the composite (average) share price compared to the Nikkei 400 Index, rebased to 2010



Source: Chatham House analysis of Thomson Reuters data (2018).

[70] Tsukimori, O. (2016), 'Japan court upholds injunction to halt reactors in blow to nuclear power industry', Reuters, 17 June 2016, http://www.reuters.com/article/us-japan-nuclear-court/japan-court-upholds-injunction-to-halt-reactors-in-blow-to-nuclear-power-industry-idUSKCN0Z306R (accessed 20 Sep. 2017).
[71] Kyodo (2016), 'Shareholders urge Japan's utilities to end nuclear power generation', *Japan Times*, 28 June 2016, https://www.japantimes.co.jp/news/2016/06/28/business/corporate-business/shareholders-urge-japans-utilities-end-nuclear-power-generation/#.WcKPQMZrzct (accessed 20 Sep. 2017).

The credit ratings agencies have been worried about the power sector for some time. In February 2016, Standard & Poor's (S&P) imposed negative rating actions on 16 parent utility companies across Europe. This included placing EDF, EnBW, E.ON and Vattenfall on 'Credit Watch', with negative implications for their long-term corporate credit ratings. S&P also placed ENGIE, RWE and Edison on Credit Watch negative, citing the fact that electricity prices were creating structural changes and that market design in the EU presented challenges for the sector.

For the Asia-Pacific region (excluding Japan), Moody's offers a mainly stable or positive outlook for the power sector, due to steady demand growth, but with potential future divergences across the region as carbon transition policies differ between countries.[72] In Japan, in 2015 Moody's noted that proposed reforms could weaken the utilities' credit quality: 'The utilities' relatively high ratings have been underpinned by their protected monopoly position, and a supportive and relatively predictable regulatory framework.'[73] In 2017, Moody's noted that the 'competitiveness of renewable generation could increase the utilities' risk of having underutilized thermal power assets'.[74]

In the US, the administration of Donald Trump has proposed new legislation that would enable coal, hydropower and nuclear generators to receive higher payments through a mechanism whereby 'certain reliability and resilience attributes of electric generation resources are fully valued', according to the US Department of Energy.[75] Independent system operators and regional transmission organizations would be required to allow certain 'resilient' power plants to get a 'fair rate of return', even when prices would otherwise be lower.[76]

Response of traditional utilities

Among the three factors shaping the first phase of electricity system transformations, traditional utilities are currently responding most clearly to the continued cost reductions and deployment of renewables. Before the COP23 UN Climate Change Conference in Bonn in November 2017, Iberdrola, Enel, EnBW, EDP, Orsted and SSE collectively called for the EU to increase its target for renewables to 35 per cent of EU energy consumption by 2030.[77] The move appeared to recognize the diminishing role and value of fossil fuel generators, which could be offset for the utilities by greater policy ambition to deploy renewables.

Privatization and liberalization have brought radical restructuring of the electricity sector, with state-owned monopolies forced to separate their business activities. In theory, new companies should enter the market and increase competition. However, the process has not fundamentally changed the operational regime, as new companies have usually been subsidiaries of established power companies. To date, these companies have not been interested in significant reform of their operational regimes, but rather have sought to maintain a business-as-usual approach.

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[72] Moody's (2017), 'Moody's: Outlook stable for APAC power sector in 2018, but business conditions to diverge on carbon transition policies', 5 December 2017, https://www.moodys.com/research/Moodys-Outlook-stable-for-APAC-power-sector-in-2018-but--PR_376351 (accessed 1 Aug. 2018).
[73] Moody's (2015), 'Moody's: Proposed reforms for Japan's electric sector could weaken the utilities' credit quality', 30 September 2015, https://www.moodys.com/research/Moodys-Proposed-reforms-for-Japans-electric-sector-could-weaken-the--PR_335554 (accessed 20 Sep. 2017).
[74] Moody's (2017), 'Moody's: Japan's utility sector will find it challenging to meet the sector's CO_2 reduction targets', 30 October 2017, https://www.moodys.com/research/Moodys-Japans-utility-sector-will-find-it-challenging-to-meet--PR_373955 (accessed 1 Aug. 2018).
[75] US Department of Energy (2017), 'Grid Resiliency Pricing Rule', 28 September 2017, https://www.energy.gov/sites/prod/files/2017/09/f37/Notice%20of%20Proposed%20Rulemaking%20.pdf (accessed 31 Jan. 2018).
[76] Cama, T. (2017), 'Trump proposes higher payments for coal, nuclear power', *The Hill*, 29 September 2017, http://thehill.com/policy/energy-environment/353067-trump-proposes-higher-payments-for-coal-nuclear-power (accessed 7 Jan. 2018).
[77] Williams, D. (2017), 'Major utilities urge EU to do more for renewable power', Power Engineering International, 11 June 2017, http://www.powerengineeringint.com/articles/2017/11/major-utilities-urge-eu-to-do-more-for-renewable-power.html (accessed 12 Dec. 2017).

The second phase of power sector transformations is set to further deconstruct energy services into smaller and distinct functions, which could be undertaken by new market actors. Unlike with previous market reforms, traditional energy companies may not be best suited to operating in these smaller market segments. In some cases, they may not even have the ability to do so.

Utility companies are aware of the technological and political transformations under way, and recognize that the pace of technological change is accelerating. In a 2016 global survey of power companies and utilities, 57 per cent of CEOs were concerned by the speed of technological change; significantly up on the 2013 share of 29 per cent. Over the same period, concern also grew over the potential shift in consumer spending and behaviour, with 64 per cent of respondents expressing concern, up from 29 per cent in 2013.[78] Corporate strategies and structures are now being adjusted to reflect these issues.

Box 4: The three responses of utilities

In general, utilities have had three options for responding to ongoing and impending changes in the power sector: transform their business; try to entrench their market position; or leave the market. These options are not mutually exclusive, and some companies are attempting to undertake more than one strategy at a time.

Transform: This involves moving away from conventional generation to a business model focused on managing electricity flows. Key elements of this model include ownership of the electricity networks; grid balancing, including storage; development of non-fossil fuel generation (usually renewables); and greater engagement with consumers, including the sale of energy services.

Entrench: Many of Europe's coal and nuclear power plants were built before the 1980s. Many of these assets are not expected to continue operating in the long term, because significant investment may be needed to meet new environmental standards. However, they have low operating costs and thus remain potentially attractive assets or investments in the short term.

Leave: Some European companies are choosing to focus their attention on new investments or parts of their existing businesses outside their home markets, particularly in North and Latin America. In such regions, the operating environment is more conducive to conventional utilities' existing business strategies – which are based on large centralized production and often fixed retail prices, and which are therefore relatively low-risk.

Leading private-sector players are already undertaking corporate reform and investing in infrastructure and technologies to address shifting markets. In 2016, German utilities E.ON and RWE separated their clean and conventional energy assets into two listed companies. In 2018, E.ON proposed buying Innogy, a renewables-focused subsidiary of RWE, and the Italian utility Enel merged with its renewables subsidiary to boost revenue growth and generate synergies.[79] GDF-SUEZ, now rebranded as ENGIE, has stated:

> The world of energy is undergoing profound change. The energy transition has become a global movement, characterized by decarbonization and the development of renewable energy sources, and by reduced consumption thanks to energy efficiency and the digital revolution.[80]

[78] PwC (2016), 'Redefining business success in a changing world: Power and utilities industry key findings', https://www.pwc.com.au/pdf/power-and-utilities-key-findings-global-ceo-survey-2016.pdf (accessed 28 Apr. 2018).
[79] Reuters (2015), 'Enel approves merger with green subsidiary', 18 November 2015, http://www.reuters.com/article/enelgreenpower-enel/enel-approves-merger-with-green-subsidiary-idUSI6N13001P20151118 (accessed 20 Sep. 2017).
[80] ENGIE (2015), 'As the world changes, all energies change with it', press release, 24 April 2015, http://www.engie.com/en/journalists/press-releases/gdf-suez-becomes-engie/ (accessed 20 Sep. 2017).

Traditional European utilities have directly filed fewer patents in recent years.[81] Energy companies can take advantage of new ownership structures by partnering with technology firms. The Italian utility Enel, for instance, has signed an agreement with Tesla of the US to test batteries in solar PV and wind plants and to integrate renewables into the grid.[82]

Japan's TEPCO announced in 2016 that it would be restructuring the company into four different parts: a nuclear and decommissioning division; a fuel and thermal capacity division; a transmission and distribution division; and a retail operation. After retail markets were liberalized in April 2016, incumbent generators began losing millions of customers. As a result, 18 months later, 8 per cent of customers (5.1 million retail customers) had switched supplier.[83]

Unlike many other traditional utilities in Europe, EDF of France does not seem to be embarking on a significant restructuring, but rather is proposing to sell existing assets in other countries to maintain its current domestic supply mix, which is dominated by nuclear power. It has announced €55 billion in investment to extend the operational lives of its current reactors.[84] EDF Energy, its UK subsidiary, is building two new European Pressurized Water Reactors (EPRs) at Hinkley Point. Despite this, EDF's annual report notes the changes in the power sector and states the following:

> The transformation of the energy sector and of society's expectations is a spur to rebalancing our assets and production mix. As well as being an invitation to develop decentralised energy solutions and services.… it's also an incentive to invest outside Europe in order to boost our growth.[85]

Press reports suggest that the French government is considering restructuring EDF, including creating a standalone company that holds all the nuclear assets.[86]

In China, despite many reforms across the country, dispatch is still centralized and incumbent generators are delaying widespread changes to the market. Local or regional planners allocate the power plants' operating hours. This is different from most markets elsewhere, which prioritize operations in real time based on the lowest bids; in some countries, preference is given to low-emission generators. However, in China some reforms are being proposed that would factor in marginal pricing, thus rewarding renewable generation over coal.[87]

In South Korea, KEPCO remains a vertically integrated power company. Attempts to liberalize the sector halted in 2004. However, in 2015 the government announced a New Energy Business Model Initiative to encourage EV development, the development of microgrids and opportunities for individual producers to sell into the grid. In late 2017, the Ministry of Energy published a power supply plan to increase renewables' share of power generation to 20 per cent by 2030, and to install an additional 47 GW of solar PV and wind capacity. Such deployment levels will require KEPCO's support.[88]

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[81] Cambini, C., Caviggioli, F. and Scellato, G. (2016), 'Innovation and market regulation: evidence from the European electricity industry', *Industry and Innovation*, 23(8), doi:10.1080/13662716.2016.1206464 (accessed 28 Apr. 2018).
[82] Enel (2015), 'Enel Green Power and Tesla join forces on the development of batteries in solar and wind plants', press release, 12 May 2015, https://www.enel.com/en/media/press/d201505-enel-green-power-and-tesla-join-forces-on-the-development-of-batteries-in-solar-and-wind-plants.html (accessed 20 Sep. 2017).
[83] Reuters (2017), 'Power sales decline for Japan's top utilities amid market liberalization', 31 October 2017, https://uk.reuters.com/article/us-japan-electricity/power-sales-decline-for-japans-top-utilities-amid-market-liberalization-idUKKBN1D01F8 (accessed 3 May 2018).
[84] World Nuclear News (2016), 'EDF faces €100 billion reactor upgrade bill, says audit office', 11 February 2016, http://www.world-nuclear-news.org/RS-EDF-faces-EUR100-billion-reactor-upgrade-bill-says-audit-office-1102164.html (accessed 20 Sep. 2017).
[85] EDF (2014), *The people who power tomorrow*, https://www.edf.fr/sites/default/files/Finance/2014_ReportActivity.pdf.
[86] Reuters (2017), 'France weighs EDF restructuring scenarios, nuclear spinoff-sources', 23 November 2017, https://www.reuters.com/article/edf-nuclear-restructuring/france-weighs-edf-restructuring-scenarios-nuclear-spinoff-sources-idUSL8N1NT3BO (accessed 2 Apr. 2018).
[87] Deign, J. (2017), 'China Faces an Uphill Renewable Energy Curtailment Challenge', Greentech Media, 17 November 2017, https://www.greentechmedia.com/articles/read/china-faces-uphill-renewable-energy-curtailment-challenge#gs.t4HXa14 (accessed 7 Jan. 2018).
[88] Reuters (2017), 'South Korea finalizes energy plan to boost renewable power generation', 29 December 2017, https://www.reuters.com/article/us-southkorea-energy-policy/south-korea-finalizes-energy-plan-to-boost-renewable-power-generation-idUSKBN1EN0KT (accessed 3 May 2018).

Iberdrola is a European utility committed to reducing its emissions by 50 per cent on 2007 levels by 2030, and to being carbon-neutral by 2050. The company operates in five countries: Spain, the UK, the US, Mexico and Brazil. It has a total installed capacity of 44 GW, of which 14.6 GW consists of renewables. The company is shifting from coal into gas and renewables in Europe, and increasing power production in Latin America. International diversification is a key component of Iberdrola's corporate strategy.[89]

[89] Iberdrola (2018), *Integrated Report*, https://www.iberdrola.com/wcorp/gc/prod/en_US/inversores/docs/IA_IntegratedReport18.pdf (accessed 1 Aug. 2018).

2. The Second Phase of Transformations

The electricity sector – already in a state of flux due to the rise of renewables, more stringent efficiency standards and market reform – is also facing a 'second phase' of transformations characterized by enhanced flexibility and the emergence of new market actors.

A high proportion of generating capacity from variable renewables (wind and solar PV) leads to higher integration costs, in particular where national power systems are designed and operated for centralized and dispatchable generators. But a plethora of parallel innovations now promise to counter this dynamic, increasing system flexibility and thereby minimizing integration costs.

The challenge for regulators is how to incentivize sufficient flexibility in a way that enables the grid to remain affordable and reliable at higher penetrations of renewables – i.e. so that consumers benefit in aggregate from low-cost renewables while poorer households do not face higher energy costs.

The early parts of this chapter describe how flexibility lies at the heart of the dilemma for the electricity sector in terms of integrating low-cost renewables without incurring high system costs. Subsequent sections describe in detail the role of key technologies and infrastructure and their wider impact on the electricity sector and traditional utilities. These technologies and infrastructure applications include EVs, electrified heating, digital infrastructure, interconnectors, stationary storage, and flexible and responsive demand.

Box 5: System integration costs – the importance of the whole system

The connection of any new generator will impose system integration costs (SIC) on the larger system, depending on the characteristics of the generator involved. Determining whole-system costs (WSC) requires the quantification of SIC in addition to either generation costs or the levelized cost of electricity (LCOE). While most analyses focus on the SIC of variable renewables, the inflexibility of nuclear plants and the relatively slow ramp rates[90] of coal generators also account for non-negligible SIC.[91]

The key determinant of the SIC of a newly connected generator is the mix of generators already within the system. The greater the diversity and flexibility of the system, the lower the SIC will be. Hence, renewable SIC vary significantly from one system to another, depending on the market share of renewables and the characteristics of the generators already in a given system.

There are several categories of SIC impacts, the quantification of each of which depends on the wider system and its flexibility. Impacts also overlap and interact, making quantification complex. Many recent studies advocate, and employ, a WSC approach to avoid double counting any impact, but such approaches require complex computational modelling.

[90] The ramp rate refers to the rate at which a dispatchable generator can alter its output of electricity.
[91] Heptonstall, P., Gross, R. and Steiner, F. (2017), *The costs and impacts of intermittency – 2016 update: A systematic review of the evidence on the costs and impacts of intermittent electricity generation technologies*, UK Energy Research Centre, doi: 10.13140/RG.2.2.17246.02888 (accessed 28 Apr. 2018).

The flexibility of the system to incorporate variable renewables at low SIC is dependent not just on the characteristics of the current system, but on the extent to which SIC impacts overlap and the market share of the generator being integrated. SIC are also increasingly determined by the uptake of emerging technologies and corresponding new system services that enable greater flexibility. SIC can broadly be divided into discrete but interacting categories (see Table 1). While these impacts exist for all generators, the descriptions of the impacts are given here in relation to renewables.

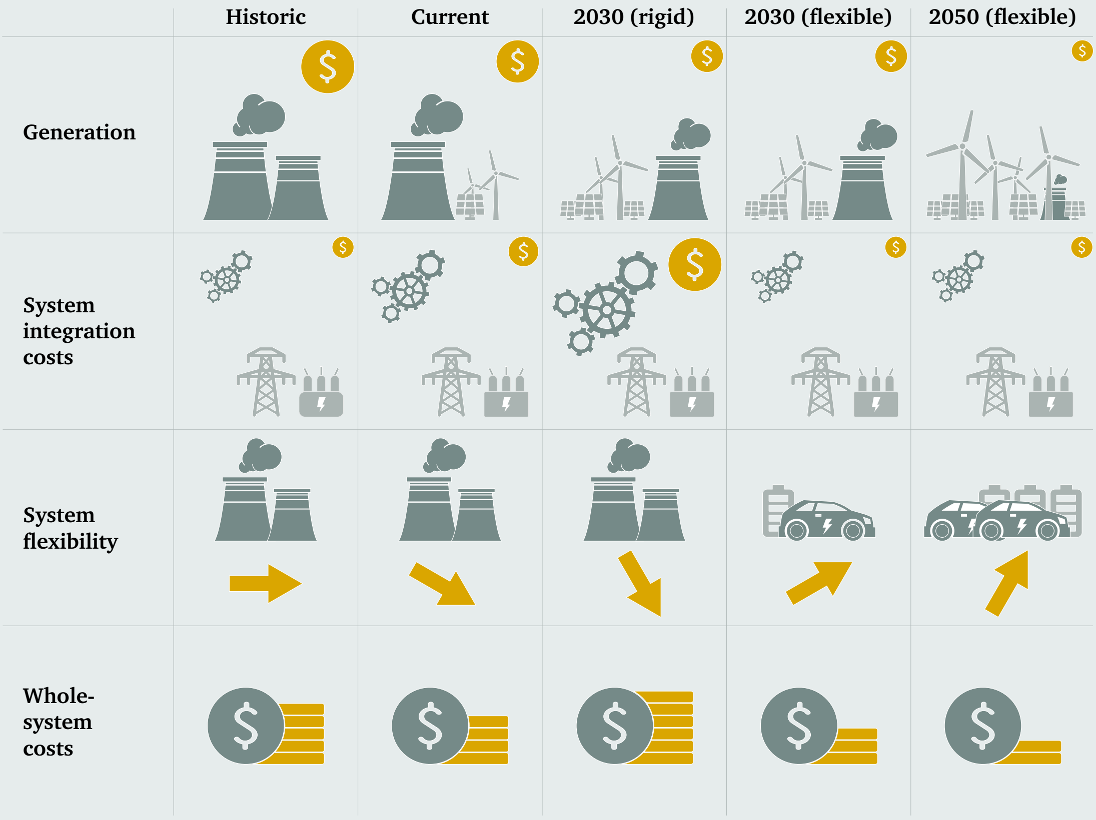
Table 1: Categories of SIC impacts in relation to renewable generators

SIC impact	Description
System balancing and reserve	Variable renewables may increase supply fluctuations, leading to increased system balancing held in reserve. SIC: $14–42/MWh (35 per cent penetration).[i]
Peak demand capacity (capacity credit)	As a proportion of installed capacity, renewables tend to replace less of the capacity required to meet peak demand than conventional generators; as such, the system capacity increases. Capacity credit is a measure of how much capacity can be replaced without reducing system reliability. SIC: $3–25/MWh (30 per cent penetration).[ii]
Network upgrading	New and reinforced network cables may be required to enable power from renewables to reach centres of demand. SIC: $7–49/MWh (30 per cent penetration).[iii]
Curtailment of renewables	Curtailment (lowering the useful power output) tends to result either from the power being transferred exceeding network capacity or from renewable supply exceeding demand.
Conventional plant ramping	Balancing renewables' variability results in 'ramping costs' – the burning of additional fuel to reach operating conditions.
Frequency regulation	The spinning inertia of conventional generators provides frequency stabilization. Renewables increase the need for dedicated frequency regulation services.
Merit order effect	Low-cost or prioritized renewable generation results in conventional generators operating for fewer hours, reducing their profitability. As their services may be still required (e.g. to provide peak demand capacity), subsidized operation (e.g. in the form of capacity credits) may be necessary.

Sources:
[i] Heptonstall, Gross and Steiner (2017), *The costs and impacts of intermittency – 2016 update*.
[ii] Ibid.
[iii] Ibid.

The most obvious overlap or interaction between impacts is that increasing the system balancing capacity held in reserve also provides the ability to meet peak demand. Therefore, costs associated with renewables in one SIC category could be offset by a reduction in another. Many SIC relate not just to renewables but to all generators. The danger of overestimating any SIC, combined with over-attribution of SIC to renewables, is a factor behind the increasing move towards WSC approaches.

Figure 10: Illustration of the change in SIC and WSC with renewable penetration and increased flexibility of EVs and battery storage



Sources: Compiled by authors.

An inflection point?

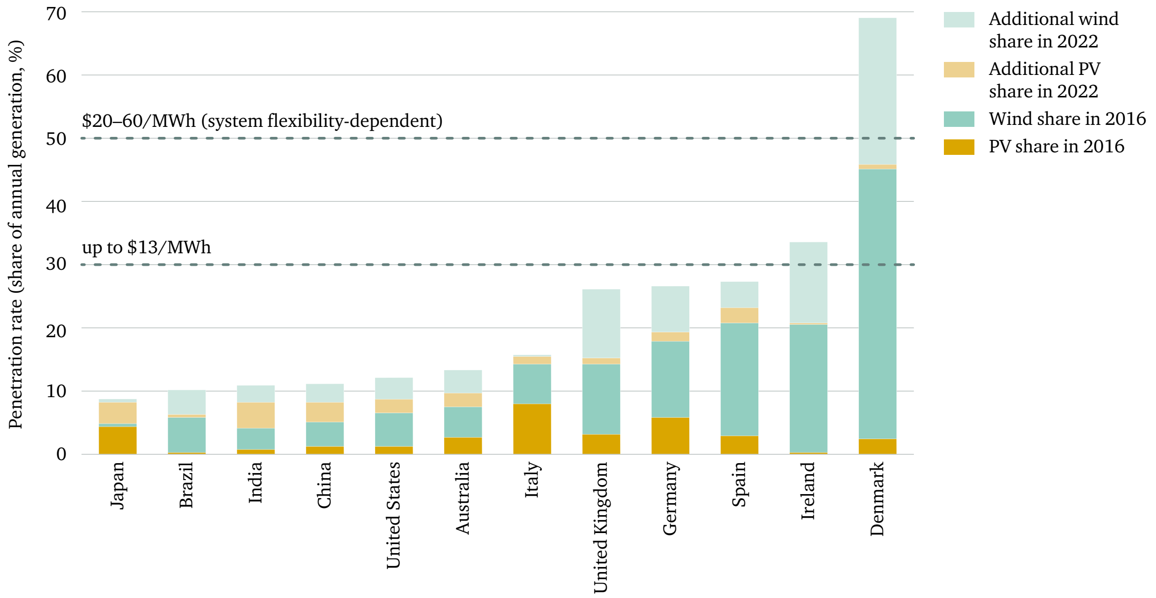
At their current penetration levels,[92] solar PV and wind power are easily absorbed by the existing power system in most markets, with minimal impacts in terms of system integration costs (SIC).[93] In China, India and the US, the penetration levels of solar PV and wind are currently at around 5 per cent, and rising rapidly. In European countries such as Spain and Germany, equivalent levels are at or marginally above 20 per cent.[94] Certain regions within the above sets of countries are exceeding national norms: for instance, in the US state of Texas, solar PV and wind power are expected to exceed 20 per cent penetration this year; the state supplied 25 per cent of wind power in the US in 2016.[95]

With these technologies expected to reach 30 per cent penetration rates in many countries in the next five years, concerns over the costs of integrating solar PV and wind power into the system have

[92] The penetration level is the share of annual generation that a particular type of generator represents.
[93] Heptonstall, Gross and Steiner (2017), *The costs and impacts of intermittency – 2016 update*.
[94] IEA (2017), *Renewables 2017*, Market Report Series, Paris: IEA, https://www.iea.org/renewables/ (accessed 6 Nov. 2017).
[95] Institute for Energy Economics and Financial Analysis (2017), 'Wind Booms, Coal Suffers in Oversupplied Texas Grid', 1 November 2017, http://ieefa.org/wind-booms-coal-suffers-oversupplied-texas-grid/ (accessed 27 Feb. 2018).

increased. For up to a 30 per cent share of generation, variable renewables' SIC are estimated to be up to $13/MWh (see Figure 11).[96] With wholesale prices in Europe and the US at 10-year lows,[97] SIC of $13/MWh would represent around 30–40 per cent of current wholesale prices. As Figure 11 indicates, as the share of generating capacity shifts increasingly to wind and solar PV, integration costs could rise substantially to between $20/MWh and $60/MWh at a 50 per cent share of generating capacity. Crucially, this range is dependent on the flexibility of the system.[98]

Figure 11: Solar PV and wind power – share of generation in relation to current and expected system integration costs



Sources: Adapted from IEA (2017), *Renewables 2017*; and UKERC.[99]

If generation costs continue to fall as renewable technology costs decline, how much will this compensate for higher SIC? A 2016 report published by Imperial College London explored a scenario in which wind generation capacity in the UK increased fivefold.[100] Under this scenario, while the SIC associated with the provision of reserve and response services increased by an order of magnitude, the falling costs of wind generation more than compensated for this – resulting in system costs falling by 33 per cent.

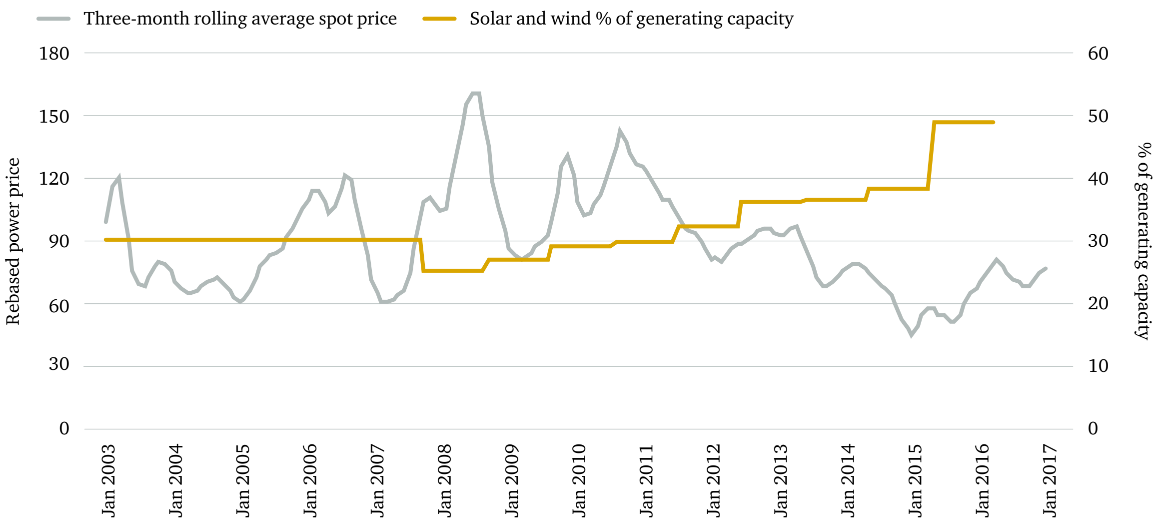
Whole-system costs (WSC) and retail tariffs are more likely to remain affordable if policymakers prioritize system flexibility alongside the integration of low-cost renewable generators. WSC should,

[96] These SIC are the average over the year, taking into account the seasonal and diurnal fluctuations of renewable output; Heptonstall, Gross and Steiner (2017), *The costs and impacts of intermittency – 2016 update*.
[97] US Energy Information Administration (2017), 'Wholesale Electricity and Natural Gas Market Data', https://www.eia.gov/electricity/wholesale/#history (accessed 6 Nov. 2017); European Commission (2017), 'Market analysis – Gas and electricity market reports', https://ec.europa.eu/energy/en/data-analysis/market-analysis (accessed 6 Nov. 2017).
[98] Heptonstall, Gross and Steiner (2017), *The costs and impacts of intermittency – 2016 update*.
[99] Ibid.
[100] Strbac, G. and Aunedi, M. (2016), *Whole-system cost of variable renewables in future GB electricity system,* joint industry project with RWE Innogy, Renewable Energy Systems and ScottishPower Renewables, https://www.e3g.org/docs/Whole-system_cost_of_variable_renewables_in_future_GB_electricity_system.pdf (accessed 28 Apr. 2018).

in theory, be passed through into the wholesale market price.[101] However, a direct comparison between SIC or WSC and the change in market price is contingent on how any particular market is structured, and may not reveal the true economic cost.[102]

Denmark is an interesting exception. Its system has a high market share of wind power (over 40 per cent of installed capacity). Wholesale prices have declined in recent years even as wind generation has increased (see Figure 12). The Danish system is unique in that a significant proportion of electricity is generated by combined heat and power (CHP). Historically, electricity generation from CHP units has followed demand for heating. The introduction since 2005 of regulations to increase the flexibility of the power generated by CHP units, combined with increased interconnector capacity, has enabled prices to remain low, even as wind power has increased its share of generation.[103]

Figure 12: Denmark – wholesale electricity prices compared to solar PV and wind power's share of generating capacity



Source: Chatham House analysis of Nordpool data, http://www.nordpoolspot.com/Market-data1/#/nordic/chart (accessed 6 Nov. 2017).

The importance and provision of flexibility

Although the Danish system is unique, it illustrates an important point: increasing the flexibility of the system as a whole can counter SIC impacts.[104] The impact of system flexibility on SIC and WSC can be illustrated by contrasting a scenario of high renewables penetration, in which system flexibility is enhanced, with a scenario weighted towards nuclear power, which is generally regarded as the least flexible generator. As demonstrated by the shaded areas in Table 2, even a low-flexibility 2030 scenario in which variable renewables account for around 50 per cent of generation could enable the WSC of

[101] Frontier Economics (2016), *Whole power system impacts of electricity generation technologies: A report prepared for the Department of Energy and Climate Change,* London: Frontier Economics Ltd, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/601345/Whole_Power_System_Impacts_of_Electricity_Generation_Technologies__3_.pdf (accessed 28 Apr. 2018).
[102] Heptonstall, Gross and Steiner (2017), *The costs and impacts of intermittency – 2016 update*.
[103] Ea Energy Analyses (2015), *The Danish Experience with Integrating Variable Renewable Energy Renewable Energy: Lessons learned and options for improvement*, study on behalf of Agora Energiewende, https://www.agora-energiewende.de/fileadmin/Projekte/2015/integration-variabler-erneuerbarer-energien-daenemark/Agora_082_Deutsch-Daen_Dialog_final_WEB.pdf (accessed 28 Apr. 2018),
[104] Strbac and Aunedi (2016), *Whole-system cost of variable renewables in future GB electricity system*.

solar PV and wind power to be lower than the levelized cost of electricity (LCOE) of nuclear power. Under this (UK-focused) scenario, it is assumed that flexibility is provided by 5 GW of battery storage, a 25 per cent uptake of flexible demand, and an expansion of interconnection from 4 GW to 10 GW.[105]

Table 2: LCOE, SIC and WSC of solar PV and wind relative to the LCOE of nuclear power in 2030, at around 50 per cent variable renewable market share, under various flexibility scenarios[106]

	Assumed LCOE ($/MWh)	System integration costs vs nuclear ($/MWh, real 2015 prices)			Whole-system costs (LCOE + SIC, $/MWh, real 2015 prices)		
		No flexibility	Low flexibility	Mega-flexibility	No flexibility	Low flexibility	Mega-flexibility
Nuclear	132.1	–	–	–	–	–	–
Offshore wind	110.1	71.1	16.4	8.1	181.2	126.5	118.2
Onshore wind	88.1	59.0	15.0	10.6	147.1	103.1	98.6
Solar PV	95.4	63.9	25.5	11.9	159.3	121.0	107.3

Note: Conversion to dollars based on historical exchange rate.[107]
Source: Adapted from Strbac and Aunedi (2016), *Whole-system cost of variable renewables in future GB electricity system.*

System flexibility can be accomplished by several means. Denmark used regulatory reform to incentivize ramping of CHP generation, and also increased interconnector capacity. Flexibility can be provided through new technologies such as battery storage, interconnectors, flexible demand (via digitalization and control) and artificial intelligence system control; as well as through non-technology-dependent measures such as regulation and market design.[108]

Although second-phase transformations of the power sector are likely to revolve around the flexible, low-cost integration of competitive renewables, the exact mix of flexibility-enabling technologies and accompanying regulations is uncertain. For instance, the deployment of EVs and battery storage is likely to vastly increase system flexibility. However, flexibility could also be enhanced by hydrogen storage, as hydrogen vehicles reduce the cost of low-carbon hydrogen production via electrolysis. Uncertainty also exists over the development of market flexibility mechanisms such as locational marginal pricing and capacity markets. The following sections investigate the technologies likely to be integral components of the second phase of transformations, and their relevance to system flexibility.

Electrification – increased demand, flexible consumption?

Because growth in electricity demand is slowing in many regions, power companies are likely to welcome further electrification. In the coming decades, EVs will be at the forefront of this process. This could be followed by electrification in the heating sector, as well as within industry. Given the impacts of the first phase of transformations, a key question for traditional utilities and the wider power system is how system flexibility will be affected by these electrification technologies. Could the benefits for utilities of increased electrical demand be undermined by greater deployment of renewables, enabled by more flexible electrification?

[105] Ibid.
[106] The SIC of wind and solar in this study were quantified against nuclear; this should not, however, be interpreted as the SIC of nuclear being zero.
[107] Internal Revenue Service (2017), 'Yearly Average Currency Exchange Rates', https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates (accessed 6 Nov. 2017).
[108] Heptonstall, Gross and Steiner (2017), *The costs and impacts of intermittency – 2016 update*.

The rise of electric vehicles

EV sales are set to increase dramatically, stimulated by government targets, policy support and sharp declines in the prices of lithium-ion battery packs. In the first quarter of 2018, worldwide EV sales grew by 59 per cent compared with the same period a year earlier. EV lithium-ion battery costs have fallen by three-quarters over the past six years.[109] Another 30 per cent reduction in lithium-ion battery prices by the end of the decade could be achievable, as global manufacturing capacity for such batteries looks set to increase sixfold by 2020.[110] Each time cumulative production of lithium-ion batteries has doubled, prices have fallen by 19 per cent.[111] A similar phenomenon, known as the 'learning rate', has helped to drive down the cost of solar PV modules in recent years.

Many large and powerful car manufacturers are entering the EV market, prompted by the speed at which the total cost of ownership of EVs is approaching that of ICE vehicles, and by government sales targets.

Unrelenting global urbanization and increasing concerns over air pollution – especially in cities where EV range is not an issue – have pushed EVs further into the political limelight. China has asked all its car manufacturers to ensure that 8 per cent of their sales come from EVs by 2018, rising to 12 per cent by 2020.[112] It has also started research into phasing out production of vehicles powered by internal combustion engines (ICEs).[113] In Europe, the UK recently joined France and the Netherlands in looking to ban sales of diesel and petrol vehicles by 2040. The Norwegian government – a pioneer in EV deployment – thinks EV subsidies will be unnecessary as early as 2025.[114]

Many large and powerful car manufacturers are entering the EV market, prompted by the speed at which the total cost of ownership of EVs is approaching that of ICE vehicles, and by government sales targets. Honda is striving to ensure that two-thirds of its global sales are electric by 2030;[115] BMW is aiming for 15–25 per cent by 2025;[116] and both Volvo and Jaguar Land Rover are targeting 100 per cent EV or hybrid sales by 2020.[117] Volkswagen has been aiming for 25 per cent for some time,[118] and Nissan's EV Leaf is doing so well that Nissan is branching into home battery storage.[119]

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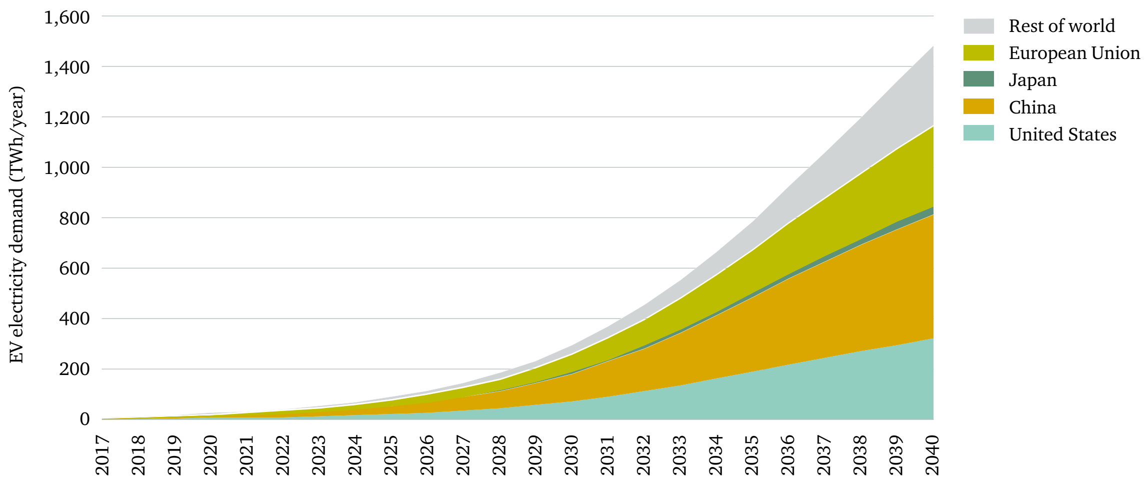
[109] Thomas, N. (2017), 'Green battery advocates accentuate the positive', *Financial Times*, 23 May 2017, https://www.ft.com/content/a6e01984-3567-11e7-99bd-13beb0903fa3?mhq5j=e3 (accessed 13 Jul. 2017).
[110] Relative to 2016, based on company announcements.
[111] Liebreich, M. (2016), 'In search of the miraculous', keynote speech at Bloomberg New Energy Finance Summit, 5 April 2016, https://www.slideshare.net/Jupiter276/state-of-the-industry-keynote-bnef-summit-2016 (accessed 5 May 2018).
[112] Clover, C. and Fei Ju, S. (2017), 'Carmakers grapple with China's electric vehicle drive', *Financial Times*, 30 April 2017, https://www.ft.com/content/efcb27d8-2991-11e7-9ec8-168383da43b7?mhq5j=e3 (accessed 12 Jul. 2017); Martina, M. and Shirouzu, N. (2017), 'China upholds strict electric car sales quotas despite industry protests', Business Insider, 13 June 2017, http://markets.businessinsider.com/news/stocks/r-china-upholds-strict-electric-car-sales-quotas-despite-industry-protests-2017-6-1002089446 (accessed 12 Jul. 2017).
[113] Xinhua (2017), 'China mulls timetable to ban fossil fuel vehicles', *China Daily,* 11 September 2017, http://www.chinadaily.com.cn/business/motoring/2017-09/11/content_31857842.htm (accessed 18 Sep. 2017).
[114] Milne, R. (2017), 'Reality of subsidies drives Norway's electric car dream', *Financial Times*, 14 June 2017, https://www.ft.com/content/84e54440-3bc4-11e7-821a-6027b8a20f23?mhq5j=e3 (accessed 11 Jul. 2017).
[115] Honda (2017), *Annual Report 2017,* http://world.honda.com/content/dam/site/world/investors/cq_img/library/annual_report/FY201703_annual_report_e.pdf (accessed 28 Apr. 2018).
[116] Lambert, F. (2017), 'BMW explains its electric vehicle plans in more details and it's going in the right direction', Electrek, 22 March 2017, https://electrek.co/2017/03/22/bmw-electric-vehicle-plans/ (accessed 28 Sep. 2017).
[117] Vaughan, A. (2017), 'Jaguar Land Rover to make only electric or hybrid cars from 2020', *Guardian*, 7 September 2017, https://www.theguardian.com/business/2017/sep/07/jaguar-land-rover-electric-hybrid-cars-2020 (accessed 18 Sep. 2017).
[118] BBC News (2016), 'VW plans huge investment to become electric cars leader', 16 June 2016, http://www.bbc.co.uk/news/business-36548893 (accessed 28 Sep. 2017).
[119] Vaughan, A. (2017), 'Nissan launches British-made home battery to rival Tesla's Powerwall', *Guardian*, 4 May 2017, https://www.theguardian.com/business/2017/may/04/nissan-launches-british-made-home-battery-to-rival-teslas-powerwall (accessed 28 Sep. 2017).

Analyst forecasts reveal the growing consensus over EV deployment rates. BNEF anticipates that by 2040 EVs will account for one-third of all vehicles on the road.[120] Even OPEC, which represents oil exporters and might be expected to remain bullish on ICEs, more than quadrupled its EV deployment forecast between 2015 and 2016. Since then, its projections have risen still further. As of November 2017, OPEC was forecasting that the global fleet of hybrids, plug-ins and pure battery EVs would total 338 million in 2040.[121]

As a result, global EV electricity demand looks set to rise by at least 7 per cent by 2040, to more than 1,400 TWh (see Figure 13) – a level 40 per cent higher than global solar PV and wind generation in 2015. These increases in electricity demand are contingent not just on growth of the global fleet of EVs, but on how driverless technology develops. EVs capable of driving themselves would potentially significantly increase the vehicle miles travelled. If driverless technology led to a 50 per cent rise in EV miles travelled, as some suggest is likely, then global EV electricity demand could reach 2,200 TWh by 2040. That said, to put this in perspective, this would be equivalent to annual average growth of just 0.4 per cent in global total electricity demand, modest in the context of historic demand growth.

Figure 13: Projected increase in EV electricity demand by country or region, 2017–40



Source: Chatham House analysis.

The use of fast-charging points could significantly inflate charging costs for EV owners. A recent study has shown that many fast-charging outlets cost the equivalent of $3–$4/gallon. However, as 80 per cent of charging occurs at home, the median annual savings on fuel costs offered by an EV compared to an ICE vehicle currently exceeds $770 in the US.[122] While such savings are significant, policy attention could nonetheless benefit from ensuring that fast-charging costs do not hinder deployment rates.

Hydrogen vehicles remain a tiny niche market. Although their implications for the future of the power sector should not be entirely discounted, only 2,500 such vehicles were sold or leased in

[120] Bloomberg New Energy Finance (2017), 'Electric Vehicles to Accelerate to 54% of New Car Sales by 2040', BNEF blog, 6 July 2017, https://about.bnef.com/blog/electric-vehicles-accelerate-54-new-car-sales-2040/ (accessed 27 Jul. 2017).
[121] Shankleman, J. (2017), 'Big Oil Just Woke Up to Threat of Rising Electric Car Demand', Bloomberg, 14 July 2017, https://www.bloomberg.com/news/articles/2017-07-14/big-oil-just-woke-up-to-the-threat-of-rising-electric-car-demand (accessed 27 Jul. 2017).
[122] Union of Concerned Scientists (2017), *Going from Pump to Plug: Adding Up the Savings from Electric Vehicles(EVs),* https://www.ucsusa.org/clean-vehicles/electric-vehicles/ev-fuel-savings#.WuRJ5sgh2MI (accessed 28 Apr. 2018).

2016,[123] a number 100 times smaller than that for EV sales in the final quarter of the same year. The deployment of hydrogen refuelling stations also lags far behind that of EV charging points: as of the end of 2016, there were only 285 hydrogen refuelling stations globally[124] – 3,000 times less than the number of EV charging points that were installed during 2016.

Box 6: Flexible EV charging

From the perspective of power utilities, transport electrification presents both opportunities and risks, depending on how EV charging profiles develop. If EV charging is staggered via smart technology, so that demand is spread over the evening when drivers return home and sufficient charging infrastructure is deployed to enable daytime charging while people are at work, then national demand profiles will flatten and peaks will reduce. Combined with increased electrical demand, this could strengthen power utilities' traditional business models, as fossil fuel generators' utilization rates[125] could increase while less reinforcement of the grid could be required.

While flattened national demand profiles could enable greater use of fossil fuel generators, smart staggering of EV charging could go further, increasing the flexibility of the system and allowing greater integration of renewables. By 2030, the UK could benefit from 11 GW of additional flexibility, equivalent to 18 per cent of current generating capacity, due to smart EV charging.[126] If smart charging were combined with powerful new methods of predicting wind speeds and solar irradiance, it could allow EVs to be charged in accordance with fluctuations in renewable supply. From the perspective of the power utilities, which own a greater proportion of fossil fuel generators, this presents a distinct risk – as it could undermine potential demand growth from transport electrification.

Investment in public EV charging infrastructure is accelerating. In 2016 it grew sevenfold globally, relative to 2015, to $6 billion, with 880,000 charging points added.[127] Smart charging requires two-way communication between the system operator and charging point, but this capability is not currently built into standard EV charging points. Many smart-charging pilot schemes are under way. In the UK, for example, £2.2 billion worth of anticipated network upgrades could be avoided if trials such as Electric Nation demonstrate the feasibility of restricted charging, or of variable-tariff-incentivized charging.[128]

Staggered smart charging could also be complemented by vehicle-to-grid (V2G) charging, whereby an EV uses a charging point to discharge power back to the grid, just as a stationary storage battery would do. Nissan is currently working with traditional utilities in Denmark and the UK, offering free electricity for drivers of the new Leaf model in return for drivers using a bi-directional charger that enables power to be transferred from the vehicle's battery back to the grid.[129] Given the anticipated speed of adoption of V2G charging, this could result in unprecedented system flexibility. To match a typical 500-MW power station's output over one hour would require around 83,000 V2G EVs fitted with 60-kWh battery banks to deplete their batteries by only 10 per cent (the calculation assumes the presence of a fleet of 330,000 such vehicles, 25 per cent of which are connected to the grid and willing to discharge to the network at a given time).

Power utilities and network operators will increasingly need to work with technology companies, EV manufacturers, policymakers and city planners to ensure that as electrical demand increases, smart staggered charging can capture the full benefits of the burgeoning EV market.

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[123] Business Wire (2017), 'Global Market for Hydrogen Fuel Cell Vehicles 2017 – Research and Markets', 18 April 2017, http://www.businesswire.com/news/home/20170418006120/en/Global-Market-Hydrogen-Fuel-Cell-Vehicles-2017 (accessed 10 Nov. 2017).
[124] Edelstein, S. (2017), 'World to have 5,000 hydrogen fueling stations by 2032: study', Green Car Reports, 27 January 2017, https://www.greencarreports.com/news/1108575_world-to-have-5000-hydrogen-fueling-stations-by-2032-study (accessed 10 Nov. 2017).
[125] The utilization rate or factor is the ratio of time that a power generator is actually in use relative to the total time that it could be in use.
[126] Stoker, L. (2017), 'Electric vehicles could add 11GW of grid flexibility by 2030', Clean Energy News, 24 November 2017, https://www.cleanenergynews.co.uk/news/transport/electric-vehicles-could-add-11gw-of-grid-flexibility-by-2030 (accessed 14 Dec. 2017).
[127] IEA (2017), *World Energy Investment 2017,* Paris: IEA, https://www.iea.org/publications/wei2017/ (accessed 28 Apr. 2018).
[128] Fleet News (2017), 'Electric Nation project to trial electric car smart charging', http://www.fleetnews.co.uk/news/car-industry-news/2017/03/06/electric-nation-project-to-trial-electric-car-smart-charging (accessed 31 Jul. 2017).
[129] Lambert, F. (2017), 'Nissan unveils new EV ecosystem to offer free power to owners with vehicle-to-grid system', Electrek, 4 October 2017, https://electrek.co/2017/10/04/nissan-ev-ecosystem-free-power-leaf-vehicle-to-grid/ (accessed 12 Nov. 2017).

Buildings and the electrification of heat

Given that electricity demand growth from EVs may not be enough to rescue the power utilities' business models, could electrification of heating support their revenues more?

The buildings sector accounts for around 32 per cent of global final energy consumption,[130] using the equivalent of more than 35,000 TWh of electricity per annum.[131] Of the 21,000 TWh of current annual global electricity demand, around 50 per cent is consumed in buildings.[132] Appliances, lighting and cooling are almost entirely powered by electricity, while a significant proportion of heating applications (including space and water heating within buildings, as well as cooking) remain unelectrified. Growth in demand for the energy services that appliances and lighting deliver is likely to be offset by increased energy efficiency. Electricity demand for cooling is also expected to grow. Globally, almost 80 per cent of energy demand in buildings is for heat.[133]

Demand for heating and cooling varies significantly between countries. That said, just 27 countries in the northern hemisphere account for 90 per cent of all residential heating. China accounts for almost 40 per cent of global residential heating demand.[134] Biomass is the dominant source of heating globally. In developed regions, coal is being replaced by electricity and gas. Gas provides 40 per cent of heating in residential buildings in the EU, and is likely to dominate up to 2040,[135] as the European gas network infrastructure is widely established. There are, nonetheless, large regional differences – in the UK, 19 per cent of electricity is already used to supply space and water heating.[136]

Decarbonization of the power sector and electrification of transport represent the principle focus of climate policy. Technologies to electrify the heating sector, such as heat pumps, are mature, but space and water heating remains largely unelectrified. This is principally because the cost competitiveness of heat pumps has remained weak. More than 7.5 million heat pump units were installed in the EU between 1995 and 2014; these produced 133.4 TWh of heat in 2014, equivalent to around 45 TWh of electricity demand.[137] The competitiveness of heat pumps varies by region, depending primarily on the capital cost of boilers, fuel prices and the heating load. Heat pumps become more competitive as the heat load increases (see Figure 14); coupling heat pumps to multiple buildings within a district heating system, as is common practice in Sweden and Denmark, increases their competitiveness. This is particularly important in the context of efforts to increase the thermal efficiency of households; doing so reduces the heating load of individual dwellings and is increasingly cost-effective.[138]

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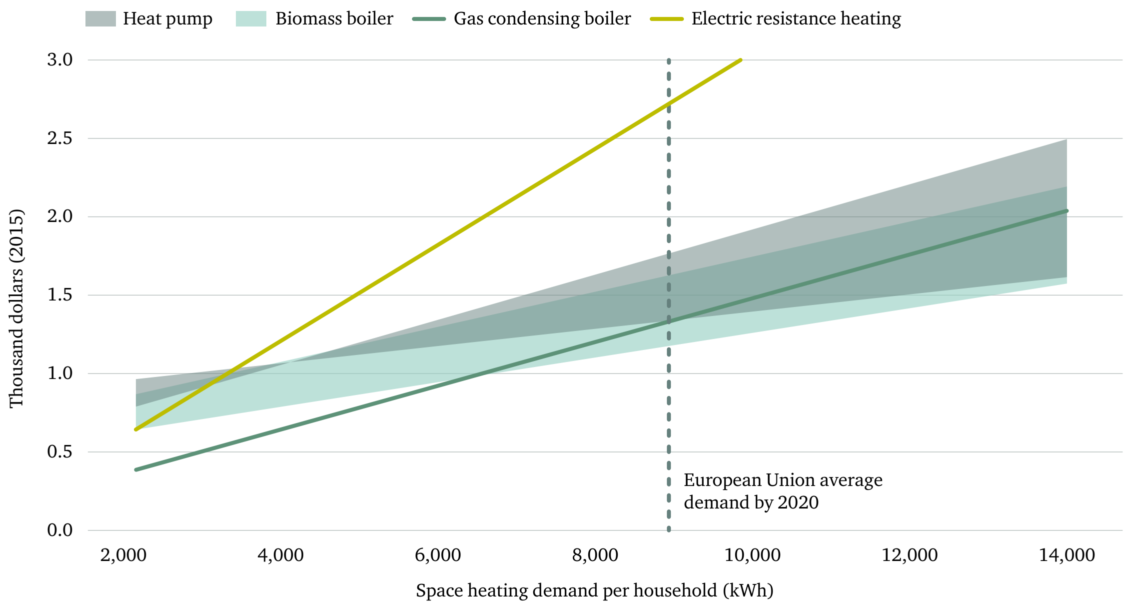
[130] Final energy consumption is the total energy consumption by end-users, such as households, industry and agriculture, across all forms of fuels and electricity.
[131] IEA (2016), *World Energy Outlook 2016*.
[132] Ürge-Vorsatz, D., Cabeza, L. F., Serrano, S., Barreneche, C. and Petrichenko, K. (2015), 'Heating and cooling energy trends and drivers in buildings', *Renewable and Sustainable Energy Reviews*, 41: pp. 85–98, doi:10.1016/j.rser.2014.08.039 (accessed 28 Apr. 2018).
[133] IEA (2016), *World Energy Outlook 2016*.
[134] Fawcett, T., Layberry, R. and Eyre, N. (2014), 'Electrification of heating: the role of heat pumps', https://www.researchgate.net/publication/281029887_Electrification_of_heating_the_role_of_heat_pumps (accessed 12 Jun. 2018).
[135] IEA (2016), *World Energy Outlook 2016*.
[136] Department for Business, Energy & Industrial Strategy (2017), 'Energy Consumption in the UK (ECUK) 2017 Data Tables', https://www.gov.uk/government/statistics/energy-consumption-in-the-uk (accessed 17 Nov. 2017).
[137] Nowak, T. and Westring, P. (2015), *European Heat Pump Market and Statistics Report 2015,* Brussels: European Heat Pump Association, http://www.ehpa.org/fileadmin/red/07._Market_Data/2015/EHPA_Market_Report_2016_-_TOC_and_Editorial.pdf (accessed 28 Apr. 2018).
[138] Rosenow, J., Sorrell, S., Eyre, N. and Guertler, P. (2017), *The EU referendum: Implications for UK Energy Policy Unlocking Britain's First Fuel: The potential for energy savings in UK housing,* policy briefing, UK Energy Research Centre/Centre on Innovation and Energy Demand, http://www.ukerc.ac.uk/publications/unlocking-britains-first-fuel-energy-savings-in-uk-housing.html (accessed 28 Apr. 2018).

Figure 14: Relative competitiveness of household heating technologies in the EU[139]



Source: IEA (2016), *World Energy Outlook 2016*.

A swift transition to electrified heating may yet occur. In northern China, district heating systems service almost half the urban floor area; 90 per cent of these systems were powered by coal in 2012.[140] Increasing concerns over air pollution are starting to result in gas shortages, as the Chinese government attempts to shift households away from the use of coal towards gas.[141] This could lead the Chinese government to direct more investment into the manufacture of heat pumps, thus lowering capital costs, a phenomenon already seen in China with solar PV and lithium-ion batteries.[142]

The UK provides a good case study of a country considering the impacts of the electrification of heating on total electricity demand. Across six 2050 UK energy scenarios (published in 2010), the average proportion of heat demand delivered by heat pumps was 67.3 per cent, resulting in 81 TWh of additional electricity demand per annum, equivalent to almost a quarter of current demand.[143] Globally, heating electrification within buildings could add 5,000 TWh of annual electricity demand by 2040, an increase of 24 per cent on current levels.[144]

A significant hurdle to the integration of heat pumps into the electricity system is the coincidence between peak demand for heating and peak demand for electricity for other uses. Peak heating demand can be significantly greater than peak electrical demand, depending on the region, resulting in electrified heating significantly increasing peak electricity demand. In the 2050 UK

[139] IEA (2016), *World Energy Outlook 2016*.
[140] IEA and Tsinghua University Building Energy Research Center (2015), *Building Energy Use in China: Transforming Construction and Influencing Consumption to 2050,* Partner Country Series, Paris: IEA, https://www.iea.org/publications/freepublications/publication/PARTNERCOUNTRYSERIESBuildingEnergy_WEB_FINAL.pdf, (accessed 28 Apr. 2018).
[141] Hornby, L. and Zhang, A. (2017), 'China hit by gas shortages as it moves away from coal', *Financial Times*, 3 December 2017, https://www.ft.com/content/21cb4ed2-d7f9-11e7-a039-c64b1c09b482 (accessed 14 Dec. 2017).
[142] Ryan, J. (2017), 'China's plans for lithium-ion battery production could overtake Tesla', *Automotive News*, 30 June 2017, http://www.autonews.com/article/20170630/OEM05/170639987/chinas-plans-for-lithium-ion-battery-production-could-overtake-tesla (accessed 14 Dec. 2017).
[143] Quiggin, D. and Buswell, R. (2016), 'The implications of heat electrification on national electrical supply-demand balance under published 2050 energy scenarios', *Energy*, 98 doi:10.1016/j.energy.2015.11.060 (accessed 28 Apr. 2018).
[144] Energy Transitions Commission (2017), *Better Energy, Greater Prosperity: Achievable pathways to low-carbon energy systems,* April 2017, http://www.energy-transitions.org/better-energy-greater-prosperity (accessed 28 Apr. 2018).

scenarios, the average peak demand increases by 70 per cent.[145] Unlike with EVs, it is much more challenging to shift demand for electrified heating to different times of the day. Consequently, increased system flexibility is less likely. One method of reducing peak demand for electrified heating is to install advanced thermal storage at the point of consumption, so that the heating load can be shifted forward in time. However, advanced thermal storage technologies, including phase-change materials, are currently prohibitively expensive.

As the burgeoning EV market requires less support, policy attention may soon start to refocus on the heating sector. Capturing the upside (for power suppliers) of increased overall electricity demand while mitigating the challenges of increased peak demand will require traditional utilities to manage many of the same trade-offs that EV integration increasingly requires of them. Cost-effective advanced thermal storage will be critical.

Box 7: Industry electrification

Across six 2040 scenarios – two each from the IEA, Shell and the International Institute for Applied Systems Analysis (IIASA) – it is anticipated that electricity will supply between 23 per cent and 38 per cent of industrial energy demand. The differences reflect variations in the sectoral demand mix, the relative cost of electrification and efficiency improvements, and the carbon mitigation options employed. Based on the average of these six scenarios, an increase of around 3,300 TWh in annual demand could be anticipated by 2040, equating to an annual growth rate of 0.6 per cent.

Many industrial processes require high-temperature heat (from 400°C to above 2,000°C).[146] The electrification technologies available to supply such temperatures are limited, and the challenges across the subsectors of industry are more diverse than for domestic or commercial sectors. Electric-arc furnaces for secondary steel production show the greatest promise in terms of delivering industrial electrification;[147] the technology currently accounts for around 29 per cent of global steel production.[148]

Flexible electricity demand within industrial processes offers substantial promise for traditional utilities seeking to strengthen their business models. As the electrical load of industrial applications is significantly larger than that of individual residential households, the economic barriers to flexibility are lower. The decision to reschedule industrial demand to weekends or night times depends primarily on the increased labour costs incurred, which may reduce as automation increases.

Future electricity demand growth

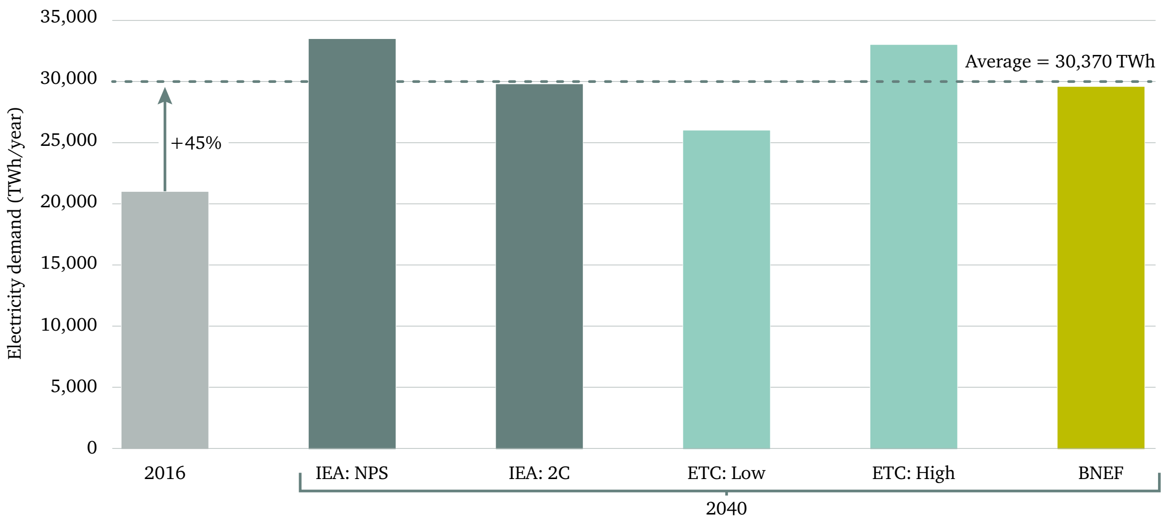
Globally, electricity demand within OECD countries – the markets for the majority of unbundled utilities – is likely to stagnate further in the coming decades, with most growth in demand originating from China, India, Southeast Asia, the Middle East and Africa.

Stagnating or even declining growth in electricity demand has been one of the principle factors undermining traditional utilities' business models. In the decade leading up to 2005, global annual

[145] Quiggin and Buswell (2016), 'The implications of heat electrification on national electrical supply-demand balance under published 2050 energy scenarios'.
[146] Fahnestock, J., Brolin, M. and Rootzen, J. M. (2017), *Industry's Electrification and Role in the Future Electricity System: A Strategic Innovation Agenda,* https://www.researchgate.net/publication/314772075_Industry%27s_Electrification_and_Role_in_the_Future_Electricity_System_A_Strategic_Innovation_Agenda (accessed 28 Apr. 2018).
[147] Other advanced electro-thermal technologies include infrared radiation, induction, microwave heating, electromagnetic radiation, electron beams, ultraviolet light and plasma technologies.
[148] World Steel (2014), *Sustainable Steel – Policy and Indicators 2014,* https://www.worldsteel.org/en/dam/jcr:89d3c840-c3fc-4a64-a485-5dea5e539f06/Sustainable+indicators+2014.pdf (accessed 28 Apr. 2018).

demand growth averaged 3.3 per cent, slowing to 2.8 per cent in the following decade.[149] Although more energy services, such as EVs, are likely to be supplied by electricity in the future, annual demand growth is still likely to slow to around 1.6 per cent out to 2040. This growth rate is derived from a comparison of five 2040 scenarios, illustrated in Figure 15.

Figure 15: Global electricity demand across a range of scenarios



Note: In relation to the IEA scenarios, NPS and 2C refer to the IEA 'new policies scenario' and '2°C compliant (450) scenario' respectively. Energy Transitions Commission (ETC): in relation to the ETC scenarios, 'Low' and 'High' refer to the degree of electrification.
Sources: IEA (2016), *World Energy Outlook 2016*; ETC (2017), *Better Energy, Greater Prosperity*; and BNEF (2017), *New Energy Outlook 2017.*

Network transformations

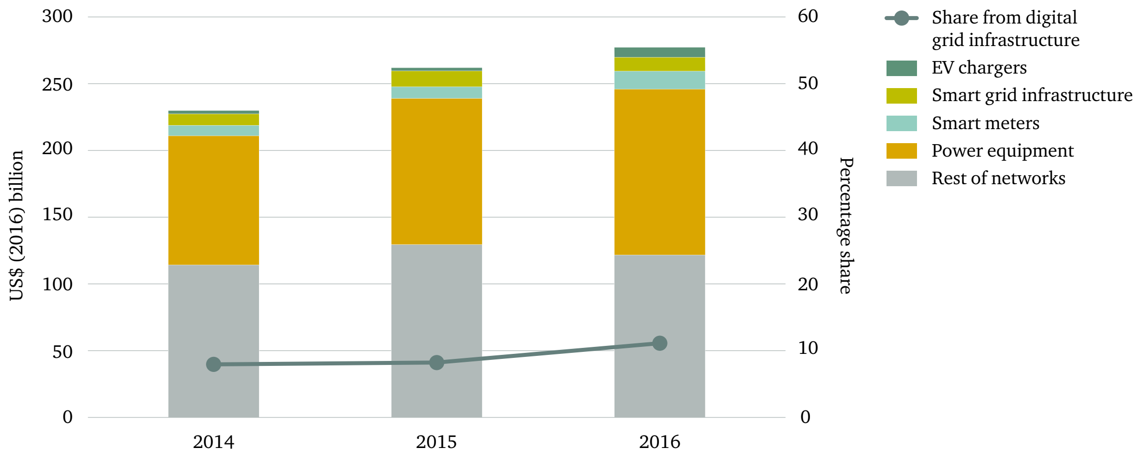
The second phase of electricity system transformations will also bring significant changes to power networks. This section looks at the digital infrastructure revolution, the expansion of interconnection between national electricity systems, and the integration of modular battery storage at various levels of the network. All are part of the wider trend of enhanced system flexibility in response to the existing deployment of renewables, and are likely to reduce the future costs of further integration of renewables.

Even though new players in the renewables sector have undermined the power utilities' stranglehold on generation, large network assets remain largely in the hands of the traditional, unbundled utilities. A 2°C world will require annual investment of at least $500 billion in renewables, 68 per cent up on 2016. Projected investment in future electricity network infrastructure, compliant with 2°C scenarios, is broadly in line with historic expenditure, at around $270 billion per annum.[150] But while the absolute amount spent on the infrastructure of electricity networks may not significantly change, the allocation of investments is showing signs of a dramatic transformation.

[149] BP (2017), *Statistical Review of World Energy 2017.*
[150] IEA (2017), *World Energy Investment 2017*; Energy Transitions Commission (2017), *Better Energy, Greater Prosperity*; New Climate Economy (2014), *Better Growth Better Climate – The New Climate Economy Report: The Global Report,* Washington DC: New Climate Economy, World Resources Institute, https://newclimateeconomy.report/2016/wp-content/uploads/sites/2/2014/08/NCE-Global-Report_web.pdf (accessed 28 Apr. 2018).

Currently 80 per cent of electricity network investments go into equipment such as cables, transformers, substations and switching gear. However, a growing proportion is being spent on the new digital infrastructure that will form the smart, flexible networks of tomorrow (see Figure 16). Almost half of such spending is intended to allow the connection of new sources of generation with new customers, the majority of whom are in non-OECD countries where networks are still growing. As such, 60 per cent of network investment decisions in 2016 in countries such as China and India were made by central government or grid monopolies, rather than by unbundled utilities.[151]

Figure 16: Share of spending on electricity network equipment by type



Sources: IEA (2017), *World Energy Investment 2017;* and NRG Expert (2016), Electricity Transmission and Distribution Database, https://www.nrgexpert.com/energy-market-research/electricity-transmission-and-distribution-database/ (accessed 28 Apr. 2018).

China offers a prime example of the need for rapid network transformation to accompany the integration of renewables into the electricity system. In the western provinces of China, which are rich in renewable resources, network investments have focused on high-voltage connections to high-demand centres in the east of the country, in order to reduce curtailments[152] of power from wind generation and solar PV. In 2016, the curtailment ratios for wind power and solar PV in China were 17 per cent and 10 per cent respectively.[153] The Chinese government is aiming to reduce curtailments to 5 per cent by 2020. The country reduced the curtailment of wind power, due to lack of grid capacity, by 7 percentage points during 2017, and officials have claimed that the problem will be solved by 2020.[154] Significant amounts of hydropower were also curtailed in Sichuan and Yunnan provinces in 2017 – 142 TWh and 314 TWh respectively – representing a five- and sixfold increase respectively on 2013.[155]

[151] IEA (2017), *World Energy Investment 2017*.
[152] When electricity is produced but is unable to reach consumers due to lack of capacity in the networks.
[153] Deign, J. (2017), 'China Faces an Uphill Renewable Energy Curtailment Challenge', Greentech Media, 17 November 2017, https://www.greentechmedia.com/articles/read/china-faces-uphill-renewable-energy-curtailment-challenge#gs.fXt1JwE (accessed 2 May. 2018).
[154] Reuters (2017), 'UPDATE 2-China can solve wasted renewable energy problem by 2020 – NEA', 16 October 2017, https://af.reuters.com/article/africaTech/idAFL4N1MR2OY (accessed 3 Aug. 2018).
[155] Standaert, M. (2017), 'Hydro Overpowers Energy Needs in China', Bloomberg, 8 June 2017, https://www.bna.com/hydro-overpowers-energy-n73014453071/ (accessed 24 Sep. 2017).

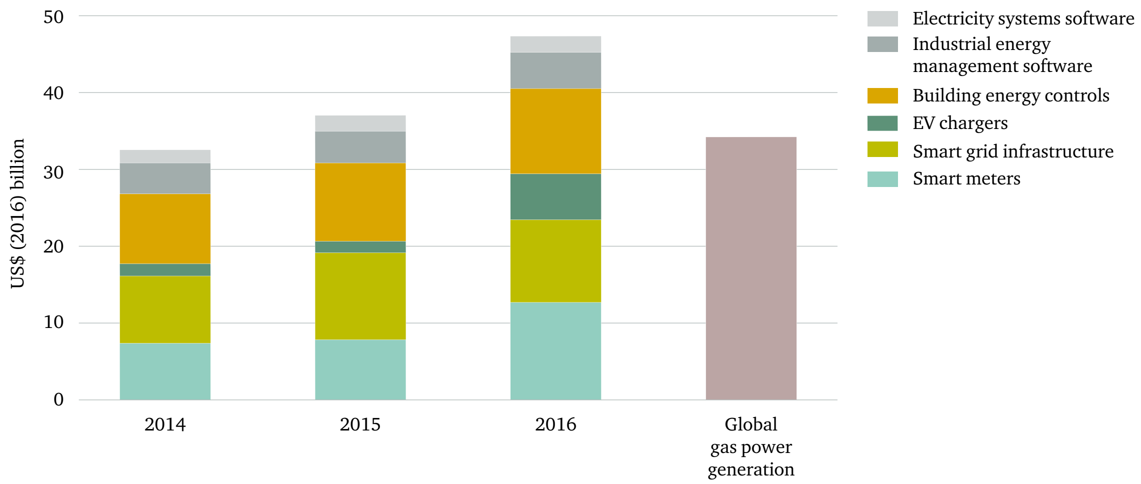
Digital infrastructure

Digital infrastructure enables consumers and traditional utilities to monitor supply and demand as well as network performance. They can use such infrastructure to gather and share data, allowing real-time modification of supply, demand and network asset operation. This in turn helps to reduce peak load stresses on the network and optimize network assets, extending their operational lifetimes and boosting their value. The result is real-time, more accurate and often lower costs for consumers and utilities.

In a 2016 global survey of the 50 largest distribution utilities, 92 per cent of respondents said they were planning to invest in digital infrastructure in the next 12 months.[156] On the demand side, these assets include smart meters, internet-connected fridges and smart EV charging facilities. For the network itself, digital infrastructure relies on advanced sensors, such as phasor measurement units (PMUs) that monitor grid stability; relay switches that detect and recover from faults in substations; and advanced feeder switches that redirect power around faults. Together these reduce the need to build costly high-voltage transmission lines, or to reinforce and upgrade substations and distribution networks. The subsequent lower network costs are another example of the reduction in SIC that is beginning to occur across the electricity system.

Digital infrastructure now represents 10 per cent of network spending; more is now spent on digital infrastructure globally than on gas power stations.[157] In 2016, around $47 billion was spent on digital smart hardware and a further $2 billion on software and computational services (see Figure 17). Smart meters within buildings accounted for the greatest expenditure ($13 billion). Spending on smart grid infrastructure (grid monitoring and sensors) totalled around $10 billion.[158]

Figure 17: World investment in digital infrastructure and software in the electricity sector, by technology



Source: IEA (2017), *World Energy Investment 2017.*

[156] Micallef, P., Skinner, G. and Bayard, J. (2016), *EY Survey: Digital grid: powering the future of utilities,* EY, http://www.ey.com/Publication/vwLUAssets/ey-digital-grid-powering-the-future-of-utilities/$FILE/ey-digital-grid-powering-the-future-of-utilities.pdf (accessed 28 Apr. 2018).
[157] IEA (2017), *World Energy Investment 2017*.
[158] Ibid.

Software may account for a relatively small share of investment, but such spending promises dramatic improvements in system flexibility. In late 2017, grid operators from across Europe were reported as being in the final stages of launching a 'digital information exchange platform' in order to develop and share new applications for managing electricity flows and the growing amounts of renewable energy.[159]

Interconnection

One of the principle options for increasing system flexibility is increased trade of electricity via interconnectors[160] across borders. During one day in May 2016 in Germany, for instance, generation from renewable sources was equivalent to almost 100 per cent of demand, but total supply exceeded demand by 16 per cent, indicating significant exports of electricity via interconnectors during this period.[161]

Increased interconnector capacities can reduce the impact of seasonal supply variations associated with some renewables, while also increasing competition and driving down wholesale electricity prices as markets become intertwined. It is estimated that the 'Capacity Allocation and Congestion Management' regulations, adopted by the EU in 2015 to enable greater interconnection-based electricity trade, could save EU consumers around €2.5 billion to €4 billion per year.[162]

The complexity of integrating electricity markets is prompting governments to pursue rapid expansion of cross-border interconnector capacity: over the 10 years ending in 2015, capacity grew by 81 per cent; it is likely to double by 2025, relative to 2015. Globally, there are currently around 12 proposals for regional grids; in 2016 high-voltage projects (regional and cross-border) accounted for 10 per cent of global transmission investment.

The scale of the infrastructure being built and planned is likely to lead to a significantly more flexible electricity system, further enabling renewable integration. Power utilities will need to adapt to this increased flexibility, and will need to acknowledge that the technical and cost limitations applying to the integration of renewables are likely to diminish.

Box 8: Microgrids in emerging power markets

Power utilities may increasingly seek to internationalize as traditional markets undergo the next phase of transformations. However, the growing number of microgrids and increased decentralization of renewable deployment within emerging economies could undermine this strategy.

In countries with a well-established centralized grid, microgrids do not make economic sense. But emerging economies and remote regions are increasingly combining hybrid renewable and storage systems with localized microgrids. Within countries where grids are already established, microgrids are relatively costly. In urban areas, the need to bury cables adds significant cost. In rural areas, long distances between buildings result in high cabling costs.

[159] Simon, F. (2017), 'European power grid operators cook up 'App Store' for smart grids', Euractiv, 6 September 2017, https://www.euractiv.com/section/electricity/news/european-power-grid-operators-cook-up-app-store-for-smart-grids/ (accessed 15 Dec. 2017).
[160] An interconnector is a high-voltage electricity cable that enables power to flow between networks, typically across international borders.
[161] Shankleman, J. (2016), 'Germany Just Got Almost All of Its Power From Renewable Energy', Bloomberg, 16 May 2016, https://www.bloomberg.com/news/articles/2016-05-16/germany-just-got-almost-all-of-its-power-from-renewable-energy (accessed 15 Dec. 2017).
[162] European Commission (2015), 'New electricity market rules allow efficient EU-wide electricity trading', 23 July 2015, https://ec.europa.eu/energy/en/news/new-electricity-market-rules-help-save-€4-bn-year (accessed 31 Mar. 2017).

In emerging economies and remote locations, where power utilities may see future growth potential, low-cost solar PV and battery storage are enabling hybrid and microgrid systems to develop before centralized grids can be established. Globally, sales of diesel generator equipment fell by 25 per cent in 2016,[163] while 36 per cent of Tesla's battery storage capacity has been sold to remote islands for microgrid applications.[164] Much of this renewed emphasis on microgrids has been stimulated by companies such as Facebook, Microsoft and others setting up the Microgrid Investment Accelerator,[165] which aims to raise $50 million by 2020 in order to accelerate the deployment of microgrids in Indonesia, India and East Africa.[166] Clearly it makes good business sense for digital media providers to enable new demand for their services by first supplying target markets with electricity. However, this may limit the opportunity for power utilities to expand into new markets.

Storage

Significant falls in the cost of lithium-ion battery storage could present the single greatest challenge to power utilities' business models. The flexibility offered by affordable storage could undermine the need for peaking gas and coal capacity as the balancing technology of choice.

> A virtuous circle is developing: the EV battery sector is finally providing increasingly affordable storage, which in turn is enabling greater integration of renewables as the system becomes ever more flexible.

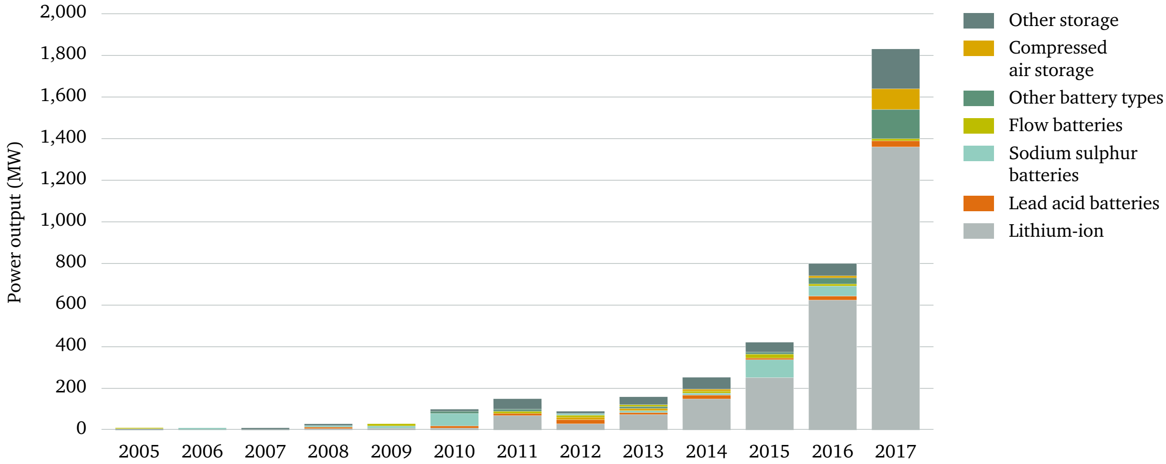
Rapid cost declines in the EV lithium-ion battery sector are enabling cost-competitive stationary battery storage. Excess production capacity is causing manufacturers to sell new lithium-ion batteries into the stationary storage market at low prices.[167] In the first half of 2017, lithium-ion batteries provided more than 90 per cent of utility-scale stationary storage. Of the 3.3 GW of installed battery capacity globally, more than 80 per cent is now lithium-ion.[168]

As such, a virtuous circle is developing: the EV battery sector is finally providing increasingly affordable storage, which in turn is enabling greater integration of renewables as the system becomes ever more flexible. This could allow EVs to be increasingly supplied by renewably generated power. The impacts on the electricity sector and power utilities will be significant, not least because vehicle manufacturers are such powerful companies.

Aurora Energy Research, a British research consultancy, estimates the 2016 intermittency SIC of solar PV in the UK at £1.3/MWh, assuming 11 GW of solar PV in the UK system. Under its 2040 scenario, which envisages capacity of 40 GW of solar PV, integration costs rise to £6.8/MWh. However, the introduction of 8 GW of battery storage could cause SIC to become negative, falling to -£3.7/MWh and thus providing a net benefit to the system rather than a cost.[169]

[163] Bloomberg New Energy Finance (2017), '3Q 2017 Frontier Power Market Outlook', BNEF blog, 31 July 2017, https://about.bnef.com/blog/3q-2017-frontier-power-market-outlook/ (accessed 10 Nov. 2017).
[164] Ibid.
[165] Pyper, J. (2017), 'Facebook, Microsoft Mobilize $50 Million for Renewable Energy Microgrids', Greentech Media, 4 April 2017, https://www.greentechmedia.com/articles/read/facebook-microsoft-mobilize-50-million-for-renewable-energy-microgrids#gs.kOxVUuA (accessed 2 Oct. 2017).
[166] Hirtenstein, A. (2017), 'Facebook, Microsoft Helping to Finance Green Power Microgrids', Bloomberg, 3 April 2017, https://www.bloomberg.com/news/articles/2017-04-03/facebook-microsoft-helping-to-finance-green-power-microgrids (accessed 17 Aug. 2017).
[167] Curry, C. (2017), 'Lithium-ion Battery Costs and Market', Bloomberg New Energy Finance, 5 July 2017, https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf (accessed 6 Oct. 2017).
[168] US Department of Energy (2017), DOE Global Energy Storage Database, https://www.energystorageexchange.org (accessed 16 Aug. 2017).
[169] Aurora Energy Research (2016), *Intermittency and the Cost of Integrating Solar in the GB power market,* https://www.solar-trade.org.uk/wp-content/uploads/2016/10/Intermittency20Report_Lo-res_031016.pdf (accessed 28 Apr. 2018).

Figure 18: Total energy storage by commissioning date, excluding pumped-hydro



Source: US Department of Energy (2017), DOE Global Energy Storage Database.

For now, electricity storage is still dominated by pumped-hydro storage. Of the 193 GW of global electricity storage, 95 per cent consists of pumped-hydro. Power utilities own just less than half of all pumped-hydro storage capacity, roughly the same share as for battery storage.[170] Due to the vast reservoirs of water that pumped-hydro schemes maintain, on average pumped-hydro storage can discharge electricity at full power capacity for 10 times longer than batteries. However, due to the modular nature of batteries, capacity – and hence capital expenditure – can be optimized for specific functions and market requirements. Batteries also provide near-instant response times, therefore supporting more services such as frequency response, distribution network reinforcement and renewable integration.

Unlike pumped-hydro, batteries are not constrained by the need for a water reservoir at high altitude. The geographical specificity required for pumped-hydro also limits the amount of storage that can be built. Batteries are more versatile, capable of providing services at the varying scales needed for transmission, distribution and end-users respectively. For this reason, batteries are increasingly considered within the category of network infrastructure.

Build times on battery projects are also rapid, as demonstrated by the six-month build time of the Tesla storage facility at Mira Loma in California, and by the new AES Energy Storage system in San Diego, which took less than six months to complete.[171] Both of these systems have been sited at substations. Many projects have not disclosed their capital expenditure. However, the authors estimate[172] capital expenditure on the Mira Loma project at $0.46 million/MWh and $3.9 million/MW, compared with an estimated $0.12 million/MWh and $2.3 million/MW for the Nant de Drance pumped-hydro project in Switzerland. Nant de Drance is in its ninth year of construction – normal for pumped-hydro projects, which can take 10–13 years to complete.

[170] US Department of Energy (2017), DOE Global Energy Storage Database.
[171] Spector, J. (2017), 'California's big battery experiment: a turning point for energy storage?', *Guardian*, 15 September 2017, https://www.theguardian.com/sustainable-business/2017/sep/15/californias-big-battery-experiment-a-turning-point-for-energy-storage (accessed 15 Sep. 2017).
[172] Chatham House calculations.

At present, electricity prices do not fully capture spatial and temporal differences, meaning that the services provided by batteries are not fully valued in the market. Batteries can be deployed at various scales, almost anywhere on the network, unlike a gas generator or pumped-hydro facility. Some electricity market regulators treat batteries as power plants that use cheap electricity, while others consider them grid assets. The European Commission's clean energy package attempts to clarify these differences by valuing flexibility. In the US, authorities in New York, Massachusetts, California and Oregon have set storage targets. By 2020, California aims to have 1.3 GW of electricity storage.[173]

The current rapid declines in the cost of lithium-ion batteries could mean that new mechanisms to capture the value of batteries will not be needed. General Electric has developed a hardware and software package that enables batteries to be integrated into any of its pre-existing steam and gas turbine power stations. These 'hybrid electric-gas turbines' can instantly respond in balancing markets, providing the generator with revenues that were previously inaccessible. At least two of these systems have been installed already, for Southern California Edison.[174] This is not only an example of a utility transforming its business to directly integrate new technology into its existing offering, but is also an instance of transformation to a model based on increased flexibility – one that will enable increased integration of renewables at low SIC.

Box 9: The next generation of batteries and a second life for the old

Next-generation battery technologies will deliver greater energy densities. Metal-air batteries could achieve a density of 800 Wh/kg, three and a half times greater than that offered by lithium-ion batteries.[175] While non-rechargeable metal-air batteries have been deployed commercially, rechargeable options are struggling[176] due to low cycle efficiencies.[177] The global metal-air battery market is expected to grow to $1.7 billion by 2018, initially dominated by zinc-air models.[178]

By around 2025, the first generation of EV batteries will need to be replaced to optimize vehicle performance, but they could still have a valuable 'second life' in stationary storage.[179] The Renault-led Powervault partnership is one of several industry initiatives exploring the use of retired EV batteries in home storage systems.[180] The business case for reuse could improve once complicated re-manufacturing processes are automated, but higher-performance next-generation batteries are likely to offer tough competition.

[173] Weaver, J. (2017), 'New York state signs law – 20% of USA has energy storage targets and mandates', Electrek, 1 December 2017, https://electrek.co/2017/12/01/new-york-energy-storage-targets/ (accessed 14 Jan. 2018).
[174] Chediak, M. (2017), 'First Battery-Natural Gas Power Plant Unveiled in California', Bloomberg, 17 April 2017, https://www.bloomberg.com/news/articles/2017-04-17/first-battery-natural-gas-power-plant-unveiled-in-california (accessed 13 Nov. 2017); Lacey, S. (2017), 'GE Can Now Put Battery Storage on Any of Its Power Plants', Greentech Media, 14 June 2017, https://www.greentechmedia.com/articles/read/ge-can-now-put-battery-storage-on-any-power-plant#gs.uqi954g (accessed 13 Nov. 2017).
[175] Bernstein (2016), *The Battery Bible: Powering the Future* [paywall].
[176] BCC Research (2014), 'Global Market for Metal Air Batteries to Reach $1.7 Billion in 2018', 14 April 2014, https://www.bccresearch.com/pressroom/fcb/global-market-for-metal-air-batteries-reach-$1.7-billion-2018 (accessed 18 Sep. 2017).
[177] Taylor, P., Bolton, R., Stone, D., Zhang, X.-P., Martin, C. and Upham, P. (2006), *Pathways for energy storage in the UK,* Centre For Low Carbon futures, http://oro.open.ac.uk/40087/2/Pathways_for_Energy_Storage_in_the_UK.pdf (accessed 28 Apr. 2018).
[178] BCC Research (2014), 'Global Market for Metal Air Batteries to Reach $1.7 Billion in 2018'.
[179] Kane, M. (2016), '95 GWh Of EV Batteries To Be Extracted From Cars By 2025', Bloomberg New Energy Finance, 15 October 2016, http://insideevs.com/bloomberg-new-energy-finance-95-gwh-of-ev-batteries-to-be-extracted-from-cars-by-2025/ (accessed 11 Jul. 2017).
[180] Renault (2017), 'Renault and Powervault Give EV Batteries a "second-life" in Smart Energy Deal', 5 June 2017, https://media.group.renault.com/global/en-gb/groupe-renault/media/pressreleases/92203/renault-et-powervault-donnent-une-seconde-vie-aux-batteries-des-vehicules-electriques1 (accessed 11 Jul. 2017).

Software for the smart grid

Software to aggregate data and control assets in functionally smarter ways will likely have the greatest impacts on the flexibility of the electricity system. Machine-learning algorithms have the potential to optimize the rules governing system balancing and congestion management, thereby dramatically increasing system flexibility.

A flexible smart grid is only achievable if balancing mechanisms – such as battery storage, interconnectors, flexible demand and digital network infrastructure – can be controlled in smarter modes. Cloud computing, artificial intelligence, machine learning and distributed computing sit within the $2 billion investment bracket (for 'software and computational services') mentioned in the earlier 'Digital infrastructure' section. Spending on software currently accounts for less than 5 per cent of the $47 billion invested in digital infrastructure.[181] However, such spending is expected to grow as development of a flexible smart grid, capable of processing and optimizing the network and wider system, progresses.

In the UK, congestion management costs have risen from £180 million to £463 million per year in five years, and in Germany from €165 million to €255 million.[182] Currently, congestion management is based on overlapping rules, services, mechanisms and safety margins, handled by humans and standard sequential algorithms. This is where artificial intelligence teams such as DeepMind are now contributing expertise. DeepMind's machine-learning optimization capabilities were used at Google to achieve a 40 per cent reduction in the energy used to cool servers.[183] DeepMind is also reportedly working with National Grid in the UK[184] to explore ways of reducing electricity demand by 10 per cent without the need for new traditional network infrastructure.

The digital and flexible demand transformation

Digitalization of the electricity system is not limited to the supply and network side. Automation technologies are also creating new capabilities for digitalized demand management. Digitalization could enable traditional utilities to increase their operational efficiency – for example, by enhancing control of infrastructure via remote sensors, improving management of supply chains, or optimizing internal accounting and customer billing.

The UK's Electricity Networks Strategy Group sees the smart, digital grid as an 'enabler for a radical departure from the operation of the current power system, with extensive balancing on the demand side'.[185] Demand could be shifted forwards and backwards in time, within both the domestic and non-domestic electricity markets. National Grid anticipates that 2 GW of flexible demand will be required by 2020 to balance the UK system.

Flexible demand can reduce peak demand and flatten national 24-hour demand profiles, increasing centralized power generators' utilization rates and strengthening power utilities' revenues. That said,

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[181] IEA (2017), *World Energy Investment 2017.*
[182] Marquina, D. and Olsen, J. (2017), 'Google Might Run the Power Grid More Efficiently: BNEF', Bloomberg New Energy Finance, 20 March 2017, http://www.fullertreacymoney.com/system/data/files/PDFs/2017/March/20th/deepmindgrid.pdf (accessed 16 Aug. 2017).
[183] DeepMind (2016), 'DeepMind AI Reduces Google Data Centre Cooling Bill by 40%', 20 July 2016, https://deepmind.com/blog/deepmind-ai-reduces-google-data-centre-cooling-bill-40/.
[184] Murgia, M. and Thomas, N. (2017), 'DeepMind and National Grid in AI talks to balance energy supply', *Financial Times*, 12 March 2017, https://www.ft.com/content/27c8aea0-06a9-11e7-97d1-5e720a26771b?mhq5j=e3 (accessed 22 Jun. 2017).
[185] Electricity Networks Strategy Group (2010), *Electricity Networks Strategy Group – A Smart Grid Routemap,* https://www.smartgrid.gov/document/electricity_networks_strategy_group_smart_grid_route_map (accessed 28 Apr. 2018).

smart meters and control of appliances could also increase system flexibility and therefore reduce SIC for renewables, offsetting the benefit to traditional generators by allowing renewables to capture greater market share.

Flexible-demand markets: the current state of play

There is around 4,000 GW of fossil fuel generation capacity worldwide, yet in 2016 there was only 56 GW of flexible demand. The latter is anticipated to expand to more than 300 GW by 2040.[186] By that time, flexible demand could account for 7.5 per cent of traditional dispatchable generation, having grown at around 7 per cent per annum.

Large commercial applications of flexible demand are already in operation. In the UK, Flexitricity was one of the first providers of national demand-side balancing services, achieved via the aggregation of large commercial consumers. In the US, Zen Ecosystems recently launched Zen HQ, a product designed to target smaller businesses that typically have not participated in flexible-demand markets due to the three- to five-year payback periods on the investments required. Currently 20 per cent of the 5.5 million commercial buildings in the US are already on energy management systems. Zen Ecosystems hopes to integrate flexible demand into such systems to enable payback periods of 12 months or less.[187]

Across the seven major organized wholesale electricity markets of North America, wholesale flexible-demand capacity has averaged around 28 GW over the past three years. The Midcontinent Independent System Operator (MISO) accounts for 11.7 GW, or more than 40 per cent of this capacity. The total generation capacity of MISO is around 191 GW,[188] or 18 per cent of US generation. Consequently, one of the largest North American electricity markets already has flexible demand capacity equivalent to 6 per cent of traditional generation capacity. Most of this flexible demand is from industrial and large commercial consumers.

Of the 1.2 GW of flexible demand included in the New York Independent System Operator (NYISO) capacity market, only 10 per cent originates from regulated utilities.[189] This is likely to change following a recent FERC ruling that exempts flexible demand from the floor price.[190] But the situation does illuminate a major barrier that traditional utilities face in participating in this flexible-demand market – nimble new market players are able to benefit from new revenue streams, while utilities are struggling to keep pace.

It is unclear how much flexible demand will compete with batteries to provide balancing services,[191] or if the two will complement and support each other. Utility-scale battery projects are likely to be disadvantaged as demand flexibility increases; however, decentralized batteries could aid household participation in flexible-demand markets. Not only will the split between battery deployment at the utility level and household level determine the outcome, but so will the relative costs. Either way,

[186] Bloomberg New Energy Finance (2017), *New Energy Outlook 2017*.
[187] Business Wire (2016), 'Zen Ecosystems Launches Fastest-Payback Energy Management System', 20 October 2016, http://www.businesswire.com/news/home/20161020005485/en/Zen-Ecosystems-Launches-Fastest-Payback-Energy-Management-System (accessed 13 Aug. 2017).
[188] Maize, K. (2017), 'MISO: Avoiding the Mess Facing Other Wholesale Competitive Electric Markets', PowerMag, 7 January 2017, http://www.powermag.com/miso-avoiding-the-mess-facing-other-wholesale-competitive-electric-markets/ (accessed 27 Sep. 2017).
[189] NYISO (2018), Annual Report in Docket No. ER01-3001-000, http://www.nyiso.com/public/webdocs/markets_operations/market_data/demand_response/Demand_Response/Reports_to_FERC/2018/20180112_NYISO2017AnnlRprtDRPrgrms_Cmplt_PUBLIC.pdf (accessed 12 Feb. 2018).
[190] Hamilton, K. (2017), 'FERC Ruling Constitutes Win for AEMA and Consumers in New York', Advanced Energy Management Alliance, 8 February 2017, http://aem-alliance.org/ferc-ruling-constitutes-win-aema-consumers-new-york/ (accessed 8 Nov. 2018).
[191] Balancing services refer to the ability of a technology to aid the supply–demand balancing of the electricity system.

as the flexibility of the system increases, the future is likely to bring greater market competition to the provision of balancing services.

With more system balancing on the demand side, the traditional role of power utilities in supplying electricity in response to uncontrolled but predictable demand will come under further threat. Traditional utilities are likely to experience increased competition for balancing services from batteries and interconnectors, and also as flexible demand gains market share in balancing markets. However, working with agile new market players could help traditional utilities to secure some of these additional revenue streams.

Importantly, while commercial and industrial flexible-demand markets are maturing, those for household electricity are yet to develop. Such markets, if successfully established, could offer utilities an opportunity to build on long-standing relationships with household consumers.

Smart meters – the entry point for smarter demand

At the heart of power demand digitalization is the smart meter. Automatic meter readings for large commercial consumers began in the 1980s. The transformation now under way is supported by the rapid deployment of smart meters featuring two-way communication (between the household and wider system), which enable time-varying pricing, monitoring and control of demand.[192] The control of appliances afforded by smart meters could help utilities to avoid some traditional network investment, as peak demand and network congestion are lessened. The European Commission anticipates that smart meters may save European countries, on average, €60 per metering point over the lifetime of each smart meter.[193] These savings could increase if SIC impacts and the benefits of flexibility are captured by cost–benefit analyses – an important next step given that almost all analyses fail to do this.

> Smart metering represents both an opportunity and a threat for traditional utilities – utilization rates of generators may increase and the need for grid reinforcement may be avoided, but this could be offset by lower electricity demand growth.

As households and commercial consumers increasingly install smart appliances, smart meters could help to reduce aggregate demand by around 3 per cent.[194] Hence, smart metering represents both an opportunity and a threat for traditional utilities – utilization rates of generators may increase and the need for grid reinforcement may be avoided, but this could be offset by lower electricity demand growth. Smart meters could also usher in new market entrants, such as those supplying technology and services for the IoT.

The biggest smart meter company by market share is Landis+Gyr, accounting for 26 per cent of global smart meter supply contracts (excluding China). Enel accounts for almost a quarter, giving the Italian utility giant a significant advantage in the digital transformation. Itron and Aclara, both based in the US, account for around 10 per cent each. Each company offers a different type of smart meter, some

[192] Schuelke-Leech, B.-A., Barry, B., Muratori, M. and Yurkovich, B. J. (2015), 'Big Data issues and opportunities for electric utilities', *Renewable and Sustainable Energy Reviews*, 52: pp. 937–47, doi:10.1016/J.RSER.2015.07.128 (accessed 28 Apr. 2018).
[193] European Commission (2017), 'Smart Metering deployment in the European Union', http://ses.jrc.ec.europa.eu/smart-metering-deployment-european-union (accessed 28 Apr. 2018).
[194] Ibid.

with greater functionality than others. All allow remote meter readings, but not all meters currently enable two-way communication or the connection of smart appliances.

Trust is key for widespread roll-out and optimized use of smart meters. A survey by Accenture found that 76 per cent of consumers did not trust their utility company.[195] In the US, 43 per cent were 'uneasy about smart meters in their homes if the information obtained could be used by utility companies to infer how many people live there and what they are doing at certain times of day'.[196] These findings are somewhat contrary to market experience. At the end of 2015, 30 US electricity suppliers had deployed smart meters to all their residential customers;[197] in the few US states that allow smart meter opt-outs, fewer than 1 per cent of customers chose to do so.[198] As household flexible-demand markets expand, it is imperative that those households vulnerable to price rises are insulated from the high-cost periods associated with time-of-use tariffs.[199]

Box 10: The smart meter revolution by numbers

The US in 2016 had an estimated 70.8 million smart electricity meters, of which 88 per cent were installed for residential customers.[200] At the end of 2016, there were 700 million gas and electricity smart meters installed globally. This global figure is expected to rise to nearly 800 million by 2020.[201] In the EU28+2, 112 million smart electricity meters had been installed at the end of 2017, representing 40 per cent of all metering points.[202] According to the terms of the EU's Electricity Directive 2009/72/EC, EU member states are required to replace 80 per cent of meters with smart meters by 2020. The European Commission estimates that 72 per cent of households (200 million) will have smart electricity meters installed by 2020, a transformation that will require €45 billion of investment.[203]

Smart appliances, the Internet of Things and a world awash with data

Smart meters are increasingly able to control appliances and equipment within homes and businesses to help achieve demand-side flexibility. In the electricity sector, these products include everything from smart fridges, washing machines and phones to huge pieces of industrial equipment.

Around 20 billion internet-connected devices globally, across a diverse set of sectors, currently make up what is known as the Internet of Things (IoT).[204] Although not all of these IoT devices are significant for the electricity system, the rapid expansion in sales of smart, internet-connected major domestic appliances (MDAs) marks a potentially consequential development. Excluding North

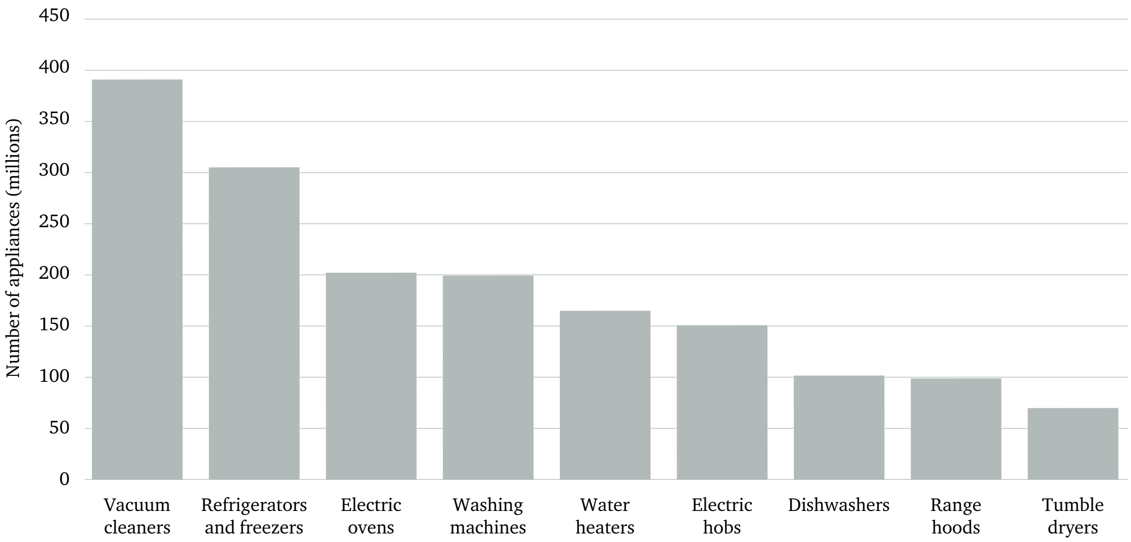
[195] Accenture (2013), *The New Energy Consumer Handbook,* https://www.accenture.com/_acnmedia/Accenture/next-gen/insight-unlocking-value-of-digital-consumer/PDF/Accenture-New-Energy-Consumer-Handbook-2013.pdf (accessed 28 Apr. 2018).
[196] Ibid.
[197] Institute for Electric Innovation (2016), *Electric Company Smart Meter Deployments: Foundation for A Smart Grid,* http://www.edisonfoundation.net/iei/publications/Documents/Final%20Electric%20Company%20Smart%20Meter%20Deployments-%20Foundation%20for%20A%20Smart%20Energy%20Grid.pdf (accessed 28 Apr. 2018).
[198] Ibid.
[199] A tariff type, wherein customers are charged at variable prices depending on the current level of demand and supply.
[200] U.S. Energy Information Administration (2013), 'Frequently Asked Questions: How many smart meters are installed in the United States, and who has them?', https://www.eia.gov/tools/faqs/faq.php?id=108&t=3 (accessed 13 Aug. 2017).
[201] Global Smart Grid Federation (2016), *GSCF Report: Smart Meter Security Survey,* http://globalsmartgridfederation.org/dashboard/uploads/BOhEC1511437168.pdf (accessed 28 Apr. 2018).
[202] Cision PR Newswire (2018), 'More than 200 million European households will have smart meters in 2023', 8 January 2018, https://www.prnewswire.com/news-releases/more-than-200-million-european-households-will-have-smart-meters-in-2023-300578405.html (accessed 30 July. 2018).
[203] Renner, S., Albu, M., Van Elburg, H., Heinemann, C., Lazicki, A., Pentinnen, L., Puente, F. and Sæle, H. (2011), *European Smart Metering Landscape Report,* Vienna: Österreichische Energieagentur – Austrian Energy Agency (AEA), https://www.sintef.no/globalassets/project/smartregions/d2.1_european-smart-metering-landscape-report_final.pdf (accessed 28 Apr. 2018).
[204] IHS Markit (2017), *IoT trend watch 2017,* https://ihsmarkit.com/Info/0117/IoT-trend-watch-2017.html (accessed 28 Apr. 2018).

America, global sales of these products more than doubled in the financial year ending March 2017, from 5.2 million in 2016 to 13.2 million.[205]

With more than 75 billion IoT devices expected to be connected to the internet by 2025,[206] the volume of data processing required for new smart energy services will be vast. Cisco, a US network equipment maker, estimates that global IoT-generated data in 2020 will total 19,000 terabytes per second, 275 times greater than the amount of data sent from data centres to end-users or devices in that year.[207]

Yet even with today's low levels of smart meter deployment, many traditional utilities are struggling to manage growing volumes of data.[208] The UK's 27 million households currently generate one meter reading per month, equivalent to 324 million meter readings per year. Once all households have a smart meter, with readings communicated every 15 minutes, 946 billion packets of data will be created each year. Once data sent from smart MDAs as well as smart meters are factored in, it is clear that the data processing required is likely to be beyond the current capabilities of traditional utilities. In 2015, there were 1.7 billion MDAs in Europe alone (see Figure 19). Although the vast majority of these were non-smart, the figure underlines the potential for growth in deployment in the future.

Figure 19: Installed stock of major domestic appliances (smart and non-smart) in Europe, 2015



Source: Europe Economics (2015), *The Economic Impact of the Domestic Appliances Industry in Europe. Report for the European Committee of Domestic Equipment Manufacturers (CECED),* London: Europe Economics, http://www.europe-economics.com/publications/the_economic_impact_of_the_domestic_appliances_industry_in_europe_finaol_report.pdf (accessed 28 Apr. 2018).

[205] GFK (2017), 'Smart major domestic appliances are connecting with households globally', 29 May 2017, http://www.gfk.com/insights/infographic/smart-major-domestic-appliances-are-connecting-with-households-globally/ (accessed 19 Sep. 2017).
[206] Lucero, S. (2016), *IoT platforms: enabling the Internet of Things*, IHS Technology white paper, March 2016, http://cdn.ihs.com/www/pdf/enabling-IOT.pdf (accessed 28 Apr. 2018).
[207] McKendrick, J. (2016), 'With Internet Of Things And Big Data, 92% Of Everything We Do Will Be In The Cloud', *Forbes*, 13 November 2016, https://www.forbes.com/sites/joemckendrick/2016/11/13/with-internet-of-things-and-big-data-92-of-everything-we-do-will-be-in-the-cloud/#543b1164ed58 (accessed 19 Sep. 2017).
[208] Lucero (2016), *IoT platforms: enabling the Internet of Things*.

The question of who owns and has access to IoT data will also be increasingly important. In the US state of Illinois, for example, the regulatory authority recently granted approval for third-party companies to access the smart meter data of the state's utility, Commonwealth Edison. For a fee of $900 per month, companies will be able to access anonymized consumption data, identified by zip code and customer segment. More granular locational information will be available for $145 per hour.[209] The aim is to encourage and support smart home and IoT energy management innovations beyond those provided by the traditional utility. Eight US states, including New York and California, are conducting utility reform studies in order to encourage similar innovations in the smart home space.

Box 11: Layers of cybersecurity

Following reports of baby monitors being hacked in 2016,[210] public attention is increasingly turning to the risks of cybersecurity around the so-called Internet of Things (IoT). Areas of concern include digitalized electricity infrastructure. Grid cybersecurity, in particular, is likely to become increasingly problematic as more access points emerge within the electricity system that hackers can exploit. In addition to IoT devices, the rapid rise of distributed energy resources is compounding the vulnerability of power grids to attack.

In December 2015, the Ukrainian grid was attacked, causing 225,000 consumers to lose power. Geopolitical tensions over the potential for state-sponsored cyberattacks, including on energy infrastructure, increased in January 2018 as the UK defence secretary claimed that Russia could cause 'thousands of deaths' by targeting UK energy infrastructure.[211]

Governments have begun to respond. US senators recently introduced a bill to ensure that imported products regularly receive security updates, have no known security vulnerabilities and have changeable passwords. In Australia, IoT products will soon be required to display a cybersecurity rating standard.[212]

The responsibility for ensuring grid cybersecurity stretches to the traditional utilities. The North American Electric Reliability Corporation (NERC) provides and enforces rules within the US and Canada that govern how power utilities and grid operators protect the grid. Compliance with NERC's Critical Infrastructure Protection framework requires multi-factor user authentication and continuous monitoring of the grid for attacks. NERC also hosts regular simulation exercises.[213] In Europe, equivalent standards and procedures are set out under the European Programme for Critical Infrastructure Protection.

The US National Institute of Standards and Technology recently provided updated non-mandatory guidelines for traditional utilities. The guidelines focus on the need to 'collect and converge monitoring information' by using commercially available products that improve the 'situational awareness of security analysts in each silo'.[214] Power utilities and grid operators are therefore being encouraged to integrate products from companies such as Cisco, Schneider, Sierra Nevada Corporation, VeriSign, Raytheon, ViaSat, Leidos, BAE Systems and IBM.[215]

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[209] Unger, D. (2017), 'Illinois regulators approve utility plan to share anonymous energy usage data', Energy News Network, 21 February 2017, https://energynews.us/midwest/illinois-regulators-approve-utility-plan-to-share-anonymous-energy-usage-data/ (accessed 20 Sep. 2017).
[210] Ross, E. (2016), 'Baby monitors 'hacked': Parents warned to be vigilant after voices heard coming from speakers', *Independent*, 30 January 2016, http://www.independent.co.uk/life-style/gadgets-and-tech/news/baby-monitors-hacked-parents-warned-to-be-vigilant-after-voices-heard-coming-from-speakers-a6843346.html (accessed 29 Jan. 2018).
[211] Allegretti, A. (2018), 'Russia could kill 'thousands' in UK power station attack, warns Defence Secretary', Sky News, 26 January 2018, https://news.sky.com/story/russia-could-kill-thousands-in-uk-power-station-attack-warns-defence-secretary-11222844 (accessed 29 Jan. 2018).
[212] Wroe, D. (2017), 'Baby monitors face mandatory cyber security rating over hacking fears', Stuff.co.nz, 15 October 2017, https://www.stuff.co.nz/technology/97888871/baby-monitors-face-mandatory-cyber-security-rating-over-hacking-fears (accessed 29 Jan. 2018).
[213] The Conversation (2017), 'Cybersecurity of the power grid: A growing challenge', 24 February 2017, http://theconversation.com/cybersecurity-of-the-power-grid-a-growing-challenge-73102 (accessed 29 Jan. 2018).
[214] US National Institute of Standards and Technology (2017), *Situational Awareness for Electric Utilities*, Special Publication 1800-7, https://www.nccoe.nist.gov/projects/use-cases/situational-awareness (accessed 28 Apr. 2018).
[215] Douris, C. (2017), 'Utilities Will Spend Billions On Cybersecurity As Threat Grows', *Forbes*, 21 September 2017, https://www.forbes.com/sites/constancedouris/2017/09/21/utilities-will-spend-billions-on-cybersecurity-as-threat-grows/#4ef09e3c6cfe (accessed 29 Jan. 2018).

3. The New Power Landscape

The previous chapter explored the technologies likely to shape the second phase of electricity sector transformations. This chapter explores the new actors and services emerging alongside these innovations, focusing on those actors and services that are shaping the digitalization of the sector. The chapter maps the ecosystem of technologies and new market actors, and discusses the new role of aggregators in managing the growing number of energy services and distributed energy resources (DERs). Utilities' technical expertise will be critical to enable digital control of these DERs, such as EVs and household batteries. The chapter investigates the opportunity for utilities to leverage their expertise within this new power landscape, specifically in relation to energy service platforms. It also studies how blockchain technology could fundamentally reshape the way in which electricity and its associated services are paid for.

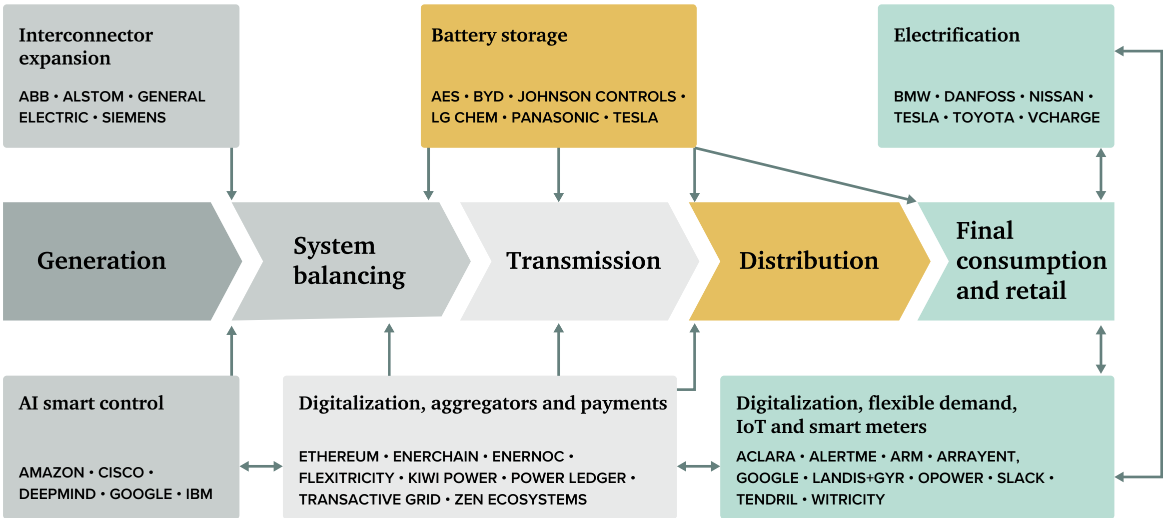
The chapter also considers some of the emerging regulations that aim to achieve a balance between ensuring innovation in energy service provision and redefining the role of utilities. Finally, the growing debate over ownership and market efficiency versus government intervention is set in the context of increasingly fragmented energy service provision.

The ecosystem of market actors providing flexibility

During the second phase of transformations, traditional utilities will need to respond to a multiplicity of challenges – many of which, if unaddressed, will further undermine their traditional business models. Peak demand could decrease as staggered smart EV charging, smart control of internet-connected appliances and the use of smart meters become more prevalent. On the one hand, this could bolster the business models of the power utilities, with EVs increasing electricity consumption and demand profiles flattening. The flip side of this argument, from the perspective of utilities' profitability, is the prospect of greater competition from renewables, as flexibility increases. This scenario will be especially likely as lithium-ion battery storage technology reaches maturity, and as artificial intelligence manages grid congestion in increasingly smart ways.

While many traditional utilities are seeking to rapidly reform their business models, the companies leading the second phase of transformations are often those new to the power sector. These challengers to incumbent players are creating services and business models that take advantage of the new technologies. The new companies vary considerably in size, ranging from small, innovative start-ups to some of the largest companies in the world – the latter including car manufacturers and internet firms benefiting from massive customer bases, strong brand recognition and, in many cases, signficant capital assets. These new market actors are encroaching on the business models of the established utilities, and reducing their generation revenues, customer bases and market control. Figure 20 shows how new technologies and associated companies are beginning to enter the electricity sector during this second phase of transformations.

Figure 20: The new market players in the electricity sector, under each aspect of the second phase of transformations



Energy service provision by new market facilitators

Traditional utilities already face a vast number of new competitors (or potential competitors) in flexible-demand markets. Google and Amazon, for example, are in talks with regulators to introduce time-of-use tariffs to enable flexible demand.[216] In order to keep pace, utilities are acquiring and investing in start-ups – for instance, the UK's Centrica paid £65 million in 2015 for AlertMe, a home energy management system that enables communication between a central control hub and wirelessly connected devices and appliances. A contrasting example is the case of Tendril, a US company that has remained private and has attracted nearly $150 million in investment, principally from Siemens, GE and ENGIE. Tendril provides 'home energy reports that [combine] behavioral science and physics-based home simulation to give customers actionable data on how they use energy'.[217] Potentially one of the biggest market disrupters of the future is Opower, which was acquired by Oracle in 2016 for $532 million.[218] Opower already provides services to 100 traditional utilities globally, such as Pacific Gas & Electric (PG&E), Exelon and National Grid, helping them to deliver digital services to consumers by analysing more than 600 billion meter reads from 60 million end-users.[219]

As regards capacity markets, traditional utilities are failing to win flexible-demand contracts. In December 2016, the Ontario Independent Electricity System Operator held its second flexible-demand capacity auction. As with many similar auctions across various jurisdictions, new players

[216] Morley, K. (2017), 'Your energy bills could be controlled by Google or Amazon under Government plans for "peak pricing"', *Telegraph*, 24 July 2017, http://www.telegraph.co.uk/news/2017/07/24/energy-bills-could-controlled-google-amazon-government-plans/ (accessed 2 Oct. 2017).
[217] Bloomberg (2017), 'Tendril Networks, Inc.: Private Company Information', https://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=20724244 (accessed 27 Sep. 2017).
[218] Gregg, A. (2016), 'Oracle agrees to buy Arlington energy data firm Opower for $532 million', *Washington Post*, 2 May 2016, https://www.washingtonpost.com/business/economy/oracle-agrees-to-buy-arlington-energy-data-firm-opower-for-532-million/2016/05/02/83739416-107f-11e6-93ae-50921721165d_story.html?utm_term=.aab74dbf1590 (accessed 27 Sep. 2017).
[219] Oracle (2017), 'Oracle and Opower', https://www.oracle.com/corporate/acquisitions/opower/index.html#close (accessed 27 Sep. 2017).

won the tenders, leaving traditional utilities struggling to participate. EnerNOC and Enershift won the largest contracts.[220] Both companies are what are termed 'aggregators' – new and necessary market players in flexible-demand provision. The ability of these new players to capture market share was demonstrated in June 2017, when Enel Green Power North America (a subsidiary of Italy's Enel) acquired EnerNOC to enter the flexible-demand market.

Box 12: Aggregators – the new intermediaries

Aggregators enable the intelligent control of millions of devices connected to the Internet of Things (IoT) and to smart meters. This is a critical role given the huge potential of the flexible-demand sector. Without aggregators, the volume of data and complexity of the system would be unmanageable for system operators.

Another dimension to this complexity comes from consumers. As more distributed energy resources (DERs) such as solar photovoltaics (PV), batteries, smart meters, IoT-connected devices, smart electric vehicle (EV) charging facilities and even vehicle-to-grid EVs are adopted, a growing number of electricity consumers could become 'prosumers', selling power and flexibility services back to the grid in an intelligent manner. But these potential prosumers are currently locked out of the market. Having millions of flexible-demand households communicating simultaneously with the wider system is technically challenging due to the volume of data that require processing in real time.[221] This is where aggregators such as VCharge, a US firm recently acquired by Ovo Energy of the UK, come in, acting as intermediaries between electricity end-users and DER owners on one side and power system participants on the other.[222]

VCharge's business model revolves around the aggregation of small distributed demand, in the form of residential electric heating, and the selling of balancing services. VCharge is looking to expand flexible balancing services to battery dispatch and EV charging. Ovo now offers a reduced residential tariff to EV owners.[223] With National Grid forecasting the need for 2 GW of flexible demand in 2020 in the UK, this type of bundled tariff offering could become more commonplace. EVs are also stimulating the creation of new tariffs in the US, with 25 electricity suppliers now offering bespoke EV tariffs that are up to 95 per cent cheaper at night.[224]

As the 2016 Ontario Independent Electricity System Operator capacity market auction showed, aggregators are nimble new market entrants. While current flexible-demand markets and their associated aggregators are engaged with non-domestic consumers, the business model of VCharge points to a looming transformation. By aggregating many small-scale DERs that would otherwise struggle to enter the market, aggregators working within the domestic market could begin to buy and sell flexibility services.

In the UK, two traditional utilities, E.ON and EDF, won 14 per cent of the contracts in last year's £14 million capacity market auction, which concluded on 22 March 2017. The biggest share (47 per cent) went to non-domestic aggregator companies EnerNOC and Kiwi Power. Smaller aggregators and large industrial entities such as Tata Steel won the remaining contracts.[225] In California, Pacific Gas & Electric anticipated losing 7.3 per cent of demand to community-owned aggregators during 2017 alone, and 21 per cent by 2020.[226] These aggregators buy power from the power utilities on behalf of their members, enabling them to negotiate better rates. Since early 2017, half of the 58 counties of California, and 300 cities, had a dedicated community aggregator.[227]

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[220] Independent Electricity System Operator (IESO) (2016), 'IESO Announces Results of Demand Response Auction', 16 December 2016, http://www.ieso.ca/corporate-ieso/media/news-releases/2016/12/ieso-announces-results-of-demand-response-auction (accessed 6 Apr. 2018).
[221] Burger, S., Chaves-Ávila, J. P., Batlle, C. and Pérez-Arriaga, I. J. (2017), 'A review of the value of aggregators in electricity systems', *Renewable and Sustainable Energy Reviews*, 77(C): pp. 395–405, https://www.sciencedirect.com/science/article/pii/S1364032117305191 (accessed 4 May 2018).
[222] Ikäheimo, J., Evens, C. and Kärkkäinen, S. (2010), *DER Aggregator Business: the Finnish Case*, Research Report, VTT Technical Research Centre of Finland, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.454.3257&rep=rep1&type=pdf (accessed 28 Apr. 2018).
[223] OVO Energy (2017), 'OVO announces acquisition of VCharge', press release, 9 February 2017, https://www.ovoenergy.com/ovo-newsroom/press-releases/2017/february/ovo-announces-acquisition-of-vcharge.html (accessed 19 Sep. 2017).
[224] Bloomberg New Energy Finance (2017), 'U.S. Utilities Offer Multiple Electric Car Charging Rates', 7 July 2017, https://about.bnef.com/blog/u-s-utilities-offer-multiple-electric-car-charging-rates/ (accessed 11 Jan. 2018).
[225] Coyne, B. (2017), 'Enernoc and Kiwi Power take biggest shares of £14m demand-side response auction', The Energyst, 23 March 2017, https://theenergyst.com/enernoc-and-kiwi-power-take-biggest-shares-of-14m-demand-side-response-auction/ (accessed 17 Aug. 2017).
[226] Eckhouse, B. and Martin, C. (2017), 'Wealthy Californians Go Green, Putting Utilities in a Squeeze', Bloomberg, 15 March 2017, https://www.bloomberg.com/news/articles/2017-03-15/california-utilities-face-competition-from-clean-power-providers (accessed 17 Aug. 2017).
[227] Ibid.

As the number of domestic DERs grows, the influence and transformational impact of flexible demand on the business models of traditional utilities will grow too. As the results of the capacity market auctions indicate, the traditional utilities appear to be lagging behind non-domestic aggregators.

However, as smart metering and the IoT start to enable greater volumes of flexible demand, the household flexible-demand market will present a new opportunity for traditional utilities. In a world awash with data, and with the ability to control appliances in functionally smarter modes, utilities could offer more comprehensive service-based packages to households, creating new value in a system where traditional business models are becoming obsolete.

New transactions, blockchain and peer-to-peer electricity trading

Certain traditional utilities are transforming payments and tariffs to capture the benefits of flexibility on the demand side. The big three Californian utilities – San Diego Gas & Electric (SDG&E), PG&E and Southern California Edison (SCE) – are in the process of finalizing time-of-use tariff structures before they switch the majority of customers to such pricing in 2019.[228] In the UK, similar transformations are under way, for instance in Ovo's new tariff offering (see Box 12). Green Energy UK offered the first time-of-use tariff in January 2017.[229]

The growing numbers of DERs and aggregators, meanwhile, are providing opportunities for new payment and transaction methods to emerge – methods that could prove to be even more disruptive to utilities than the rise of renewables and low growth in demand, in the sense that more players and competition will enter the market. One of these potentially disruptive trends is the rise of peer-to-peer transactions, facilitated by blockchain technology, which could partially replace the role of the electricity supplier as broker between producer and consumer.

As a secure system for payments and transactions, blockchain is potentially disruptive for electricity trading. It could enable peer-to-peer transactions in which trusted intermediaries such as banks or traditional utilities are partially displaced or no longer needed.[230] Blockchain consists of a distributed list of data records, called blocks, that continually grows. Blocks are verified by a distributed network of encrypted computers. To modify a previously verified block, each node on the network needs to be simultaneously modified, as each node is continuously verifying the others.

Ethereum is a blockchain protocol that offers greater functionality and speed than previous protocols, such as Bitcoin. This new functionality includes smart contracts to facilitate and administer contracts between peers.[231] Blockchain applications are beginning to emerge within the energy sector. These applications broadly fall within three categories:[232]

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[228] Environmental Defense Fund (2017), 'Getting it right with time-of-use pricing in California', fact sheet, https://www.edf.org/sites/default/files/factsheet_time-of-use_0.pdf (accessed 28 Apr. 2018).
[229] Ward, A. (2017), 'Households offered first time-of-use energy tariff', *Financial Times*, 2 January 2017, https://www.ft.com/content/ac3b2788-d0eb-11e6-b06b-680c49b4b4c0 (accessed 20 Sep. 2017).
[230] Nakamoto, S. (2008), 'Bitcoin: A Peer-to-Peer Electronic Cash System', https://bitcoin.org/bitcoin.pdf (accessed 28 Apr. 2018).
[231] Buterin, V. (2014), 'Ethereum: A Next-Generation Cryptocurrency and Decentralized Application Platform', *Bitcoin Magazine*, 23 January 2014, https://bitcoinmagazine.com/articles/ethereum-next-generation-cryptocurrency-decentralized-application-platform-1390528211/ (accessed 17 Aug. 2017).
[232] Dena (German Energy Agency) (2016), *Blockchain in the energy transition. A survey among decision-makers in the German energy industry*, Berlin: Deutsche Energie-Agentur GmbH (dena) and ESMT European School of Management and Technology GmbH, https://www.dena.de/fileadmin/dena/Dokumente/Meldungen/dena_ESMT_Studie_blockchain_englisch.pdf (accessed 28 Apr. 2018).

1. Facilitation of energy bill payments – in this application, the utility still plays the central role of structuring the tariff and receiving payment.
2. Handling of transactions for energy generation when the physical location of the generator is known. With this type of transaction, blockchain enables a household with a DER to sell power to a neighbour, potentially without the need for a utility. However, this requires smart-contract functionality.
3. Incorporation of big data and predictive task automation within the blockchain, enabling flexible balancing services.

An example of the first application is BlockCharge,[233] a joint project between Slock.it and the German utility Innogy. By incorporating a 'smart plug' with the Ethereum protocol, BlockCharge aims to provide universal charging of EVs from any public charging point, negotiating the charging price and facilitating the payment process. Europe's biggest utilities are also trialling blockchain EV charging using a protocol called Enerchain.[234] In other developments, pilot projects are under way in which DERs sell power directly to consumers, via peer-to-peer payments facilitated by Ethereum smart contracts, without the need for a utility as an intermediary. Predictive task automation also remains an area of development for blockchain protocols, and could enable greater penetrations of renewables in the future power system.

At the more disruptive end of the spectrum of blockchain applications, where peer-to-peer transactions are facilitated without the need for the utility, is TransActive Grid. In 2016, the US company connected five prosumer homes (in this case, homes that were fitted with solar PV installations) to five consumer households, enabling the latter to buy excess power from the former.[235] The homes were connected to a microgrid, so power was not transferred via a utility-owned grid. A similar pilot scheme, called Power Ledger, is happening in Perth, Australia. Such new modes of payment could lead to households partially migrating away from the retail electricity market and instead sourcing power from prosumers.

Although blockchain can facilitate payments for electricity between peers, electricity must still be physically transferred along distribution networks. This poses regulatory and pricing barriers. Regulations will need to be updated for peer-to-peer power transactions. The traditional utilities that own the grid infrastructure will need to ensure payments for their services are captured in the transactions.[236] However, proposals are being developed in which aggregators' services and blockchain peer-to-peer transactions are merged, so that the aggregator acts in effect as the regulatory buffer for the prosumer, with households paying a retail tariff alongside any peer-to-peer payments they make via blockchain.[237]

If blockchain is to become significantly disruptive, the regulations governing the transmission of power on grids will need to adapt to allow prosumers to sell DERs directly across the grid. Currently regulations prohibit this. If peer-to-peer transactions of this nature were to become a significant

[233] Burger, C. (2017), 'Blockchain and smart contracts: Pioneers of the energy frontier', *International Business Times*, 15 December 2017, https://www.ibtimes.co.uk/blockchain-smart-contracts-pioneers-energy-frontier-1651650 (accessed 02 Feb. 2018).
[234] Zha, W. (2017), 'Europe's Biggest Utilities Join Blockchain Energy Trading Trial', Bloomberg, 29 May 2017, https://www.bloomberg.com/news/articles/2017-05-29/europe-s-biggest-utilities-join-blockchain-energy-trading-trial (accessed 20 Sep. 2017).
[235] Gifford, J. (2016), 'Power Ledger expands trials of blockchain electricity trading', RenewEconomy, 28 October 2016, http://reneweconomy.com.au/power-ledger-expands-trials-blockchain-electricity-trading-38771/ (accessed 25 Sep. 2017).
[236] PwC (2015), *Blockchain – an opportunity for energy producers and consumers?,* https://www.pwc.com/gx/en/industries/assets/pwc-blockchain-opportunity-for-energy-producers-and-consumers.pdf (accessed 28 Apr. 2018).
[237] Lavrijssen, S. and Carrillo Parra, A. (2017), 'Radical Prosumer Innovations in the Electricity Sector and the Impact on Prosumer Regulation', *Sustainability*, 9(7), doi:10.3390/su9071207 (accessed 28 Apr. 2018).

component of the electricity market, utilities would lose their ability to capture value in the exchange between generator and consumer. However, grid utilities would still be in a position to charge for infrastructure costs within peer-to-peer transactions. These transformations are only just emerging, but unbundled utilities will need to adapt to market innovations given the fundamental shift that could ensue.

Transforming traditional utilities' role and business models

Traditional utilities are entering the digital space primarily in order to optimize their existing capital-intensive infrastructure. Since 2010, investment in grid infrastructure by unbundled utilities has remained stagnant at $100 billion per annum. In contrast, their expenditure on digital infrastructure grew by 20 per cent in 2016 alone.[238]

On the one hand, the emergent digital, flexible smart grid could benefit traditional utilities, as the need to invest in existing, capital-intensive infrastructure may be partially mitigated by digitalized infrastructure. On the other hand, traditional utilities may lose market share as emerging players begin to offer new services to consumers, or even as prosumers begin to use DERs. During the first phase of the sector's transformations, liberalization and competition opened many retail markets to new players. Service-oriented offerings from new market actors are, however, likely to be far more disruptive. The emergent EV charging tariff is leading the way in terms of offering specific tariffs for specific services – in this case, time-of-day-based charging of EVs. With Google and Amazon backing flexible-demand tariffs, there is the prospect of many more households being offered the service of having appliances controlled remotely, by algorithms in the cloud, perhaps in combination with one of the many new green tariffs now on offer.

It is clear that a new business model is emerging, one that provides energy service platforms for DER-owning prosumers. These platforms consist of networks that connect multiple producers and consumers, providing tools, services and rules to enable participants' interaction and hence the creation of new marketplaces. Online services in other sectors, such as Uber (transport), Airbnb (lodging) and eBay (online marketplace) exemplify such platform businesses. With the aggregation of the various forms of DERs within marketplace platforms, it is possible to envisage the development of a growing array of new services and packages that are tailored for the owners of DERs. The CEO of Commonwealth Edison, a US utility, has publicly stated her desire to transform the business by shifting from a utility business model to an energy platform model.[239]

The services offered on these platforms might also include the prosumer model of households being able to choose locally produced solar PV power. These platforms could also help DER owners comply with regulations (which currently inhibit households selling power directly to the grid), perhaps even using blockchain-based smart-contract protocols for transactions. Platforms would derive their revenues from a range of business models, including traditional consumer or supplier charges, transaction fees, advertising and premiums.

Such platforms already exist within the electricity system. Non-domestic flexible-demand aggregators are prime examples. Kiwi Power, EnerNOC and Flexitricity are aggregator platforms to which commercial and industrial electricity consumers grant third-party control of their systems in

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[238] IEA (2017), *World Energy Investment 2017*.
[239] Bade, G. (2016), 'Chicago's REV: How ComEd is reinventing itself as a smart energy platform', Utility Dive, 31 March 2016, https://www.utilitydive.com/news/chicagos-rev-how-comed-is-reinventing-itself-as-a-smart-energy-platform/416623/ (accessed 13 Jan. 2018).

order to participate in flexible-demand markets. Many existing electricity suppliers are in a prime position to use their established relationships with households – such as in the setting of retail tariffs – to create some of the first energy service platforms.

Across jurisdictions, transmission and distribution networks are currently operated by various entities. The distribution networks tend to be operated by so-called distribution network operators (DNOs), which themselves are often subsidiaries of unbundled utilities. Traditional utilities therefore have valuable experience in distribution network operation and maintenance.

Importantly, for those traditional utilities that currently operate distribution networks, energy service platforms are likely to require the formation of what have been termed 'distribution system platforms' (DSPs) or 'distribution system operators' (DSOs).[240] The difference between DNOs and DSOs is subtle but important. DNOs are responsible for overseeing connection of DERs, but they generally do not oversee or facilitate dispatch and coordination.

To ensure the ability of DSOs to create efficient and fair markets, new regulations and accountability to an independent regulator will be needed, perhaps requiring an independent or even not-for-profit DSO.

Many conceive of future DSOs as facilitating platforms that will provide such coordination services;[241] the DSO backbone would be essential to enable competition between various platforms within one distribution network, while maintaining interoperability. One utility might form the DSO, enabling regulated utilities as well as independent and unregulated energy service platform providers to meet the service needs of electricity consumers and prosumers. The DSO would also need to provide open and transparent system access, and operate market mechanisms developed by the platforms, alongside performing the essential duties of maintaining system safety and reliability, currently undertaken by the DNO.[242]

The model of multiple and competing energy service platform providers, facilitated by the DSO platform, is not dissimilar to that of telecommunication networks. For instance, in the UK, Openreach – a subsidiary of BT – operates the fibre-optic cables that are the backbone of the system. On top of this platform, BT and other internet and communication providers and their various platforms compete to offer services to consumers. To ensure the ability of DSOs to create efficient and fair markets, new regulations and accountability to an independent regulator will be needed, perhaps requiring an independent or even not-for-profit DSO.[243]

Pilot projects such as Australia's Decentralized Energy Exchange (deX) offer insights into how an energy service model enabled by platforms and DSOs might function.[244] Sponsored by the Australian Renewable Energy Agency (ARENA), deX attempts to bring together DERs in a competitive market structure. DSO-type functionality is provided by GreenSync software in collaboration with network

[240] Newton, P. (2017), 'Turning distribution network operators into system operators', *Utility Week*, 28 June 2017, https://utilityweek.co.uk/turning-distribution-network-operators-into-system-operators/ (accessed 12 Jan. 2018); Cross-Call, D. (2017), 'The Promise of Platform-based Grids', Rocky Mountain Institute, 17 April 2017, https://www.rmi.org/news/promise-platform-based-grids/ (accessed 14 Jan. 2018).
[241] Newton (2017), 'Turning distribution network operators into system operators'; Cross-Call (2017), 'The Promise of Platform-based Grids'.
[242] Trabish, H. (2014), 'Jon Wellinghoff: Utilities should not operate the distribution grid', Utility Dive, 15 August 2014, https://www.utilitydive.com/news/jon-wellinghoff-utilities-should-not-operate-the-distribution-grid/298286/ (accessed 12 Jan. 2018).
[243] Ibid.
[244] deX (2017), 'deX: Decentralised Energy Exchange', https://dex.energy/ (accessed 13 Jan. 2018); Vorrath, S. (2017), 'Greensync launches world-first exchange to trade stored household solar power', RenewEconomy, 23 February 2017, http://reneweconomy.com.au/greensync-launches-world-first-exchange-trade-stored-household-solar-power-49889/ (accessed 13 Jan. 2018).

operators United Energy and ActewAGL. Bids and offers from multiple DERs are aggregated from solar PV, batteries and flexible demand within individual deX households, to provide the DNO with the least-cost balancing mechanisms it requires. In essence, the GreenSync software provides the DNO with the same software functionality that a full DSO would provide. As such, the pilot project is a step along the path towards a DSO model that enables a platform marketplace of services.[245] The GreenSync system also allows transactions to be effected via digital wallets, an arrangement one step away from blockchain peer-to-peer payments.

Modern economies are built on a series of interacting platforms, the most successful of which tend to enable the greatest number of participants to compete in a given marketplace. In many regards electricity grids are natural infrastructural platforms, enabling traditional utilities to compete within the grid platform. The rise of a variety of small-scale flexible DERs within the distribution grid, enabled by digitalization, is creating the need for a new layer of energy platform business models and service offerings that extend to the prosumer. To take advantage of the opportunities this presents, traditional utilities will need to reconceive their role still further, moving away from business models based around ownership of capital-intensive generation infrastructure. Thus, rather than using digital infrastructure to optimize their existing asset bases, they will need to build entirely new infrastructure-light business models, platforms and services.

Regulating transformations

Digital infrastructure and technologies that increase the flexibility of the electricity system are currently disadvantaged, compared to traditional generators and network infrastructure, when it comes to financial valuations. Currently, electricity prices do not fully capture the spatial and temporal differences between supply and demand. Consequently, demand flexibility, location-specific congestion management and the ability to install batteries in a modular, distributed manner are not appropriately valued in the market.

Reforms of electricity markets are required to create efficient market signals for these new forms of smart flexibility and congestion management, as well as for DERs. Locational marginal pricing – in which electricity prices reflect the physical limits of the network as well as the difference in value between locations – offers a potential alternative to reduce network congestion, although it is politically unpopular as it can cause electricity costs to rise in areas of high demand. Equally, scaling up transmission investment to enable greater flows of renewable power from regions of high supply to regions of high demand is costly. The European Commission's clean energy package of 2016 attempts to ensure that network operators are rewarded based on investments (such as in digital infrastructure) that minimize the need for capital-intensive projects, as costs are passed on to consumers via tariffs.

In the UK in 2017, the Energy Networks Association began the Open Networks Project, aimed at exploring the transformation of DNOs into DSOs, supporting flexibility and providing platforms for new markets and services for customers. The UK regulator, government and nine DNOs are participating in the project.

[245] Vorrath, S. (2017), 'Big energy players back major power shift, as GreenSync unveils deX', RenewEconomy, 1 September 2017, http://reneweconomy.com.au/big-energy-players-back-major-power-shift-as-greensync-unveils-dex-91413/ (accessed 14 Jan. 2018).

New York's Reforming the Energy Vision (REV) is perhaps the most all-encompassing set of reforms to attempt to move traditional utilities from a cost-of-service business model to a 'service platform' model in which providers create marketplaces, sell system data, charge transaction fees and create flexibility. REV differs from reforms in other US states. For instance, California has set specific targets, such as for storage and EVs, whereas REV has taken a system-wide approach that targets the transformation of the actors underpinning and operating the electricity system itself.

REV provides for incumbent utilities to continue as distributors of energy even as they become marketplace operators. The DNOs themselves become DSPs – that is, providing the platform between suppliers and consumers of energy. REV reforms recognize that 'macrogrid' entities serve a public good in decentralizing the energy system.[246] Since its formation in 2014, REV has stimulated innovation and experimentation. Not all projects have been successful. ConEdison began implementing a 'virtual power plant', consisting of 300 households, that was supposed to integrate DERs such as solar PV and storage. But the project ran into difficulties and was suspended in April 2017.[247] Of 17 REV projects, five principally involve utilities creating market and service platforms. Central Hudson Gas & Electric's CenHub Marketplace also integrates product and service offerings with advice to households on consumption patterns.[248] Meanwhile, Connected Homes, by ConEdison in partnership with Opower, attracted almost 129,000 unique visitors to its marketplace platform in the third quarter of 2017.[249]

REV's aim of integrating more DERs presents increased cybersecurity challenges. If thousands of small DERs communicate via the internet with a DSO, this increases the number of connections vulnerable to cyberattack. REV and its associated DSPs recognize the need to strengthen protocols to prevent such attacks; the DSPs are responsible for ensuring that the DERs communicating with their platforms are safe.[250]

Box 13: Government engagement and ownership

The trend in the power sector over the past decade has been one of liberalization and privatization, albeit implemented to various degrees in different parts of the world. This trend, along with the establishment of independent regulators, has led to shrinking state involvement in the power sector, particularly as governments have relied on the market to deliver national policy objectives concerning power supply.

However, a significant proportion of global power generation remains in full or partial public ownership. In the US, 48 million citizens get their electricity from public-sector companies. In the EU, many of the largest power generation companies, including EDF (France), Vattenfall (Sweden), Enel (Italy) and RWE (Germany), are fully or partially owned by national or regional governments. Many of the power giants in Asia similarly are under partial or total government ownership; these firms include KEPCO (South Korea) and most of the conventional Chinese generators.

[246] Sturtevant, J. L. (2016), 'New York's reforming the energy vision— opportunities and obstacles on the horizon', Sullivan & Worcester LLP, Lexology, 11 May 2016, https://www.lexology.com/library/detail.aspx?g=bbeb89a4-810f-47fc-bae1-c6271e366f99 (accessed 14 Jan. 2018).
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In some countries, the number of power companies in public ownership is increasing. For instance, in Germany the number of municipally owned power companies has increased over the past decade.[251] Globally, there is a mix of public and private ownership of networks – the Chinese State Grid remains state-owned and, as of 2018, is the second-largest company in the world by revenue, behind Walmart.[252] In the UK, National Grid is run as a private company operating the gas and electricity transmission networks; it also has significant operations in North America.

As demonstrated by the 2015 Paris Agreement on climate change, there is political acceptance at national and international levels of the need for rapid and near-total decarbonization if the most serious consequences of climate change are to be avoided. However, this commitment needs to be backed up by strong policy interventions. In market-based systems, an array of mechanisms have been used to try to stimulate or discourage certain technologies – for example, feed-in tariffs have been introduced in an effort to stimulate low-carbon renewables, while emissions performance standards have sought to discourage high-emission generators. However, market interventions, especially when required to deliver rapid change, can have unintended consequences for other market actors, potentially necessitating government intervention in other areas. This can sometimes conflict with policy objectives. For example, capacity mechanisms, with their associated financial assistance, in the UK are given to fossil fuel generators, including coal plants, to help ensure security of supply, even though clear targets exist to reduce the use of carbon in the sector.

This has already raised questions about the efficiency and ability of the electricity market to deliver decarbonization.[253] As greater flexibility is introduced into the system, it is likely that where market systems dominate, they will fragment further, possibly requiring a further suite of government market support mechanisms. This may reduce market efficiency to such an extent that direct or indirect government ownership of the grids would be economically more beneficial.[254]

As EV deployment rates accelerate and battery costs fall, flexibility is likely to increase, enabling greater penetration of renewables while avoiding increased SIC. This will herald the entrance into the electricity sector of a new wave of market players that are likely to use innovative technologies to offer new services to consumers. It is, however, the broader set of digitalization technologies that may truly revolutionize flexibility.

Among various aspects of digitalization occurring in the sector, those likely to prove the most disruptive for the traditional utilities are applications of flexible digitalization that create new services and fragment old ones. These new services range from creating the means to aggregate household consumption and open up residential flexible-demand markets to creating new modes of transactions and connecting millions of DERs to platforms of interacting prosumers. The power landscape will undoubtedly shift. The traditional utilities will need to ensure that they capitalize on the opportunities these new technologies bring, by developing new energy services to prevent further erosion and fragmentation of their business models.

[251] Hall, D. (2016), *Public ownership of the UK energy system – benefits, costs and processes*, London: Public Services International Research Unit (PSIRU), University of Greenwich, http://www.psiru.org/sites/default/files/2016-04-E-UK-public.pdf (accessed 28 Apr. 2018).
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4. Conclusions

Electricity is a vital societal resource; ensuring the secure, affordable supply of electricity is a fundamental task of governments. During the past decade, the power sector has undergone a profound disruptive shock. This 'first phase' of transformations has been driven by three major factors: unprecedented deployment rates of renewable energy; slower than expected or stagnating demand growth, due to tougher energy efficiency standards; and, in many jurisdictions, market reform. This has led to solar PV and wind power becoming the largest sources of new capacity.

As this trend continues, solar PV and onshore wind power will become the lowest-cost generators globally, driving increased deployment of those technologies. Continued and accelerating deployment of renewables is likely to further depress utilization rates for conventional power stations, impairing the economic performance of coal, gas and nuclear generators. For example, the contribution of solar PV and wind power to electricity generation in the EU increased from 2.5 per cent to 13.0 per cent between the end of 2006 and the end of 2016. In the same period, the average share price of the major power utilities in Europe halved.

A second phase of transformations is emerging, driven by and intimately linked to the first. Renewable deployment will continue, joined by the electrification of transport and heating. Electrification is paramount to achieving climate and air quality targets. As the electricity sector increasingly dominates the wider energy system, flexibility will likely define this second phase of transformations, and will be the key enabler for ensuring affordable electricity.

Governments seeking to encourage entrants to the market for the provision of electricity system flexibility will need to develop new market and regulatory mechanisms that balance two imperatives: appropriately valuing the evolving suite of ancillary flexibility services; and ensuring that core principles of energy security, affordability and environmental protection are upheld.

The business models of power utilities have historically been based on predictable and steadily growing demand, supplied from large coal-fired, nuclear or gas-fired power stations that economically are designed to run at predictable levels of output. A number of new technologies are crucial to enhancing system flexibility: smart EV charging, battery storage, digitalization with intelligent control, and demand-side management. These will complement or replace the existing flexibility mechanisms, currently provided by power plants' operational regimes and the use of interconnectors.

This second phase of flexibility transformations is likely to turn out to be more wide-reaching than the changes to date. Many traditional utilities have recognized this, but they are often either unaware of, or unable to adapt to, the pace of change. Shareholders and asset managers will need to recognize the risks of traditional utilities failing to keep pace with sector transformations.

Maintaining reliable and affordable electricity systems that integrate greater penetrations of renewables will be a priority for policymakers, regulators and the wider market. As penetration levels of renewables reach around 30 per cent, countries could experience increased integration costs. Therefore, country-specific policies need to be developed to ensure that whole-system costs remain affordable. The integration challenge is attracting some of the world's most economically powerful companies, many with roots in the transport or digital sectors. These companies, if they successfully meet consumers' needs, may well dominate the power sector in the coming decades.

If EV charging is controlled by smart technology, then national demand profiles could flatten as electricity demand becomes more even throughout the day, increasing the efficiency of the system. However, smart EV charging could go further, enhancing system flexibility and allowing greater integration of renewables at lower cost, especially if combined with vehicle-to-grid technology. However, these benefits will not occur unless manufacturers, regulators and policymakers soon recognize the system benefits of smart electrification.

A virtuous circle is developing, in which the EV battery sector is enabling increasingly affordable battery storage, in turn supporting greater integration of renewables. Batteries already offer economic solutions for a range of short-term functions, including frequency response, distribution network reinforcement and integration of renewables. The modular nature of batteries enables their cost and size to be optimized for their function; this, combined with their speed of deployment, will likely increase competition with traditional market-balancing mechanisms. Traditional utilities are well placed to invest in larger, capital-intensive, grid-scale battery storage facilities, as well as in the integration of batteries into conventional power stations.

> Technological innovation is signalling the extent to which the power sector could change, but unless new regulatory structures and incentives are put in place so that new market actors can operate profitably, then the necessary rapid structural reforms are unlikely to be achieved.

Digitalization will enable traditional utilities to become more operationally efficient by enhancing control of infrastructure via remote sensors, improving management of supply chains, and optimizing internal accounting and customer billing. Digitalization also raises the prospect of flexible-demand services expanding, including into the household market. Flexible demand presents both an opportunity and a threat for traditional utilities – utilization rates of generators may increase, and grid reinforcement may be avoided, but will these benefits be offset by lower barriers to the integration of renewable energy? To counter competition from new market entrants, traditional utilities could offer more comprehensive service-based packages to existing household consumers, creating new value as their traditional business model disappears.

The ownership of, and capacity to analyse, data from the Internet of Things will dictate which market players can offer new services to consumers. Internet giants such as Google are already entering the market with skills beyond those of the traditional utilities. Working with new, nimble market players to provide flexible demand could allow traditional utilities to secure additional revenue streams.

New payment and transaction methods are emerging. Peer-to-peer transactions facilitated by blockchain could partially replace the need for electricity suppliers to play the role of broker between producer and consumer. If changes to regulations enable such payment methods to become the norm, electricity suppliers could use their established retail tariff relationships to offer similar services, such as selling low-cost power from newly built solar PV and wind farms, or selling energy stored in utility-owned grid-connected battery storage facilities.

Pilot schemes in New York show how regulators are encouraging traditional utilities to develop energy service platform business models. Regulators, governments and utilities will need to work together to design the rules and protocols for such platforms, which will enable the connection of distributed energy resources (DERs) and the emergence of associated new services. Traditional utilities, particularly network operators, could develop energy service platforms by working with regulators on distribution system operator rules and protocols. These energy service platforms could enable utilities and new actors to build digital infrastructure-oriented business models to provide new services to customers and enable the connection of the growing numbers of DERs.

Grid cybersecurity is a growing concern, demanding that traditional utilities integrate advanced digital security technologies. Technology specialists, such as Cisco, will play an increasingly fundamental role in ensuring security of supply and guarding against reputational damage from avoidable cyberattacks.

The likely extent and potential pace of the second phase of electricity sector transformations raise fundamental questions for generators, grid operators, regulators and governments. Technological innovation is signalling the extent to which the power sector could change, but unless new regulatory structures and incentives are put in place so that new market actors can operate profitably, then the necessary rapid structural reforms are unlikely to be achieved. The extent to which the power market is segmented by separate incentive schemes also raises questions about the role of the state in potentially owning and running the sector.

Appendix 1: Additional Notes

Figure 3: Sources

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Abbreviations and Acronyms

BNEF	Bloomberg New Energy Finance
CCS	carbon capture and storage
CHP	combined heat and power
CO_2	carbon dioxide
DER	distributed energy resource
deX	Decentralized Energy Exchange
DNO	distribution network operator
DSO	distribution system operator
DSP	distribution system platform
EBITDA	earnings before interest, taxes, depreciation and amortization
EDF	Elecricité de France
EPR	European Pressurized Water Reactor
EV	electric vehicle
FERC	Federal Energy Regulatory Commission
GHG	greenhouse gas
GW	gigawatt(s)
GWh	gigawatt hour(s)
ICE	internal combustion engine
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
KEPCO	Korea Electric Power Corporation
kWh	kilowatt hour(s)
LCOE	levelized cost of electricity
LED	light-emitting diode
MBTU	million British Thermal Units
MDA	major domestic appliance
MEPS	Minimum Energy Performance Standards
MISO	Midcontinent Independent System Operator
MW	megawatt(s)
MWh	megawatt hour(s)
NDC	Nationally Determined Contribution
NERC	North American Electric Reliability Corporation
NYISO	New York Independent System Operator
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PG&E	Pacific Gas & Electric
PMU	phasor measurement unit
PV	photovoltaic
REV	Reforming the Energy Vision

R&D	research and development
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
S&P	Standard & Poor's
SIC	system integration costs
TEPCO	Tokyo Electric Power Company
TWh	terawatt hour(s)
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
V2G	vehicle-to-grid
WSC	whole-system costs

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